Analysis of High Yielding Mechanism of Rice Varieties Belonging to Different Plant Types

I. Comparison of growth and yield characteristics and dry matter production

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Abstract : To clarify the high yielding characteristics of new rice varieties bred recently in the Tohoku region of Japan, their growth and yield characteristics and dry matter production were examined in 1994 and 1995, as compared with those of Hitomebore and Kiyonishiki, popular cultivars in the region.

The grain yields of the cultivars and strains used were in a relatively high level, ranging from 650 to 815 g m⁻². The sequence of grain yield was Fukuhibiki > Ouu 316, Kiyonishiki > Ouu 327 > Hitomebore. High grain yields in Fukuhibiki and Ouu 316 of the panicle weight type with short culm were mainly due to the large number of spikelets m⁻², which was mainly determined by the large number of spikelets per panicle. Fukuhibiki was also characterized by a large grain weight and a high percentage of ripened grains. The percentage of ripened grains was mainly governed by the ripened grains on the secondary rachis branch, which closely related to sink size. The high percentage of ripened grains of Fukuhibiki was due to the high percentage of ripened grains on the secondary rachis branch. The grain yield in Ouu 327 of the big grain type was mainly due to a fairly high percentage of ripened grains and markedly large grain weight, although this strain had a small number of panicles and spikelets m⁻². As compared with Hitomebore, Fukuhibiki and Ouu 316 with low plant length showed large weights of total dry matter and extremely large weights of dry panicles, which contributed to their large harvest indices. The results suggest that high yielding Fukuhibiki and Ouu 316 possess the excellent characteristics of dry matter production and distribution.

Key words : Ear characteristics, Harvest index, High yielding variety, Panicle weight type with short culm Plant type, Rice, Secondary rachis branch.

異なる草型の水稲品種の多収性機構の解析 第1報 生育特性、収量構成要素および乾物生産特性の比較：王 英典・黒田栄喜・平野 貢・村田孝雄（岩手大学農学部）

要 旨：東北地方を対象に、最近育成された多収性水稲品種・系統の生育および乾物生産特性と収量および収量構成要素について、1994年および1995年の両年にわたって、当地方の主要な普及品種であるひとめぼれおよびキヨニシキを対照として比較・検討した。供試した各品種・系統の収量は、650～815 g m⁻²の範囲にあり、ふくひびき>奥羽316号、キヨニシキ>奥羽327号>ひとめぼれの順に多収であった。短稈穂重型のふくひびきと奥羽316号は、1穂粒数が多いことによりm²当たり粒数が多かった。最も収量が多かったふくひびきは、千粒重が大きい割には登熟歩合が高い傾向があった。登熟歩合の程度は、2次枝梗着生粒の登熟歩合と密接な関係が認められたが、ふくひびきは、2次枝梗着生粒が多いにもかかわらず、それらの登熟歩合がかなり高かった。大粒型の奥羽327号は、穂数が少なく、m²当たり粒数も少なかったが、千粒重が非常に大きく、登熟歩合も高かった。ひとめぼれに比べて、草丈の低いふくひびきと奥羽316号は、収穫期における全乾物重がわずかに大きかったが、それらの穂重は明らかに大きかった。この関係から、両者の収穫指数は、ひとめぼれよりかなり高くなった。以上の結果、ふくひびきと奥羽316号は、乾物生産および分配において優れた性質を備えていることが推察された。

キーワード：草型、収穫指数、水稲、多収性品種、短稈穂重型、2次枝梗、穂相。

The selection of cultivars based on the concept of an ideal plant type has contributed remarkably to the increase of rice yield¹⁵⁾. The breeding of high yielding rice has been carried out in the direction from the panicle-number type to the partial panicle number type, or to the partial panicle weight type⁵⁾. Recently, some superior high yielding rice cultivars were bred by hybridizing the *japonica* type with the

semidwarf *indica* type¹⁾. These cultivars were characterized by large numbers of spikelets per panicle and small grain weights, or by small numbers of spikelets per panicle and large grain weights. These two directions have been recognized as possible ways to realize high grain yield in rice.

In recent years, some superior high yielding varieties were bred in the Tohoku region of

Japan. Among them, some varieties belonging to the panicle weight type were reported to exhibit high yielding potentials^{1,2)}. However, the characteristics of yield establishment and dry matter production for these varieties are yet to be properly clarified. In this experiment, new high yielding varieties of the panicle weight type, including a cultivar and a strain with the characteristic of a large panicle and a strain of a big grain, were used to examine their growth characteristics, yield establishment and dry matter production characteristics as compared with those of two cultivars widely cultivated in the Tohoku region.

Materials and Methods

The experiment was conducted in the paddy field of the Faculty of Agriculture, Iwate University in 1994 and 1995. Five medium-maturing genotypes of rice (*Oryza sativa* L.) were used. They were Hitomebore (Hito) of the partial panicle number type and Kiyonishiki (Kiyo) of the partial panicle weight type, popular cultivars in the Tohoku region; Ouu 316 (O316) and Fukuhibiki (Fuku), a new high yielding strain and cultivar of the panicle weight type; and Ouu 327 (O327), a new strain of the big grain type. The characteristics of plant type for these cultivars and strains were outlined in Table 1.

Seedlings of 3.2-4.0 leaf age were transplanted with three plants per hill. The basal dressing was applied at a rate of 6.50, 13.65 and 9.75 g m⁻² of N, P₂O₅ and K₂O, respectively, in each treatment in both years. In 1994, different treatments of planting densities were designed. They were 22.2 hills m⁻² in the standard cultivation plot (STD), 27.8 hills m⁻² in the dense planting treatment (DPT) and 16.7 hills m⁻² in the sparse planting treatment (SPT). In every treatment of planting densities, top dressing was applied at a rate of

5.00, 0.43 and 3.64 g m⁻² of N, P₂O₅ and K₂O, respectively. In 1995, different treatments of top dressing were designed. The rate of N, P₂O₅ and K₂O application was 5.00, 0.43 and 3.64 g m⁻² in the standard cultivation plot (STD) and 10.00, 5.56 and 11.28 g m⁻² in the excessive fertilizer treatment (EFT). The planting density was the same in all treatments, at 22.2 hills m⁻² in both top dressings.

The experiments were designed using one plot for each treatment in 1994, and using three repeated plots in 1995. The yield, yield components and ear characteristics were investigated with the samples from STD in 1994. Grain yields were determined with 63 hills from one plot in 1994, and with 126 hills from three plots in 1995. At the time of harvest, the total dry weight and panicle dry weight were measured with 12-16 hills from STD, and the harvest index was calculated.

Results

1. Growth characteristics

Each variety showed a similar change in growth characteristics in both years. No obvious difference was observed in the plant length of each variety between different planting densities, but every variety showed a higher plant length in EFT than in STD. The average plant lengths of O316 and Fuku were lower than those of Hito and Kiyo, and that of O327 was the highest (Fig. 1A). At the maximum tiller number stage (Fig. 1B), the average numbers of culms m⁻² of O316 and Fuku were smaller than those of Hito and Kiyo, and that of O327 was the smallest. At the ripening stage, the number of panicles m⁻² of each variety was smaller in SPT than in STD. The number of panicles m⁻² of Kiyo changed radically in different treatments. The average numbers of panicles m⁻² of O316 and Fuku were significantly smaller than those of Hito

Table 1. Characteristics of plant type for the varieties used in the experiment.

Cultivars (Strains)	Plant type	Characteristics
Hito	Partial panicle number type	Short and thin culm
Kiyo	Partial panicle weight type	Short culm
O316	Panicle weight type	Short and thick culm, large panicle, small grain
Fuku	Panicle weight type	Short and thick culm
O327	Panicle weight type	Long and very thick culm, small number of panicles, very big grain

and Kiyo, and that of O327 was significantly smaller than other varieties (Fig. 1B). The decrease in the number of culms m^{-2} from the maximum tiller number stage to the ripening

Fig. 1. Plant length at ripening stage (A) and the number of culms or panicles m^{-2} at the maximum tiller number stage and ripening stage (B). Difference among varieties was tested by the analysis of variance, and t-test was carried out at 5% significant level and the same letter represented no significant difference.

Symbols: ●, STD (1994); ○, STD (1995); ■, DPT (1994); ⊕, EFT (1995); ▲, SPT (1994).

stage was at a similar rate in every variety.

All tillers of every variety were only from the primary and secondary tillers. As shown in Table 2, O316, Fuku and O327 showed smaller numbers of total culms per hill than Hito. In the numbers of primary and secondary tillers per hill, O316, Fuku and O327 were smaller than Hito, especially in the number of secondary tillers per hill. Consequently, the small percentage of secondary tillers in the total culms was observed in O316, Fuku and O327. Each variety showed a similar change in the number of panicles per hill as the number of culms per hill. On the other hand, the percentages of productive culms in main culms and primary tillers were not different among varieties. A high percentage of productive culms in secondary tillers was observed in Hito and Fuku, and the lowest percentages of productive culms in primary and secondary tillers were observed in O327. In the characteristics described above, Kiyo of the partial panicle weight type was intermediate between Hito and new varieties. As described above, the difference in the number of total culms or total panicles was mainly caused by the number of the secondary tillers among varieties.

2. Grain yield and yield components

In every treatment of each variety, the grain yield was achieved over $650 g m^{-2}$ in both years (Fig. 2). The sequence of average grain

Table 2. Total culms, main culms, primary tillers and secondary tillers per hill at the maximum tiller number stage and ripening stage under standard cultivation conditions in 1994.

Cultivars (Strains)	Total culms	Main culms	Primary tillers	Secondary tillers
At the maximum tiller number stage (I)				
Hito	$36.3 \pm 8.8 (100)$	$3.0 \pm 0.0 (8.3)$	$17.4 \pm 1.3 (47.9)$	$15.8 \pm 2.2 (43.5)$
Kiyo	$30.9 \pm 7.6 (100)$	$3.0 \pm 0.0 (9.7)$	$16.4 \pm 1.0 (53.1)$	$11.5 \pm 1.4 (37.2)$
O316	$28.9 \pm 6.9 (100)$	$3.0 \pm 0.0 (10.4)$	$15.1 \pm 1.3 (52.2)$	$10.8 \pm 2.0 (37.4)$
Fuku	$25.7 \pm 6.2 (100)$	$3.0 \pm 0.0 (11.8)$	$14.1 \pm 1.2 (54.9)$	$8.6 \pm 1.8 (33.5)$
O327	$20.3 \pm 5.4 (100)$	$3.0 \pm 0.0 (14.8)$	$12.6 \pm 1.3 (62.1)$	$4.8 \pm 1.1 (23.6)$
At the ripening stage (II)				
Hito	$27.6 \pm 0.6 < 76.0 >$	$3.0 \pm 0.1 < 100.0 >$	$15.9 \pm 0.0 < 91.4 >$	$8.7 \pm 0.7 < 55.1 >$
Kiyo	$23.1 \pm 0.6 < 74.8 >$	$2.9 \pm 0.1 < 96.7 >$	$15.6 \pm 0.4 < 95.1 >$	$4.6 \pm 0.5 < 40.0 >$
O316	$21.2 \pm 0.6 < 73.4 >$	$3.0 \pm 0.1 < 100.0 >$	$13.8 \pm 0.1 < 91.4 >$	$4.4 \pm 0.7 < 40.7 >$
Fuku	$20.4 \pm 0.6 < 79.4 >$	$3.0 \pm 0.0 < 100.0 >$	$12.6 \pm 0.3 < 89.4 >$	$4.8 \pm 0.3 < 55.8 >$
O327	$14.4 \pm 0.1 < 70.9 >$	$2.9 \pm 0.1 < 96.7 >$	$9.9 \pm 0.1 < 78.6 >$	$1.5 \pm 0.2 < 31.3 >$

Values at the maximum tiller number stage were the means and standard deviations of 16 hills from one place, and the values at the ripening stage were the means and standard deviations of 3 places (16 hills per place). Figures in () represented the percentages of main culms, primary tillers and secondary tillers in total culms, and the figures in < > represented the percentages of productive culms (II/I).

yields was Fuku > O316, Kiyo > O327 > Hito. The DPT, SPT and EFT did not remarkably affect the grain yields in every variety. The ranges of grain yields in different treatments were relatively large in Kiyo and Fuku. The average grain yield of Fuku was around 760 g m⁻², about 11% higher than that of Hito. The average grain yields of O316 and Kiyo were about 7%, while O327 was about 4% higher than that of Hito.

The contribution of yield components to grain yield was evaluated using the result of STD in 1994 (Table 3). The numbers of panicles m⁻² of O316 and Fuku were around 20%, and that of O327 was around 40% less than those of Hito and Kiyo. The numbers of spikelets per panicle of O316, Fuku and O327

were much larger than that of Hito, and those of O316 and Fuku were slightly larger than that of Kiyo. The number of spikelets per panicle of O327 was similar to that of Kiyo. Consequently, O316 and Fuku achieved about 50,000 and 42,000 spikelets m⁻², about 12,000 and 4,000 spikelets larger in number than that of Hito, respectively. The O327 achieved about 27,000 spikelets m⁻², about 11,000 spikelets smaller in number than that of Hito. Kiyo obtained about 47,000 spikelets m⁻². The percentage of ripened grains of O316 was slightly lower, and that of Fuku was slightly higher than those of Hito and Kiyo. The grain weight of O316 was smaller, and that of Fuku was larger than those of the two cultivars. The percentages of ripened grains and the grain weight of O327 were much larger than those of the two cultivars.

3. Ear characteristics and the percentage of ripened grains on different rachis branches

The numbers of primary rachis-branch (PRB) and secondary rachis branch (SRB) of O316 and Fuku were large, especially their numbers of SRB, which was significantly large. The numbers of PRB and SRB of O327 were also larger than that of Hito and were similar to that of Kiyo (Table 4). A difference in the number of spikelets per rachis branch on either PRB or SRB was not observed in every variety. Consequently, the number of spikelets per panicle was mainly determined by the number of spikelets on SRB. The percentage of ripened grains on SRB was lower than that on PRB in every variety. The percentage of ripened grains on PRB was not quite different among varieties, but that on SRB was signifi-

Fig. 2. Grain yields at the different planting densities and fertilizer application levels in 1994 and 1995.

Symbols were the same as in Fig. 1. Difference among varieties was tested by the analysis of variance, and t-test was carried out at 5% significant level and the same letter represented no significant difference. Figures in the parentheses represented the relative values to Hito.

Table 3. Grain yields and yield components under standard cultivation conditions in 1994.

Cultivars (Strains)	No. of panicles m ⁻²	No. of spikelets per panicle	No. of spikelets m ⁻² (x1,000)	Percentage of ripened grains	1,000 grain weight (g)	Grain yield (g m ⁻²)
Hito	591.3 ± 21.6a	64.7 ± 0.2d	38.3 ± 1.5c	79.9 ± 2.3b	22.34 ± 0.16c	684.6 ± 50.3b
Kiyo	546.9 ± 17.6b	85.4 ± 1.9c	46.7 ± 1.8a	76.5 ± 4.4bc	21.90 ± 0.02d	782.0 ± 55.2a
O316	464.7 ± 15.6c	107.9 ± 2.0a	50.2 ± 2.2a	72.1 ± 2.6c	20.55 ± 0.07e	742.9 ± 37.8ab
Fuku	432.2 ± 2.7d	98.0 ± 0.8b	42.3 ± 0.1b	80.1 ± 1.7b	23.27 ± 0.15b	789.3 ± 12.8a
O327	336.7 ± 6.8e	81.3 ± 3.2c	27.4 ± 1.6d	86.3 ± 0.9a	30.91 ± 0.36a	731.2 ± 41.7ab

Grain thickness in the calculation of yield and yield components was over 1.8 mm. Figures represented the means and standard deviations of 3 places (5 hills per place). Difference among varieties was tested by the analysis of variance, and t-test was carried out at 5% significant level and the same letter represented no significant difference.

cantly different. As compared with Hito and Kiyo, Fuku showed a higher percentage of ripened grains on SRB and O316 showed a lower one, whereas the O327 showed a significantly higher percentage of ripened grains on SRB than other varieties.

As described above, the percentage of ripened grains seems to correlate with the number of spikelets m^{-2} . The grain weight of O327 was much larger than those of other varieties. Consequently, the ripening ability of variety was analyzed based on the relationship between the percentage of ripened grains and sink size in PRB and SRB. As shown in Fig. 3, the sink size in PRB was larger than that in SRB in every variety, and the difference of sink size in PRB was obviously smaller than that in SRB among varieties. The percentages of ripened grains were negatively correlated with sink sizes in both PRB ($r = -0.789$) and SRB ($r = -0.560$) among varieties used. Hito, the partial panicle number type, showed a very low percentage of ripened grains

although its sink size was small in SRB. This characteristic of Hito was very different from those of the varieties of panicle weight and

Fig. 3. Relationship between the sink size and the percentage of ripened grains on PRB and SRB.

**Represented the difference at 1% significant level.

Symbols : □, PRB ; ●, SRB.

Table 4. Ear characteristics and the percentage of ripened grains on different rachis branches under standard cultivation conditions in 1994.

Cultivars (Strains)	No. of rachis branches per panicle		No. of spikelets per panicle		Percentage of ripened grains	
	PRB	SRB	PRB	SRB	PRB	SRB
Hito	7.8±0.3c	8.9±1.1d	41.0±1.5d	24.7±2.9e	89.5±2.3ab	69.1± 9.2bc
Kiyo	9.0±0.2b	13.2±0.8c	46.7±1.5c	38.1±2.8c	85.8±4.7ab	68.3±12.0bc
O316	10.6±0.4a	17.7±1.4a	53.8±2.4a	53.6±4.2a	85.1±4.4b	60.0± 7.1c
Fuku	10.2±0.5a	15.3±1.8b	51.2±3.4ab	47.1±5.6b	90.7±2.9a	76.3± 3.6ab
O327	9.4±0.4b	11.7±1.4c	49.0±3.4bc	32.5±4.4d	89.3±2.1ab	85.5± 0.9a

Figures represented the means and standard deviations of 3 places (3 hills per place). Grain thickness in the calculation of the percentage of ripened grains was over 1.8 mm. Difference among varieties was tested by the analysis of variance, and t-test was carried out at 5% significant level and the same letter represented no significant difference.

Table 5. Total dry weight, panicle dry weight and harvest index under standard cultivation conditions in 1994 and 1995.

Cultivars (Strains)	Total dry weight (g m^{-2})		Panicle dry weight (g m^{-2})		Harvest index (%)	
	1994	1995	1994	1995	1994	1995
Hito	1,501.5	—	781.3	—	52.0	—
Kiyo	1,515.3	1,518.7	853.9	777.4	56.4	51.2
O316	1,526.5	1,534.6	850.5	795.3	55.7	51.8
Fuku	1,542.4	1,595.8	889.0	824.5	57.6	51.7
O327	1,451.6	1,513.5	773.4	748.2	53.3	49.4

Data of Hitomebore were not taken because of lodging in 1995.

partial panicle weight types. Consequently, the relationship of the percentage of ripened grains and the sink size in SRB among varieties of panicle weight and partial panicle weight types except Hito was calculated to be significant ($r = -0.965^{**}$), but the relationship in PRB did not change much among these varieties, except for Hito ($r = -0.756$).

4. Total dry weight, the panicle dry weight and the harvest index

As shown in Table 5, the total dry weight of O316 and Fuku was larger, and that of O327 was smaller than those of Hito and Kiyo. The panicle dry weights of O316 and Fuku were markedly larger than that of Hito and similar to that of Kiyo. The panicle dry weight of O327 was similar to that of Hito and slightly smaller than that of Kiyo. Consequently, the harvest indices of O316 and Fuku were larger than that of Hito and similar to that of Kiyo. The harvest index of O327 was slightly larger than that of Hito and lower than that of Kiyo.

Discussion

1. Grain yield and yield components

The number of spikelets m^{-2} or sink size is the primary determinant of grain yield for cereal crops¹³. The expanded sink size is necessary to increase rice yield potential and is mainly enlarged by increasing number of spikelets m^{-2} or/and by increasing grain weight in high yielding cultivars^{1,4,6,7,11,14,15}. The increase in the number of spikelets m^{-2} is mainly caused by the increase in the number of spikelets per panicle in some high yielding cultivars^{3,4,9,11,12,16}. The results of this study indicate that the large numbers of spikelets m^{-2} of O316 and Fuku were also attributable mainly to the large numbers of spikelets per panicle. The expanded sink sizes mainly depended on the increase in the number of spikelets m^{-2} on SRB in O316 and Fuku and in the grain weight on SRB in O327. Furthermore, they showed relatively high ripening ability to produce their large sink sizes on SRB. In high yielding varieties of Nanjing 11 (*indica* cultivar) and Milyang 23 (*indica-japonica* hybrid cultivar)^{9,10,13}, the large numbers of spikelets m^{-2} were mainly due to large panicles. As compared with these cultivars, O316 and Fuku showed similar number of spikelets m^{-2} , which was due to the larger number of panicle m^{-2} , although the number

of spikelets per panicle was about 50 smaller than the two cultivars. Furthermore, O316 and Fuku showed a higher percentage of ripened grains. On the other hand, the characteristic of relatively large grain weight of O327 contributed to enlarge its large sink size, and O327 achieved a high percentage of ripened grains. These characteristics would be the reasons for higher grain yields in O316, Fuku and O327.

It has been pointed out that the varieties of panicle weight type hold the characteristics of a large number of spikelets and low percentage of ripened grains on SRB, which limited the percentage of ripened grains as whole panicles^{3,9,12}. This experiment also demonstrated that the percentage of ripened grains as whole panicles was governed by the percentage of ripened grains on SRB, and the percentage of ripened grains on SRB closely related to the sink size. As compared with Hito, Fuku and O327 showed relatively higher percentage of ripened grains on SRB, although they had larger sink sizes in SRB. This characteristic was attributable to their high percentages of ripened grains as whole panicles. On the other hand, the low percentages of ripened grains as whole panicles in O316 and Kiyo were due to their low percentages of ripened grains on SRB, and this was mainly due to their very large sink sizes in SRB. The results suggest that to produce large sink size for the varieties of panicle weight type or partial panicle weight type, the improvement of the ripening ability of spikelets on SRB would be significant for enhancing the yield level of the panicle weight and partial panicle weight types.

2. Total dry matter production and the harvest index

In recent years, accompanying the shortening culm length, the plant type has been improved through the breeding of high yielding rice varieties. The results of Takeda *et al.* revealed that low productivity of dry matter before heading in the cultivars of panicle number type with short culm was correlated with their low plant lengths¹⁰. Kuroda *et al.* demonstrated that the productivity of dry matter in high yielding cultivar of panicle weight type with long culm was larger than that in the cultivar of panicle number type with short culm⁴. These results suggest that it

is necessary to improve the productivity of biomass for the cultivars of short culm in the breeding of rice in future. In this experiment, O316 and Fuku showed slightly large total dry weights, although their plant lengths were short. This result indicated that O316 and Fuku would have excellent characteristics for dry matter production. In this experiment, harvest index was larger in O316 and Fuku than in Hito. As compared with *indica-japonica* hybrid cultivars^{6,8,9,12)}, the grain yields of O316 and Fuku were higher, and their sink sizes were further improved. However, the total dry weights of O316 and Fuku were not obviously different from those of the hybrid cultivars. As compared with Takanari¹⁶⁾, a new high yielding cultivar, the total dry weights of O316 and Fuku were lower, but their harvest indices were fairly larger. Consequently, it is inferred that O316 and Fuku have the excellent translocation ability of dry matter to their panicles. The clarification of the characteristics of the dry matter production and the accumulation of the carbohydrate in panicles for O316 and Fuku will be significant to understand their large harvest indices and high grain yields.

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References

1. Higashi, T. 1988. Present situation and research subject in future of breeding for superior high yielding rice cultivars. *Agriculture and Horticulture*. 63 : 793—799**.
2. ———, S. Saito, R. Ikeda, Y. Sunohara, S. Matsumoto, M. Inoue, Z. Oyamada, M. Yamaguchi, H. Kowata and M. Yokoo 1994. Breeding of a high yielding rice cultivar "Fukuhibiki". *Bull. Tohoku Natl. Agric. Exp. Stn.* 88 : 15—38*.
3. Jiang, C.Z., T. Hirasawa and K. Ishihara 1988. Physiological and ecological characteristics of high yielding varieties in rice plants. I. Yield and dry matter production. *Jpn. J. Crop Sci.* 57 : 132—138*.
4. Kuroda, E., T. Ookawa and K. Ishihara 1989. Analysis on difference of dry matter production between rice cultivars with different plant height in relation to gas diffusion inside stands. *Jpn. J. Crop Sci.* 58 : 374—382*.
5. Maruyama, K. and H. Nakane 1992. High yielding. In Kushibuchi, K. ed., *Rice Breeding in Japan*. Agriculture and Technique Society, Tokyo. 231—243**.
6. Maruyama, S., N. Kabaki and K. Tajima 1988. Growth response to nitrogen in japonica and indica rice varieties. I. Varietal differences in the rate of increase in straw weight and number of spikelet due to nitrogen fertilization. *Jpn. J. Crop Sci.* 57 : 470—475*.
7. Murayama, N. 1966. Investigation of the level up in rice yield. *Agriculture Technique*. 21 : 101—106**.
8. Saitoh, K., H. Shimoda and K. Ishihara 1990. Characteristics of dry matter production process in high yielding rice varieties. I. Canopy structure and light intercepting characteristics. *Jpn. J. Crop Sci.* 59 : 130—139*.
9. ———, ——— and ——— 1993. ———, VI. Comparisons between new and old varieties. *Jpn. J. Crop Sci.* 62 : 509—517*.
10. Takeda, T., M. Oka and W. Agata 1983. Characteristics of dry matter and grain production of rice cultivars in the warmer part of Japan. I. Comparison of dry matter production between old and new types of rice cultivars. *Jpn. J. Crop Sci.* 52 : 299—306*.
11. ———, ——— and ——— 1984. ———, II. Comparison of grain production between old and new types of rice cultivars. *Jpn. J. Crop Sci.* 53 : 12—21*.
12. ———, ———, K. Uchimura and W. Agata 1984. ———, III. Comparison between dry matter production of Japanese and new Korean cultivars. *Jpn. J. Crop Sci.* 53 : 22—27*.
13. ——— 1984. Physiological and ecological characteristics of higher yielding varieties of lowland rice with special reference to the case of warmer area in Japan. In *The Crop Science Society of Japan ed., Potential Productivity and Yield Constraints of Rice in East Asia*, Proc. Intl. Crop Science Symposium. Fukuoka, Japan. 125—139.
14. Tanaka, A., J. Yamaguchi, Y. Shimazaki and M. Shibata 1968. Historical changes in the plant type of rice cultivars in Hokkaido. *J. Sci. Soil and Manure, Japan*. 39 : 526—534*.
15. Tsunoda, S. 1986. History and perspectives of plant type investigation. *Recent Progress in Breeding*. Japan Breeding Society. 28 : 29—39*.
16. Xu, Y. F., T. Ookawa and K. Ishihara 1995. Comparison of dry matter production and yield during 1991~1994 between rice cultivars Takanari and Nipponbare. *Jpn. J. Crop Sci.* 64 (Extra issue 2) : 43—44*.

* In Japanese with English summary or abstract.

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