Studies on the Occurrence of "Tomehagare", a Newly Found Physiological Disease of Rice, and Its Preventive Measures*

I. Symptoms and occurrence of "Tomehagare" and nutritional status of the diseased plants

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INTRODUCTION

Strange-looking rice plants, the flag leaves of which changed their color with the occurrence of small reddish brown spots, so-called "Tomehagare" were observed in the paddy fields along the River Mana, Fukui Prefecture, Japan. They seem to have initiated in 1961, and the extent of the affected area was estimated to be about 1000 hectares, recording 3000 hectares at largest in 1967.

There are many papers reporting the similar symptoms in which the color of leaves changes to reddish brown. Many of them were caused by the nutritional disorders like the symptoms of "Akagare"^{2,5,9)} in Japan. Recently, "Akagare" type diseases were classified into three major types according to their causes^{2,5,9)}. All of the "Akagare" type diseases took place in the rice plant from the early to the middle stage of growth. In Japan as well as in other rice-growing countries in Asia, no information has so far been presented¹⁾ on the

symptom like "Tomehagare", which literally means withering away of the flag leaf and occurring at the ripening stage.

Several experiments have been conducted in the localities of Ono City since 1967 in order to clarify the physiological mechanism and find the remedial measures for this disease. The results will be reported in the serial papers.

1. Symptoms and conditions of the occurrence of "Tomehagare".

1) Symptoms.

The symptoms are characterized as follows: It occurs after heading stage, showing an obvious progress especially under the hot weather (table 1). First, small reddish brown spots appear on the interveins at the tip of the flag leaves, then they gradually spread through interveins downward from the tip to the bases of the leaves. Finally, the whole leaves turn reddish brown. Also the second leaves from the top are often affected in a severe case.

The disease begins to appear depending on the

Table 1 Annual changes in the grade of "Tomehagare" occurrence in relation to the temperature

Year	Maximum temperature after heading of Honenwase				Grade of "Tomehagare" occurrence
	0~5 days	6~10 days	11~15 days	mean	
1964	33.6°C	34.8°C	34.6°C	34.3°C	4
1965	32.8	33.1	32.8	32.9	3
1966	28.2	33.5	33.5	31.7	2
1967	34.5	34.7	33.5	34.2	5
1968	33.5	31.6	28.4	31.2	1

Grade of "Tomehagare" occurrence was observed on the customarily cultivated farmers field on the spots and expressed by numerals from 1 to 5 in increasing severity, according to the same method as in the chapter 3.

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weather conditions; in normal years its beginning is around August 10 and the symptoms become most distinguishable during 10 days after that; and, in a hot summer, the end of July as well.

Reddish brown color peculiar to the symptom reduces towards the maturing stage and turns grayish so that it becomes difficult to distinguish the diseased plants from the normal ones.

2) Locality and vicissitude.

The disease was widely seen in the field on the alluvial soil along the River Mana and was serious at Tsuchifugo where many branch streams meet into the main current of the Kuzuryu River. Even at the 15 km downstream from this site, the rice plants were fairly affected by this disease (fig. 1).

The result of the surveys showed that the symptoms prevailed with little regularity, but generally more serious at the water exit than at the water inlet of

a paddy field. However, it did not always occur on the neighboring fields even if they received the same irrigation water. The affected field could be easily recognized from a long distance because of the distinct reddish brown color of upper leaves.

3) Properties of the paddy soil on which "Tomehagare" occurred.

The disease occurred mainly on well-drained paddy fields belonging to an "Akiochi" district, where the soil was characterized by the deficiency of iron, silica, nitrogen and so on, excluding manganese which was quite in excess (table 2). Moreover, in the concerned fields, the ground water level was lower and the soil mainly consisted of sand in the surface layer and gravels of medium size in the lower layer, being associated with the great water percolation (5–10 cm/day). Therefore oxidative conditions of the soil occasionally develop in addition to its poor fertility. These tendencies seem to be common to all of the soils on which "Tomehagare" occurred.⁴⁾

2. Changes in the longevity of the leaf and yield components of the rice affected by "Tomehagare".

MATERIALS and METHODS

A survey was conducted in order to know the influence of "Tomehagare" on ripening of the rice plants in 1967, when "Tomehagare" occurred most seriously. One hundred diseased and healthy stems were collected and leaves were separated according to the position on the stem. The rate of fresh area per whole leaf and number of fresh leaves per one hundred stems were measured.

Iodine-starch reaction test was applied to the sheaths and culms by soaking them into an iodo-potassium solution for ten minutes. The results were

Fig. 1 Occurrence of "Tomehagare" disease in the paddy fields of Ono and Katsuyama city

Table 2 Chemical properties of the soil at Kamigojoho in Ono city (per 100 g soil)

Horizon	pH (KCl)	N	CEC	Exch. base			Available		Free	Easily reducible
				CaO	MgO	K ₂ O	P ₂ O ₅	SiO ₂	Fe ₂ O ₃	MnO
cm		%	me	mg	mg	mg	mg	mg	%	mg
1 (0~13)	4.1	0.11	9.8	123	10.4	10.9	11.1	9.3	0.98	26.7
2 (13~20)	4.4	0.33	9.5	165	15.5	7.5	15.8	7.9	1.06	38.1
3 (20~38)	4.5	0.19	8.2	174	14.5	8.1	12.7	8.5	1.77	56.9

expressed by the ratio of colored length to the whole culm and leaf sheath and by the developed tint which was ranked in ten classes, in increasing order. The yield components were also measured.

RESULTS and DISCUSSIONS

1) Longevity of the leaf.

Half area of the fourth leaf from the top in the normal plants was still alive on July 27 (table 3), while in the diseased ones, those leaves lower than the third one already withered away on the same date. After this time, the symptoms extended rapidly with progress of ripening, but further progress of the leaf withering was not so rapid as with the normal ones. As a result, upper leaves of the affected plants

remained green and longer than those of the normal ones with a larger green areas at the maturing stage on August 19. Similar trend was also observed in the decrease in the number of fresh leaves. Thus little difference in total living leaf area could be noted at this stage between the diseased and the normal plants.

2) Relationships between the symptoms and iodine-starch reaction on the sheath and the culm.

The iodine-starch reaction may provide some information on carbohydrate accumulation in the plant.¹⁾ As is seen in table 4, iodine-starch reaction was complete in the culms and showed higher percentage areas on the sheaths of the normal rice plants on July 27, while it decreased abnormally in

Table 3 Comparison of the leaf state between normal and diseased plants according to the position on stem

Plants	Leaf position from top	Ratio of fresh area per whole leaf			Number of fresh leaves per 100 stems		
		July 27	Aug. 9	Aug. 19	July 27	Aug. 9	Aug. 19
Normal	Flag (1)	0.95	0.20	0.20	100	96	96
	Second	0.99	0.19	0.20	100	84	83
	Third	0.93	0.16	0.15	100	85	80
	Fourth	0.43	0.0	0.0	70	0	0
Diseased	Flag (1)	0.74	0.46	0.25	100	91	90
	Second	0.86	0.50	0.30	100	100	98
	Third	0.0	0.0	0.0	0	0	0
	Fourth	0.0	0.0	0.0	0	0	0

Sampled plot	Transplanting	Heading	Maturity	Sampled at Tsuchifugo of Ono city. Variety: Honenwase.
Normal	May 12	July 22	Aug. 23	
Diseased	May 4	July 19	Aug. 19	

Table 4 Iodine-starch reaction in culm and sheath

Plants	Leaf position from top	Culm			Sheath		
		July. 27	Aug. 9	Aug. 19	July 27	Aug. 9	Aug. 19
Normal	Flag (1)	67 (1.0)	0	0	100 (1.0)	0	0
	Second	100 (4.5)	0	0	67 (2.0)	0	0
	Third	100 (5.5)	0	0	42 (4.5)	0	0
	Fourth	100 (5.5)	0	0	13 (1.5)	0	0
	Fifth	100 (6.0)	0	0	0 (0)	0	0
Diseased	Flag (1)	100 (1.0)	0	0	100 (1.5)	0	0
	Second	13 (1.0)	0	0	38 (1.5)	0	0
	Third	10 (0.5)	0	0	18 (1.0)	0	0
	Fourth	0 (0)	0	0	0 (0)	0	0
	Fifth	0 (0)	0	0	0 (0)	0	0

Number gives the ratio of colored length to the whole and leaf sheath, respectively.

() shows developed tint of the iodine-starch reaction which was divided into 10 classes, in the increasing order.

Table 5 Comparison of yield components between normal and diseased plants (Honenwase, 1967)

Plants	Culm length	Panicle length	Panicle number	Panicle wt. per hill	Wt. of one panicle	Spikelet number per panicle	Wt. of 1000 grains	Percentage of ripened grains
	cm	cm		g	g		g	%
Normal	80.1	18.9	31.0	35.8	1.24	58.8	24.7	79.3
Diseased	78.5	18.1	34.0	34.2	1.08	55.7	21.6	64.9

Same samples as in Table 5 3—4.

the diseased plants, especially in the culms in the deepness of blue color developed. These facts would suggest shortage of carbohydrate nutrients or their stagnant translocation at this stage.

3) Influence on the yield components.

The length of culms and the number of spikelets per panicle of the diseased plants were slightly less than those of the normal ones, while panicles were in reverse relation. As a result, the number of spikelets per hill were almost equal. As to other yield components, the percentage of ripened grains and the 1000 kernel weight were lower by about 12 and 18 per cent, respectively (table 5). These facts suggest that the plants would grow up smoothly until the number of spikelets per ear was determined, and then most of the yield components became deteriorated with the occurrence of "Tomehagare". Such depressed grain development of the diseased plants might be attributed to a decrease in starch production and its subsequent decrease in translocation.

3. Changes in mineral nutrient contents of the leaf blades in the diseased plants.

MATERIALS and METHODS

The degree of "Tomehagare" symptoms was classified into five groups according to the size of colored area of the flag leaves, grade 1: <20%, 2: 20–40, 3: 40–60, 4: 60–80, 5: >80.

In 1968, Honenwase was sampled on August 10, 20 days after heading, the beginning of "Tomehagare" occurrence and then on August 31, the maturing stage.

Leaf blades of the samples were oven-dried and analyzed of their inorganic elements according to the usual chemical analysis methods in the station. Nitrogen was analyzed by means of semi-micro Kjeldahl method. As to other inorganic elements such as Fe_2O_3 , P_2O_5 , MnO , MgO , and K_2O , the samples

were subjected to the ignition method and inorganic analysis using colorimeter. Other analyses were made according to the ordinary procedures.

RESULTS and DISCUSSION

1) Nutrient contents in the leaf blades of "Tomehagare" plants.

As can be seen in fig. 2, nutrient contents of the blade both in the flag and the second leaf taken from 20 days after heading to maturity changed similarly. Contents of some elements such as nitrogen, potassium and phosphorus were lower at maturity than those at 20 days after heading, while iron and silica gave the opposite behavior.

Irrespective of those differences, however, those element contents decreased more and more as the symptom of the disease became more distinct with an exception of phosphorus in the flag leaf at maturity. Magnesium also seemed to have decreased with the severity of the symptom.

In contrast, contents of manganese was extremely high in the diseased leaf, especially at the maturity ranging from 2000 to 5000 ppm in the flag leaf.

Critical content of manganese in the leaf blade to cause manganese toxicity was shown by Saito and others^{7,8)} as 1000 ppm. The symptom was characterized by the reddish brown spots developing on the interveins of the leaf blades, rolling inward and finally withering away. Unlike this manganese toxicity symptom, which occurred on the lower leaves, "Tomehagare" appeared first on the flag leaves and spread downward.

According to Tanaka's¹⁰⁾ report, however, manganese toxicity was not visible on the rice plants even if manganese content of the leaves exceeded 3000 ppm, as far as the growth media for the plant were nutritious enough. In this case, a high level of iron might have some role for inactivating excess manganese in

the plant. Therefore the manganese content itself is not considered a sole cause for the nutritional disorder.

"Tomehagare" is thus quite different from other nutritional disorders like "Akagare"^{2,3,9)} and "Bronzing"⁶⁾ in the high content of manganese accompanied probably by iron deficiency.

Such an abnormal manganese uptake by the plant might be mainly ascribed to the high level of available manganese in the soil and partly due to the use of special manganese compound fertilizer "Mitsukane" which was practised by the farmers on the concerned fields for as long as ten years. It contained 10% of manganese and was applied as the basal to the field at the rate of 100 to 180 kg per 10a every year.

2) Malnutrition in the diseased leaf blade.

In contrast to high contents of manganese, those of silica, nitrogen, phosphorus, potassium and iron were lower in the diseased leaf blade; silica content was around 8%, and this might be low enough to cause its deficiency in the plant¹¹⁾. Okuda and Takahashi⁵⁾ reported that the rice plant was likely to be seriously injured by the lack of silica under high iron and manganese level in the soil. One of the important roles of silica in high silica plants like the rice plant was said to prevent them from absorbing these heavy metals in excess. In other words, deficiency in silica would lead to uptake of manganese in excess to a toxic level for the plant due to its antagonistic reaction.

Iron was the element which showed a great change next to manganese in the affected leaf blade. The fact that "Tomehagare" appeared in the "Akiochi", autumn-declined, paddy fields where iron content in the soil was smaller than that in other normal fields, implies that iron deficiency might be related to the occurrence of this disease. To make the situation worse, iron became inactive under the oxidative condition (Eh6: +250 mV, the 3rd of August, 1969) and at this high level of oxidative-reductive potential in the soil, more manganese would remain available than iron. Therefore, manganese in excess in combination with such state of malnutrition would have caused its toxicity symptoms in the "Tomehagare" plants.

Fig. 2 Relationships between the occurrence of "Tomehagare" and content of nutrients in the leaf blade (1968)

Grade shows the ratio of colored length to the whole leaf blade length, taking the wholly colored blade as 5.

3) Ratio of iron to manganese.

Since iron and manganese are strongly antagonistic, against each other, the Fe/Mn ratio is considered to indicate a nutritional balance in the rice plant²⁾.

It has been ascertained that there is a positive relationship between the occurrence of "Bronzing"

Fig. 3 Relation between the grade of “Tomehagare” symptom and Fe/Mn ratio in the leaves of Honenwase (1968)

Grade is the same as in fig. 2.

and the Fe/Mn ratio.⁶⁾ The same trend is also recognized in “Akagare”⁸⁾. On the contrary, the Fe/Mn ratio is negatively correlated to the occurrence of “Tomehagare” disease as shown in fig. 3. Calculating from fig. 3, critical Fe/Mn ratio to cause “Tomehagare” seems to be lower than 0.20 on the flag leaves. Hence, the latter disorder can be regarded as manganese toxicity associated with iron deficiency in the soil, which might in turn lead to the excessive uptake of manganese by the plant, causing a metabolic disturbance.

SUMMARY

Around 1961 in Fukui Prefecture, a peculiar phenomenon of rice plant was discovered in a comparatively well-drained paddy field along the River Mana, where flag leaves of the plants withered away after turning reddish brown at an early ripe stage in August. The phenomenon was called “Tomehagare” which literally means withering of the flag leaf.

In view of the characteristic symptoms different from those of other physiological diseases in its time of appearance stage and unfavorable influence upon the maturity and yield of rice grains, special attention has been paid by the authors to make research for the cause and remedial measures of the disease. Results obtained up to date are summarized as follows:

1. “Tomehagare” was considered to be caused by a nutritional disorder. Incidence of the disease was associated with such fields, as extremely high in available manganese, but low in most of the nutritional elements in the soil.

2. The chemical composition of affected upper leaves showed high manganese content as high as 2000~5000 ppm and low content of other nutrients, deficiency being suspected on iron and silica in combination with a low iron-manganese ratio in the plant.

3. “Tomehagare” took place seriously in hot summer on comparatively well-drained fields where such an oxidative condition developed in the soil as would make iron inactive but allow the rice plant to uptake manganese to an excessive extent.

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〔和 文 摘 要〕

真名川流域における「水稻止葉枯れ症」の発生機作 および防止対策について

第1報 「止葉枯れ症」の発生概況と葉身養分の変化

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福井県九頭竜川上流の真名川流域に昭和36年ごろから止葉に赤枯れ症状が発生し、登熟に悪影響がみられた。このため昭和42年より本症の防止対策と発生機作について現地試験、調査分析を実施した。

1. この症状は登熟期に止葉の先端から赤褐色に枯れ第2葉におよんだ。発生は出穂後高温の続く年に著しく、収量構成要素のうち登熟歩合や千粒重など、後期に決定される形質への影響が大きい。

2. 罹病稲の止葉から2,000~5,000 ppm の高いマンガン含量が分析されたが、逆に、窒素、珪酸、鉄等の含量が少なく、稲体の養分バランスの指標とされる Fe/Mn 比が著しく低くなり、結局マンガン過剰による体内の代謝異常にもとづく、生理病と認められた。

3. この症状は主として、透水の良い乾田に発生しており、マンガン含量は高いが、その他の養分は相対的に低く土壌肥沃度が低いいため、マンガンと鉄、珪酸などとの拮抗作用から稲体養分の不均衡を招きやすい傾向があつた。

4. このことが誘因となつて、登熟期の秋落ち症状を呈するような場合に発生することが、葉鞘のヨードデンプン反応の結果からうかがわれた。