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Characteristics of Spikelets and Vascular Bundles in Panicle of Japonica Rice Cultivar, 'Iksan 435'

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ABSTRACT

Spikelet and vascular bundle development in rice panicles is considered to be the important elements in determining the genotype's yield capacity and translocation ability of assimilates into grains, respectively. This study was conducted to clarify the varietal differences of the spikelet and vascular bundle formations among three rice cultivars; Iksan 435 (japonica), Dongjinbyeo (japonica) and Namcheonbyeo (Tongil-type). Iksan 435 had more primary rachis branches (PRBs), secondary rachis branches (SRBs) and spikelets per panicle than Dongjinbyeo, but less than Namcheonbyeo. Among three cultivars, Namcheonbyeo showed the highest spikelet number per panicle which were differentiated SRBs mainly on PRBs of lower rachis nodes. And Namchenbyeo showed the highest number of large vascular bundle (LVB) as well as small vascular bundle (SVB) and it displayed the largest diameter of LVB. Between the two japonica cultivars, the numbers of LVBs and SVBs were significantly higher in Iksan 435 than those in Dongjinbyeo. The PRBs to LVBs ratio of Namcheonbyeo was twice as large as those of Dongjinbyeo and Iksan 435. These results indicate that the newly bred cultivar, Iksan 435, has improved yield capacity by increasing the number of especially rachis branches and spikelets formation as well as 1,000 grain weight, compared to other former japonicas.

Keywords : high yield, panicle, panicle weight type, rice, spikelet, vascular bundle.

Grain yield is directly affected by the number of spikelets that differentiate and develop in panicles. Thus the spikelet development and the efficient accumulation of assimilates in the grain constitute important elements of rice yield. Many studies have been done on the development of reproductive organs and panicle structure in rice and their varietal and environmental variations (Hasegawa et al., 1994; Kang et al., 1997; Komatsu et al., 1984). These studies have shown that considerable variation in panicle structure exists among the varietal groups: japonica, indica and Tongil-type. In most modern high yielding cultivars, e.g., Tongil-type, F1 hybrid and IRRI's new plant type (NPT) line, the higher yielding capacity results from the ability to form larger number of SRBs leading to increased spikelets (Kang et al., 1997; Kang & Wada, 1997; Peng et al., 1995; Sasahara et al., 1982; Yamamoto et al., 1991). Also the spikelet formation and panicle structure are influenced by experimental conditions such as nitrogen supply, planting density, temperature, shading, phytohormones treatment and water management, etc. (Hasegawa et al., 1994; Kobayashi & Horie, 1994; Matsuba, 1991; Matsushima, 1957). Korean rice breeders succeeded in developing high yielding Tongil-type cultivars via indica/japonica cross and these cultivars were broadly cultivated in the 1970s and contributed to the increase of rice production in Korea. Because Tongil-type cultivars had some defects, such as low palatability, the area soun to Tongil-type rice rapidly decreased in the 1980s. Since the 1980s rice breeders have placed a lot of effort on developing high yielding cultivars with high quality and taste.

A japonica cultivar 'Iksan 435' with superior high yielding potential and good quality was developed at the National Honam Agricultural Experiment Station (NHAES), RDA. The regional adaptation trial during 1997~1998 showed that the yield potential of this cultivar was 10~30% higher than those of other major japonica cultivars. The physiological and morphoecological characteristics for the increased yield of this cultivar, however, have not been elucidated.

The purpose of this study was to clarify the varietal characteristics of spikelet and vascular bundle formation of Iksan 435, and compare them with other japonica and Tongil-type cultivars.

MATERIALS AND METHODS

Rice culture

Three cultivars were used: two japonica, Iksan 435 and Dongjinbyeo, and one Tongil-type, Namcheonbyeo. These cultivars were grown on Aeric-Fluventic Haplaquent (Chonbuk series) fine silty loam soil at the paddy field of the NHAES, in 1997. Pregerminated seeds were sown in a nursery bed on May 22 and 3-leaf stage seedlings were transplanted in the paddy

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field on June 1.

Planting density was 24.3 hills m^{-2} (row distance: 30 cm, hill distance: 14 cm) and each hill consisted of 4~6 plants. The plots were fertilized at a rate of 110 kg N, 70 kg P_2O_5 and 80 kg ha^{-1}. Half of the nitrogen was applied as basal dressing before planting, and the rest was applied by split application at a rate of 2:2:1 as top dressing, tillering, spikelet formation and heading stage, respectively. 70% of K fertilizer was applied as basal dressing before planting and 30% as top dressing at the spikelet formation stage, respectively, and P was applied as basal dressing before planting. Other management practices followed the standard method of NHAES.

Measurement of rachis branches, spikelets and vascular bundles

For the observation of vascular bundles and the rachis branch and spikelets, ten panicles of main culm were collected at 7 days after heading. Panicle samples were preserved in FAA solution (formalin, acetic acid, 70% ethanol with a 1:1:18 ratio by volume). The generated and degenerated rachis branches and spikelets on each panicle node were counted from six randomly selected panicles out of the ten using both a dissecting microscope and the naked eye. Classification of differentiation dimension the of spikelets and SRBs on their PRB or SRB was as described in the previous studies (Kang & Wada, 1997; Sasahara et al., 1982). The internode part on 2 cm below neck node was sectioned with a cryostat microtome (CRYOCUT 1800, Reichert jung, Germany). After staining the section on a slide glass with safranin solution, culm diameter, thickness of culm wall, number and diameter of LVBs and SVBs were measured using an optical microscope. Yield and lodging degree were surveyed following the standard method of RDA.

RESULTS AND DISCUSSION

Growth and yield

Comparison of various agronomic traits among three cultivars is shown in Table 1. Heading dates of Iksan 435, Namcheonbyeo and Dongjinbyeo were 15, 18 and 19 August, respectively. Culm length was longest

Table 1. Comparison of major agronomic characters of Iksan 435, Dongjinbyeo and Namcheonbyeo.

Cultivar	Heading date	Culm length (cm)	Panicle length (cm)	Panicles per m^2	Ripening ratio (%)	1000 grain weight (g)	Milled rice yield (kg $10a^{-1}$)	Lodging degree (0-9)
Iksan 435	Aug. 15	85	21.2	312	92	27.9	657	3
Dongjinbyeo	Aug. 19	81	19.1	336	96	25.1	553	1
Namcheonbyeo	Aug. 18	76	22.1	356	86	21.8	654	0

Table 2. Means±s.d. of rachis branches and spikelets.

Panicle traits	Iksan 435	Dongjinbyeo	Namcheonbyeo	L.S.D.(P=0.05)
No. of PRB	11.8±1.0	9.0±0.7	10.5±0.8	1.0
No. of SRB	28.9±3.9	15.5±3.3	33.5±4.4	4.8
No. of TRB	0	0	3.2±2.3	
No. of SRB and TRB per PRB	2.4	1.7	3.5	
Generated spikelets no. of PRB	65.2± 4.9(46.2%)*	49.9±4.3(54.6%)	56.4± 5.1(32.9%)	5.9
Generated spikelets no. of SRB	62.3±12.9(44.2%)	37.0±7.9(40.5%)	99.6±12.7(58.0%)	
Generated spikelets no. of TRB	0	0	5.7±6.0(3.3%)	14.0
Degenerated spikelets no. of PRB	0	0	0	
Degenerated spikelets no. of SRB	13.5±5.4(9.6%)	5.2±4.1(5.7%)	7.4±6.3(4.3%)	6.6
Degenerated spikelets no. of TRB	0	0	2.5±3.0(1.5%)	
Total No. per panicle				
Generated spikelets	127.5±13.4	86.9±10.4	161.7±19.4	18.3
Degenerated spikelets.	13.5±5.4(9.6%)	5.2±4.1(5.7%)	9.9±6.7(5.8%)	6.8
Differentiated spikelets	141.0	91.4	171.6	
Differentiated spikelets no. per PRB	5.5	5.5	5.4	
Differentiated spikelets no. per SRB	2.6	2.7	3.1	

* ( ) : the percentage to total differentiated spikelets per panicle,
PRB : primary rachis branch, SRB: secondary rachis branch, TRB: tertiary rachis branch.

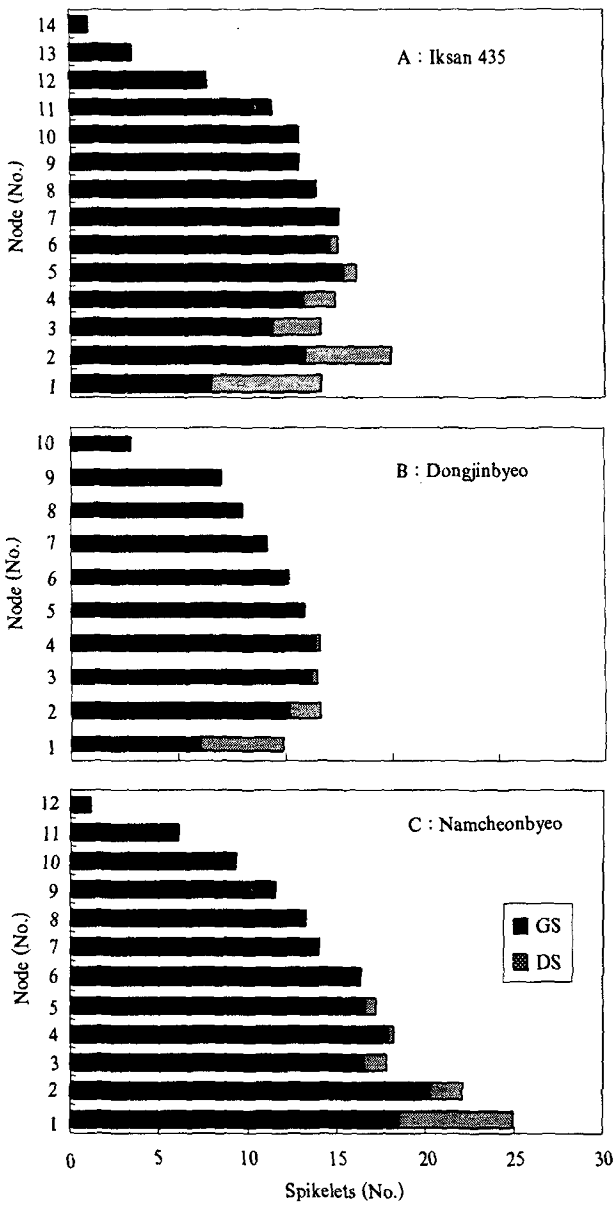

Fig. 1. Nodal distribution of generated and degenerated spikelets on rachis of main culm of three cultivars, Iksan 435 (A), Dongjinbyeo (B) and Namcheonbyeo (C). The rachis node numbers are in arcropetal order from neck node. DS: degenerated spikelets, GS: generated spikelets.

in Iksan 435 with 85cm and shortest in Namcheonbyeo with 76cm, and Iksan 435 and Namcheonbyeo have longer panicles than Dongjinbyeo. 1,000 grain weight of Iksan 435 was considerably heavier than Dongjinbyeo and Namcheonbyeo. The percentage of ripened grains was in the order of Dongjinbyeo (96%) > Iksan 435 (92%) > Namcheonbyeo (86%). Milled rice yields of Iksan 435 and Namcheonbyeo were almost the same and they were 20% higher than that of Dongjinbyeo. Field lodging at maturity was most severe in Iksan 435.

Rachis branch and spikelets formation within a panicle

In this study spikelets per PRB were nearly the same among three cultivars ranging between 5.4~5.5 (Table 2), which was in good agreement with those of many previous reports (Kang & Wada, 1997; Manaka & Matsushima, 1971; Sasahara et al., 1982; Komatsu et al., 1984). These results indicate that there is a narrow genotypic variation in spikelet formtion on PRB. However, the total number of PRBs and their spikelets per panicle were largest in Iksan 435 with 11.8 and 65.2, but smallest in Dongjinbyeo with 9.8 and 49.9, respectively. And a large varietal difference was observed especially in the number of SRBs and spikelets per panicle. In the present study the number of SRBs and spikelets per panicle of Namcheonbyeo were nearly two and three times higher than those of Dongjinbyeo, respectively (33.5 vs 15.5 and 99.6 vs 37.0). In Namcheonbyeo SRBs and tertiary rachis branches (TRBs) were differentiated mainly on the lower nodes (Table 2. Fig. 1). On the other hand, Iksan 435 had a relatively higher number of SRBs and spikelets per panicle than Dongjinbyeo. The total number of differentiated spikelets per panicle were 160, 128 and 87 in Namcheonbyeo, Iksan 435 and Donginbyeo, respectively.

Kang et al. (1997), one of the present authors, pointed out that the Tongil-type cultivar (Milyang 23) showed higher differentiation on SRBs and TRBs and their spikelets during the spikelet formation stage. And many differentiated spikelets on Tongil-type cultivars were also easily degenerated before heading especially on SRBs of lower rachis nodes, whereas japonica rice showed relatively lower differentiation and degeneration of SRBs and their spikelets (Kang & Wada, 1997; Sasahara et al., 1982). Those characteristics of Tongil-type rice might be derived from indica (Sasahara et al., 1982; Komatsu et al., 1984). In this study, however, the total number of differentiated and degenerated spikelets per panicle in Namcheonbyeo were relatively lower than those of the previous results using Tongil-type cultivars (Kang & Wada, 1997; Sasahara et al., 1982; Komatsu et al., 1984), although different cultivars and culture conditions were used.

As mentioned above, a big difference was detected in terms of panicle type between Dongjinbyeo and Iksan 435, especially in the number of PRBs per panicle and SRBs per PRB and consequently their total spikelets. Increased spikelets per panicle was one of the most important factors for high yielding capacity in most high yielding cultivars, e.g., Tongil-type, F_1 brid and NPT, although their excessively formed

Table 3. Means of culm, large vascular bundle (LVB), small vascular bundle (SVB) and their sectioned areas on the internode 2 cm below the panicle node.

Cultivar	Culm diameter	Culm wall thickness	Diameter		Number		Section area per panicle		Spikelet no. per section area
			LVB	SVB	LVB	SVB	LVB	SVB	
	µm				No. Culm^{-1}		mm^2 p^{-1}		No. mm^{-2}
Iksan 435	1653± 99	373±14	148±8	70±5	11.4±0.4	21.7±1.5	0.196	0.083	505
Dongjinbyeo	1514±109	361±22	151±7	70±5	9.7±0.2	16.9±0.5	0.174	0.065	382
Namcheonbyeo	2105± 78	345±19	164±8	79±4	17.3±0.8	18.0±1.0	0.365	0.088	379
L.S.D.(P=0.05)	129.0	22.9	9.5	5.8	0.65	1.33			

[†]Means±s.d.

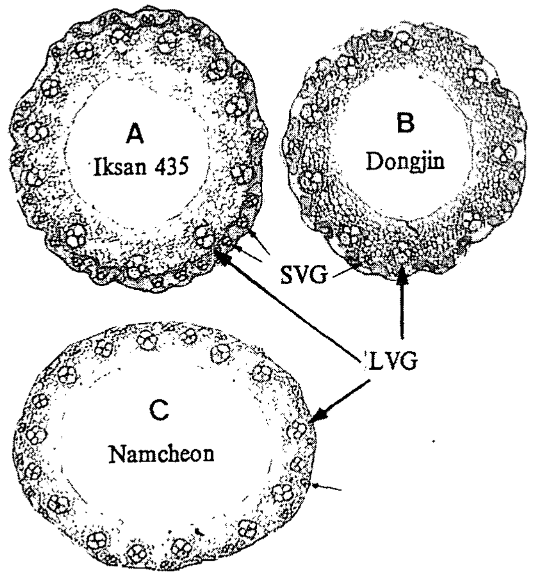

Fig. 2. Photos of transverse section of the internode 2 cm below panicle node, showing large vascular bundles (LVBs; large arrows) and small vascular bundles (SVBs; small arrows) of three cultivars; Iksan 435 (A), Dongjinbyeo (B) and Namcheonbyeo (C).

spikelets may also have caused the reduction of the ripening ratio (Peng et al., 1995; Sasahara et al., 1982; Yamamoto et al., 1991). Accordingly, panicle characristics of Iksan 435 and Namcheonbyeo may be improved by increasing the number of PRBs and SRBs and by decreasing the degenerated number of SRBs and their spikelets, compared to the other japonica and Tongil-type cultivars, respectively.

Vascular bundles

Vascular bundles on a panicle have an important role for translocating the assimilates and water from the leaves and stem into the grains. The LVBs of neck internodes are connected to both the PRB and the flag leaf node (Takeoka, 1977; Fukushima & Akita, 1997). Culm diameter of just below the neck node was largest in Namcheonbyeo, while culm wall thickness was largest in Iksan 435 among the cultivars tested (Table 3). Among the three cultivars, Namcheonbyeo showed the largest number of LVBs as well as the largest diameters of LVB and SVB. The diameters of LVB and SVB were not significantly different between Iksan 435 and Dongjinbyeo while the number of LVBs and SVBs were significantly higher in Iksan 435 than Dongjinbyeo. Total sectioned area of LVB was about two times larger in Namcheonbyeo than both Iksan 435 and Dongjinbyeo. Differentiated spikelet number per unit sectioned area of LVBs and SVBs was similar in Dongjinbyeo and Namcheonbyeo (382 and 379 mm^{-2}). Whereas Iksan 435 showed the highest number, 505 mm^{-2}. These differences between Iksan 435 and other cultivars may have influenced the differences in ripening ratios at the harvest stage (Table 1).

In the internode just below the neck node, LVBs were arranged radially in the peripheral zone of the stem at about equal distances from each other (Fig. 2). In Namcheonbyeo, a SVB was located between two LVBs in a peripheral region nearer the epidermis, therefore the number of LVBs and SVBs per stem were almost similar. In Iksan 435 and Dongjinbyeo two or three SVBs were found between two LVBs in several regions, therefore the number of SVBs were larger than those of LVBs in both cultivars. In this study the number of LVBs and PRBs were nearly the same in Iksan 435 and Dongjinbyeo, while in Namcheonbyeo the number of LVBs (17.3±0.8) were substantially greater than that of PRBs (10.5±0.8) (Table 2; Fig. 2). The reason why the number is similar between LVBs and PRBs in japonica, may be explained by the findings that in japonica, one LVB of neck internode entered rachis and travelled upper to each PRB without fusion to each other (Fukushima & Akita, 1997; Hayashi, 1976; Lee et al., 1992; Matsushima, 1957). While in indica cultivars two or three

LVBs entered from rachis to PRB and some of them fused together, with the LVB to PRB ratio about two. Therefore, LVB and SVB in Namcheonbyeo show the typical indica characteristics.

In high yielding cultivars, including Iksan 435 and Namcheonbyeo the physiological and morpho-ecological basis in assimilation and translocation ability for increasing the larger grains are quite important, and some follow- up studies dealing with these topics will be continuously carried out by the present authors.

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