Yield and Related Traits in Two *Japonica* Rice Lines Carrying *Ur1* Gene

Stanis Malangen[a], Takumi Iwakura[b], Toru Hata[b], Takeshi Akaoka[b], Amol Dahal[b], Masayuki Murai[b,] *

[a] *United Graduate School of Ehime University, Matsuyama, Ehime, 790-8566, Japan*
[b] *Faculty of Agriculture, Kochi University, Monobe, Nankoku, Kochi, 783-8502, Japan*
** Corresponding author: Faculty of Agriculture, Kochi University, Monobe, Nankoku, Kochi, 783-8502, Japan*
Tel.: +81- 088-864-5120; Fax: +81- 088-864-5200 (common)
muraim@kochi-u.ac.jp

Abstract

Ur1 (Undulate rachis-1) is an incompletely dominant gene on chromosome 6 in rice, being characterized by undulation of primary and secondary rachis branches. *Ur1* increases not only the number of secondary branches per panicle but also spikelet number per single secondary branch, resulting in a large spikelet number per panicle. This genic effect can increase grain yield by enlarging sink size. We examined the yielding abilities of the two *Ur1*-carrying lines under field conditions (mid-April sowing and early-May transplanting in two experimental years). The two *Ur1*-carrying lines (MR79 and MR53) were selected from 108 recombinant inbred lines (F8 generation) originating from 108 F2 plants of the cross of 'Nishihikari' × an isogenic line of Taichung 65 carrying both *Ur1* and *sd1-d*. 'Hinohikari', a leading variety in southern Japan was the check variety in the present study, being denoted by "Hi". Additionally, 'Nishihikari' ("Ni"), a high yielding variety adaptable to fertile land, was employed. They were grown under three fertilizer levels (4, 8 and 16 of Ng/㎡ in total) and two fertilizer levels (12 and 21 of Ng/㎡ in total), together with P and K elements, in 2003 and 2005, respectively. Yield and other traits were measured. The results at 21 of N g/㎡in 2005 are described as follows. In yield (brown rice, g/㎡), the lines-varieties were ranked in the order MR79 (728) > MR53 (723) > Ni (695) > Hi (558). MR79 and MR53 had 170 g/㎡ (30%) and 165 g/㎡ (30%) higher yields, respectively, than Hi. Regarding spikelet number per panicle, they were in the order MR79 (132.7) > MR53 (116.0) > Hi (94.5) > Ni (90.5). As for panicle number per ㎡, Ni and Hi were higher than MR79 and MR53, although the difference is smaller than that in the previous trait. Regarding ripened-grain percentage, Ni (88.9%) and MR53 (85.0%) were higher than MR79 (79.8%) and Hi (79.2%). Regarding sink size (single-grain weight × fertilized-spikelet number per ㎡), they were in the same order as in yield. The yield of MR79 (728 g/㎡) was outstandingly high as compared with yield levels of ordinary *japonica* varieties in southern Japan. This high yield was due to its more spikelets per panicle caused by *Ur1*, its ripened-grain percentage being maintained at almost 80%. Moreover, MR79 had significantly higher yield than MR53, Ni and Hi at 12 of N g/㎡ in 2005 as well as at the three fertilizer levels in 2003. Hence, MR79 had outstanding high yields at the low to high fertilizer levels. MR79 was 14-18 days later in 80%-heading date than the rather late variety Hi in all cultivated conditions in the two years. MR79 was higher-yielding than the rather–early line MR53 in every environmental conditions. The lateness of MR79 might be advantageous to attain high yield. MR79 has high eating quality comparable to that of Hi, one of high eating-quality varieties in Japan. Consequently, MR79 could be a super-high yielding variety with exceptionally late maturity in southern Japan.

Keywords： *rice, Ur1 gene, spikelet number per panicle, sink size, yield*

Introduction

Ur1 (Undulate rachis-1), located on chromosome 6 (Sato & Shinjyo, 1991), is an incompletely dominant gene of rice, being characterized by undulation of primary and secondary rachis branches. *Ur1* increases not only number of secondary branches per panicle but also spikelet number per secondary branch, resulting in a large spikelet number per panicle (Nagao *et al*., 1958; Murai & Iizawa, 1994). This genic effect can increase grain yield by enlarging sink size

(Murai & Iizawa, 1994; Murai *et al.*, 2002 and 2005 b). However, *Ur1* decreases both ripened-grain percentage and 1000-grain weight.

Murai *et al.* (2005 a) preliminarily reported that a *japonica Ur1*-carrying line Murai 79 (hereafter "MR79") had a higher yield than the levels of ordinary *japonica* varieties in southern Japan, due to its higher sink size caused by more spikelets per panicle, which was derived from the cross of a Japanese commercial variety and an isogenic line of Taichung 65 carrying *Ur1*. MR79 and another *Ur1*-carrying line "MR53" were used in the present study, which possess extremely late and rather early heading times, respectively. The two lines, a representative variety of southern Japan 'Hinohikari' and a *japonica* high-yielding variety 'Nishihikari' were grown under three fertilizer levels in 2003 and two fertilizer levels in 2005. Yield, its components and other traits were measured for the lines-varieties. On the basis of two-year data, characteristics of the two *Ur1*-carrying lines were examined. We discuss utility of the lines in southern Japan.

Materials and Methods

Development of two Ur1-carrying lines

The highest-yielding F1 in the yield tests for various F1 hybrids with the *Ur1* / + genotype (Murai *et al*., 1997 and 2003) was used for developing recombinant inbred lines with and without *Ur1*. Its maternal and paternal parents were 'Nishihikari' and an isogenic line of Taichung 65 carrying both *Ur1* and *sd1-d* (dee-geo-woo-gen dwarf), respectively. The F2 population was grown in 1992, and the generation was progressed to F8 generation without selection in glasshouse condition. In 1999, the 108 F9 lines originating from the respective 108 F2 plants were grown in a paddy field; the two most well-ripened lines carrying *Ur1*, viz. MR53 and MR79 were selected from *Ur1*-carrying lines by field observation. The uniformity (non-segregation) of MR53 and MR79 was confirmed from 2000 to 2003 (F14 generation).

Field experiments

Besides MR53 and MR79, 'Nishihikari' and 'Hinohikari', (denoted by "Ni" and "Hi" respectively) were used for the field experiments. Ni is a short-culm and panicle-number type variety possessing the highest lodging tolerance in southern Japan (Nishiyama, 1982). Hi is a leading variety in southern Japan, which possesses rather-late heading, rather long culm, rather many panicles.

The two *Ur1*-carrying lines, Ni and Hi were seeded in mid April and transplanted to a paddy field of the faculty of Agriculture, Kochi University, Japan in early May, in the two experimental years (Table 1). Two seedlings per hill were transplanted at a spacing of 30.0 x 15.0 cm. They were grown under three fertilizer levels (4, 8 and 16 of N g/㎡ in total) and two fertilizer levels (12 and 21 of N g/㎡ in total) together with P and K elements, in 2003 and 2005, respectively (Table 1). The randomized block design with three replications was adopted for all combinations of the lines-varieties and fertilizer levels in each year.

Measurements of yield and other traits

All panicles of about 30 hills were sampled from each plot at maturity, and the panicle weight of each hill was checked after cutting just at their panicle bases after air-drying. Out of nine hills randomly selected from about 30 hills of each plot, five hills having intermediate panicle weights were selected. The panicles in the five hills were threshed, and all spikelets in each hill were counted. Grains after hulling (hereafter "grain") were sieved at 1.7 mm to select ripened grains by thickness. All ripened grains in each of the five hills were counted, and were weighed. The percentage of ripened-grain weight to panicle weight in the five selected hills of each plot was calculated; then, the ripened-grain weight (yield) of 30 hills of each plot was estimated from this percentage.

Table 1. Fertilizer application, dates of sowing and transplanting for MR78, MR53, Ni and Hi in the experiments in 2003 and 2005

Year	Total amount of fertilizer applied (N g/m^2)[2)]	Basal dressing (N g/m^2)[2)]	Top dressing (N g/m^2)[2)]
2003 [1)]	16.0	8.0[3)]	8.0[5)]
	8.0	4.0[4)]	4.0[5)]
	4.0	2.0	2.0[5)]
2003 [2)]	21.0	7.0[6)]	14.0[7)]
	12.0	4.0	8.0[7)]

[1)] Dates of sowing and transplanting were April 16 and May 9 in 2003, and April 20 and May 8 in 2005.
[2)] P2O5 and K2O elements were applied at the same level as N element
[3)] The 6.0 g/m^2 of each nutrient element was applied with LONG® 100 type, Chisso Asahi Fertilizer Co., Ltd. (about 7% of each nutrient element is readily available) six days after transplanting. In additional to 2.0 g/m^2 of each nutrient element applied with an ordinary chemical fertilizer before puddling.
[4)] The 2.0 g/m^2 of each nutrient element was applied with LONG® 100 type, in addition to 2.0 g/m^2 of each nutrient element applied before puddling.
[5)] LONG® 100 type was applied on June 30 for MR53, July 27 for MR 79, July 14 for Ni ('Nishihikari') and July 9 for Hi ('Hinohikari').
[6)] The 3.0 g/m^2 of each nutrient element was applied with LONG® 100 type six days after transplanting. In additional to 4.0 g/m^2 of each nutrient element applied with the ordinary chemical fertilizer before puddling.
[7)] Another slow-release coated fertilizer, LONG® 100 type, Chisso Asahi Fertilizer Co., Ltd. (about 3% of each nutrient element is readily available) was applied on May 20 for MR53, June 2 for MR79, June 9 for Ni and June 5 for Hi.

Results and Discussion

In yield, the lines-varieties were ranked in the order MR79 > MR53 > Ni > Hi at every fertilizer level in the two years: MR79 and MR53 were 30 to 70% and 23 to 48%, respectively, higher than Hi in the five environments (Table 2). Regarding spikelet number per panicle, they were in the order MR79 > (or ≒) MR53 > Hi > (or ≒) Ni at each of the fertilizer levels in the two years. In this trait, MR79 and MR53 were 24 to 40% and 21 to 30%, respectively, higher than Hi in the five environments. As for panicle number per m^2, MR79, MR53 and Ni were 95-110%, 92-100% and 103-111%, respectively, of Hi in the two years, although the difference among the four lines-varieties in this trait was smaller than that in the previous trait in every environment. In ripened-grain percentage, Hi was around 80% and the lowest among the lines-varieties in every environment. MR53 was similar to or not so different from Ni in every environment. MR79 was not significantly different from Ni in all environments except at 21 of N g/m^2 in 2005. In terms of 1000-grain weight, Ni was heavier than the other lines-variety, and either MR53 or MR79 was similar to or not so different from Hi in both years. Regarding sink size, they were in the same order as in yield. In culm length, MR79 was similar to Hi. MR53 was rather longer than low-height Ni in both years. They had panicle lengths within the ranges of 2.1 and 2.5 cm in 2003 and 2005, respectively, although varietal difference was detected. MR53 and MR79 were 11-17 days earlier and 14-18 days later, respectively, in 80% heading date than Hi in the two years.

The higher the fertilizer level, the higher the yield in each line/variety in each year (Table 2). Similar fertilizer responses were noticed in both spikelet number per panicle and panicle number per m^2, although the latter trait was more responsive than the former trait in each line/variety in both years. All line-varieties except MR53 had the lowest ripened-grain percentage at 4 of N g/m^2 in 2003, whereas they had higher values at 12 of N g/m^2 than at 21 of N g/m^2 in 2005. However, range caused by fertilizer effect within each line/variety was less than 5.1% inclusive in each of the years. Every line/variety had little higher 1000-grain weight at 16 of N g/m^2 than at 4 of N g/m^2 in 2003, but such consistent response was not detected in 2005.

Regarding sink size (single-grain weight × fertilized-spikelet number per m^2), they were in the same order as in yield (Table 2). The yield of MR79 at 21 of N g/m^2 in 2005 (728 g/m^2) was outstandingly high as compared with yield levels of ordinary *japonica* varieties in southern Japan. This high yield was due to its more spikelets per panicle caused by *Ur1,* and its ripened-grain percentage being maintained at almost 80%. Furthermore, MR79 had significantly higher yield than MR53, Ni and Hi at the other four environments. Hence, the high yielding ability of MR79 was stable over the low to high fertilizer levels.

Table 2. Yield and other traits of MR79, MR53, Ni and Hi at the three fertilizer levels in 2003 and two fertilizer level in 2005

Trait	**year**	**Fertilizer Level (N g/m^2)**	**MR79**		**MR53**		**Ni ('Nishihikari')**		**Hi ('Hinohi-kari')**	**LSD**
Yield	2003	16	673 a	(149)	612 b	(136)[2)]	554 c	(123)	451 de	37
		8	626 b	(165)	549 a	(145)	478 a	(126)	379 a	
		4	553 c	(170)	481 a	(148)	442 a	(136)	326 a	
	2005	21	728 a	(130)	723 a	(130)	695 a	(124)	558 a	32
		12	662 c	(131)	626 a	(123)	572 a	(113)	507 a	
Spikelets/ panicle	2003	16	103.8 ab	(124)	107.4 a	(128)	80.6 de	(96)	83.6 d	5.2
		8	101.4 bc	(130)	101.8 bc	(130)	76.5 ef	(98)	78.3 ef	
		4	102.0 b	(137)	96.9 c	(130)	74.1 f	(100)	74.3 f	
	2005	21	132.7 a	(140)	116.0 c	(123)	90.5 de	(96)	94.5 d	6.3
		12	123.8 b	(134)	111.2 c	(121)	85.2 e	(92)	92.1 d	
Panicle/ m^2	2003	16	338 b	(107)	309 c	(97)	336 a	(106)	317 b	14
		8	317 b	(110)	288 cd	(100)	314 b	(109)	287 cd	
		4	289 c	(105)	268 e	(98)	304 b	(111)	274 de	
	2005	21	354 bcd	(95)	360 bc	(96)	389 a	(104)	374 ab	20
		12	326 ef	(96)	312 f	(92)	349 cd	(103)	339 de	
Ripened grain percent-tage	2003	16	94.0 ab	(115)	91.6 b	(112)	94.1 ab	(115)	82.0 c	2.7
		8	95.3 a	(117)	93.0 ab	(114)	93.2 ab	(114)	81.6 cd	
		4	92.4 b	(117)	92.4 b	(117)	92.7 ab	(117)	78.9 d	
	2005	21	79.8 c	(101)	85.0 b	(107)	88.9 a	(112)	79.2 c	2.4
		12	84.9 b	(104)	88,9 a	(109)	85.5 b	(105)	81.3 cb	
1000-grain weight[1)] (g)	2003	16	20.4 cde	(98)	20.2 e	(97)	21.7 a	(105)	20.8 c	0.4
		8	20.4 cde	(99)	20.2 e	(98)	21.3 b	(103)	20.6 cd	
		4	20.3 de	(100)	20.1 cde	(99)	21.1 b	(104)	20.3 de	
	2005	21	19.5 d	(97)	20.4 b	(102)	22.2 a	(111)	20.0 c	0.4
		12	19.3 d	(97)	20.3 bc	(101)	22.5 a	(112)	20.0 c	
Sink size[3)] (g/m^2)	2003	16	695 a	(141)	640 b	(130)	567 c	(115)	492 de	38
		8	640 b	(151)	566 c	(134)	492 de	(117)	422 f	
		4	577 c	(155)	496 d	(133)	458 ef	(123)	373 g	
	2005	21	827 a	(131)	780 b	(123)	733 c	(116)	631 de	32
		12	726 c	(129)	659 d	(117)	618 e	(110)	562 f	
Culm length (cm)	2003	16	73.5 a	(97)	65.9 b	(87)	63.6 c	(84)	75.6 a	2.1
	2005	21	77.0 a	(191)	66.1 b	(87)	64.6 b	(85)	75.9 a	2.4
Panicle length (cm)	2003	16	20.3 ab	(110)	19.7 b	(107)	20.5 a	(111)	18.4 c	0.8
	2005	21	22.8 a	(112)	21.6 b	(106)	20.5 c	(101)	20.3 c	0.9
80%-heading date	2003	4-16	Aug.22		July 28/29		Aug.13		Aug.9	
	2005	12-21	Aug.23/24		July 21		Aug.11		Aug.7	

[1)] Brown rice weight after sieving at 1.7mm, being adjusted into 15% moisture. [2)] Percentage to H in parentheses [3)] Single-grain weight x fertilizer-spikelet number per m2. Values followed by the same letter within each year in a trait are not significantly different at the 0.05 level being determined by LSD in the table.

MR79 was 14-18 days later in 80% heading date than the rather late variety Hi in all environmental conditions in the two years. MR79 was higher-yielding than the rather–early line MR53 in every environmental condition. The lateness of MR79 might be advantageous to attain high yield. MR79 has high eating quality comparable to that of Hi, one of excellent-taste varieties in Japan (Murai, unpublished). Consequently, MR79 could be a super-high yielding variety with exceptionally late maturity in southern Japan.

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