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Initial Study of the Response of Ultra Early Maturing Rice Genotypes to Drought Stress Conditions in Vegetative and Generative Phase

(Studi Awal Respons Genotipe Padi Ultra Genjah terhadap Kondisi Cekaman Kekeringan pada Fase Vegetatif dan Generatif)

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ABSTRAK

Perubahan iklim global menyebabkan meluasnya daerah dengan risiko kekeringan. Cekaman kekeringan pada tanaman padi terutama terjadi di lahan gogo, tadah hujan, dan irigasi terbatas. Perakitan varietas yang cocok untuk daerah-daerah tersebut diharapkan dapat meningkatkan hasil padi secara nyata. Padi umur genjah efektif untuk mengantisipasi cekaman kekeringan fase generatif di akhir musim hujan melalui mekanisme *escape*. Namun demikian, kekeringan yang tidak dapat diprediksi yang dapat terjadi pada awal, tengah, maupun akhir musim tanam memerlukan varietas yang betul-betul toleran terhadap cekaman kekeringan. Penggabungan sifat umur genjah dan toleran kekeringan diharapkan mampu mengantisipasi kondisi cekaman kekeringan. Penelitian ini bertujuan untuk mengetahui respons 23 genotipe padi umur genjah yang terdiri atas 3 varietas unggul, 10 varietas lokal, dan 10 galur introduksi yang diberi perlakuan optimum, tercekam kekeringan pada fase vegetatif (diairi hingga 7 hari setelah tanam dan diairi kembali ketika cek peka mengering), dan generatif (diairi hingga 28 hari setelah tanam dan diairi kembali hanya jika cek peka mengering). Penelitian dilakukan di Kebun Percobaan BB Padi di Sukamandi pada MK 2009. Genotipe yang diuji diberi perlakuan pengairan tersebut di atas tanpa ulangan untuk mengetahui secara deskriptif kondisi karakter-karakter penting genotipe-genotipe yang diuji pada ketiga kondisi pengairan tersebut. Hasil penelitian menunjukkan bahwa berdasarkan karakter hasil, Indeks Cekaman Kekeringan (IKK; *Drought Sensitifity Index*, DSS), Nilai Relatif (*Relative Values*, RV), dan keragaan agronomi, galur OM 1490 teridentifikasi toleran terhadap cekaman kekeringan fase vegetatif dan generatif dengan hasil 28,17 g/tanaman, 24,11 g/tanaman, dan 24,72 g/tanaman pada kondisi optimum, tercekam vegetatif, dan generatif. OM 1490 telah dilepas sebagai varietas Inpari 13 pada tahun 2010 dan varietas ini telah digunakan dalam kegiatan pemuliaan tanaman menghasilkan galur-galur harapan yang baru.

Kata kunci: padi, kekeringan, hasil, sangat genjah.

ABSTRACT

Global climate change has caused the spread of drought prone areas. Drought stress for rice mostly happen in upland, rainfed, and limited irrigation lowland areas. Development of varieties suitable for those areas would significantly increase rice yield. Early maturing genotypes are useful to anticipate predictable early or terminal drought by escape mechanism. Nevertheless, unpredictable drought happening during early, mid season and final planting season results in the need of genuinely drought-tolerant genotypes. Combining early maturing and drought tolerant seems to be highly powerful to anticipate drought. This research was aimed to study the response of 23 early maturing rice genotypes consisting of 3 released varieties, 10 local varieties, and 10 introduced lines. The genotypes were exposed to vegetative (watered until 7 days after transplanting and rewater when the susceptible check was drying) and generative phase (watered until 28 days after transplanting and rewatered only if susceptible check was drying), drought stress conditions, and also optimum condition. The experiment was conducted in ICRR Experimental Station in Sukamandi during Dry Season (DS) of 2009. The genotypes were treated with three watering conditions mentioned above without replication to initially see the descriptive statistics of some agronomic traits of the genotypes under the mentioned conditions. The results showed that based on yield, Drought Sensitifity Index (DSS), Relative Values (RV), and agronomic performance, OM 1490 had been identified as tolerant to vegetative and generative drought stresses. It yielded 28.17 g/plant, 24.11 g/plant, and 24.72 g/plant at optimum, vegetative, and generative drought condition, respectively. OM 1490 had been released as Inpari 13 in 2010 and it had beed utilized for further breeding effort resulting new promising lines.

Keywords: rice, drought, yield, very early maturing.

INTRODUCTION

One of the major constrain in increasing rice yield is drought stress that occur every year. Global climate change had increased the risk of long dry season that caused drought (IPCC, 2001). Drought not only in upland and rainfed lowland areas, but also in irrigated areas. There are around 2.05 millions ha of rainfed lowland areas (BPS, 2004) and there are also many lowland areas with limited irrigation supply.

There are three type of drought occurence in rice, i.e. early (at vegetative phase), intermitten mid season (at vegetative to generative phase), and late season drought (at generative phase) (Fischer *et al*., 2003b). Drought at vegetative phase could be occured at first planting of rainy season and generative drought stress at second planting of rainy season or for the areas with very short rainy season or limited irrigation supply areas.

Very early maturing genotypes are useful to have drought escape in predictable stress areas, by planting time management. Nevertheless, in unpredictable drought areas, tolerance to drought is necessary. There are some drought tolerant rice varieties (based on description), such as Situ Patenggang (2003), Situ Bagendit (2003), Inpago 4 (2010), Inpago 5 (2010), Inpago 6 (2010), Inpago 7 (2011), Inpago 8 (2011), and Inpago 9 (2012) those are for upland and one lowland rice, i.e. Inpari 10 Laeya (2009) (BB Padi, 2013). Nevertheless, there is still lacking of drought tolerant with early maturing characteristics. Every early maturing varieties tolerant to drought would hopefully crop index and assure the yield stability in the drought prone areas.

This research was aimed at studying the respond of very early maturing rice genotypes to vegetative and generative phase drought stress conditions to identify drought tolerance gene(s) donors for further breeding programs.

METHODOLOGY

The experiment was conducted in Sukamandi ICRR experimental Station from July to end of October 2009 (DS). Twenty three early maturing genotypes consisted of 3 released varieties, 10 local varieties, and 10 introduced rice lines were grown under three condition, i.e. drought stress during vegetative (watered until 7 days after transplanting and was dried until the susceptible check die/scor 9 or water level was below 15 cm, and then dried again after one rewatering), generative (watered until 28 days after transplanting and was dried until the susceptible check die/scor 9 or water level was below 15 cm, and then dried again after one rewatering), and control (optimum). For this initial study, there was no replication made in each treatment. Five PVC pipes of 1 m deep were installed in every block of treatment to measure the sol water status. Water tension was measured by Tension Meter PAT.P. seri D-8. Double band and burried plastic to avoid water penetration was built between each treatment blocks. Transplanting was done into 21 days old seedlings, 2–3 plants/hill, with 25 cm x 25 cm planting space for 1.5 m x 3 m plot size. Fertilizer application was conducted three times, i.e.: 100 kg/ha urea, 100 kg/ha SP36, and 100 kg/ha KCl as foundation, 100 kg/ha urea was applied after first unweeding (vegetative); the latest is 100 kg/ha urea and 50 kg/ha KCl was applied after panicle initiation. For drought treated plots, fertilizers were applied as long as the land is still permited for watering.

Observation was made on plant height (10 random plants), tiller number (10 random plants), heading date, maturing date, number of grains/ panicle (3 random plants), seed set (3 random plants), 1.000 grain weight, and yield (g/plant from the harvested plant entire of each plot). Drought Sensitivity Index (DSI) value and Relative Value (RV) were calculated to yield trait of each line in each treatment. The lower the DSI and the higher the RV means increasing of tolerance. DSI and RV were calculated as follows (Fischer and Maurer, 1978):

$$DSI = \frac{1 - (Xd/Xp)}{1 - (Yd/Yp)}$$

DSI = drought sensitifity index to drought, Xd = yield average of genotype i at drought, Xp = yield average of genotype i at optimum, Yd = yield average of all genotypes at drought, Yp = yield average of all genotypes at optimum.

$$RV = \frac{Yd}{Yo}$$

RV = relative value, Yd = yield under certain drought condition, Yo = yield under optimum condition.

RESULTS AND DISCUSSION

Drought condition was achieved during the experiment, since the rain was very few (Table 1) during the season and the plants were severely affected by the drought treatments. The soil potential at vegetative and generative stage at each vegetative and generative drought stress blocks were all more than -13 kpa indicating the drought stress occurence during the experiment. The plant at vegetative and generative drought treatment blocks showed proportionally drought stress severity symptoms such as leaf wilting and drying. The yield under optimum condition varied from 4.48 g/plant (Niawtew) to 32.74 g/plant (Ramces) with average of 21.59 g/plant. The other highest yield genotypes were Silugonggo (29.86 g/plant), OM 4498 (29.57 g/plant), Umbul-umbul (28.57 g/plant), Kali Bogor (28.49 g/ha), and OM 1490 (28.17 g/plant).

Yield, Drought Sensitivity Index, and Relative Value

The yield under drought at vegetative stage was ranged from 0 g/plant (Ramces, Silugonggo, OM 4498, Umbul-umbul, Ranau, Ratna, Beo Rayak) to 24.21 g/plant (Sunting Baringin) with the average of 7.09 g/plant. Seven genotypes failed to yield under this condition. The highest yield was also achieved by OM 1490 (24.11 g/plant), Celebes (16.67 g/plant), Kali Bogor (16.18 g/plant), Situ Patenggang (13.54 g/plant), and ADT 30 (10.83 g/plant). Some genotypes failed to produce grain in both drought conditions. Drought at generative phase caused absorption of water in root zone for plant transpiration and lacking of water caused permanent wilting and death of the plant (Fischer and Fukuai, 2003). It might be the treatment was severely happen, the weather was very dry and irrigation management might be bias to be less than needed. Nevetheless, this effort had resulted taft condition for drought selection that hopefully resulted strongly drought tolerant genotypes.

Drought at generative phase gave more severe yield reduction to the plants, ranging from 0 g/plant (Ramces, Silugonggo, OM 4498, Umbul-umbul, Ratna, Beo Rayak, Aen Mutu, Kali Bogor, Celebes, and Sunting Baringin) to 24.73 g/plant (OM 1490) with the average of 3.5g/plant. Nine genotypes fail to yield under this condition, those mostly the same with the seven genotypes fail under vegetative drought condition. The other highest yield was also achieved by Faram Bagade (13.13 g/plant), N22 (10.69 g/plant), ADT 30 (8.15 g/plant), Goar Sail (4.62 g/plant), Padi Baian (4.48 g/plant) (Table 2).

The above results showed that drought treatment reduce plant yield. Drought at vegetative phase reduces the yield of 67%, while generative 84%. It means that the stress was really affecting the plant and it is good for selection. Drought at vegetative phase is not merely affecting vegetative growth, but it will affect generative phase growth of the plant (Sukiman *et al*., 2010).

Yield reduction under generative phase drought is greater than vegetative stress. It showed

Table 1. Rainfal occurence in Sukamandi during July to November 2009.

Time	Plant growth phase	Volume (mm)
16 September 2009	Generative	10
13 October 2009	Filling	30
1 November 2009	Maturing	1
9 November 2009	Maturing	9

Rainfall happened very few after the plant flowered that not disrupt the drought treatment.

Table 2. Yield, drought sensitivity index (DSI), and relative value (RV) of 23 very early maturing rice genotypes under optimum, vegetative drought, and generative drought conditions, Sukamandi DS 2009

Genotype	Remark	Yield (g/plant)			Vegetative drought		Generatif drought	
		Opt	Veg	Gen	DSI	RV	IKK	RV
N22	Introduced	25.90	9.23	10.69	0.96	0.36	0.70	0.41
Ranau	Local	27.40	0.00	2.99	1.49	0.00	1.06	0.11
Aen Mutu	Local	17.53	7.46	0.00	0.86	0.43	1.19	0.00
Situ Patenggang	Released var	12.12	13.54	0.36	-0.17	1.12	1.16	0.03
Sunting Baringin	Local	24.67	24.21	0.00	0.03	0.98	1.19	0.00
Mudgo	Introduced	21.13	2.36	2.69	1.32	0.11	1.04	0.13
Beo Rayak	Local	10.27	0.00	0.00	1.49	0.00	1.19	0.00
Ramces	Local	32.74	0.00	0.00	1.49	0.00	1.19	0.00
Ratna	Local	24.38	0.00	0.00	1.49	0.00	1.19	0.00
Silugonggo	Released var	29.86	0.00	0.00	1.49	0.00	1.19	0.00
Celebes	Released var	26.48	16.67	0.00	0.55	0.63	1.19	0.00
Padi Baian	Local	13.43	1.39	4.48	1.34	0.10	0.80	0.33
Sansari	Local	9.59	0.45	1.04	1.42	0.05	1.06	0.11
Niawtew	Introduced	4.48	5.43	4.31	-0.32	1.21	0.05	0.96
ADT 30	Introduced	15.83	10.83	8.15	0.47	0.68	0.58	0.51
Faram Bagade	Introduced	15.00	10.77	13.13	0.42	0.72	0.15	0.88
Goar Sail	Introduced	16.30	5.67	4.62	0.97	0.35	0.86	0.28
Umbul-umbul	Local	28.57	0.00	0.00	1.49	0.00	1.19	0.00
OM 4498	Introduced	29.57	0.00	0.00	1.49	0.00	1.19	0.00
OM 5930	Introduced	27.12	7.07	1.49	1.10	0.26	1.13	0.06
OM 1490	Introduced	28.17	24.11	24.72	0.21	0.86	0.15	0.88
AS 996	Introduced	27.50	7.69	1.88	1.07	0.28	1.11	0.07
Kali Bogor	Local	28.49	16.18	0.00	0.64	0.57	1.19	0.00
Average		21.59	7.09	3.50	0.93	0.38	0.95	0.21

that drought stress during vegetative stage more affecting rice plant. Taslim *et al*. (1989) reported that drought at primordia to maturity phase in rice plant could reduce yield from 4.6 t/ha to 1.5 t/ha (67.39%). Gardner *et al*. (1991) reported that panicle initiation is the critical time of rice plant to drought. Water supply during this period was for panicle formation. Lacking of water in this period would defect panicle initiation. Water supply is also used for grain filling. On the other hand, Fischer *et al*. (2003b) also reported that the most sensitive period of rice plant to drought is 10 days prior to anthesis until 5 days after anthesis.

Lafitte (2003) mentioned that for drought screening treatment, the drought should reduce the yield up to 50%. Direct selection into yield trait under drought condition is effective to find high yielding genotypes tolerant to drought (Atlin, 2003; Bernier *et al*., 2007; Kumar *et al*., 2014; Venuprasad *et al*., 2007; Venuprasad *et al*., 2008). Drought tolerant genotypes is genotypes having high yield under drought stress (Atlin, 2003). The genotypes must have highyielding capability under optimum condition, so that farmers get high yield if the drought stress is not occured. IRRI had conducted selection uder drought and having around twenty varieties released in various country includes Indonesia (Inpago LIPI Go 1 and Inpago LIPI Go 2) (Kumar *et al*., 2014).

The measure of yield reduction due to drought stress could be seen from DSI and RV (Fischer and Maurer, 1978). The DSI value of drought at vegetative stage compared to optimum condition showed that the genotypes ranged from -0.32 (Niawtew) to 1.49 (Ramces) with the average of 0.93. On the other hand, drought at generative stage had DSI ranged from 0.05 (Niawtew) to 1.19 (Ramces) with the average of 0.95. It also indicated that drought stress at generative stage giving more effect to rice plant.

The RV of the materials at vegetative drought stress condition showed that the value was ranged from zero (seven failed genotypes) to 1.21 (Niawtew). Relative value more than one showed that the yield under drought stress is higher than optimum condition. Nevertheless, Niawtew had very low yield that the bias might be high. Situ Patenggang had RV of 1.12 with the actual yield of 12.12 g/plant under optimum and 13.54 at vegetative drought condition. Situ Patenggang had relatively low yield under optimum, but it had relatively high yield under vegetative drought, i.e. five highest yield among the tested genotypes. It indicated that Situ Patenggang is a variety that appropriate for drought condition. Nevertheless, if the drought stress is not happened, the yield will remain relatively low.

RV of drought under drought at generative stage showed that it ranged from zero (the nine failed genotypes) to 0.96 (Niawtew). It means the the yield of Niawtew reduced very little due to generative drought stress. Nevertheless, it has low actual yield, thus not beneficial to farmers. Niawtew might be a good source of high RV to improve high yielding variety. OM 1490 had relatively high RV under generative drought, i.e. 0.88 and had relatively high yield i.e. 28.17 g/plant under optimum (sixth highest yield among tested genotypes) and 24.72 g/plant (second highest yield among tested genotypes). OM 1490 had also relatively high RV under vegetative drought (0.88; second highest among tested genotypes) and high actual yield under vegetative drought (24.11; second highest yield among tested genotypes). It means that OM 1490 is relatively an ideal genotype for drought condition.

Based on yield, DSI, and RV, it was selected OM 1490 as high yielding drought tolerant rice genotypes (Table 2). OM 1490 was then released as Inpari 13 at 2010 (Suprihatno *et al*., 2011). Many crosses and muation materials had been made from Inpari 13 and recently being selected and testing the yield. Direct selection into yield is relatively effective to get high yielding drought tolerant genotypes (Venuprasad *et al*., 2007). Ramses (32.74 g/plant) had the highest yield under optimum, but it was not considered as drought tolerant genotype, since it has no yield under drought condition.

High yielding approach is useful for areas having yield reduction less than 50% due to drought stress. For areas with unpredictable water supply and severing more than 50% yield reduction, highly tolerant variety is needed. Very early maturing variety would be useful to escape from drought in weather predictable areas (Fischer and Fukuai, 2003).

Agronomic Performance

Agronomic performance of the plant affected by drought treatment. Drought stress tended to reduce plant height, productive tiller number, filled grain/panicle, 1.000 grain weight and off course yield as mentioned above. On the other hand, drought stress tended to increase heading date, growth duration, and unfilled grain/panicle.

The average of heading date under optimum condition was 61 days after sowing, while under vegetative and generative phase drought was 63 days. Most early flowering genotypes under optimum condition were ADT 30, Padi Baian, Sansari, and Niawtew those flower at 43 days after sowing, while at vegetative drought the most early flowering ones were ADT 30, Padi Baian, Sansari, Niawtew, Faram Bagade, and Goar Sail those flowered at 43 days after sowing. At generative drought condition, the most early flowering genotypes were ADT 30, Padi Baian, Sansari, Niawtew, and Goar Sail those matured at 43 days after sowing. It seems that very early maturing genotypes relatively had stabile heading date under various condition. It might due to physyological capacity of the plant to give flowering had reach the limit and drought stress could not significantly giving more delay on flowering of the plant.

For other traits, drought stress make the plant stature shorter than normal (average 100.04 cm). Vegetative drought had plant height of 86.46 cm while generative drought 23.56 cm. Under drought stress, shoot growth is reduced compared to root (Sharp and Davies, 1979; Wu and Cosgrove, 2000).

Fukuai and Cooper (1995) reported that low to medium level of drought stress reduced leaf broadening and photosynthesis, thus reduced yield. Drought stress reduced relative humidity in the leaf, transpiration decrease, assimilation rate low, and leaves growth rate decrease that became narrower especially during vegetative stage, and increasing of prolin production (Kusmarwiyah *et al*., 2006).

The average of growth duration under optimum condition was 96 days after sowing, while under vegetative drought was the same 96 days and under generative drought it was delayed (100 days). The most early maturing genotypes detected were ADT 30, Padi Baian, Sansari, Niawtew, Faram Bagade, Goar Sail, and Umbul-umbul those matured at 82 days after sowing.

Drought stress at vegetative phase did not reduced productive tiller number (17 tiller), but generative drought reduced tiller number (15 tiller). Drought stress reduced strongly filled rice grain from average 19 grain (optimum) to 11 grain (vegetative drought) and 11 (generative drought). Drought stress increase unfilled rice grain from average 20 grain/panicle to 22 grain/panicle (vegetative drought) and 23 grain/panicle (generative drought). Drought stress reduced seed set from 46.99% (optimum) to 31.62% (vegetative drought) and 28.03% (generative drought). Sukiman *et al*. (2010) reported that drought stress at panicle initiation and flowering increases un-filled grain/panicle, unfilled grain weight/panicle, and percentage of unfilled grain/panicle.

Drought stress reduced 1.000 grain weight from 24.73 g (optimum) to 21.37 g (vegetative drought) and 23.34 g (generative drought). Drought at panicle initiation to maturity reduced 1.000 grain weight around 10.43% and filled grain/panicle up to 33.11% that inturn reduced grain yield (Taslim *et al.,* 1989). Drought, that happen during gametogenesis would increase unfilled grains and during filling period would reduce 1.000 grain weight (O'toole and Chang, 1979) and in turn it could reduce yield up to 50% (Lafitte, 2003).

Based on agronomic, yield components, yield, DSI, and RV above, OM 1490 had acceptable characteristics such as ealy maturing (104 days after sowing) not very short stature (95.36 cm at optimum condition), medium grain size (25.5 g/1.000 grain), tiller number around 20, and seed set around 50%. It seems that OM 1490 (Inpari 13) would be appropriate for rainfed lowland condition, in which drought is mostly happen. It is also relatively resistant to BPH and survive in some endemic areas in West Java and Central Java Province.

More dissemination of this variety might helpful to increase yield in rainfed lowland areas while providing necessary technology such as manual thresing to anticipate hard shattering characteristic of Inpari 13. By introducing high yielding drought tolerant variety, the yield and production from rainfed lowland areas hopefully would increase. Rainfed lowland areas is very potential, nevertheless it had not significant increase of rice yield during last three decades, but irrigated rice double the yield (Fischer *et al*., 2003a). Microclimate of rainfed lowland condition very diverse that giving more variation on yield among not so wide areas (Fischer *et al*., 2003b). It

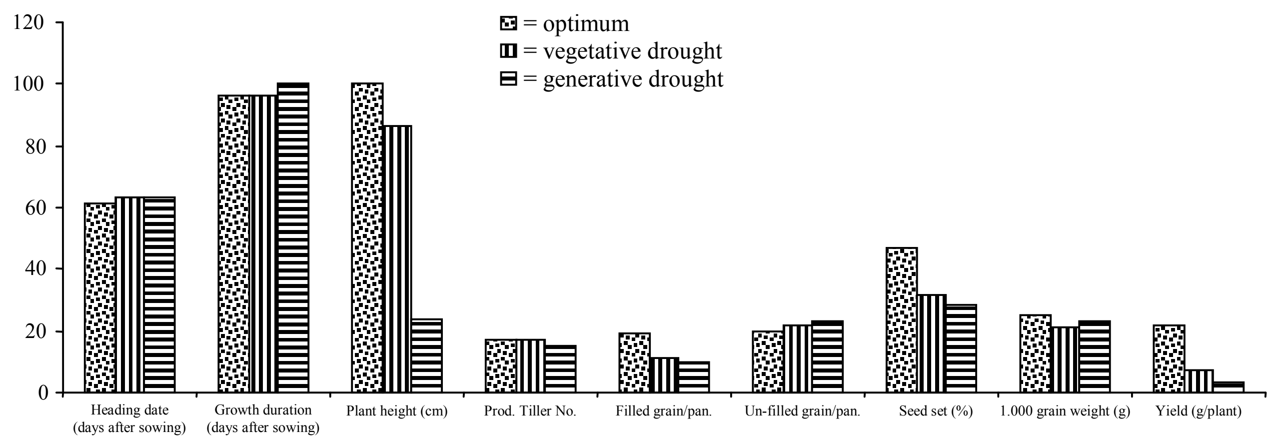

Figure 1. Agronomic traits, yield components and yield under optimum, vegetative, and generative phase drought condition, 23 genotypes, Sukamandi, DS 2009.

is different case with irrigated rice that one variety could be a mega variety. Thus, more choises in needed to fit up with every single variation in the targeted areas. Inpari 13 had been used in the further breeding programs and some promising results were arised.

This reasearch unintendedly identify some genotypes those were categorized as ultra early maturing (ultra genjah, Indonesian), i.e. those having growth duration less than 90 days. Some of them were then used for ultra early maturing variety in ICRR. Some promising materials had also been resulted.

CONCLUSIONS

There was a variation among genotypes to respond to drought condition. Sunting Baringin (24.21 g/plant) and OM 1490 (24.11 g/plant) had relatively high yield under vegetative drought stress condition, such as OM 1490 (24.72 g/plant) and Faram Bagade (13.13 g/plant) were relatively better adapted to terminal stress condition such as. In general, drought at generative stage is more affecting plant yield. Based on the yield under vegetative and genertaive drought stress condition above, OM 1490 that was released as Inpari 13 at 2010 was indicated to have drought tolerance for vegetative as well as generative growth phase. Further breeding effort using OM 1490 had been conductedand had resulted new promising lines.

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REFERENCES

Atlin, G. 2003. Improving drought tolerance by selecting for yield. In: K.S. Fishe, R. Lafitte, S. Fukuai, G. Atlin, and B. Hardy, editors, Breeding rice for drought-prone environments. IRRI, Manila, Philippines. p. 14−21.

BB Padi. 2013. Deskripsi varietas padi. BB Padi. Badan Litbang Pertanian, Sukamandi.

Bernier, J., A. Kumar, V. Ramaiah, D. Spaner, and G. Atlin. 2007. A Large-effect QTL for grain yield under reproductive stage drought stress in upland rice. Crop Sci. 47:507–588.

Badan Pusat Statistik. 2004. Statistik Indonesia 2003. Badan Pusat Statistik, Jakarta, Indonesia.

Fischer, R.A. and R. Maurer. 1978. Drought resistance in spring wheat cultivars. Aust. J. Agric. Res. 29:897–912.

Fischer, K.S. and S. Fukuai. 2003. How rice responds to drought. In: K.S. Fischer, R. Lafitte, S. Fukuai, G. Atlin, and B. Hardy, editors, Breeding rice for drought-prone environtments. IRRI, Manila, Philippines. p. 32−36.

Fischer, K.S., G. Atlin, A. Blum, S. Fukuai, R. Lafitte, and D. Mackill. 2003a. About this manual. In: K.S. Fischer, R. Lafitte, S. Fukuai, G. Atlin, and B. Hardy, editors, Breeding rice for drought-prone environtments, editors, IRRI, Manila, Philippines. p. 1−3.

Fischer, K.S., S. Fukuai, R. Lafitte, and G. McLaren. 2003b. Know your target environtment. In: K.S. Fischer, R. Lafitte, S. Fukuai, G. Atlin, and B. Hardy, editors, Breeding rice for drought-prone environtments. IRRI, Manila,Philippines. p. 5−11.

Fukuai, S. and M. Cooper. 1995. Development of drought-resistant cultivar using physiomorphological traits in rice. Field Crop. Res. 40:67–86.

Gardner, F.P., R.B. Pearce, dan R.L. Mitchell. 1991. Fisiologi tanaman budidaya. Universitas Indonesia Press, Jakarta.

Inter-governmental Panel on Climate Change. 2001. Climate change 2001: The scientific basis. Contribution of working group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK-New York.

Kumar, A., S. Dixit, T. Ram, R.B. Yadaw, K.K. Mishra, and N.P. Mandal. 2014. Breeding high-yielding drought-tolerant rice: genetic variation and conventional and molecular approaches. J. Exp. Bot. 65(21):6265−6278.

Kusmarwiyah, R., D. Indradewa, dan Suyadi. 2006. Kajian fisiologis cekaman kekeringan pada jagung manis. Agrosains 19(3):225–235.

Lafitte, R. 2003. Managing water for controlled drought in breeding plots. In: K.S. Fischer, R. Lafitte, S. Fukuai, G. Atlin, and B. Hardy, editors, Breeding rice for drought-prone environment. IRRI, Philippines. p. 23–26.

O'Toole, J.C. and T.T. Chang. 1979. Drought resistance in cereals−Rice: A case study. In: H. Mussel and R. Staples, editors, Stress physiology in crop plants. Wiley-Interscience, New York. p. 373–405.

Sharp, R.E. and W.J. Davies. 1979. Solute regulation and growth by roots and shoots of waterstressed maize plants. Planta 147:43–49.

Sukiman, H., Adiwirman, dan S. Syamsiyah. 2010. Respon tanaman padi gogo (*Oryza sativa* L.) terhadap stress air dan inokulasi mikoriza. Berita Biologi 10(2):249–257.

Suprihatno, B., A.A. Daradjat, Satoto, E. Lubis, Baehaki, S.E. Sudir, S.D. Indrasari, I.P. Wardana, dan M.J. Mejaya. 2011. Deskripsi varietas padi. Balai Besar Penelitian Tanaman Padi, Sukamandi.

Taslim, H., S. Partohardjono, dan Djunainah. 1989. Bercocok tanam padi sawah. Dalam: Buku Padi 2. Puslitbangtan, Bogor.

Venuprasad, R., H.R. Lafitte, and G.N. Atlin. 2007. Response to direct selection for grain yield under drought stress in rice. Crop Sci. 47:285–293.

Venuprasad, R., M.T. Sta Cruz, A. Amante, R. Magbanua, A. Kumar, and G.N. Atlin. 2008. Response to two cyclus of divergent selection for grain yield under drought stress in four rice breeding populations. Field Crop Res. 107:232–244a.

Wu, Y. dan D.J. Cosgrove. 2000. Adaptation of root to low water potentials by changes in cell wall extensibility and cell wall proteins. J. Exp. Bot. 51(350):1543–1553.