Development of a Forefront One-Shot Basal Application Fertilizer "Rakuichi®" for Paddy Rice
– A Fertilizer Exclusive for Rice Varieties such as "Koshihikari" which has a Good Taste but Falls Over Easily because of its Long Culm –

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We have developed "Rakuichi®", a forefront one-shot basal application fertilizer for paddy rice varieties such as Koshihikari which has a good taste but falls over easily because of its long culm. Thanks to the fertilizer coating technologies of Sumitomo Chemical, "Rakuichi®" uses world-first technology to control releases of both fertilizer and the uniconazole-P plant growth regulator. Just by applying "Rakuichi®" at the basal application time, efficacy of the fertilizer is raised at the best additional fertilization time and continues to the late growth stage, something which is impossible for conventional one-shot basal application fertilizers because of the risk of lodging. This report outlines the characteristics and effects of "Rakuichi®" on rice growth, yield and grain quality.

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Foreword

1. Fertilization of rice varieties with good taste

In recent times, the situation regarding rice cultivation in Japan has become more severe than previously through factors such as an increase in low-priced rice imports, a chronic surplus in domestic production which has resulted from a reduction in the amount of rice consumption, and a drop in market prices. Because of this, rice growers are confronted with the problem of how they can produce good-quality and good-tasting rice which is acceptable to consumers.

There has been a change in trends in Japan since the 1980s regarding the varieties of rice which are being planted, away from 'short culm/high yield' varieties (the stalk of rice plants is called the 'culm') such as the Nipponbare variety toward 'long culm/good-tasting' varieties such as Koshihikari which have a good taste but which tend to fall over more easily because of their longer culms. Of the 1,684,000 hectares of rice under cultivation in Japan in 2006, Koshihikari made up 628,000 hectares, making it the most popularly cultivated variety[1)], and the planting area devoted to Koshihikari and related varieties is continuing to increase.

In line with the trends in rice varieties, fertilizer application methods are also changing to suit the characteristics of these varieties. The fertilizer application stages for the cultivation of paddy rice can be broadly divided into two stages. The first of these stages is the 'basal' stage which occurs at the point before or during the transplanting of seedlings, in order to promote initial growth and to increase the number of tillers (panicles).

The second stage of fertilization is the 'additional' stage which is carried out before heading of the plants occurs, and is done in order to promote ripening of the spikelets (**Fig. 1**). Additional fertilization for short culm/high yield varieties such as Nipponbare generally consists of a first application of fertilizer (Application I) during the young panicle formation stage (about 25 days before heading) which is the time when the young panicle are developing, and a second application

Days	0	+20	+50					
			–45 ~ –40	–25	–18 ~ –15	0	0 ~ +40	+40
Growth stage	Transplanting	Initiation of tillering	Maximum tillering	Young panicle formation	Latter stage of spikelet differentiation	Heading	Ripening	Maturing
Fertilizer application	Basal			Additional I	Additional II			

Fig. 1 Growth stage and fertilizer application time of paddy rice in Japan

of fertilizer (Application II) about seven to ten days after that.

On the other hand, long culm/good-tasting varieties such as Koshihikari grow a longer culm when nitrogenous fertilizer is added during the young panicle formation stage, so that it is more likely for the problem of reduced yield through lodging (flattening of the rice plant) to occur as a result. Because of this, the Additional I application period for long culm/good-tasting varieties is generally delayed until the latter stage of spikelet differentiation (15 to 18 days before heading) or later. In this way, when cultivating long culm/good-tasting varieties, the Additional I application of fertilizer increases the number of spikelets and boosts the yield, but with the potential disadvantage that if a mistake is made with the application period, lodging may occur which will reduce yield.

2. Revolutionary new Sumishort® technology

Sumitomo Chemical developed its special Sumishort® fertilizer containing a lodging reduction agent as a new functional fertilizer for overcoming the problem of lodging which can easily occur with long culm/good-tasting varieties. Its purpose was to help reduce lodging of the rice plants while also allowing nitrogenous fertilizer to be supplied at the optimum period (young panicle formation stage). Sumishort® contains the lodging reduction agent Uniconazole-P which suppresses the development of culms during the young panicle formation stage while also allowing the fertilizer to be applied during the optimum period, which means that it could be used both for reducing lodging and ensuring stable high yields in long culm/good-tasting varieties. Sumishort® can be considered as a radical new functional fertilizer which revolutionizes the fertilizer application systems which have been used for long culm/good-tasting varieties until now.

3. Movement away from split application to basal fertilizer application

Nowadays, with the aging of the population of farmers engaged in rice production and the increased reliance on side businesses, there has also been a trend toward collective farming by village, and an increase in the area of land under cultivation has also seen an increase in the number of large-scale farming enterprises every year. In this modern age there is an increased demand for reductions in labor input and energy consumption, and the fertilization methods for rice plants are also showing a trend away from split systems of fertilizer application to an era where a one-shot basal application of fertilizer is carried out and additional fertilizer applications are not necessary. One-shot basal application of fertilizer has been made possible by the development of technology for coating the fertilizer with a layer of resin and controlling the release of the fertilizer component (**Fig. 2**).

Sumitomo Chemical has also developed its own unique coated fertilizer technology called Sumicoat® for one-shot basal application fertilizer so that the necessary amount of fertilizer is supplied during the period necessary for the corresponding development of the rice plants. Different types of coated fertilizers with different release periods and release patterns for the fertilizer component have been developed, so that the basal application can be carried out in closer accordance with factors such as the variety of plant, the cultivation methods and the local weather patterns for the area of cultivation. However, even with this type of one-shot basal fertilizer application, the release period for nitrogenous fertilizer component needs to be delayed for long culm/good-tasting varieties so that there was an urgent need develop a fertilizer which could reduce lodging and increase yield.

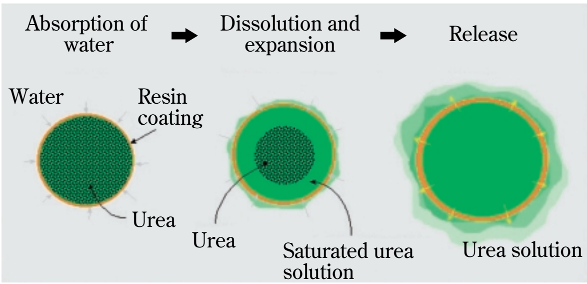


Fig. 2 Diagram showing coated fertilizer release

4. Development of Rakuichi® one-shot basal application fertilizer for long culm/good-tasting rice varieties

Rice cultivators have thus been looking for the development of a fertilizer which shows stability and effectiveness during the optimum additional fertilizer application period for long culm/good-tasting rice varieties. Their requirements have been for the development of a new functional fertilizer which can ensure stable yields and improved product quality, one which is a single-shot basal application fertilizer using technology such as Sumicoat®, while also eliminating the worry of lodging in the way that Sumishort® does.

In order to respond to these requests, we investigated coating technology for controlling the release of the fertilizer component and the Uniconazole-P lodging reduction agent. The result was that for fertilizer containing Uniconazole-P we succeeded in developing technology whereby factors such as the type of membrane, agent amount and coating conditions could be optimized so that even if the fertilizer was applied during the transplanting stage, the Uniconazole-P would only be released during the period when the culms were growing longer. This coated fertilizer containing Uniconazole-P was blended with fast-acting fertilizer and coated fertilizer to produce Rakuichi® (development code : SSDF), a forefront one-shot basal application fertilizer which can supply fertilizer to the plants in quantities that are neither too great or too small at the time required by the growing plants, while also removing the worry of lodging by long culm/good-tasting varieties.

Features of Rakuichi® and its effects on cultivation of paddy rice

1. Controlled release by the use of Sumitomo Chemical's coating technology

(1) Controlled release of Uniconazole-P

As mentioned above, Sumitomo Chemical has already succeeded in developing technology for controlled release fertilizers, but because Uniconazole-P is a hydrophobic chemical compound, technology is required which is different from the conventional technology for controlled release fertilizers with high solubility in water. In addition, in order to obtain the full effectiveness from Uniconazole-P, the release speed needs to be controlled within a narrow range, so that it was necessary to develop controlled release technology with a precision that was greater compared to controlled release fertilizers.

In general, the mechanism of movement of a substance through a membrane is understood from Fick's laws of diffusion. In the present case, the drug concentration on the receptor side is 0 (zero), so that in other words it can be assumed that a sink condition exists (**Fig. 3**).

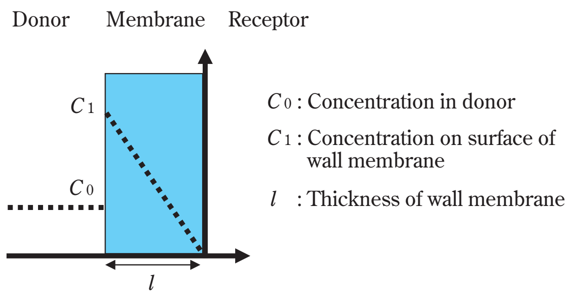
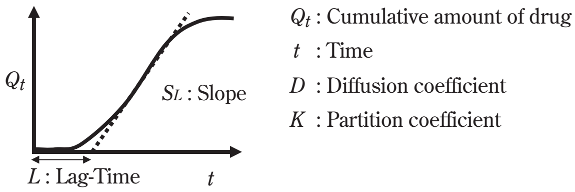


Fig. 3 Diffusion of drug through a wall membrane

The relationship between the drug permeation amount and time for diffusion of drugs through a plane sheet normally describes a sigmoidal curve as shown in **Fig. 4**. The diffusion coefficient for the drug within the membrane is calculated form the time lag by applying steady-state approximation to Fick's diffusion equation, and the partition coefficient of the drug between membrane and donor solution is calculated from normal conditional trends.

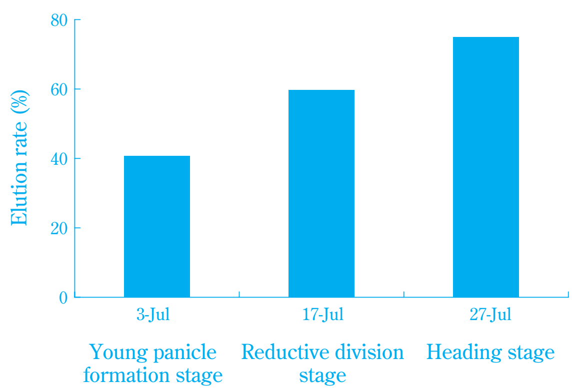


$$Q_t = \frac{DKC_0}{l}\left(t - \frac{l^2}{6D}\right) \qquad L = \frac{l^2}{6D} \qquad S_L = \frac{DKC_0}{l}$$

Fig. 4 Diffusion of drug through a plane sheet

Hydrophobic Uniconazole-P has physical properties which are substantially different from water-soluble fertilizers, and it has a different diffusion coefficient and partition coefficient. This theory was used to adjust the dispersion coefficient and partition coefficient while carrying out our investigations in order to arrive at the optimum resin composition, resin quantity and coating conditions. In addition, strict process control and quality control were carried out during actual production in our plant in order to ensure that products were stable in their target level of quality.

Fig. 5 shows the results of release tests carried out in a rice paddy field (at the Sumitomo Chemical Kasai Experimental Farm) using the coated fertilizer containing Uniconazole-P which was obtained in this way. The coated fertilizer containing Uniconazole-P was placed inside nylon stockings and submersed to within 5 cm from the surface of the soil. Samples were collected at regular daily intervals and the release of the Uniconazole-P from the coated fertilizer was measured. The Uniconazole-P was gradually released from the coated fertilizer, and approximately 80% of it had been released by the last week in July. At the Kasai Experimental Farm, the increase in the length of the culm starts from around the last week in June and is finished by about the first week in August during the heading stage. July is the period during which the culm increases in length the most, and the majority of Uniconazole-P was released during this period.



Sumitomo Chemical Kasai Experimental Farm (2000)

Fig. 5 Release rate of Uniconazole-P in paddy field

Rakuichi® is the first example in the world of the application of technology for controlling the release of a hydrophobic compound and a fertilizer component simultaneously to obtain efficacy during the necessary period. It is the first time that such precise release control technology has been successfully developed.

(2) Controlled release of nitrogenous compound

Rakuichi® controls the release of both the Uniconazole-P lodging reduction agent and the fertilizer component (nitrogenous component).

The nitrogen release patterns for Sumitomo Chemical's Sumicoat® Koshihikari (M) one-shot basal fertilizer for Koshihikari varieties and for Rakuichi® 21 were estimated based on temperature conditions for Nagaoka City in Niigata Prefecture (**Fig. 6**). Because the release rate for the nitrogenous component of the coated fertilizer is dependent on the water temperature, the results given were produced by computer simulation based on actual test data for the water temperature and the release rate and on AMeDAS air temperature data. The vertical axis shows the release rate (%) for the nitrogenous component on a daily basis. For Koshihikari (M), the release rate was suppressed on July 10th which corresponds to the young panicle formation stage. On the other hand, for Rakuichi® 21, the fertilizer component was released on July 10 without the suppression of the release rate which was evident for Koshihikari (M). In the case of Rakuichi®, the Uniconazole-P was released during the young panicle formation stage, so that fertilization effectiveness could be increased without lodging occurring. In this way, Rakuichi® proved to be a revolutionary one-shot basal application fertilizer which precisely controls the release of both Uniconazole-P and the fertilizer component.

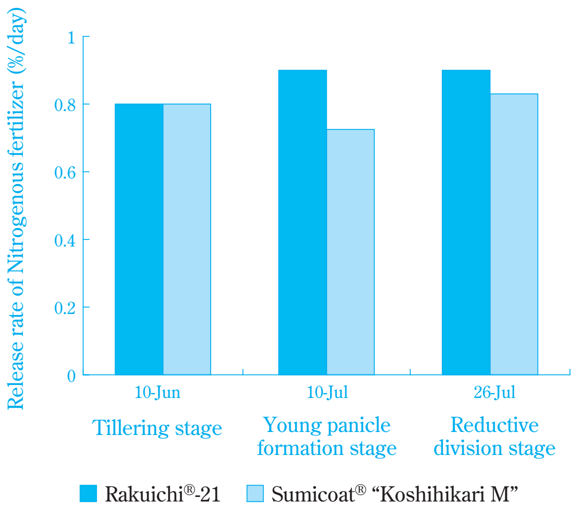
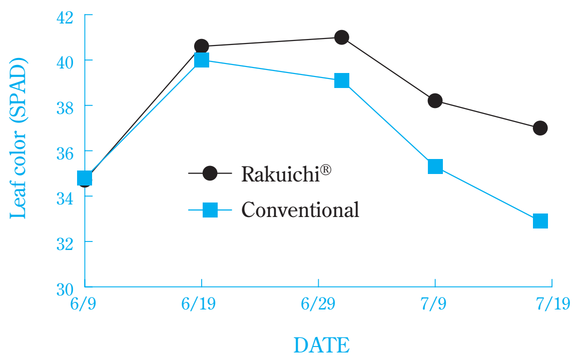


Fig. 6 Simulation of N release rate from coated fertilizer calculated from temperature data at Nagaoka city in Niigata prefecture

As an example of cultivation testing in an actual rice paddy, **Fig. 7** shows the changes in leaf color in plots at the Niigata Agricultural Research Institute Sado Agricultural Technology Center which were planted in 2003. Some plots were fertilized with Rakuichi®, while others were fertilized following conventional fertilization methods. The graph shows the results of investigating the leaf colors (SPAD values) at each growing stage in order to understand the nitrogen release pattern and the absorption responsiveness of the paddies. When the conventional plots and the Rakuichi® plots are compared, we can see that the leaf colors changed at about the same rate for both plots until June 19th. After this, the leaf color in the conventional plots gradually deteriorated from June 29th, but the leaves became darker in the Rakuichi® plots, and even by July



Niigata Agricultural Research Institute Sado Agricultural Technology Center (2003)

Fig. 7 Changes in color for leaves applied with Rakuichi®

19th there was very little deterioration in leaf color. The young panicle formation stage occurred on July 20th, so from the changes in leaf color we could see that fertilization effectiveness was being maintained at a high level even up until the young panicle formation stage.

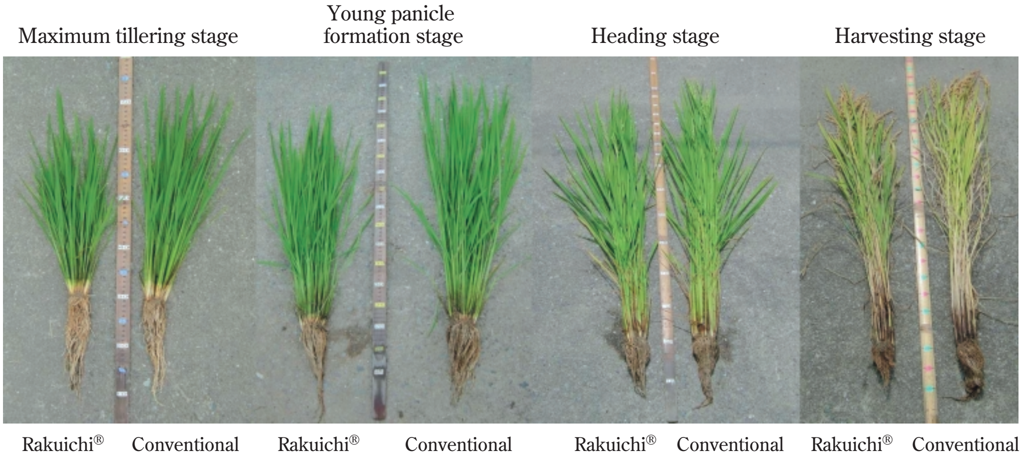
These tests showed that the Rakuichi® plots had very little deterioration in their leaf color and the vitality (photosynthetic performance) of the plants was maintained at a high level during the latter growth stages.

The final dehulled grain yields were 606kg/10a for the Rakuichi® plots and 569kg/10a for the conventional plots.

2. Effect on plant height, culm length and lodging reduction

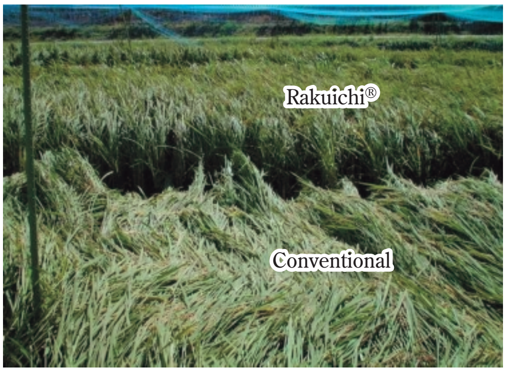
The paddies which were applied with Rakuichi® showed changes in the plant shapes resulting from the Uniconazole-P and fertilization patterns compared to the plots where the conventional system of fertilization was used. The plant heights were shorter from about one month after planting, and during each of the maximum tillering stage (end of June to beginning of July) where the number of stems is at its greatest, the young panicle formation stage (beginning to middle of July) and the heading stage (end of July to beginning of August), a comparison with conventionally fertilized plots showed that the plant length in the Rakuichi® plots was approximately 10% shorter (**Fig. 8**). In addition, the length of the culms was also kept shorter, so that at the ripening stage, the culms in the Rakuichi® plots were still shorter in length by approximately 10%. Because of the shorter culms, the lodging moments of the plants were smaller, with the result that fertilization using Rakuichi® reduced the amount of lodging which occurred (**Fig. 9**).

Fig. 10 shows the changes in plant height which occurred in this example of cultivation using Rakuichi® during the previously-mentioned tests carried out at the Niigata Agricultural Research Institute Sado Agricultural Technology Center in 2003. The plant height on June 9th (32 days after transplanting) was about the same for both the Rakuichi® plots and the conventional plots, but by June 19th (42 days after transplanting), the Rakuichi® plots were shorter compared to the conventional plots, and by July 18th (72 days after transplanting), the height in the Rakuichi® plots was 68.8 cm, whereas the height in the conventional plots was



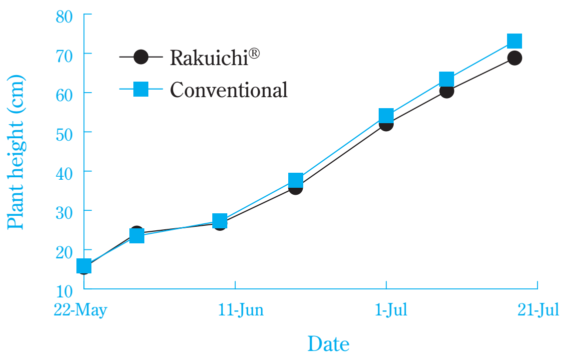
Sumitomo Chemical Kasai Experimental Farm (2001)

Fig. 8 Shape of paddy rice (Koshihikari) applied with Rakuichi®



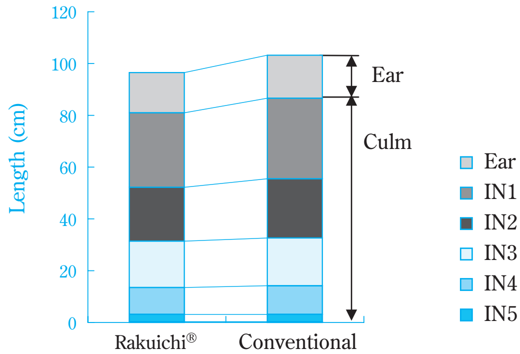
Sumitomo Chemical Kasai Experimental Farm (2001)

Fig. 9 Reduction of lodging by Rakuichi®



Niigata Agricultural Research Institute Sado Agricultural Technology Center (2003)

Fig. 10 Changes in height of plants applied with Rakuichi®



Niigata Agricultural Research Institute Sado Agricultural Technology Center (2003), IN : Internode

Fig. 11 Length of internode and ear applied with Rakuichi®

73.1 cm, meaning that the plants in the Rakuichi® plots were 4.3 cm shorter.

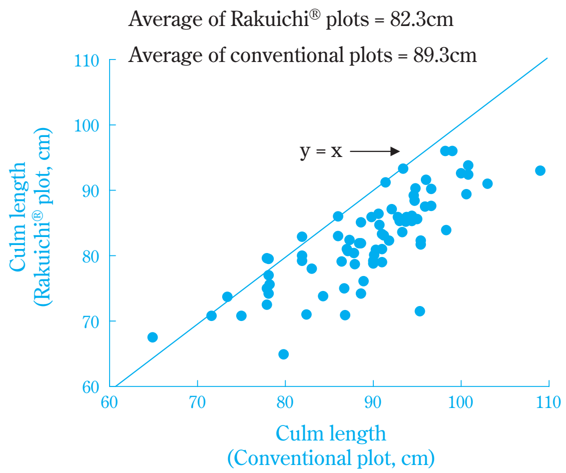
The culm lengths were 81.0 cm for the Rakuichi® plots and 86.6 cm for the conventional plots, meaning that the culm lengths in the Rakuichi® plots were 5.6 cm shorter. When the internodal lengths of the culms were investigated, the distances between all nodes tended to be shorter (**Fig. 11**).

The internodal lengths for the culms become longer when starting from the lowest node and going in order to the highest node. In general, the lower internodal lengths (No. 4 and No. 5) are the ones which have the main influence on lodging[3]. In the Rakuichi® plots, Uniconazole-P appears to have been released during each node growth stage, so that all internodal distances were reduced. The amount of lodging occurring by October 3rd (immediately before harvesting) was evaluated on a five-point scale (0 (none) to 4 (complete)) by means of a remote visual inspection of lodged plant groupings, and the results were 2.4 for the Rakuichi® plots and 3.0 for the conventional plots, indicating that lodging in the Rakuichi® plots had been reduced because of the shorter culm lengths.

Results were collated from 75 paddy field trials conducted using Rakuichi® in the seven years from 1999 to 2005 (conducted both within and outside of Sumitomo Chemical).

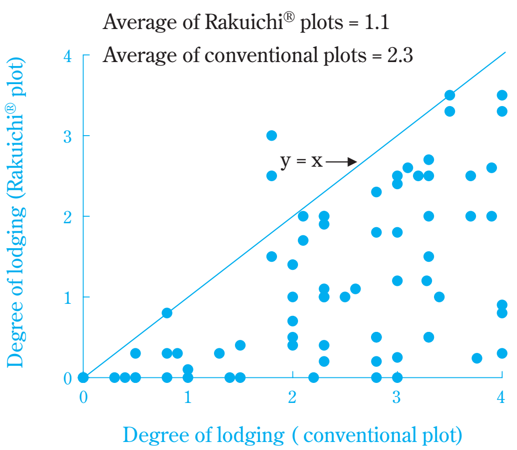
The average value for culm lengths was 82.3 cm for the Rakuichi® plots and 89.3 cm for the conventional plots, meaning that the culm lengths in the Rakuichi® plots were 7.0 cm shorter (**Fig. 12**).

The result of this was that the final degree of lodging was 1.1 for Rakuichi® plots and 2.3 for conventional plots, showing that lodging in the Rakuichi® plots had been reduced by 1.2 points (**Fig. 13**).



75 paddy field trials from 1999 to 2005

Fig. 12 Effect of Rakuichi® on culm length of paddy rice



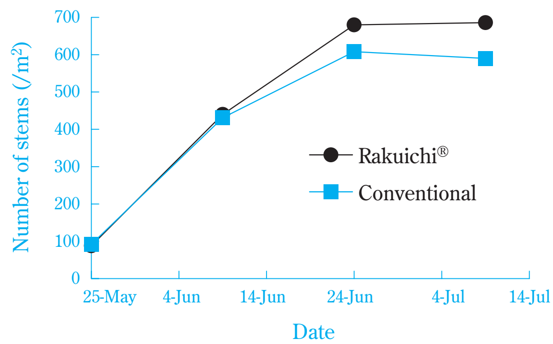
75 paddy field trials from 1999 to 2005, 0 : none ~ 4 : complete

Fig. 13 Effect of Rakuichi® on lodging of paddy rice

3. Effect on increase in number of panicles and yield

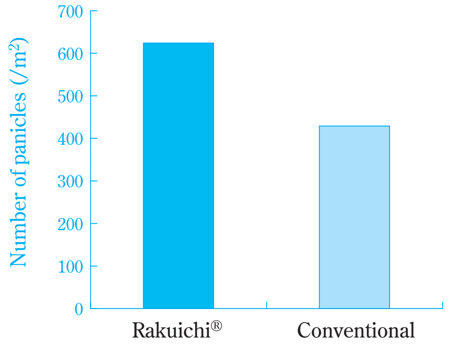
A feature of the paddies cultivated using Rakuichi® was that the number of stems was easy to maintain. Because an increase in the number of stems is linked to an increase in the number of panicles, it also has an effect on the final yield. Because of this, in cold-temperature growing regions where the initial growth activity can be reduced as a result of low temperatures, it is important to maintain the number of stems, and so they are also ideal places for the use of Rakuichi®. If we look at changes in the number of stems by cultivation using Rakuichi®, it can be seen that an increase begins approximately one month after transplanting, and the number compared to conventional plots increases by approximately 10% during the period from the maximum tillering stage to the young panicle formation stage. In addition, the plots cultivated using Rakuichi® showed not simply an increase in the number of stems, but the proportion of stems which produced panicles (the number of panicles), or in other words the percentage of productive tillers also increased.

Fig. 14 shows the number of stems (number of panicles) in test results for an actual example of cultivation using Rakuichi® was carried out by the Japan Association for Advancement of Phyto-Regulators (Ibaraki Prefecture) in 2002. The number of stems in Rakuichi® plots remained smaller than that for conventional plots for up to 15 days after transplanting, but from 30 days onward this trend reversed, until after 60 days the Rakuichi® plots had 686 stems/m^2, 16% more than the conventional plots which had 590 stems/m^2. The number of panicles was 624 panicles/m^2 for the Rakuichi® plots, an increase of 45% over 429 panicles/m^2 for the conventional plots, and the percentage



The Japan Association for Advancement of Phyto-Regulators (Ibaraki, 2002)

Fig. 14 Changes of number of stems applied with Rakuichi®



The Japan Association for Advancement of Phyto-Regulators (Ibaraki, 2002)

Fig. 15 Effect of Rakuichi® on number of panicles

of productive tillers also increased by 20.4 percentage points (**Fig. 15**).

In order to investigate the increase in the number of panicles as a result of cultivation using Rakuichi®, we investigated the factors that made up the yield amount. (**Table 1**) (The Japan Association for Advancement of Phyto-Regulators, Ibaraki Prefecture, 2002). The dehulled grain yield (kg/10a) is determined by a product of four factors which are the number of panicles, the number of spikelets per panicle, the percentage of ripened grains and the 1,000 grain weight. The Rakuichi® plots showed an increase in the number of panicles but a reduction in the number of spikelets per panicle, but the percentage of ripened grains and the 1,000 grain weight were about the same for both Rakuichi® and conventional plots.

The number of spikelets (1,000 grains/m^2) per unit area is a product of the number of panicles and the number of spikelets per panicle. In other words, in Rakuichi® plots, the increase in the number of panicles meant an increase in the number of spikelets per unit area, and thus an increase in the yield.

Data for the dehulled grain yield and the factors comprising the yield from the 75 paddy field trials conducted using Rakuichi® in the seven years from 1999 to 2005 (conducted both within and outside of Sumitomo Chemical) was used to analyze the reasons for the increased yield from Rakuichi®. Each factor compris-

Table 1 Effect of Rakuichi® on grain yield, yield components and degree of lodging

Plot	Number of panicles (/m^2)	% of productive tillers	Number of spikelets/ panicle	Number of spikelets (10^3/m^2)	% of ripened grains	1,000 grain weight (g)	Dehulled grain yield (kg/10a)	Degree of lodging (0 : none~ 4 : complete)
Rakuichi® 25	624	91.0	56.2	35.1	84.0	22.6	642	0.3
Ratio (Rakuichi®/Conventional,%)	(145)	(129)	(82.1)	(119)	(98.8)	(102)	(116)	(23)
Conventional	429	70.6	68.4	29.4	85.0	22.1	552	1.3

* The Japan Association for Advancement of Phyto-Regulators (Ibaraki, 2002)

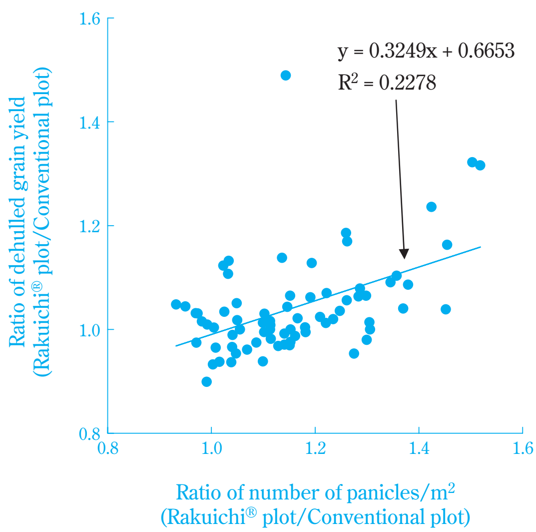


Fig. 16 Relationship between ratio of number of panicles/m^2 and ratio of dehulled grain yield

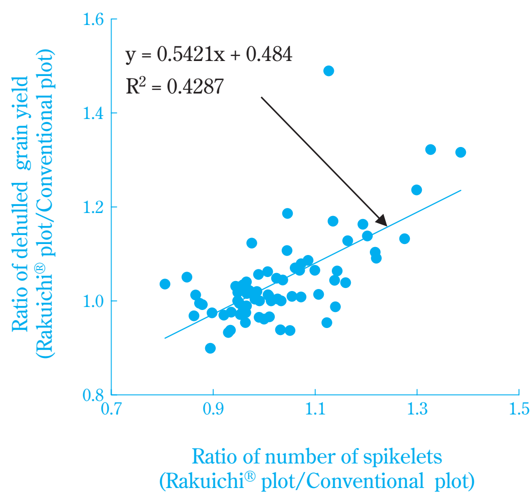


Fig. 17 Relationship between ratio of number of spikelets and ratio of dehulled grain yield

ing the yield was compared between the values for the conventional plots and those for the Rakuichi® plots to investigate the interrelationship between them and the dehulled grain yield. The results show that of the factors comprising the yield, the number of panicles and the number of spikelets per unit area showed a positive correlation (**Fig. 16** and **Fig. 17**). It can thus be said that the stable yield increases from cultivation using Rakuichi® occur as a result of increases in the number of panicles and the number of spikelets per unit area, and the shape of the plants and factors comprising the yield in rice paddies cultivated using Rakuichi® are close to those for short culm/high yield varieties.

4. Taste and quality of external appearance

For the same variety of product, the one that tastes better is generally the one with the lower protein content in the dehulled grains[4]. And so we investigated the protein content (by dry weight) in the dehulled grains from the 61 paddy field trials conducted using both Rakuichi® and conventional fertilizer in the six years from 2000 to 2005 (conducted both within and outside of Sumitomo Chemical) (**Fig. 18**). The results show that the average protein content for the Rakuichi® plots was 7.3%, while for the conventional plots it was almost the same at 7.4%. In recent years there has been a reduction in the amount of nitrogenous fertilizer applied in order to produce rice with a lower protein content, and the conventional plots would appear to have received less nitrogenous fertilizer than the Rakuichi® plots. Under such conditions, protein content is about the same in plots cultivated using Rakuichi®, and it by no means loses anything in the way of taste comparison either.

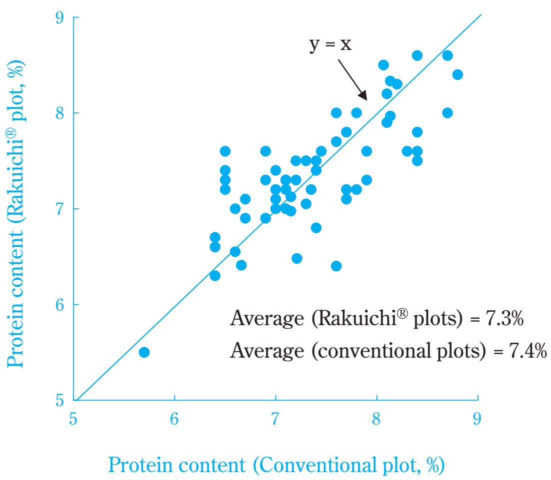


Fig. 18 Comparison of protein content in dehulled rice grain

The external appearance of the dehulled rice is evaluated with a grade of 1st which has perfect grains 70% or higher and a grade of 2nd for 60% or higher, and the grade has an effect on the retail price for dehulled rice. In recent years, high temperatures at the time of heading coupled with insufficient nitrogen during the latter stages, an excessive number of spikelets, a drop in root activity and an exhausting of soil productivity have combined to cause a drop in starch supply levels, and this has tended to cause an excess of white unripened grains, some with a milky-whiteness in the areas with insufficient starch that can be seen with the naked eye[5]. If this occurs a lot, then the external appearance of the rice is judged to be bad, and so improving the external appearance is an important consideration.

Therefore the rate of milkiness (%) appearing in the grains cultivated in Rakuichi® plots was investigated. **Table 2** shows the results of investigations into the external appearance carried out at the Fukui Prefecture Agricultural Experimental Research Station in 1999. The graded (perfect grain) percentage (%) was 76.5% for Rakuichi® plots and 62.9% for conventional plots, with the percentage for Rakuichi® being higher by 13.6 percentage points. Of the grains inspected, milky-white grains accounted for 10.4 percentage points, white core grains accounted for 0.6 percentage points and white belly and other unripened grains accounted for 2.6 percentage points , all of which were low figures. It is known that one-shot basal application fertilizers blended with coated fertilizers reduce the occurrence of

Table 2 Effect of Rakuichi® on quality of dehulled rice grain

Plot	Perfect grain	Imperfect grain			
		Milky white grain	White core grain	White belly grain	Other
Rakuichi® 15	76.5	14.3	0.7	4.9	3.6
Ratio (Rakuichi®/Conventional, %)	(122)	(58)	(54)	(65)	(100)
Conventional	62.9	24.7	1.3	7.5	3.6

* Fukui Prefecture Agricultural Experimental Research Station (1999)

milky-white grains[6]. Because Rakuichi® is also a one-shot basal application fertilizer blended with coated fertilizer, plots cultivated using Rakuichi® would be expected to have an improved external appearance with a lower rate of unripened grains including milky-white grains.

5. Plant shape and degree of ripeness

A reason why the occurrence of unripened grains including milky-white grains is reduced in plots which have been cultivated using Rakuichi®, apart from the reason mentioned above, concerns the possibility that there is a link between the changes in plant shape and improved ripening. In general, ripening is expressed as a ripening percentage (percentage of ripened grains to total grains), and there is a negative correlation between this percentage and the number of spikelets per unit area. However, Rakuichi® plots showed an increase in the number of spikelets per unit area, but the ripening percentage was about the same as that for conventional plots (Table 1). Therefore, in order to consider what was the cause of the improvement in the ripening percentage for Rakuichi® plots, we investigated the plant shape and panicle positions during the ripening stage. Firstly, we investigated the plant shapes for the Rakuichi® plots. Normally the plants in the conventional plots had a large angle (between the culm and the leaf) for the upper leaves, so that the lower leaves do not receive so much sunlight and die off, with the result that the amount of photosynthesis is reduced[7]. In contrast, the plants in the Rakuichi® plots tended to have smaller angles for the top leaf (flag leaf) and the second-top leaf and they stood up straighter (**Table 3**). Because the top leaves of the Rakuichi® plants stood up straighter, the lower leaves could still receive sunlight even into the latter ripening period, so that the amount of photosynthesis could be maintained. From the above, it is conjectured that because the top leaves stood up straighter on plants in the Rakuichi® plots and light could reach down to the thicker parts of the stem, the amount of photosynthesis carried out by the plants increased and this promoted ripening, and also the reduced amount of lodging also maintained a light-receiving posture during the ripening period which also maintained photosynthesizing performance. Sekimoto and Nishikawa (1993) reported that the same trends occurred in the plant shape of Koshihikari when Sumishort® was used[8].

Next we investigated the panicles of the plants in the Rakuichi® plots. In the plots cultivated using Rakuichi®, the number of panicles increased, but the number of spikelets decreased. This reduction in the number of spikelets has a close relationship to the ripening of the spikelets. **Table 4** shows an example of tests carried out on Rakuichi® plots and conventional plots by checking the number of spikelets per rachis-branch. The rachis branches of the panicles can basically be divided into primary (panicle stem) and secondary

Table 3 Effect of Rakuichi® on angles between leaf and culm

Plot	Culm length (cm)	Degree of lodging (0 : none ~ 4 : complete)	Angle between leaf and culm (°)		Dehulled grain yield (kg/10a)
			Flag leaf	Second highest leaf	
Rakuichi® 15	81.6	1.3	21.0	21.0	602
Ratio (Rakuichi®/Conventional, %)	(84.4)	(33.3)	(68)	(72)	(127)
Conventional	96.7	3.9	31.0	29.0	475

* Sumitomo Chemical Kasai Experimental Farm (2003)

Table 4 Effect of Rakuichi® on panicles and spikelets of paddy rice

Plot	Number of panicles/m^2	Number of spikelets/panicle	Number of spikelets (10^3/m^2)			% of spikelets	
			Total	Primary rachis-branch	Secondary rachis-branch	Primary rachis-branch	Secondary rachis-branch
Rakuichi® 15	453	75.9	34.3	19.0	15.3	55.4	44.6
Ratio (Rakuichi®/Conventional, %)	(116)	(89.7)	(104)	(117)	(92)	(112)	(88)
Conventional	391	84.6	32.9	16.3	16.6	49.5	50.5

* Sumitomo Chemical Kasai Experimental Farm (2003)

(panicle branch) rachis-branches. For the Rakuichi® plots, there was a higher proportion of primary rachis-branches (55.4%) and the proportion of secondary rachis-branches where unripened grains more commonly form was lower (44.6%). The spikelets which grew on the secondary rachis-branches were later in their maturing from the initial onset, and so the resulting reduction in the amount of starch accumulated caused a higher possibility of unripened grains[9]. The lower number of spikelets growing on the secondary rachis-branches is also another factor contributing to the lower incidence of white unripened grains in the Rakuichi® plots. From the above explanations, it appears that the reduction in the number of spikelets growing on the secondary rachis-branches of plants in the Rakuichi® plots caused an improvement in the ripening, which led to a higher yield and better external appearance.

Method of using Rakuichi®

1. Product lines and directions for use, and applicable regions and grades

Rakuichi® is a blend of coated fertilizer containing Uniconazole-P, coated ureas and compound fertilizer, and different formulations are available with a variety of urea coatings with different numbers of release days to cater to different cultivation regions, cultivation methods and plant varieties. The Rakuichi® 21, 25, 27 and 20S product lines were registered as fertilizers and chemicals for agricultural use in October 2005. **Table 5** shows the directions for use and the applicable rice varieties and regions for each Rakuichi® product line. The method and application period for Rakuichi® 21, 25 and 27 is the basal application as a whole layer application during plowing and puddling. In addition to application as a whole-layer application fertilizer during plowing and puddling, Rakuichi® 20S can also be applied as a side dressing during transplanting. In all cases the application is a one-shot basal application. The application amounts are 22.5 – 30kg/10a for Rakuichi®21, 25 and 27 and 30 – 40kg/10a for Rakuichi® 20S. The applicable regions and rice varieties range over Koshihikari in Hokuriku, Kanto and the western Japan plains for Rakuichi®21, Koshihikari in Tohoku, Kanto and the highlands of Kanto and western Japan for Rakuichi®25, Akitakomachi and Hitomebori in Tohoku and also early plantings of Koshihikari in March or early April in western Japan for Rakuichi®27. Rakuichi®20S is useful for Koshihikari in sandy soil regions where the nitrogenous component is easily released and as a side dressing for Koshihikari.

2. Factors in setting target yields

Target yields and factors in setting target yields will vary depending on things such as the weather, regional conditions such as soils and cultivation management practises such as density of planting. **Table 6** shows target yields and yield factors in Niigata Prefecture for Rakuichi®21 which were compiled based on the results of tests carried out at the Niigata Agricultural Research Institute Sado Agricultural Technology Center in 2003.

Targets for paddies cultivated using Rakuichi® are based on a number of panicles which is 10 – 15% higher than for paddies using conventional fertilizer, which maintains a larger number of spikelets per unit area

Table 5 Product lines and directions for use of Rakuichi®

Product lines		Rakuichi® 21	Rakuichi® 25	Rakuichi® 27	Rakuichi® 20S	
Ingredient (%)	N-P_2O_5-K_2O	21 – 11 – 10	25 – 10 – 8	27 – 10 – 7	20 – 11 – 11	
	Uniconazole-P	0.004	0.004	0.004	0.002	
package (kg)		15	15	15	20	
Directions for use	Application period	Plowing ~ puddling			Transplanting	Plowing ~ puddling
	Application amount (kg/10a)	22.5 ~ 30	22.5 ~ 30	22.5 ~ 30	30 ~ 40	
	Application method	Whole layer application			Side dressing	Whole layer application
	Number of applications	1				
Target areas		Hokuriku, Kanto and western Japan	Tohoku, highlands of Kanto and western Japan	Tohoku, area of planting on March or early April	Hokuriku, Kanto and western Japan	Sandy soil area
Target varieties		Koshihikari	Koshihikari	Akitakomachi, Hitomebore, Koshihikari	Koshihikari	

Table 6 Target yield and yield components (Niigata prefecture)

	Rakuichi® 21	Conventional
Number of hills (/m²)	18	18
Number of panicles (/hill)	26.5	23.1
Number of spikelets (/panicle)	66.5	71.6
% of ripened grains	88	82
1,000 grain weight (g)	21.5 ~ 22	21.5 ~ 22
Dehulled grain yield (kg/10a) (1)	606 ~ 614	525 ~ 537
Number of panicles (/m²)	478	415
Number of spikelets (× 10³/m²)	31.7	29.7
Maximum number of tillers (/m²)	600 ~ 730	540 ~ 676
% of producive tillers	79.7 ~ 65.5	76.9 ~ 61.4
% of grains over 1.85mm thickness	92.4	91.8
% of perfect grains	90.3	88.1
% of protein content in dehulled grains	6.3	6.6

(1) Yield is calculated on the yield components.

because of the increase in the number of panicles, and the ripening percentage and 1,000 grain weight are similarly higher. The target for the dehulled grain yield (kg/10a) should be 5 – 15% higher in line with the increase in the number of spikelets per unit area. The targets for the perfect grains (%) and protein content (%) of dehulled grain are the same or higher than conventional plots.

Future topics and outlook

The situation for rice cultivation in Japan will continue to become more severe in coming years. Increases in low-priced imports, reductions in the quantity of rice consumed and a downward trend in prices all mean that rice farmers must continually seek ways to reduce labor inputs and costs, and consideration must also be given to good quality and good taste as demanded by consumers. In light of these issues, the groundbreaking Rakuichi® product developed by Sumitomo Chemical differs from conventional fertilizer applications for good-tasting rice varieties such as Koshihikari because it takes the concepts introduced by Sumishort® of increasing the supply of nitrogen during the young panicle formation stage and suppressing the elongation of the culms and the concepts introduced by Sumicoat® one-shot basal application fertilizer for use with a variety of different plant varieties, cultivation methods and cultivation areas.

As the population of rice farmers in Japan continues to age and farmers engage in sideline businesses, the burden placed on them for summertime fertilizer application increases, and so we can predict that application methods will change from the current conventional systems toward one-shot basal application systems. Rakuichi® is an ideal product to suit the needs of Japanese rice farmers in the future because it is suitable for use with long culm/good tasting varieties of rice such as Koshihikari which are favored by consumers even in regions where lodging of the plants can easily occur, plus it also omits the additional application phases for such fields and it provides stable yields.

However, the cultivation of paddy rice is not only a matter of fertilization. Each rice-growing region has different weather patterns, soil types, cultivation methods and plant varieties, so that cultivation management methods for Rakuichi® which are suitable for each different region are needed. Basically the optimization of planting density, water depth and the degree of irrigation and drying-out, and from the point of view of fertilisation, optimization of the plowing depth and fertilizer amount, are all factors that need to be considered. In addition, the development of new product lines for different cultivation regions is also a subject which we would like to address in future investigations.

Rakuichi® is the world's first controlled-release one-shot basal application fertilizer containing a lodging reduction agent. Rakuichi® has the potential to contribute greatly to improving and developing the environment for the cultivation of good-tasting rice varieties such as Koshihikari in Japan.

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Reference

1) Nourinsuisan Toukei Heisei 18-nensan Suito no Hinshubetsu Shukakuryo [Ministry of Agriculture, Forestry and Fisheries Statistics on Rice Varieties and Their Yields in 2006]. Japanese Ministry of Agriculture, Forestry and Fisheries ; 2007.
2) Ouchi S, Nishikawa A, Okada S. Sumitomo Kagaku **1996-I** 4 [SUMITOMO KAGAKU **1996-I** 4] ; 1996.
3) Saito Y, Hokuriku Sakumotsu Gakukaiho [Proceedings in Hokuriku Crop Science] ; 1991 ; Vol. **26**, p.125.
4) Obuchi K, Oishii kome wa doko ga chigau ka [What is different about good-tasting rice?] ; Rural Culture Association ; 1992 ; p.56.

5) Suito no Kouon Shogai no Kokufuku ni mukete (Kouon Shogai Taisaku Repouto) [Report on Measures against Disorder of Paddy Rice Caused by High Temperatures] ; Japanese Ministry of Agriculture, Forestry and Fisheries ; 2006.
6) Koshihikari no Zenryo Motogoe Sehiho ni yoru Nyuhakuryu no Hassei Keigen to Genmai Hinshitsu no Koujo [Research Report : One-shot Basal Application Fertilizer for Koshihikari Reduces Milky-white Grains and Improves Quality of Dehulled Grains] ; Fukui Prefecture Agricultural Experimental Research Station ; 1999.
7) Matsuo T ed. Inagaku Taisei Daini kan Seirihen ['Physiology' in Science of the Rice Plant Vol. 2] ; Rural Culture Association ; 1990 ; p.564.
8) Sekimoto H, Nishikawa A. Nihon Dojo Hiryogaku Zasshi [Japanese Journal of Soil Science and Plant Nutrition] ; 1993 ; **64** (6), 662.
9) Matsuo T ed. Inagaku Taisei Daini Kan Seirihen ['Physiology' in Science of the Rice Plant Vol. 2] ; Rural Culture Association ; 1990 ; p.104.

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