

## GENETIC VARIABILITIES OF AGRONOMIC TRAITS AND BACTERIAL LEAF BLIGHT RESISTANCE OF HIGH YIELDING RICE VARIETIES

### *Variabilitas Genetik Sifat Agronomis dan Ketahanan terhadap Penyakit Hawar Daun Bakteri pada Varietas Unggul Padi*

Nafisah<sup>a\*</sup>, Celvia Roza<sup>a</sup>, Nani Yunani<sup>a</sup>, Aris Hairmansis<sup>a</sup>, Tita Rostiati<sup>a</sup>, and Ali Jamil<sup>b</sup>

<sup>a</sup>Indonesian Center for Rice Research,  
Jalan Raya 9 Sukamandi, Subang 41256, West Java, Indonesia  
Phone: +62 260 520157, Fax: +62 260 520158

<sup>b</sup>Directorate General of Food Crops, Ministry of Agriculture, Republic of Indonesia

\*Corresponding author: [n.nafisah143@gmail.com](mailto:n.nafisah143@gmail.com)

Submitted 7 February 2019; Revised 16 October 2019; Accepted 14 November 2019

#### ABSTRACT

Hundred of high yielding and bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*, Xoo) resistant rice varieties released since the 1960s are important sources of genetic materials for exploring superior genotypes. The study aimed to evaluate the genetic resistance of 177 rice varieties to Xoo and their agronomic traits. The evaluations were conducted at the Indonesian Center for Rice Research Experimental Station during the wet season (December 2015-March 2016). The bacterial leaf blight resistance was evaluated for Xoo pathotypes III, IV, and VIII using the clipping method. The genetic variation among genotypes was categorized as low (0–10%), medium (10–20%), and high (>20%), whereas the heritability was categorized as low (0–30%), medium (30–60%), and high (>60%). The variability of resistance to Xoo pathotypes, grain yield, and spikelet fertility was low, while the variability of plant height, productive tiller number, filled grain, and total spikelet was medium, and the variability of unfilled grain number was high. The 29 varieties were categorized as superior based on their agronomic traits or resistance to Xoo pathotypes. In conclusion, Batutegi and Fatmawati were superior in the total spikelet number, while Rojolele and Inpari 2 were supreme in the thousand-grain weight. Dodokan had a very short maturity, and Inpari 24, Conde, Kalimas, Angke, Inpari 17, and Inpara 8 had the highest resistance to Xoo pathotypes. The study implies that the identified rice superior genotypes could be used as genetic materials to design cross combinations for higher yield potential and BLB resistance varietal improvement.

[**Keywords:** Inbred rice, plant resistance, *Xanthomonas oryzae* pv. *oryzae*]

#### ABSTRAK

Ratusan varietas unggul baru (VUB) padi tahan terhadap penyakit hawar daun bakteri (*Xanthomonas oryzae* pv. *oryzae* atau Xoo) yang sudah dirilis sejak tahun 1960-an merupakan sumber materi genetik penting dalam perakitan varietas unggul padi. Penelitian ini bertujuan untuk mengevaluasi sifat ketahanan terhadap patotipe Xoo dan sifat agronomis 177 VUB padi. Penelitian dilaksanakan di kebun percobaan Sukamandi, Balai Besar Penelitian Tanaman Padi pada musim hujan (Desember 2015-Maret 2016). Evaluasi sifat ketahanan terhadap Xoo

patotipe III, IV, dan VIII dilakukan dengan metode pengguntingan. Variabilitas genetik sifat-sifat genotipe yang diuji dikategorikan rendah (0–10%), sedang (10–20%), dan tinggi (>20%), sedangkan heretabilitas dikelompokkan menjadi rendah (0–30%), sedang (30–60%), dan tinggi (>60%). Variabilitas sifat ketahanan terhadap patotipe Xoo, hasil gabah, dan fertilitas malai termasuk rendah. Sementara itu variabilitas sifat tinggi tanaman, jumlah anakan produktif, jumlah gabah isi, dan jumlah gabah total tergolong medium, sedangkan variabilitas sifat jumlah gabah hampa termasuk tinggi. Sebanyak 29 VUB padi memiliki sifat superior berdasarkan sifat agronomis atau ketahanan terhadap patotipe Xoo. Varietas Batutegi dan Fatmawati memiliki keunggulan pada sifat jumlah gabah total, Rojolele dan Inpari 2 unggul dalam sifat bobot 1.000 butir gabah, dan Dodokan unggul dalam sifat umur sangat pendek. Sementara Inpari 24, Conde, Kalimas, Angke, Inpari 17, dan Inpara 8 memiliki sifat ketahanan tertinggi terhadap patotipe Xoo. Varietas yang memiliki sifat-sifat superior sangat potensial untuk digunakan sebagai materi genetik dalam merancang kombinasi persilangan untuk memperbaiki sifat potensi hasil tinggi dan ketahanan tanaman padi terhadap patotipe Xoo.

[**Kata kunci:** Padi inbrida, ketahanan tanaman, *Xanthomonas oryzae* pv. *oryzae*]

#### INTRODUCTION

Rice is one of the most important cereal crops within Asia where about 89% of the world's rice was produced (Milovanovic and Smutka 2017). It is a staple food for more than 80% of Indonesian people, accounting for 62.1% of the energy intake. The average consumption of rice in the period of 2013–2017 was at around 96.78 kg per capita (Hariyanto et al. 2018). Indonesian population projected to increase by 24.5% over the next four decades, from 250 million in 2015 to 311 million in 2050 (Trisia et al. 2016); therefore, it needs about 48.2 million tons of milled rice (The Ministry of Trade 2015).

Improving yield potential of crop varieties through plant breeding has been a critical component of global food security, especially for rice and the other major cereals (Khush 2013). In Indonesia, rice breeding programs started in the early 1900's, but only after the 1960's the breeding and selection techniques emphasized for good grain quality, high yield, short straw, and disease resistance (Harahap et al. 1972). High yielding rice varieties had an important role in increasing rice production and contributed to 56% of the national rice production, while the interaction of water management, yield, and fertilizer contributed up to 75% (Syahri and Sumantri 2016).

Bacterial leaf blight (BLB) caused by *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) is the main disease of rice, especially in Asia and Africa (Ronald 1997) that causes annual yield losses of 50% (Fred et al. 2016). In India, the yield losses due to BLB ranged from 65 to 95% (Nayak et al. 2008). In Indonesia, the yield losses in the wet season were 21–36%, while in the dry season ranged from 18 to 28% (Suparyono et al. 2004). The use of high yielding varieties (HYVs) and resistant to BLB is the most effective way to control the disease to minimize yield losses (Khush et al. 1989). However, to effectively control the BLB, breeders are challenged by the existing of multiple *Xoo* pathotypes. There were 11 *Xoo* pathotypes found and their distribution and dominance varied across times and locations (Ogawa 1993). Sudir et al. (2009) reported that the most dominant *Xoo* groups in Indonesia were pathotypes III, IV, and VIII. The pathotype III was dominant in Yogyakarta, South Sulawesi, and South Sumatra Provinces; the pathotype IV dominated in North Sumatra, Lampung, and West Nusa Tenggara; while the pathotype VIII was dominant in West Java, Banten, Central Java, and East Java (Sudir and Yuliani 2016).

To be able to develop a variety with a set of desirable characteristics, rice breeders need to be sure that the germplasm sources have desirable genetic variability (Guimaraes 2009). The choice of parents for the potential crosses was a key success to broaden a variability in particular traits (Janwan et al. 2013). The use of HYVs, valuable germplasm, as a donor or a recurrent parent for breeding program of a particular trait will be more easily and faster compared to local varieties and wild relatives. For further utilization in the breeding program, the thorough knowledge of the existing genetic variation for potential target traits was required (Wani and Khan 2006).

The history of rice breeding programs in Indonesia reviewed (Susanto et al. 2003). Indicated parents for rice breeding improvements originated from local varieties and international germplasm collections. At present about 5831 rice accessions are available as a germplasm

collection in the Indonesian Center for Rice Research/ICRR (Yunani and Satoto 2018), including 177 HYVs released in 1955–2015. These varieties, however have not been evaluated systematically for their resistance to *Xoo* pathotypes.

Various rice genotypes resistant to *Xoo* reported from different lines, i.e. 22 IRBB lines, five new high yielding varieties, 22 local varieties (Susanto and Sudir 2012), and some promising lines (Yuriyah et al. 2013). Local rice varieties resistant to *Xoo* identified from Banten (Ali et al. 2012), Sulawesi (Khaeruni et al. 2016), and Aceh (Hadianto et al. 2015). Although the resistance characteristics of released rice varieties showed to most dominant *Xoo* pathotypes, they might have no longer effective to control the BLB in the fields due to changing of new *Xoo* pathotypes (Sudir and Suprihanto 2006, Suprihatno et al. 2010, Susanto and Sudir 2012, Khaeruni et al. 2016).

Yield is a complex trait and a product of many related traits called yield components which are highly influenced by environments (Li et al. 1997, Zeng et al. 2017). Studying the genetic variability, in particular the heritability of yield-related traits will help to determine the usefulness of the germplasm for breeding and inform the selection of the most effective breeding strategies.

The variability and heritability of yields and yield components in rice found in certain  $F_2$  populations (Kristamtini et al. 2016, Widyayanti et al. 2017), local varieties (Ahmad et al. 2015, Buhaira et al. 2014, Zein 2012), and some upland rice varieties (Faiqon et al. 2017, Faiqon et al. 2017). However segregant population has been reported by Nafisah et al. (2007) and Habarurema et al. (2012). Sitaresmi et al. (2018) also reported the morphological similarity of irrigated and upland rice varieties, but little information on the relationships of *Xoo* resistance and their agronomic traits found elsewhere. The study aimed to evaluate the genetic resistance to *Xoo* and agronomic traits of 177 rice varieties. Information obtained from this study may be useful for further genetic improvement programs of resistant and high yielding rice varieties.

## MATERIALS AND METHODS

### Experimental Site

The field trial was conducted at the Indonesian Center for Rice Research (ICRR) experimental station at Sukamandi, Subang, West Java [6°21'10" and 107°39'20"; 14 m above sea level] during the wet season from December 2015 to March 2016. The microclimate conditions during the experiment were recorded air temperature (24.67–32.01°C), humidity (47.37–75.37%),

rainfall (227.20 mm), wind speed ( $6.16 \text{ ms}^{-1}$ ), and global solar radiation ( $557.81 \text{ MJ m}^{-2} \text{ day}^{-1}$ ) (ICCR wheater station)

### Plant Materials

A total of 177 HYVs of rice representing different agroecosystems (irrigated, upland, rainfed and swampy) released in 1955–2015 (Hermanto et al. 2009, Suprihatno et al. 2010, Wahab et al. 2017) were evaluated. They were inbred rice varieties obtained from the ICRR working collection (supplementary material).

### Field Experiment

The trial was conducted under an irrigated condition and arranged in a randomized block design with three replications. The 21 old seedlings (the day after sowing) were planted in  $0.5 \text{ m} \times 5 \text{ m}$  plot size with  $25 \text{ cm} \times 25 \text{ cm}$  planting space. The agronomic practices followed the standard practical procedure. The fertilizer dosage of 300 kg urea, 100 kg SP36, and 50 kg KCl per ha were applied three times at 14, 28, and 35 days after transplanting. Main pests and diseases were intensively controlled following the principle of integrated pest and disease management.

### BLB Resistance Evaluation

*Xanthomonas oryzae* pv. *oryzae* (*Xoo*) pathotypes III, IV and VII, the most dominant pathotypes in Indonesia (Sudir et al. 2009), were collected from ICRR Plant Pathology Laboratory and used in the resistance screenings at the generative stage (the panicle initiation stage, 50 days after transplanting) under field conditions. To prepare the inoculum, *Xoo* isolates stored in the glycerol at a constant temperature of  $-20^{\circ}\text{C}$  were streaked on nutrient agar plates and grown at  $27\text{--}30^{\circ}\text{C}$  for 48 hours. The cultures were suspended in sterilized distilled water and adjusted spectrophotometrically to a concentration of  $10^9 \text{ cfu ml}^{-1}$  ( $\text{OD} = 0.3$  at  $600 \text{ nm}$ ). Six rice plants having five leaves were selected from each genotype tested then inoculated with each pathotype of *Xoo* following the previous method (Kauffman et al. 1973). The BLB infection was evaluated at two weeks after inoculation following the Standard Evaluation System (SES) for Rice (International Rice Research Institute 2014) (Table 1).

### Agronomic Characterization

The agronomic traits evaluated were grain yield, plant height, productive tiller number, heading date, unfilled and filled grain number per panicle, panicle fertility, and

**Table 1. Bacterial leaf blight resistance criteria of rice genotypes used in the study (IRRI 2014).**

Scale	Percentage of lesion length (%)	Category
1.	1–5	Resistant
3.	6–12	Moderately resistant
5.	13–25	Moderately susceptible
7.	26–50	Susceptible
9.	51–100	Highly susceptible

thousand-grain weight (IRRI 2014). The grain yield was determined from a single row plot with the moisture content adjusted to 14%. Five hills per plot representing each plot and each variety were measured for their plant height, productive tiller number, and filled and unfilled grain number. The plant height was measured from the ground to the tip of the highest panicle. The heading date was calculated from the time of sowing to 50% of plants in each plot were flowering. The unfilled grains or filled grains per panicle were the totals of unfilled or filled grain number divided into the productive tiller number. The panicle fertility was calculated from percentage of the number of filled grains to the total number of filled grains and unfilled grains. The thousand-grain weight was measured from 1000 selected filled grains.

### Data Analysis

The variance and the principal component analysis were done using the statistical tool IRRISTAT 7.02 and STAR nebula 2013 (Statistical Tool for Agricultural Research), respectively. The genetic variations amongst the genotypes were assessed based on the following parameters, i.e., phenotypic ( $\sigma_p^2$ ) and genotypic variance ( $\sigma_g^2$ ) (Singh and Chaudary 1985) and categorized as low (0–10%), medium (10–20%), and high (>20%) as indicated by Sivasubramanian and Menon (1973), whereas the heritability was categorized as low (0–30%), medium (30–60%), and high (>60%) (Johnson et al. 1955)

## RESULTS AND DISCUSSION

### Bacterial Leaf Blight Resistance

Normally, HYV resistance to BLB had been evaluated before varietal release and documented in Decree of Varietal Release. However, information on HYV resistance to BLB for varieties released before 2002 was very general, without specified the kind of *Xoo* pathotypes (supplementary material). The development of science and technology made plant pathologists

able to identify different *Xoo* pathotypes and found the most dominant pathotype in Indonesia. (Kementerian Pertanian 2018).

The percentage of lesion length showed that most Indonesian HYVs had moderate resistance to *Xoo* pathotype III (score 1–3), and susceptible (score 1–7) to both pathotypes IV and VIII. Three main *Xoo* isolates used in this study (pathotype III, IV and VIII) were the most dominant pathotypes in the paddy field. pathotype III was less virulent than pathotype VIII and the most virulent was pathotype IV (Suparyono et al. 2004). All Indonesian HYVs were either resistant or moderately resistant to pathotype III. On the other side, most HYVs were moderately susceptible against pathotype VIII and either moderately susceptible or highly susceptible to pathotype IV, and only several varieties were resistant to the pathotype.

We identified Kalimas as a resistant variety to three *Xoo* pathotypes (III, IV and VIII), suggesting their new information to enrich the ICRR database (ICRR 2019). Interestingly, Kalimas was released for its advantage as resistance to the tungro virus and originated IRRI lines (Suprihatno et al. 2010).

The result showed some changes in HYVs resistance to BLB especially to pathotype IV and VIII (supplementary material). Some varieties earlier reported to be resistant against pathotype IV and VIII like Ciherang, Inpari 1, Inpari 6, Inpari 11, Inpari 25, Inpari 31, and Inpari 33 (Hermanto et al. 2009, Suprihatno et al. 2011, Wahab et al. 2017), were no longer resistant to the two pathotypes. Inpari 33 had shorter durability of resistance compared to Inpari 32. Although the Inpari 32 and Inpari 33 released in the same year, however: Inpari 32 still showed moderate resistance to pathotype VIII, while Inpari 33 became susceptible (supplementary material). The breakdown of Inpari 33 resistance was probably due to the changes in pathotype virulence, as commonly happen to crop-pathogen. Also Ciherang was reported to be susceptible to pathotype IV and VIII in the previous study (Susanto and Sudir 2012), while IR36 released in 1978 became susceptible to pathotype IV in 1982. The durability of variety resistance to *Xoo* pathotype influenced by the period of the varietal development (Sudir and Suprihanto 2006). In contrast, several varieties earlier reported to be susceptible to pathotype VIII became resistant to moderately resistant, such as Inpari 24, Inpari 29, and Inpari 30. It supposed that the homozygous locus controlling the resistance to the *Xoo* had not fixed when they were tested. The selection during seed development and advanced generations may enhance the level of homozygous of desirable genes. The duration of rice resistance to *Xoo* pathotypes was affected by the speed of strain change, composition and dominance of strains, frequency of planting, and composition of varieties with

different gene backgrounds planted in a given time (Ogawa 1993).

Out of 177 varieties, twenty varieties were resistant to *Xoo* pathotype VIII and five varieties were resistant to *Xoo* pathotype IV (Table 2). Five varieties resistant to three *Xoo* pathotypes had IR64 genetic background and supposed carried *xa5* and *Xa7* genes. The existence of *xa5* and *Xa7* genes in Conde and Angke confirmed by Tasliah (2012), while the resistant genes in Inpari 24 was derived from BIO 12-MR-1-4-PN-6 and red rice (local varieties). Bio12 was a double haploid line derived from IR64 and *O. rufipogon* conferring *Xa21* and *Xa23* genes (Kadir et al. 2009). IR64 was one of the predominant rice varieties planted by farmers (Mackill and Khush 2018), however its *Xa4* was susceptible to the *Xoo* isolates from Indonesia (Qi and Mew 1989). It supposed that Inpara 8 and Inpari 24 also conferred the *Xa4* gene; however, the presence of other resistant genes in the plant improves the varietal resistance. Tasliah (2012) found that the most important *Xa* genes in Indonesia were *xa5*, *Xa7*, and *Xa21*. Furthermore, pathogenicity tests of the *Xoo* isolates showed that *xa5*, *Xa7*, and *Xa21* resistance genes were still effective against BLB pathogens originated from West Sumatra, West Java, Central Java, South Sulawesi, and West Kalimantan (Tasliah et al. 2013). Notable that this study results could enrich the data of HYV resistance to BLB and update their status in Indonesia, indicating their usefulness for recommending farmers to plant the varieties in BLB endemic areas (Sudir et al. 2012, Yuliani et al. 2017).

The useful life span for many resistant cultivars is only few years due to the resistance breakdown. The resistance to *Xoo* pathotype is one of the important factors for HYV to be utilized by farmers. Regardless of their effectiveness, *Xoo* pathotype IV had virulent genes that able to break the resistance of *Xa1*, *Xa2*, *Xa4*, *Xa7*, *Xa10*, *Xa11*, and *Xa14* genes. While pathotype VIII could break the resistance of *Xa1*, *Xa2*, *Xa3*, *Xa4*, *Xa7*, *Xa10*, *Xa11*, and *Xa14* genes (Hifni and Kardin 1998). Therefore, it was very important to pyramide those three effective genes (*xa5*, *Xa7*, and *Xa21*) to have the durable resistant variety. Varieties widely adopted by farmers like Ciherang, IR64, Mekongga, Situbagendit, and Cigeulis (Ruskandar 2015) had at least moderate resistance to pathotype IV when released.

### Grain Yield and Yield Components

Grain yield ranged from 3.17 to 9.52 t ha<sup>-1</sup>, and most varieties produced grains of 6–7 t ha<sup>-1</sup>. The highest and lowest grain yield were Ciherang and Dandang, respectively. Six varieties (Cigeulis, Adil, Situgitung,



**Table 2. The high yielding varieties of rice resistant to moderately resistant to at least two pathotypes of bacterial leaf blight (BLB).**

Entry#	Variety name	Year <sup>1</sup> released	Agro- ecosystem <sup>1</sup>	Genetic background	Resistance to BLB (varietal description data) <sup>a</sup>				Current data of resistance to BLB		
					RIII	RIV	RVIII	Not specify	RIII	RIV	RVIII
13	Gajah Mungkur	1994	Upland	IRAT 112	-	-	-	na	3	5	3
20	Conde	2001	Irrigated	IR64 <sup>*6</sup> /IRBB7	R	R	R		1	1	3
26	Inpago 6	2010	Upland	IRAM2165/NC1281	-	-	-	na	1	5	3
47	Inpara 4	2010	Swampy	IR49830-7-1-2-3/ <sup>3</sup> Swarna	-	R	R		1	5	3
50	Inpara 8	2014	Swampy	IRBB7/Cinglone//Memberamo/IR64	R	MR	MR		1	3	3
59	IR36	1978	Irrigated	IR1561-228//4*IR24/O.nivara///CR94-13	-	-	-	R	3	7	3
61	IR42	1980	Irrigated	IR2042/CR94-13	-	-	-	R	3	5	3
98	Digul	1996	Irrigated	IR196441/IR64//IR196441	-	MR	-		3	5	3
105	Kalimas	2000	Irrigated	PSBRC2/IR39292-142-3-2-3	-	-	-	na	1	3	3
109	Angke	2001	Irrigated	IR64 <sup>*6</sup> /IRBB5	R	R	R		1	3	3
110	Ciujung	2001	Irrigated	IR64/RP1837-715-3-2	R	R	R		1	5	3
125	Logawa	2003	Irrigated	Cisadane/Bogowonto// <sup>2*</sup> Cisadane	R	-	-		1	5	3
152	Inpari 16	2011	Irrigated	Ciherang/ Cisadane// Ciherang	R	MS	MS		3	7	3
153	Inpari 17	2011	Irrigated	Bio9-MR-V3-11-PN-5// IR64*3/IRBB21	R	R	R		1	3	3
159	Inpari 23	2012	Irrigated	B11738RS(Gilirang/ BP342F-MR-1-3// Gilirang)	R	MR	S		3	5	3
160	Inpari 24	2012	Irrigated	Bio 12 – MR-1-4-PN-6/ Beras Merah	R	MR	MS		1	1	1
165	Inpari 29	2012	Irrigated	IR69502-6-SKN-UBN-1-B-1-3/KAL- 9418F//Pokhali/Angke	MS	S	S		1	5	3
166	Inpari 30	2012	Irrigated	Ciherang/IR64 sub1//Ciherang	MS	S	S		3	5	3
168	Inpari 32	2013	Irrigated	Ciherang/IRBB64	R	MR	MR		1	5	3
173	Inpari 43	2015	Irrigated	Wu Feng Zhan/IRBB5//Wu Feng Zhan	R	MR	MR		3	3	3

Remark a\*: Hermanto et al. (2009), Suprihatno et al. (2010) and Wahab et al. (2017)

Na = not available, R = resistant, MR = moderately resistant, S = susceptible,

score 1 = resistant, 3 = moderately resistant, 5 = moderately susceptible, 7 = susceptible

Cirata, Bahbutong, Tukad Balian, Gajah Mungkur, and Inpari 26) produced grains of 8 t ha<sup>-1</sup>.

Ciherang and Cigeulis were the major varieties adopted by farmers showing their wide adaptability. Ciherang and Cigeulis occupied about 47.6% and 3.15% of rice irrigated area, respectively (Ruskandar 2015). While Situgintung, Cirata, Bahbutong, and Gajah Mungkur were the old upland rice varieties (Hermanto et al. 2009). Both Inpari 26 and Tukad Balian released in the same decade with Ciherang, and Adil was very old irrigated rice varieties. The yield performance in this study supported the stagnant yield of modern rice varieties (Peng et al. 1999, Peng et al. 2000).

Yield components observed in this trial included plant height, productive tiller number, heading date, total grain number, spikelet fertility, and thousand-grain weight. Plant height represented the stature of the plant. IR36, the first semi-dwarf variety adopted by farmers in Indonesia, had the lowest plant height (93 cm), while Remaja was the highest (175 cm). Under the irrigated condition, the taller variety

might have more susceptible to lodging. Ciherang, the most popular rice variety under irrigated condition had 123 cm plant height. In the past decades, upland rice varieties had taller plant height compared to irrigated variety, however, in the recent decade, the breeder tends to develop shorter varieties (supplementary material). Thus, different agroecosystems might have different preferences for plant height.

Productive tiller number of HYVs ranged from 9 to 21 tillers, with an average of 16 tillers. Batutegi was the least, and Cisokan was the most. Tiller number for most varieties ranged from 13 to 17 tillers. There was no variety with tiller number significantly higher than that of Ciherang (19 tillers). Productive tiller number was the important yield component that determined grain yield. Yuan (2017) proposed that to reach a yield potential up to 15 t ha<sup>-1</sup>, the productive tiller number per square meter should be 250 tillers. Therefore, using 25 cm x 25 cm planting spacing, the average of productive tiller number per plant should be not less than 16 tillers.

Plant growth duration is a very important trait that determines grain yield in HYVs. The heading date affected biomass production. Varieties with longer growth duration will have a chance to produce higher biomass (Peng et al. 1999, Yuan 2017). Generally, the local variety had a long growth duration compared to HYVs. The heading date of HYVs ranged from 69 to 99 days with 82 days on average. Dodokan had the shortest and Inpara 4 had the longest heading date. In this study, the heading date for Ciherang was 76 days, even most Indonesian rice varieties had 75–90 days.

Total grain number per panicle ranged from 85 to 319 grains, the highest was Batutugi and the lowest was Inpari 2. The grain number of Ciherang was 148 grains. Three varieties (Batutugi, Inpari 42, and Inpari 43) had a grain number significantly higher than that of Ciherang (>188 grains). Out of 177 HYVs, 60 varieties had a total grain number higher than that of Ciherang.

The spikelet fertility ranged from 50.23 to 90.84%, the highest was Yuwono and the lowest was Lusi. There was no variety with spikelet fertility significantly higher than that of Ciherang. However, two varieties had spikelet fertility more than 90% (Yuwono and Inpari 42). Out of 177 HYVs, 37 varieties had spikelet fertility similar to Ciherang.

Thousand-grain weight of HYVs ranged from 19.07 to 37.4 g, with an average of 28.1 g. Batur had the lowest and Rojolele had the highest thousand-grain weight,

while Ciherang had 26.90 g. Three varieties, Gajah Mungkur, Inpari 2, and Rojolele, had a thousand-grain weight higher than 35 g. These varieties were very potential as a donor to increase grain yield by improving panicle weight. Thousand-grain yield or panicle weight is a very important trait determining the yield potential (Yuan 2017). This study demonstrated that several superior yield component traits better than those of Ciherang existed among the HYVs evaluated which was potential for improving yield potential and BLB resistance.

### Phenotypic and Genotypic Variability

The phenotypic coefficient of variation (PCV) of HYVs was low for resistance to *Xoo* pathotype IV and VIII and heading date; medium for resistance to pathotype III, plant height, productive tiller number, spikelet fertility, and thousand-grain weight; and high for filled grain number, unfilled grain number, total spikelet number, and grain yield. While the genetic coefficient of variation (GCV) was low for resistance to all three pathotypes, heading date, spikelet fertility, thousand-grain weight, and grain yield; medium for plant high, productive tiller number, filled grain number, and total spikelet number; and high for unfilled grain number (Table 3). The estimated PCV was higher than GCV for all the traits indicating greater environmental

**Table 3. Mean squares, genotypic coefficient of variation, phenotypic coefficient of variation for bacterial leaf blight resistance, yield and yield components of some high yielding rice varieties.**

Varian source	Race 4 <sup>T</sup>	Race III <sup>T</sup>	Race VIII <sup>T</sup>	Plant height	Prod tiller number	Heading date	Unfilled grain	Filled grain	Total spikelet number	Spikelet fertility	Thousand grain weight	Grain yield per ha
Variety	0.16**	0.22**	0.14**	536.01**	12.34**	83.85**	568.21**	1281.71**	1977.88**	184.09**	24.48**	2.55**
Block	0.78**	2.00**	1.11**	89.75 <sup>ns</sup>	161.84**	0.38 <sup>ns</sup>	34225**	4108**	13859.2**	452.70**	0.48 <sup>ns</sup>	5.30*
Error	3.78E-02	7.00E-02	4.99E-02	32.73	3.84	4.8	202.21	498.41	651.96	74.06	3.8	1.37
Total	8.18E-02	0.13	8.45E-02	200.01	7.25	32.24	337.19	767.44	1146.74	112.39	10.51	1.7
CV (%)	8.7	18.3	10.9	4.7	12.4	2.7	41.66	20.8	18.01	11.3	6.9	18.2
LSD <sub>5%</sub>	0.31	0.42	0.36	9.19	3.15	3.52	22.83	35.85	41.16	13.8	3.13	1.88
Ranged	1-7	1-3	1-6	93-175	9-21	62-100	4-139	59-218	63.2-319	40.94-96.41	19.06-37.34	3.17-9.52
Stdev	9.90E-01	0.72	8.10E-01	13.38	2.04	5.66	18.28	20.63	33.70	10.55	2.86	0.92
Mean	5.15	2.2	4.27	122.12	15.81	82.01	34.14	107.6	141.75	76.19	28.1	6.44
$\sigma_p^2$	0.08	0.12	0.08	200.49	6.67	31.08	322.03	759.51	1082.55	135.43	10.70	1.76
$\sigma_g^2$	0.04	0.05	0.03	167.76	2.83	26.28	119.92	261.10	425.36	61.36	6.89	0.39
Heritability (%)	0.52(M)	0.42(M)	0.38(M)	0.84(H)	0.42(M)	0.85(H)	0.37(M)	0.34(M)	0.44(M)	0.45(M)	0.64(H)	0.22(L)
GCV	4(L)	10(L)	4(L)	11(M)	11(M)	6(L)	32(H)	15(M)	15(M)	8(L)	9(L)	10(L)
PCV	6(L)	16(M)	7(L)	12(M)	16(M)	7(L)	53(H)	26(H)	23(H)	14(M)	12(M)	21(H)

<sup>T</sup>=sqrt transformation \*\* different at P < 0.01, \* different at P < 0.05, <sup>ns</sup> = not significantly different; GCV = genotypic coefficient variation, PCV = phenotypic coefficient variation, L = low, M = medium, H = high

influence on these traits for total variation. High GCV and PCV indicated that selection might be effective based on these characters and their phenotypic expression would be a good indication of the genotypic potential (Singh et al. 2011, Asante et al. 2019)

The low GCV suggested the low variability for these characters in the present experimental materials and, therefore the little scope for improvement of these traits (resistance to *Xoo* pathotypes III, VIII, and IV, heading date, spikelet fertility, thousand-grain weight, and grain yield). Introducing the different genetic resources instead of using the existing varieties as donor parents is very crucial. The low genetic variability for resistance to *Xoo* pathotypes in HYVs supposed due to the same genes involved controlling the HYVs resistance, which was *xa5*, *Xa7* and *Xa21*. Currently, 40 genes conferring resistance to various *Xoo* pathotypes have been designated in a series from *Xa1* to *Xa43* (Kim and Id 2019), and some have been introgressed to IR24 genetic background as isogenic lines (IRBB lines). Susanto and Sudir (2012) reported the resistance of 22 IRBB lines to three dominant *Xoo* pathotypes. Among them, there was no line resistant to one of the three pathotypes except IRBB 10 which showed moderately resistant to pathotype III. Some new series of IRBB lines identified more effective genes for three pathotypes of *Xoo*.

Yield is a complex agronomic trait controlled by multiple genes but primarily determined by three-component traits such as filled grain number per panicle, panicle number per plant, and thousand-grain weight (Wang et al. 2014). Based on the result of GCV in this study, improvement of grain yield using the existing varieties as parents will be effective by increasing productive tiller number, filled grain number, and total spikelet number and lowering unfilled grain number.

### Heritability

Estimation of heritability and genetic advance is essential for the selection based on phenotypic expression (Johnson et al. 1955). Heritability plays a key role in the selection based on improvement of a crop because it implies the extent of transmissibility of traits into the next generations (Mazid et al. 2013, Wang et al. 2014). Thus, high heritability coupled with high genetic advance could be the key target of selection based on the morphological traits. If the heritability of a character is high, then selection for such character could be fairly easy due to the relatively small contribution of the environment to the phenotype. On the other hand, for characters with low heritability, selection may be considered difficult or virtually impractical due to the masking effect of the environment (Singh et al. 2011).

In this study, the broad-sense heritability estimate for resistance to BLB for all three *Xoo* pathotypes (III, IV, VIII) in HYVs was medium. The study is the first to report the heritability for resistance to three *Xoo* pathotypes in HYVs. Several studies reported the wide range of broad-sense heritability (-0.19%; 0.30%; 0.65%) for BLB resistance in three populations with different genetic backgrounds (Nafisah, Daradjat and Suprihatno 2007) and in  $F_2$  populations derived from Nerica's resistant varieties and common susceptible HYVs (Habarurema et al. 2012). The high heritability in the segregation population enhances the possibility of selecting plants for superior resistance.

The heritability estimate resulted from this study was high for plant height, heading date, and thousand-grain weight; medium for productive tiller number, total spikelet number per panicle, filled grain number, unfilled grain number and spikelet fertility; and low for grain yield. This results was conformity with the finding of Sohrabi et al. (2012), Zein (2012), Mazid et al. (2013), Oladosu et al. (2014), and Ahmad et al. (2015) for heading date, thousand-grain weight, total spikelet number per panicle, filled grain number, unfilled grain number and spikelet fertility; Mazid et al. (2013), Ahmad et al. (2015)), and Bagati et al. (2016) for tiller number and thousand-grain weight; and Li et al. (1997) and Asante et al. (2019) for the grain yield. The low heritability in grain yield indicated that the epistasis might control grain yield (Li et al. 1997). The high heritability indicated a preponderance of additive gene action in the expression of the traits mentioned above. Therefore simple selection is effective in an early generation. The low heritability estimate indicated the influence of the non-additive gene controlling the trait and confirmed an effective selection of superior genotypes in advanced generations when the maximum homozygosity is fixed (Habarurema et al. 2012).

### Phenotypic Similarity

Principle component analysis (PCA) was used to assess the genetic diversity of quantitative traits. Eight important traits, including resistance to *Xoo* pathotypes (III, VIII and IV), plant height, tiller number, heading date, total spikelet fertility, spikelet fertility, thousand-grain weight, and grain yield were chosen to reveal the phenotypic similarity among the HYVs using PCA.

Three PCA explained 59% of the variance, and four PCA accounted for 70% of the variance. The eigenvector showed that the first principle component was strongly correlated with the increased scale of resistance to all *Xoo* pathotypes (IV, III, and VIII), plant height (PH), and grain yield (GY). Increase in scale of

resistance associated with an increase in susceptibility to BLB. While the second principal component was strongly correlated with plant height (PH), total spikelet number (TSN), heading date (HD), and spikelet fertility (FER). The third principle component was strongly correlated with tiller number (TN), heading date (HD), spikelet fertility (FER), and thousand-grain weight (Table 4), while the fourth PC highly correlated with thousand-grain weight (TGW).

The adjacent genotypes have a higher similarity than those far apart. The magnitude of genetic variability showed that the genotypes with high positive PCA1 had more GY, higher PH, but more susceptible to BLB (pathotype III, IV, and VIII), whereas the those with high positive PCA2 had higher PH, HD, TSN, less TN, and fertility. Biplot for PCA1 and PCA2 showed that genotype 19 (Bututeji) was superior in TSN and PH. The genotype 10 (Situgintung) was superior in PH. Both genotype 1 (Jelita) and 5 (Ranau) had similarities in TSN (Figure 1). High PCA3 score correlated with long growth duration or longer HD, high TN, less FER. Genotype 7 (Batur), 82 (C-22), 28 (Barito), 47 (Inpari 4), and 35 (Batanghari) had long growth duration, more tiller number, and less spikelet fertility (Figure 2). Some varieties with excellent agronomic traits are very potential as donor parents for particular (Table 5).

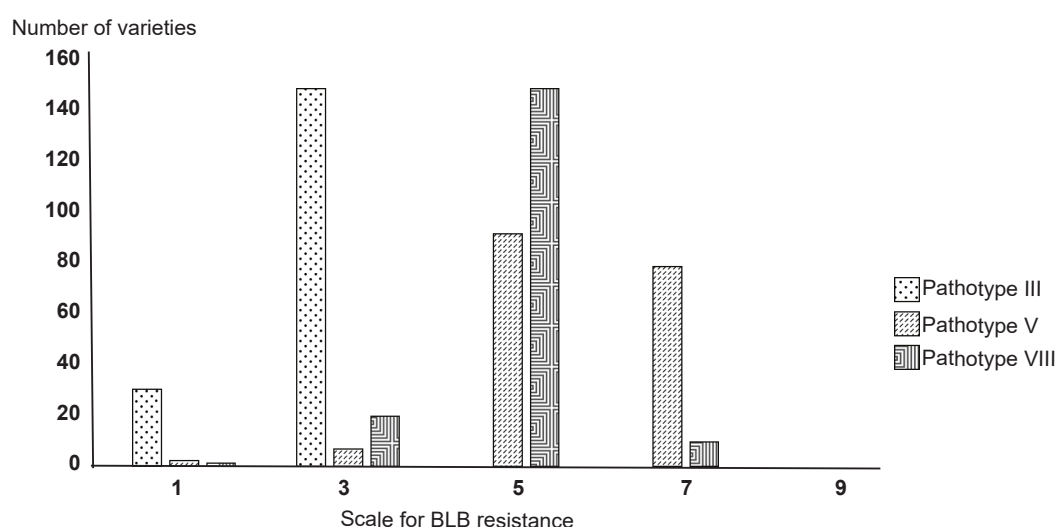
Several superior rice varieties such as Inpari 42 (genotype 173) and Inpari 43 (genotype 174) had been introduced in Indonesia in 2009 under Green Super Rice Program. These varieties showed good adaptability and high yield in some regions in Indonesia and recent days have been under dissemination to the farmers. Our study revealed that both Inpari 42 and Inpari 43 showed a higher total grain number and high fertility.

Generally, our finding showed that Indonesian HYVs harbor a wide range of genetic variation. Several of HYVs identified for specific traits that may have some potential value to improve the HYVs rice resistant to BLB. Many traits had the GCV of more than 10% such as plant height, filled grain number, and total spikelet fertility, and the highest GCV (32%) confirmed for unfilled grain number. Using a genotype with a high grain yield, high spikelet fertility, high total spikelet number, less unfilled grain number as a donor may improve the yield potential.

The unfilled grain in rice is a complex trait, the end of product controlled by physiological traits such as grain filling, photosynthesis rate, and environmental factors.

**Table 4. Eigenvectors for yield and yield components of high-yielding rice varieties and resistance to bacterial leaf blight.**

Variables	PC1	PC2	PC3	PC4	PC5
Resistance to BLB					
Race IV	0.48	-0.23	0.22	-0.03	0.20
Race III	0.50	-0.13	0.16	-0.01	-0.02
Race VIII	0.47	-0.23	0.28	0.05	0.06
Plant height	0.33	0.47	-0.09	0.13	0.16
Tiller number	-0.25	-0.34	0.45	-0.01	-0.35
Heading date	-0.14	0.33	0.47	0.23	-0.08
Total spikelet number	0.17	0.56	0.01	-0.37	-0.07
Spikelet fertility	0.02	-0.32	-0.46	-0.43	0.14
Thousand-grain weight	0.08	-0.09	-0.38	0.78	0.00
Grain yield	0.29	0.04	-0.25	-0.03	-0.88



**Figure 1.** Distribution frequency of high yielding rice varieties for resistance to three pathotypes of bacterial leaf blight (BLB); resistance scale: 1 = resistant; 3 = moderately resistant; 5 = moderately susceptible; 7 = susceptible; 9 = highly susceptible.



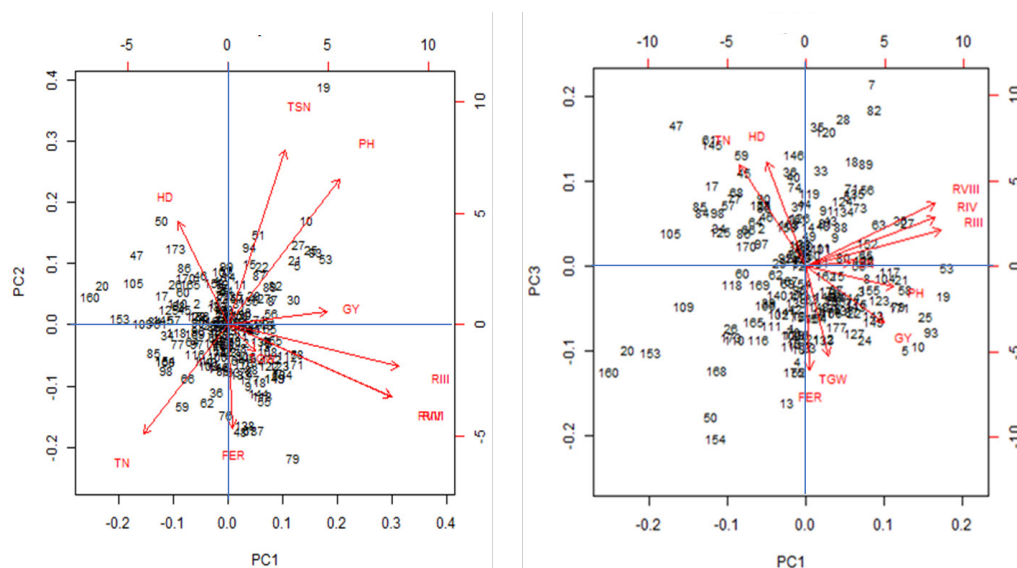


Figure 2. Biplot for PCA 1 and PCA2 (left side), PCA1 and PCA3 (right side) for bacterial leaf blight resistance, yield and yield components of high-yielding rice varieties

Table 5. Superior agronomic traits of high yielding rice varieties

Character	Variety	Range
Yield (t ha <sup>-1</sup> )	Ciherang, Adil, Bahbutong, Tukad Balian, Cirata, Situgintung, Cigeulis, Inpari 26	8–9.5
Long duration (das)	Cirata, Inpara 4	97–99
Short duration (das)	Dodokan, Silugonggo, Inpari 18	62–69
Productive tiller number	Cisokan, Inpari 9 Elo, IR36, Adil, Indragiri, Inpara 2	20–21
Total spikelet number	Batutegi, Inpari 43, Inpari 42, Fatmawati, Wayrarem, Situgintung	200–319
High spikelet fertility (%)	Yuwono, Inpari 42, Mekongga	90
Thousand-grain weight (g)	Rojolele, Inpari 2, Gajah Mungkur	35–37

Improving rice yield potential has been the main breeding objective in many countries years, and many scientists proposed different strategies. In Indonesia, breeding for new plant type (NPT) has been done and successfully released Fatmawati variety in 2003. However, the variety was not successfully adopted by farmers because it had a high unfilled grain, rapid leaf senescence, poor grain filling, and less panicle number (Makarim and Ikhwan 2010). According to Liang et al. (2017), there was no fixed model for describing a perfect combination of plant type, leaf morphology, spike size, and grain number, especially when considering ecological conditions. The model should follow the principle and maintaining of source-sink and maximize the use of light energy based on large panicle type.

Overall, this study could revealed several potential parents amongst HYVs improving yield and resistant of rice to Xoo pathotypes. To have more comprehensive information on influence of environments factor to the agronomic traits and response to BLB disease, a study should be done in multiple environments and several seasons.

## CONCLUSION

Several high yielding rice varieties had superior yield-related traits which were potential as a donor for improving grain yield and resistance to BLB. Ciherang had the highest grain yield, Rojolele had the heaviest thousand-grain weight, Yuwono had the highest fertility, Batutegi was a potential donor for total spikelet number, Cisokan had the highest tiller number, Dodokan and Inpari 18 had the shortest growth duration, Cirata and Inpara 4 had the longest growth duration, while Inpari 24, Conde, Angke, Kalimas, Inpari 17 and Inpara 8 were resistant to Xoo pathotype III, IV and VIII. Overall the genotypic coefficients of variations among the traits were low to medium. An effort to explore and introduce some germplasm from different source genes is needed to broaden the genetic variability.

## ACKNOWLEDGMENTS

The authors would like to thank Mr M. Ramdan K and Ms Euis and all persons who involved in the field research. The study was financially supported by the Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture, Republic of Indonesia.

## REFERENCES

- Ahmad, F., Hanafi, M.M., Hakim, M.A., Rafii, M.Y., Arolu, I.W. & Abdullah, S.N.A. (2015) Genetic divergence and heritability of 42 coloured upland rice genotypes (*Oryza sativa*, L.) as revealed by microsatellites marker and agro-morphological traits. *PLoS One*. [Online] (September 22), 1–18. Available from: doi:10.1371/journal.pone.0138246.
- Ali, S.F., Hastuti, D. & Saylendre, A. (2012) Uji ketahanan 10 tanaman padi varietas lokal Banten terhadap penyakit hawar daun bakteri (*Xanthomonas oryzae* pv. *oryzae*) pada fase persemaian. *Jurnal Agroekoteknologi*. [Online] 4 (1), 1–7. Available from: doi:http://dx.doi.org/10.33512/j.agrtek.v4i1.612.
- Asante, M.D., Adjah, K.L. & Annan-afull, E. (2019) Assessment of genetic diversity for grain yield and yield component traits in some genotypes of rice (*Oryza sativa* L.). *Journal of Crop Science and Biotechnology*. [Online] 2019 (10), 123–130. Available from: doi:10.1007/s12892-019-0008-0.
- Bagati, S., Singh, A.K., Salgotra, R.K., Bhardwaj, R., Sharma, M., Rai, S.K. & Bhat, A. (2016) Genetic variability, heritability and correlation coefficients of yield and its component traits in Basmati rice (*Oryza sativa* L.). *Sabara Journal of Breeding and Genetics*. 48 (4), 445–452.
- Buhaira, Nusifera, S., PL, A. & Alia, Y. (2014) Penampilan dan parameter genetik beberapa karakter morfologi agronomi dari 26 aksesori padi (*Oryza Spp* L.) lokal Jambi. *Jurnal Penelitian Universitas Jambi Seri Sains*. 16 (2), 33–42.
- Faiqon, M.M., Supriyanta & Wulandari, R.A. (2017) Pendugaan parameter genetik komponen hasil untuk seleksi tidak langsung tanaman padi (*Oryza sativa* L.) berdaya hasil tinggi. *Vegetalika*. 6 (2), 14–24.
- Fred, A.K., Kiswar, G., Yi, G. & Kim, K.-M. (2016) Screening rice cultivars for resistance to bacterial leaf blight. *Journal of Microbiology and Biotechnology*. [Online] 26 (5), 938–945. Available from: doi://dx.doi.org/10.4014/jmb.1510.10016.
- Guimaraes, E.P. (2009) Rice breeding. In: Carena, M.J. (ed.) *Cereals*. [Online] ViV, Springer Science + Business Media, LLC 2009, pp.99–126. Available from: doi:10.1007/978-0-387-72297-9.
- Habarurema, I., Asea, G., Lamo, J., Gibson, P., Edema, R., Séré, Y. & Onasanya, R.. (2012) Genetic analysis of resistance to rice bacterial blight in Uganda. *African Crop Science Journal*. 20 (Supplement s1), 105–112.
- Hadianto, W., Hakim, L. & Bakhtiar (2015) Ketahanan beberapa genotipe padi terhadap penyakit hawar daun bakteri (*Xanthomonas oryzae* Pv. *oryzae*). *Jurnal Hama dan Penyakit Tumbuhan Tropika*. [Online] 15 (2), 152–163. Available from: doi:10.23960/j.hptt.215152-163.
- Harahap, Z., Siregar, H. & Siwi, S.. (1972) Breeding rice varieties in Indonesia. In: *Rice Breeding*. Los Banos Laguna Philippines, International Rice Research Institute (IRRI), pp.141–145.
- Hariyanto, B., Sugiatmi, Anggit, G. & Maulad, A. (2018) *Direktori perkembangan konsumsi pangan*. Badan Ketahanan Pangan Kementerian Pertanian.
- Hermanto, W, D.S. & Hikmat, E. (2009) *Deskripsi Varietas Unggul Padi 1943-2009*. Bogor, Pusat Penelitian dan Pengembangan Tanaman Pangan.
- Hifni, H.R. & Kardin, M.K. (1998) Pengelompokan isolat *Xanthomonas oryzae* pv. *oryzae* dengan menggunakan galur isogenik padi IRRI. *Hayati Journal of Biosciences*. 5 (3), 66–72.
- International Rice Research Insitute (2014) *Standard Evaluation System for Rice* (SES). June 5th. Philippines, International Rice Research Institute.
- Janwan, M., Sreewongch, T. & Sripichitt, P. (2013) Rice breeding for high yield by advanced single seed descent method of selection. *Journal of Plant Sciences*. [Online] 8 (1), 24–30. Available from: doi:10.3923/jps.2013.24.30.
- Johnson, H.W., Robinson, H.F. & Comstock, R.. (1955) Estimates of genetic and environmental variability in soybeans. *Agronomy Journal*. 47 (7), 314–318.
- Kadir, T.S., Hanarida, I., Utami, D.W., Koerniati, S., Ambarwati, A.D., Apriana, A. & Sisharmini, A. (2009) Evaluasi ketahanan haploid ganda silangan IR64 dan *Oryza rufipogon* terhadap hawar daun bakteri pada Stadia bibit. *Buletin Plasma Nutrafah*. [Online] 15 (1), 13–19. Available from: doi:10.21082/blpn.v15n1.2009.p13-19.
- Kauffman, H.E., Reddy, A.P.K., Hsieh, S.P.Y. & Merca, S.D. (1973) An improved technique for evaluating resistance of rice varieties to *Xanthomonas oryzae*. *Plant Disease Report*. 57 (6), 537–541.
- Kementerian Pertanian, R.I. (2018) tentang *keputusan Menteri Pertanian Republik Indonesia Nomor 1091/HKI.140/C/05/2018*. p.127 halaman.
- Khaeruni, A., Najamuddin, E., Wijayanto, T. & Syair (2016) Ketahanan berbagai kultivar padi lokal terhadap penyakit hawar daun bakteri. *Jurnal Fitopatologi Indonesia*. [Online] 12 (3), 89–95. Available from: doi:10.14692/jfi.12.3.89.
- Khush, G., Mackill, D. & Sidhu, G.S. (1989) Breeding rice for resistance to bacterial blight. In: *Proceedings of the international Workshop on Bacterial Blight of Rice*. Manila Philippines, International Rice Research Institute, pp.2–246.
- Khush, G.S. (2013) Strategies for increasing the yield potential of cereals: Case of rice as an example. *Plant Breeding*. [Online] Available from: doi:10.1111/pbr.1991.
- Kim, S. & Id, R.F.R. (2019) A novel resistance gene for bacterial blight in rice , Xa43 (t) identified by GWAS , confirmed by QTL mapping using a bi-parental population. *Plos One*. [Online] 14 (2), 1–13. Available from: doi: https://doi.org/10.1371/journal.pone.0211775 February.
- Kristamtini, Sutarno, Wiranti, E.W. & Widyayanti, S. (2016) Kemajuan genetik dan heritabilitas karakter agronomi padi beras hitam pada populasi F2. *Penelitian Pertanian Tanaman Pangan*. [Online] 35 (2), 119–124. Available from: doi:http://dx.doi.org/10.21082/jpftp.v35n2.2016.p119-124.
- Li, Z., Pinson, S.R.M., Park, I.W.D., Paterson, A.H. & Stanselt, J.W. (1997) Epistasis for three grain yield components in rice (*Oryza sativa* L.). *Genetics*. 145, 453–465.
- Liang, T., Zheng-jin, X.U. & Wen-fu, C. (2017) Advances and prospects of super rice breeding in China. *Journal of Integrative Agriculture*. [Online] 16 (5), 984–991. Available from: doi:10.1016/S2095-3119(16)61604-0.
- Mackill, D.J. & Khush, G.S. (2018) IR64 : a high-quality and high-yielding mega variety. *Rice*. [Online] 11 (18), 1–11. Available from: doi:https://doi.org/10.1186/s12284-018-0208-3 REVIEW.
- Makarim, A.K. & Ikhwan (2010) Yield responses of two rice varieties to agronomic traits. *Indonesian Journal of Agriculture*. 3 (2), 81–86.
- Mazid, M.S., Rafii, M.Y., Hanafi, M.M., Rahim, H.A., Shabanimoferad, M. & Latif, M.A. (2013) Agro-morphological characterization and assessment of variability, heritability, genetic advance and divergence in bacterial blight resistant rice genotypes. *South African Journal of Botany*. [Online] 86 (86), 15–22. Available from: doi:10.1016/j.sajb.2013.01.004.
- Milovanovic, V. & Smutka, L. (2017) Asian countries in the global rice market. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*. [Online] 65 (2), 679–688. Available from: doi:10.11118/actaun201765020679.
- Nafisah, Daradjat, A.A. & Suprihatno, B. (2007) Heritabilitas karakter ketahanan hawar daun bakteri dari tiga populasi tanaman

- padi hasil seleksi daur siklus pertama. *Penelitian Pertanian Tanaman Pangan*, 26 (2), 100-105. 26 (2), 101-105.
- Nayak, D., Shanti, L., Bose, L., Singh, U. & Nayak, K. (2008) Pathogenicity association in *Xanthomonas oryzae* pv. *oryzae* - the causal organism of bacterial blight of rice. *ARNP Journal of Agricultural and Biological Science*. 3 (1), 12-27.
- Ogawa, T. (1993) Methods and Strategy for Monitoring Race Distribution and Identification of Resistance Genes To Bacterial Leaf-Blight (*Xanthomonas-Campestris* Pv *Oryzae*) in Rice. *Jarq-Japan Agricultural Research Quarterly*. 27 (2), 71-80.
- Oladosu, Y., Rafii, M.Y., Abdullah, N., Abdul Malek, M., Rahim, H.A., Hussin, G., Abdul Latif, M. & Kareem, I. (2014) Genetic variability and selection criteria in rice mutant lines as revealed by quantitative traits. *Scientific World Journal*. [Online] 2014, 1-12. Available from: doi:10.1155/2014/190531.
- Peng, S., Cassman, K.G., Virmani, S., Sheehy, J. & Khush, G. (1999) Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. *Crop Science*. 39 (November), 1552-1559.
- Peng, S., Laza, R., Visperas, R., Sanico, A. & Cassman, K.G. (2000) Grain yield of rice cultivars and lines developed in the Philippines since 1966. *Crop Science*. 40 (2), 307-314.
- Qi, Z. & Mew, T. (1989) Types of Resistance in rice to bacterial blight. In: *Proceedings of the International Workshop on Bacterial Blight of Rice*. Manila the Philippines, International Rice Research Institute, p.235.
- Ronald, P.C. (1997) The molecular basis of disease resistance in rice. *Plant Molecular Biology*. 35 (1-2), 179-186.
- Ruskandar, A. (2015) Pemanfaatan benih padi berlabel di tingkat petani Riau. *Jurnal Agrijati*. 28 (1), 145-157.
- Singh, R.K. & Chaudary, B.. (1985) *Biometrical Methods in Quantitative Genetic Analysis*. 3, New Delhi, Kalyani Publishers.
- Singh, S.K., Singh, C.M. & Lal, G.M. (2011) Assessment of genetic variability for yield and its component characters in rice (*Oryza sativa* L.). *Research in Plant Biology*. 1 (4), 73-76.
- Sitairesmi, T., Yunani, N., Nafisah, Satoto & Daradjat, A.A. (2018) Analisis kemiripan morfologi varietas unggul padi periode pelepasan 1980 - 2011. *Buletin Plasma Nutfah*. 24 (1), 31-42.
- Sivasubramanian, S. & Menon, M. (1973) Heterosis and inbreeding depression in rice. *Journal, Madras agricultural*. 60, 1139-1144.
- Sohrabi, M., Rafii, M.Y., Hanafi, M.M., Siti Nor Akmar, A. & Latif, M.A. (2012) Genetic diversity of upland rice germplasm in Malaysia based on quantitative traits. *The Scientific World Journal*. [Online] 2012, 1-9. Available from: doi:10.1100/2012/416291.
- Sudir, Nuryanto, B. & Kadir, T.S. (2012) Epidemiologi, patotipe, dan strategi pengendalian penyakit pada tanaman padi. *Iptek Tanaman Pangan*. 7 (2), 79-87.
- Sudir & Suprihanto (2006) Perubahan virulensi strain *Xanthomonas oryzae* pv. *oryzae*, penyebab penyakit hawar daun bakteri pada tanaman padi. *Penelitian Pertanian Tanaman Pangan*. 25 (2), 100-107.
- Sudir, Suprihanto & Kadir, T.S. (2009) Identifikasi patotipe *Xanthomonas Oryza* pv. *oryzae*, penyebab penyakit hawar daun bakteri di sentra produksi padi di Jawa. *Penelitian Pertanian Tanaman Pangan*. 28 (3), 131-138.
- Sudir & Yuliani, D. (2016) Composition and distribution of *Xanthomonas oryzae* pv. *oryzae* pathotypes, the pathogen of rice bacterial leaf blight in Indonesia. *Agrivita*. [Online] 38 (2), 174-185. Available from: doi:10.17503/agrivita.v38i2.588.
- Suparyono, Sudir & Suprihanto (2004) Pathotype profile of *Xanthomonas oryzae* pv. *oryzae* isolates from the rice ecosystem in Java. *Indonesian Journal of Agricultural Science*. [Online] 5 (2), 63-69. Available from: doi:http://dx.doi.org/10.21082/ijas.v5n2.2004.p63-69.
- Suprihatno, B., Daradjat, A.A., Satoto, SE, B., Suprihanto, Setyono, A., Indrasari, S.D., Wardana, I.P. & Sembiring, H. (2010) *Deskripsi Varietas Padi*. Sukamadi, Balai Besar Penelitian Tanaman Padi.
- Susanto, U., Daradjat, A.A. & Suprihatno, B. (2003) Perkembangan pemuliaan di Indonesia. *Jurnal Penelitian dan Pengembangan Pertanian*. 22 (3), 125-131.
- Susanto, U. & Sudir (2012) Ketahanan genotipe padi terhadap *Xanthomonas oryzae* pv. *oryzae* patotipe III, IV, dan VIII. *Penelitian Pertanian Tanaman Pangan*. 31 (2), 108-114.
- Syahri & Sumantri, U.S. (2016) Penggunaan varietas unggul tahan hama dan penyakit mendukung peningkatan produksi padi nasional. *Jurnal Penelitian dan Pengembangan Pertanian*. [Online] 35 (1), 25-36. Available from: doi:http://dx.doi.org/10.21082/jp3.v35n1.2016.p25-36.
- Tasliah (2012) Gen ketahanan tanaman padi terhadap bakteri hawar daun (*Xanthomonas oryzae* pv. *oryzae*). *Jurnal Penelitian dan Pengembangan Pertanian*. [Online] 31 (3), 102-112. Available from: doi:http://dx.doi.org/10.21082/jp3.v31n3.2012.p%25p.
- Tasliah, Mahrup & Prasetyono, J. (2013) Identifikasi molekuler hawar daun bakteri (*Xanthomonas oryzae* pv. *oryzae*) dan uji patogenisitasnya pada galur-galur padi isogenik. *Jurnal Agrobiogen*. [Online] 9 (2), 49-57. Available from: doi:http://dx.doi.org/10.21082/jbio.v9n2.2013.p49-57.
- The Ministry of Trade (2015) *Pra-Outlook Ekonomi Pertanian* 2016. (September 2015), Badan Pengkajian dan Pengembangan Kebijakan Perdagangan, Kementerian Perdagangan.
- Trisia, M., Metaragakusuma, A., Osozawa, K. & Hu, B. (2016) How to feed 311 million of Indonesian people by 2050? Advancing local food adaptation and food security policy. *ICoA Conference Proceedings*, 7 - 9 November 2015. [Online] 3 (November 2015), 49-54. Available from: doi:http://dx.doi.org/10.18502/kl.v3i3.417.
- Wahab, M. I., Satoto, Sasmita, P., Guswara, A. & Suharna (2017) Deskripsi Varietas Unggul Padi. *Badan Penelitian dan Pengembangan Pertanian*.
- Wang, X., Pang, Y., Zhang, J., Zhang, Q., Tao, Y., Feng, B., Zheng, T., Xu, J. & Li, Z. (2014) Genetic background effects on QTL and QTL  $\times$  environment interaction for yield and its component traits as revealed by reciprocal introgression lines in rice. *Crop Journal*. [Online] 2 (6), 345-357. Available from: doi:10.1016/j.cj.2014.06.004.
- Wani, M.R. & Khan, S. (2006) Estimates of genetic variability in mutated populations and the scope of selection for yield attributes in *Vigna radiata* (L.) Wilczek. *Egyptian Journal of Biology*. 8, 1-6.
- Widyayanti, S., Basunanda, P., Mitrowihardjo, S. & Kristamtini (2017) Keragaman genetik dan heritabilitas karakter agronomi galur F4 padi beras hitam. *Penelitian Pertanian Tanaman Pangan*. 1 (3), 191-200.
- Yuan, L. (2017) Progress in super-hybrid rice breeding. *The Crop Journal*. [Online] 5 (2), 100-102. Available from: doi:10.1016/j.cj.2017.02.001.
- Yuliani, D., Sudir & Mejaya, M.J. (2017) Komposisi dan dominasi patotipe *Xanthomonas oryzae* pv. *oryzae* penyebab hawar daun bakteri pada tanaman padi dengan pola tanam tidak serempak. *Jurnal Penelitian Pertanian Tanaman Pangan*. 1 (2), 133-142.
- Yunani, N. & Satoto (2018) *Pengelolaan database plasma nutfah padi*. Sukamandi.
- Yuriyah, S., Utami, D.W. & Hanarida, I. (2013) Uji ketahanan galur-galur harapan padi terhadap penyakit hawar daun bakteri

- (*Xanthomonas oryzae* pv. *oryzae*) ras III, IV, dan VIII. *Buletin Plasma nutfah*. 19 (3), 53–60.
- Zein, S. (2012) Parameter genetik padi sawah dataran tinggi. *Jurnal Pertanian Terapan*. [Online] 12 (3), 196–201. Available from: doi:<http://dx.doi.org/10.25181/jppt.v12i3.217>.
- Zeng, D., Tian, Z., Rao, Y., Dong, G., Yang, Y., Huang, L., Leng, Y., Xu, J., Sun, C., Zhang, G., Hu, J., Zhu, L., Gao, Z., Hu, X., Guo, L., Xiong, G., Wang, Y., Li, J. & Qian, Q. (2017) Rational design of high-yield and superior-quality rice. *Nature Plants*. [Online] 3 (17031), 1–5. Available from: doi:10.1038/nplants.2017.31.