

Chapter 9

The Effect of High Temperature on Vietnamese Rice Cultivars and Rice Cultivation Strategy to Cope with High Temperature

Loc Thuy TRAN

Summary: Vietnam is one of the most vulnerable countries to extreme weather caused by climate change, such as high temperature and flooding. High temperature is the major factor affecting the rice grain yield and quality, especially during the flowering stage. In our experimental field, the grain yield of Vietnamese rice cultivars fell to 81.5% and 79.4% of normal when the highest daytime temperature remained above 36°C. The variable with the greatest impact on grain yield was spikelet sterility induced by high temperature. A low seed set was recorded in some popular Vietnamese rice cultivars, such as “OM4900” and “OM18” under high-temperature conditions. The pollen viability and germination of the Vietnamese rice cultivar decrease when the highest daytime temperature remains above 36°C. In addition, the chalkiness rate of Vietnamese rice cultivars increased under high temperature. Thus, understanding the potential impacts of high temperature is necessary for scientists and local authorities in designing mitigation and adaptation plans. Our research investigates the effect of heat stress on the flowering stage and management options for Mekong Delta, Vietnam, which include using (i) heat-tolerant cultivars, (ii) early morning flowering trait to avoid the heat in the noon, (iii) rice cropping adjustment, and (iv) crop management.

1. Introduction

Vietnam is one of the world's leading rice producers and exporters, thanks to its extensive network of fertile river deltas, favorable climate conditions, and centuries-old agricultural expertise. The Red River Delta region accounts for 18% of Vietnam's total rice production according to the General Statistics Office of Vietnam (GSO 2020). This area is characterized predominantly by alluvial soil types, which provide excellent growing conditions. The temperature ranges from 22–27°C throughout the year, creating an ideal climate for rice cultivation. Farmers in this northern region maintain two distinct crop seasons: the Spring season from January to May, and the Autumn season, from June to November.

The Mekong Delta is Vietnam's primary rice-producing region, contributing a substantial 52% of the country's total rice production (GSO 2020). This region benefits from highly fertile alluvial soils and maintains slightly warmer temperatures, averaging between 25 and 27°C. The favorable climate allows for a more intensive cultivation schedule, with farmers able to manage either two or three crop seasons annually: the Summer–Autumn season (April–July), the Autumn–Winter season (July–October), and the Winter–Spring season (November–February).

Global air temperatures rose by approximately 0.5°C during the 20th century, as documented by the Intergovernmental Panel on Climate Change (IPCC 2001). This warming trend is expected to accelerate, with temperatures projected to increase between 2.0°C and 4.5°C by the end of the 21st century, according to more recent IPCC assessments (2007). The IPCC's 2007 report projects a steady warming rate of about 0.2°C per decade over the next several decades. This ongoing temperature rise poses significant concerns, as heat stress can severely impact agricultural productivity and reduce the nutritional quality of food crops

— particularly rice — potentially threatening global food security.

Therefore, this study aims to explore the potential impacts of high temperature on rice, which is critically necessary for scientists and local authorities in their efforts to design and implement effective mitigation and adaptation measures in both the short and long term.

2. Temperature and Rice Production

Rice plants thrive in a specific temperature range between 27°C and 32°C, which provides optimal conditions for growth and grain development. When temperatures exceed this ideal range, the plants experience physiological stress that negatively impacts their productivity and grain formation. Even brief periods of exposure to temperatures surpassing 35°C can cause significant damage to the rice plants' cellular structures and metabolic processes, ultimately leading to reduced grain filling and diminished harvest yields. The sensitivity to high temperatures makes rice particularly vulnerable to thermal stress during critical growth stages, especially during flowering and grain development periods. Figure 9.1 shows the impacts of temperature on the growth stage of rice production.



Growth stage	Seedling	Tillering	Booting	Anthesis	Flowering	Grain formation	Grain ripening
Threshold temperature (°C)	35	32		33.7	35	34	29-30
Symptoms	Poor growth of seedling	Reduced tillering and height	Decreased number of pollen grains	Poor anther dehiscence and sterility	Floret sterility	Yield reduction	Reduced grain filling
Source	Yoshida, 1981	Yoshida, 1977	Tinarle et al., 1989	Kobayashi et al., 2011	Jagadish et al., 2007	Morita et al., 2005	Yoshida, 1981

Figure 9.1. Threshold Temperatures at Rice Growth Stages

Source: Author's Review

This study attempts to (1) examine how Vietnamese rice (*Oryza sativa* L.) cultivars respond to high temperatures during grain filling under field conditions and (2) identify heat-tolerant breeding materials to develop new cultivars better suited for Vietnam's future climate.

3. Material and Method

In this study, field experiments were conducted in 2015 and 2016 in the paddy field of Okayama University, Okayama, Japan (Faculty of Agriculture 34°40'N, 133°55'E) (Figure 9.2). The field experiments involve the following steps:

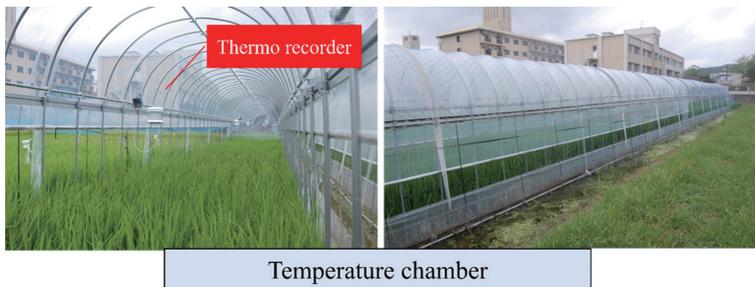


Figure 9.2. Field Experiment

Source: Author's experiment

1. Rice cultivation: Fourteen rice cultivars commonly grown in Vietnam's Mekong Delta were used in this experiment. The Cuu Long Delta Rice Research Institute in Can Tho, Vietnam, provided the cultivars.
2. Temperature treatment: The side-opened plastic chamber was covered with transparent plastic film. A transparent divider split the chamber into two equal sections at the center. One half

served as the control plot (CT), as its air temperature matched the outside temperature.

3. Measurement of air temperature: Air temperature was recorded at 10-minute intervals throughout the growing period.
4. Yield and yield component: For sterility analysis, three replications (20–30 g) of spikelets were collected from 20 hills. To determine the percentage of sterile spikelets, panicles were threshed, and the spikelets were separated by submerging them in a specific gravity solution. Spikelets were classified based on their specific gravity: filled grains ($\geq 1.06 \text{ g cm}^{-3}$), partially filled grains ($\geq 1.0 \text{ g cm}^{-3}$), and sterile spikelets ($< 1.0 \text{ g cm}^{-3}$).
5. Grain appearance quality: Grains with white parts covering more than 20% of their total surface area — such as a white belly, white center, or white back — were recorded as chalky grains.
6. Fertility and pollen viability

4. Results and Discussion

(1) The Impacts of Temperature on Sterile Grain

The result from Figure 9.3 shows that high temperatures increased spikelet sterility across cultivars. OM6161 and OM4900 showed the highest sensitivity, with sterility increases of 22.3% (2015) and 25.7% (2016), respectively. Several other cultivars showed significant increases, while OM8923 remained most resilient with minimal changes (2.9% in 2015, 1.1% in 2016).

The Effect of High Temperature on Vietnamese Rice Cultivars and Rice Cultivation Strategy to Cope with High Temperature

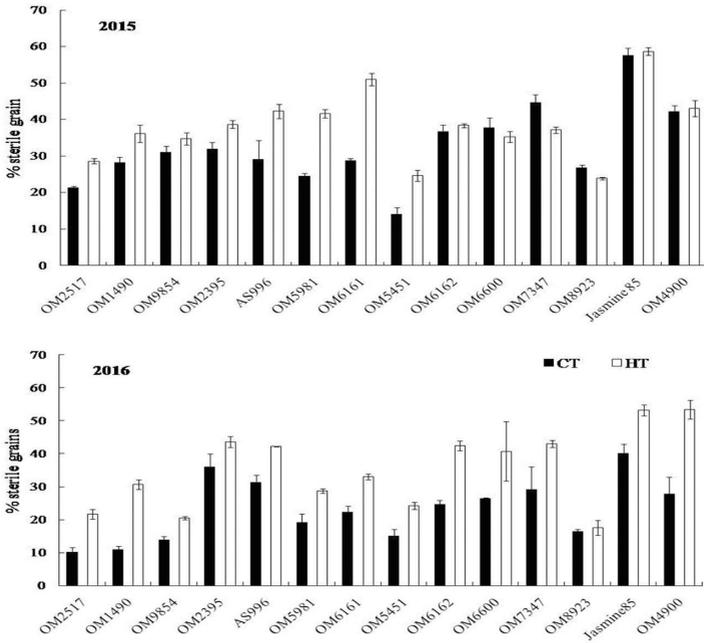


Figure 9.3. The Impacts of Temperature on the Percentage of Sterile Grain in 2015 and 2016

Note: CT — Control Temperature Group and HT — High Temperature Treatment Group. Source: Author’s calculation

(2) The Impacts of Temperature on Grain Yield

Grain yields differed significantly between CT and HT treatments in both years (Table 9.1 and 9.2). CT yields averaged 568 and 636 g m⁻² in 2015 and 2016, while HT yields were lower at 463 and 505 g m⁻², representing decreases of 105 and 131 g m⁻² respectively. High temperatures reduced spikelets per panicle by 4.1–4.5% and increased sterility. Jasmine85 showed the lowest HT yields, while OM6161,

OM6162, Jasmine85, and OM4900 all experienced yield reductions exceeding 30% under HT conditions.

Table 9.1. Yield and Yield Components of 14 Vietnamese Cultivars in Control and High Temperature Treatment in 2015

Cultivar	Treatment	No. of panicle/m ²	No. of spikelets/panicle	% ripened grain	1000-grains weight(g)	Grain yield(gm ⁻²)
OM2517	CT	288	108	75.9	25.2	596.1
	HT	285	110	68.2	25.3	539.1
OM1490	CT	341	111	69.4	23.2	609.6
	HT	306	127	60.5	22.4	534.0
OM9854	CT	307	113	65.0	23.9	535.1
	HT	271	113	59.1	23.9	434.2
OM2395	CT	300	120	64.0	27.1	628.1
	HT	240	121	56.5	27.4	450.7
AS996	CT	245	129	66.4	26.8	561.9
	HT	278	124	54.0	26.8	499.9
OM5981	CT	327	105	72.7	25.6	637.9
	HT	294	107	56.1	25.2	443.7
OM6161	CT	299	108	70.5	25.2	571.3
	HT	257	103	47.6	25.5	318.9
OM5451	CT	286	101	80.8	24.7	574.3
	HT	271	98	71.3	24.7	465.6
OM6162	CT	209	147	60.2	24.5	452.9
	HT	228	135	59.4	17.4	317.2
OM6600	CT	219	152	58.5	24.5	478.4
	HT	207	144	62.3	25.0	463.0
OM7347	CT	216	138	61.3	25.5	465.0
	HT	233	147	51.5	25.2	442.7
OM8923	CT	318	118	70.3	25.5	670.0
	HT	269	105	72.0	25.1	511.5
Jasmine85	CT	237	128	39.4	25.7	307.0
	HT	192	112	38.2	26.2	215.5
OM4900	CT	250	146	54.3	25.1	497.1
	HT	191	131	53.2	25.3	337.0
	Cultivar	**	**	**	**	**
	Treatment	**	NS	*	NS	**

Source: Author's calculation

*The Effect of High Temperature on Vietnamese Rice Cultivars and Rice Cultivation
Strategy to Cope with High Temperature*

Table 9.2. Yield and Yield Components of 14 Vietnamese Cultivars in Control and High Temperature Treatment in 2016

Cultivar	Treatment	No. of panicle m ⁻²	No. of spikelets/ panicle	% of ripened grain	1000 grains weight (g)	Grain yield (g m ⁻²)
OM2517	CT	228	119	87.1	26.6	692
	HT	220	120	75.0	26.2	572
OM1490	CT	211	139	87.3	24.1	677
	HT	236	142	66.1	23.9	583
OM9854	CT	209	129	81.7	24.7	598
	HT	220	137	70.5	23.9	559
OM2395	CT	193	140	59.9	26.6	474
	HT	207	141	52.9	27.3	464
AS996	CT	227	133	65.4	25.7	558
	HT	226	127	54.6	26.9	463
OM5981	CT	219	135	76.2	24.7	611
	HT	237	134	65.0	25.6	579
OM6161	CT	260	141	76.5	25.2	778
	HT	216	136	64.4	25.1	521
OM5451	CT	233	127	81.4	24.7	652
	HT	223	137	71.8	23.8	574
OM6162	CT	174	210	72.4	23.7	691
	HT	162	182	55.4	23.5	422
OM6600	CT	192	202	70.5	23.8	715
	HT	199	188	57.3	22.7	529
OM7347	CT	163	202	68.8	24.7	613
	HT	164	182	54.9	24.4	440
OM8923	CT	251	138	81.6	25.2	783
	HT	259	131	79.2	24.4	723
Jasmine85	CT	151	168	55.8	24.5	380
	HT	140	149	44.6	24.4	249
OM4900	CT	191	185	70.4	24.6	673
	HT	199	168	45.3	24.4	404
	Cultivar	**	**	**	**	**
	Treatment	NS	*	**	NS	**

Source: Author's calculation

(3) The Impacts of Temperature on Grain Chalkiness

High temperatures significantly increased grain chalkiness across cultivars (Figure 9.4). Chalkiness differences between the control (CT) and high-temperature (HT) treatments ranged from 0.72–10.1% in 2015 and 0.1–10.8% in 2016. OM8923 (2015) and OM5981 (2016) showed the highest increases at 10.1% and 10.8% respectively, while OM2517, AS996, and OM6161 also showed notable increases. According to Wang et al. (2007), high temperatures during the ripening stage cause chalky grain by creating an imbalance in carbohydrate metabolism between sink and source. Figure 9.5 depicts the heading stage in the net house (control) and the temperature control chamber (treatment).

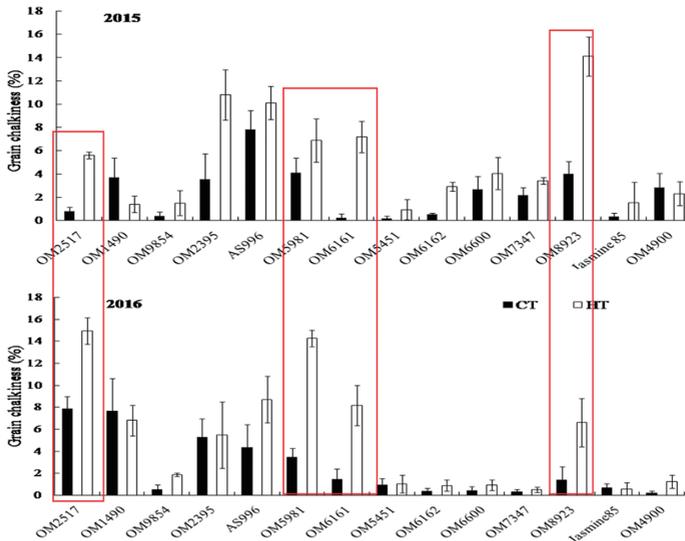


Figure 9.4. Effect of High Temperature on Percentage of Chalky Grains in Vietnamese Cultivars (vertical bar indicate SD of means (n=3))
Source: Author’s calculation

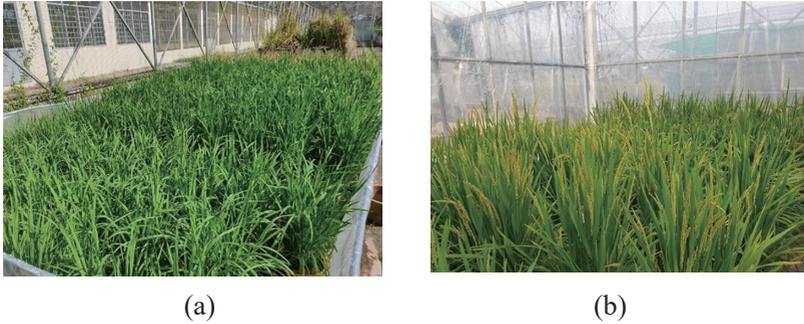


Figure 9.5. The Heading Stage in (a) Net house (Natural condition) and (b) Temperature chamber (High temperature treatment)
Source: Author’s experiment

(4) The Impacts of Temperature on Pollen Viability

Figure 9.6 depicts the relationship between temperature and pollen viability, showing the pollen viability percentage (A) and observed pollen viability by microscope in cultivar “OM5451” (B) according to different regimes at the flowering stage. Different letters indicate significant differences at $p \leq 0.05$.

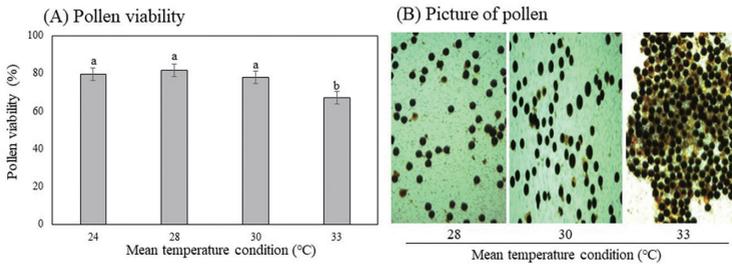


Figure 9.6. Temperature and Pollen Viability in Rice
Source: Author

Figure 9.7 depicts the pollen germination percentage (A) and observed pollen germination by microscope in cultivar “OM5451” (B) according to different regimes at the flowering stage. Different letters indicate significant differences at $p \leq 0.05$.

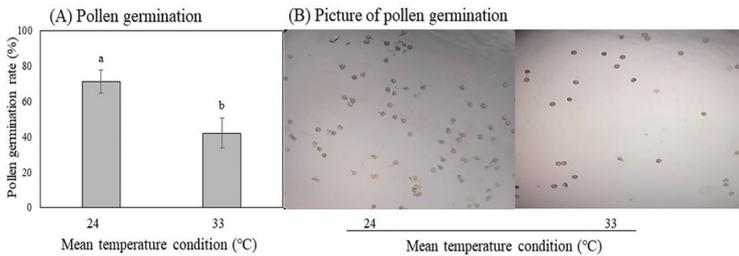


Figure 9.7. Temperature and Pollen Germination in Cultivar OM5451
Source: Author

Figure 9.8 shows the correlation between mean temperature and fertility rate (A), pollen viability (B). The correlation between the percentage of fertility rate and pollen viability (C).

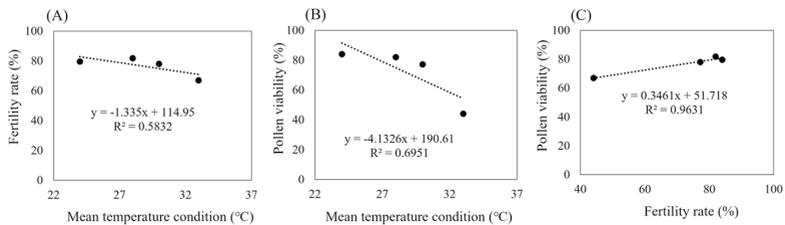


Figure 9.8. Relationship between Temperature and Fertility Rate and Pollen Viability, between Fertility Rate and Pollen Viability
Source: Author

(5) Rice Cultivation Strategy to Cope with High Temperature

1) Heat Tolerance Cultivars (HTC)

In tolerant genotypes, the large amount of pollen on the stigma appeared to compensate for reduced pollen growth under high temperature during the flowering stage (Mackill et al. 1982). Other varieties of high-temperature-tolerant cultivars dehiscence more easily than those of susceptible cultivars and contribute to pollination under high-temperature conditions (Satake and Yoshida 1978 and Mackill et al. 1982). The anther locule walls in HTC were thicker and better developed, which promoted pollen grain swelling by retaining water in the locules (Matsui et al. 2001). Some cultivars of the International Rice Research Institute (IRRI) showed adaptive ability to high temperature at the anthesis stage. Cultivar: IR86991-146-2-1-1 was found to be more tolerant to heat stress at the flowering stage with higher yield and pollen viability (80-100%) (Masuduzza et al. 2016).

2) Early Morning Flowering Trait

The timing of flowering during the day is important because spikelet sterility is induced by high temperatures during or 1–3 hours after anthesis in rice (Satake and Yoshida 1978). Some wild-type flowers are as early as 0600h (*Oryza officinalis*) or as late as 1700h (*Oryza australiensis*), with a few flowers during the night (Jagadish et al. 2015). In general, indica rice flowering peaks before 1200h and japonica rice flowering peaks after 1200h (Wang et al. 2019). In the report of Raju et al. (2017), a near-isogenic of early morning flowering line (IR64+qEMF3) effectively minimized spikelet sterility by 71% during the dry season under field conditions, compared to tropical and subtropical cultivars.

3) Crop Management

To reduce the canopy temperature during the flowering stage,

adjusting the rice planting and the microclimate in the field can also alleviate heat damage. Increasing the row spacing between rice plants is beneficial for air circulation in paddy fields, leading to a decrease in the canopy temperature (Wang et al. 2019). Moreover, some previous studies show that applying fertilizer management also mitigates the effects of high temperature during the flowering stage (Wang et al. 2019; Wu et al. 2013). Applied biochar and phosphorus fertilizer before transplantation alleviated the damaging effects of high temperature on pollen germination, another dehiscence, and greater pollen retention and germination (Shah et al. 2015). Micronutrient fertilizers (Silicon, KH_2PO_4 , ZnSO_4 , Na_2SeO_3) and natural abscisic acid can increase the capacity for spikelet fertilization under heat-stress conditions (Wang et al. 2019; Wu et al. 2013).

5. Conclusion

Our study found significant differences in grain yield between control (CT) and high temperature (HT) conditions. Under HT, we observed decreased panicles per m^{-2} , spikelets per panicle, and increased sterility in 2015–2016. Spikelet sterility was the primary factor reducing yield. OM1490, OM4900, OM5981, AS996, OM6162, and OM6161 showed high sterility sensitivity, while OM8923 and OM2517 demonstrated tolerance. HT also increased grain chalkiness in several cultivars, including OM8923, OM5981, OM2517, AS996, and OM6161. With Vietnam projected to see a 2.3°C temperature rise by 2100 and 10–20 more days above 35°C annually, these findings provide crucial insights for breeding heat-tolerant rice cultivars.

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*The Effect of High Temperature on Vietnamese Rice Cultivars and Rice Cultivation
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(in Chinese)*

9. Dr. Loc Thuy TRAN



Chapter 9. The Effect of High Temperature on Vietnamese Rice Cultivars and Rice Cultivation Strategy to Cope with High Temperature

Dr. Loc Thuy Tran is Deputy Head at the Agronomy Department, Cuu Long Delta Rice Research Institute. He received his master's and Ph.D. degrees in Agriculture from the Graduate School of Environmental and Life Science, Okayama University. He worked as a visiting researcher at the National Institute of Crop Science in Korea from April 2019 to January 2020. His research includes evaluating the effects of high temperature and salinity on OM rice; collaborating with local authorities, NGOs, and commercial companies to implement projects in CLLRI and the Mekong Delta; and managing Agronomy department projects related to alternative wet and dry irrigation techniques that reduce greenhouse gas emissions.