An Injury to Rice Plants Caused by Photochemical Oxidants in Japan

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Since about 10 years ago, an unknown leaf injury of rice plants has been observed in central Japan (Kanto district). The injury symptom resembles that of Akagare disease which develops reddish brown flecks on the upper surface of leaf blades. In late June of 1971, outbreaks of this unknown leaf injury have been reported in Saitama, south Tochigi and southwest Ibaragi prefectures[1]. Recently, the frequent occurrence and wide distribution of this injury have been observed in many rice growing areas of Japan. In 1974, Nakamura et al.[4] and Matsuoka et al.[2] demonstrated that this injury was not of pathological origin but was associated with photochemical oxidants (hereinafter referred to as oxidants). The purpose of this paper is to demonstrate that oxidants cause Akagare-like injury to rice plants. The symptoms of injury and the effects of oxidants on growth, yield and physiological activities of rice plants are described.

Etiology of injury

It was found that the appearance of Akagare-like injury in rice leaves was consistently related to the high concentrations of oxidants in the air (Table 1). The concentration level of oxidants was always higher than 11 pphm* on the day prior to the appearance of the injury in rice growing seasons of 1974 and 1975 at the Central Agricultural Experiment Station, Konosu, Saitama. During the same growing period, rice plants were placed in two chambers, one of which was supplied with the filtered air (oxidants from the polluted air were removed with activated carbon) while the other with the unfiltered ambient air.

Table 1. Oxidant concentrations measured one day before the appearance of visual injury in rice leaves at Konosu, Saitama from 1974 to 1975[4]

Date (1974)	Oxidants* (pphm hr)	Date (1975)	Oxidants* (pphm hr)
1 May	11	22 May	17
17 May	20	28 May	20
29 May	22	9 June	19
9 June	15	17 June	15
16 June	27	23 June	16
29 June	18	26 June	17
9 July	14	9 July	18
23 July	21	15 July	24
28 July	17	19 July	19
4 Aug.	20	23 July	15
6 Aug.	20	31 July	18
13 Aug.	15	2 Aug.	17
20 Aug.	14	12 Aug.	15
5 Sept.	14	21 Aug.	13
		27 Aug.	18

* max. concentration

Plants placed in the unfiltered air chamber developed small flecks of bronzing and chlorosis on leaf blades as a result of high concentrations of oxidants. In contrast, plants receiving the filtered air were completely free from the injury and other leaf disorders. The leaf injury occurred during this period was not due to other pollutants such as NO_x or SO_2 because injurious levels of these pollutants were not detected.

Rice plants developed lesions when fumigated with ozone for a few hours at 10–15 pphm

* pphm: part per hundred million

in a controlled-environment fumigation chamber under natural light. The lesions produced by the ozone fumigation were identical to those caused by oxidants under natural conditions.

These results indicate that the Akagare-like injury on rice leaves was caused by the exposure to high levels of oxidants, and that ozone might be responsible for the Akagare-like injury.

Description of the injury

The injury symptoms are characterized by numerous small, punctate, reddish brown to dark brown or bleached chlorotic flecks which develop on the upper surface of leaf blades just one day after the exposure to high levels of oxidants. Large lesions resulting from the coalescence of smaller ones also appear on the lower surface of leaf blades. The lesions were frequently absent from the shaded parts of leaves. The most severe injury occurred generally on the middle to top portion of the second youngest, fully expanded leaf. The 4th to 10th-leaf-stage of growth was most sensitive to the injury. When injured leaves became old, they lost their chlorophyll and turned to be chlorotic much faster than healthy leaves.

Comparison between oxident injury and Akagare disease

Visual symptoms and histological examinations of the injured leaves distinguished the injury due to oxidants from Akagare disease in the field. The injury due to oxidants and ozone was concentrated primarily in the mesophyll cells surrounding the stomata (Plate 1 B, C and Table 2). In Akagare disease (types I, II, and III), however, the reddish-brown spots were present in all mesophyll cells. This result is similar to those reported by Takasaki et al.[9].

Examination of the leaf surface by scanning electron microscopy showed that guard cells were damaged by the oxidant injury

Table 2. Differences in the distribution of reddish-brown spots to the vicinity of stomata on rice leaves between the oxidant injury and Akagare disease[4]

Type of injury	Number of reddish-brown spots counted	Number of reddish-brown spots located around the stomata
Oxidants injury	58	45 (77.6%)
Akagare I	76	25 (32.9%)
〃 II	53	21 (39.6%)
〃 III	135	10 (7.4%)

(Plate 1-e). Therefore, the stomata failed to close in case of the oxidant injury, in contrast to the stomata on leaves affected by Akagare disease as well as on healthy leaves (Plate 1-d). Thus, the injury caused by oxidants can readily be distinguished from Akagare disease.

Varietal differences

It was found that rice cultivars differed in their sensitivity to ozone exposure. Cultivars were ranked according to their sensitivity to oxidants and ozone[6]. The most sensitive cultivars were Akibare, Harebare and MGS-359, whereas the most tolerant were Bohshitoh, Tongil, Totoh and Reishikoh while many cultivars were ranked between the two groups (Table 3).

Effect on growth, yield and physiological activity

Experiments were conducted to investigate the physiological damage to rice plants caused by oxidants[5,7]. Rice plants were grown in separate filon chambers with filtered or unfiltered ambient air from the transplanting stage to maturity (6 June to 15 October 1975, at Konosu). Visible injury on leaf blades and the reduction in growth and yield were observed with plants grown in the unfiltered air chamber. The plants grown in the filtered air chamber showed no visible leaf injury, and produced more panicles and spikelets per hill,

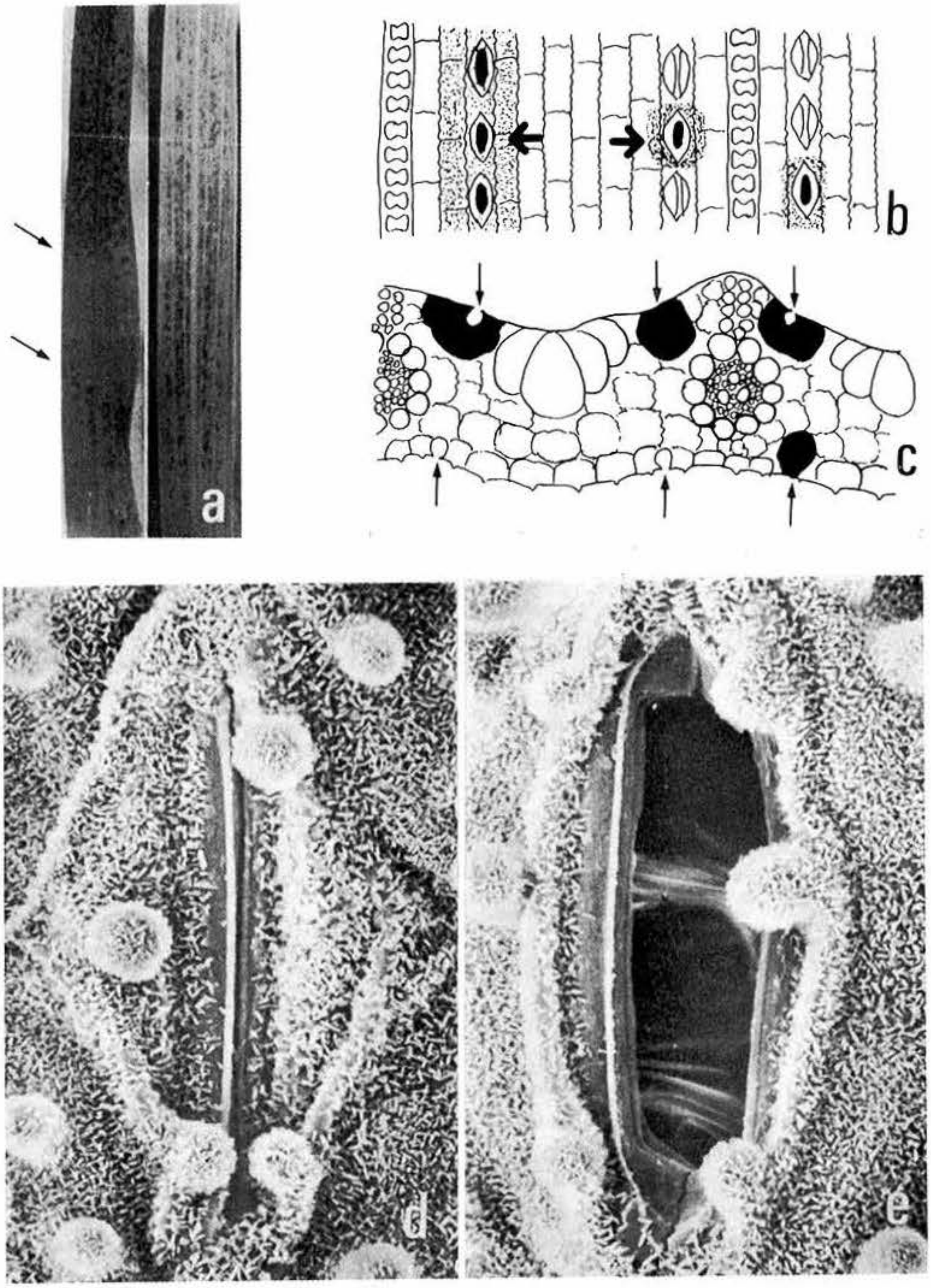

Plate 1. Oxidant injury in rice plants

a: Visual symptoms of oxidant injury on leaf blade. b: Surface. c: Cross section of injury lesion on leaf blade. Arrows point to stomata. d and e: Scanning electron micrograph of a stomata ×3,000. d: healthy leaf. e: injured leaf.

Table 3. Differences in the sensitivity of rice cultivars to oxidant injury[6)]

Most sensitive	Akibare, Harebare, Boro-8, MGS*-359, MGS*-859
Sensitive	Aikoku, Ginbohzu, Hayanishiki, Hatsukaori, Kagahikari, Hohnenwase, Todorokiwase, Shinanokogane, Akebono, Tamayodo, Kochihibiki, wakaba, Nohrin-6, Nohrin-8, Nohrin-22, Akitsuho, Setohomare, Senbonasahi, Ohzora, Minehikari, Kihoh, Nihonbare, Ariake, Tsukubanishiki, Tatsumimochi, Naozanemochi, IR-265, IR-279, Nato
Intermediate	Sensyoh, Waseaikoku, Kogane, Asahisen, Fujisaka-5, Fujiminori, Reimei, Kiyonishiki, Koshihikari, Nohrin-1, Nohrin-25, Kitamusashi, Tonewase, Kochikaze, Nihonmasari, Sachikaze, Manryoh, Hohyoku, Reihoh, Tsukushibare, IR-8, Zenith, Shinkoh, Tsukimimochi, Hinoyamamochi
Tolerant	Moritawase, Jyohsyuh, Toyonishiki Kusabue, Harukaze, Kantoh-53, IR-127, Magnolia, Tyohkoku, Sabini, Dawn, century-patna
Most tolerant	Totoh, Reishikoh, Bohshitoh, Tongil, Te-Tep, Akamai

Note *: MGS=Mutant lines of Nohrin-8 (viridis)

Table 4. Effect of air filtration on growth and yield of rice[5)]

	Number of panicles/hill	Number of spikelets/hill	Percent. of ripened grains	Unhulled grains/hill
Filtered	15.3 (103%)	1698 (108%)	91.4	35.3 g (113%)
Control (unfilterd)	14.0 (100%)	1572 (100%)	89.7	31.4 g (100%)

with a greater percentage of ripened grains and higher yield, as compared to the plants grown in the unfiltered chamber (Table 4).

It can be considered that the reduction in growth and yield of rice plants in the unfiltered chamber was due primarily to oxidants, because high concentrations of oxidants, averaging 3.88 pphm, and relatively low concentrations of other pollutants such as NO (1.06 pphm), NO_2 (1.50 pphm) and SO_2 (0.86 pphm) were monitored hourly at Konosu throughout the experimental period. Nakajima et al.[3)] and Takasaki et al.[8)] reported the yield reductions of rice plants amounting to 16% and 17% at Tachikawa and Chiba, respectively.

Photosynthesis was measured with a single leaf blade of the above test plants. The results shown in Table 5 indicated that photosynthesis of plants in the unfiltered air chamber was lower than that of plants in the filtered air chamber. The decreased photosynthesis measured with plants grown in the unfiltered chamber may be due to lower chlorophyll levels in their leaves. Chlorosis or premature senescence occurred as a sign of the injury caused by an exposure to oxidants. Ethylene evolution from the leaf blades was measured as a possible indicator of senescence. Abnormally high ethylene evolution was detected in leaves immediately after a treatment with ozone (Table 6). From these results, it was postulated that ethylene evolution might be a cause of the senescence.

Table 5. Photosynthesis and chlorophyll content in rice leaves grown in a filtered or unfiltered air chamber[5)]

Leaf	Photosynthesis (CO_2 mg/hr/leaf)		Chlorophyll (mg/g F. W.)	
number	Filtered	Control (unfiltered)	Filtered	Control (unfiltered)
1	10.11 (107%)	9.41	2.97 (104%)	2.85
2	6.59 (156%)	4.23	4.23 (175%)	2.42
3	4.23 (163%)	2.59	3.99 (194%)	2.06

* The fully expanded uppermost leaf is referred to 1 in leaf number. Measurement was made on 24, 25 July, 1975.

Based on these detrimental effects of oxi-

Table 6. Ethylene evolution from rice leaves exposed to ozone[7)]

Leaf number*	Ethylene** evolved by indicated hours after ozone exposure***			
	2 hours		4 hours	
	Control	Ozone	Control	Ozone
1	0.6	25.0	2.0	32.5
2	0.4	34.3	2.8	44.6
3	0.9	22.2	3.6	36.1

* Same as in Table 5.
** nl per gram (F. W.)
*** Test plants were exposed to 20 pphm ozone for 2 hours.

dants on rice plants, it is concluded that the prevalence of oxidants at high concentrations in the air may become a potential threat for sustaining high yields of rice in Japan.

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