EFFECTS OF UV-B RADIATION ON GROWTH AND DEVELOPMENT OF RICE CULTIVARS (*ORYZA SATIVA* L.).

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Abstract

Serious issues about the changes in the environmental conditions on earth associated with human activities have arisen, and the interest in these problems has increased. It is urgent to determine how the expansion of terrestrial UV-B radiation due to the stratospheric ozone depletion influences living matters. In this connection, we have been investigating the effects of UV-B radiation on the growth of rice cultivars (*Oryza sativa* L.). We report here some physiological and genetic aspects of resistance to inhibitory effects of UV-B radiation on growth of rice cultivars as described below.

Elevated UV radiation containing large amount of UV-B and a small amount of UV-C inhibited the development of leaves and tillers, the increase in biomass production, the elongation of plant height, the photosynthetic rate and the chlorophyll content in rice plants in a phytotron. Similar results were obtained in experiments, in which elevated UV-B radiation (transmission down to 290 nm) was applied instead of UV-B radiation containing a small amount of UV-C. The inhibitory effects of UV radiation was alleviated by the elevated CO_2 atmospheric environment or by the exposure to the high irradiance visible radiation. The latter suggested the possibility that the resistance to the effects of UV radiation was either due to a lower sensetivity to UV radiation or to a greater ability to recover from the injury caused by UV radiation through the exposure to visible radiation. The examination of cultivar differences in the resistance to UV radiation-caused injuries among 198 rice cultivars belonging to 5 Asian rice ecotypes (*aus, aman, boro, bulu and tjeleh*) from the Bengal region and Indonesia and to Japanese lowland and upland rice groups showed the followings: Various cultivars having different sensitivities to the effects of UV radiation were involved in the same ecotype and the same group, and that the Japanese lowland rice group and the *boro* ecotype were more resistant. Among Japanese lowland rice cultivars, Sasanishiki

(one of the leading varieties in Japan) exhibited more resistance to UV rakiation, while Norin 1 showed less resistance, although these two cultivars are closely related. It was thus indicated that the resistance to the inhibitory effects of UV radiation of rice cultivars is not simply due to the difference in the geographical situation where rice cultivars are cultivated. Form the genetic analysis ofresistance to the inhibitory effects of UV radiation on growth of rice using F_2 plants generated by reciprocally crossing Sasanishiki and Norin 1 and F_3 lines generated by self-fertilizing F_2 plants, it was evident that the resistance to the inhibitory of elebated UV radiation in these rice plants was controlled by recessive polygenes.

I. Introduction

Recent research has established that chlorofluoromethanes and other gases associated with human activities cause a reduction in the statospheric ozone concentration. Such reduction may lead to an increase in UV-B radiation reaching the Earth's surface. It is therefore urgent to determine how to expansion of terrestrial UV-B radiation influences living matters. In this connection, investigations involving the whole plant and complete life cycle conducted in the phytotron or greenhouse aue required. Especially, studies conducted in the field are invaluable, because they would be helpful in anticipating the potential changes in productivity of crops due to environmental changes. They will also be indispensable in the search for genetic food resources that may survive in or may adapt to the cnvironmental changes. On the other hand, in spite of the global impotance of cereals as staple food crops, a few studies have examined the effects of UV-B radiation on cereals. There is a noteworthy study on soybeans, in which Murali and Teramura (1986) and Termura *et al.* (1990) examined the potential for alterations in the yield and seed quality of soybeans grown for 6 years in the field. They reported the necessity for multiple-year experiments and the need to increase the understanding of the interaction between UV-B radiation and other environmental stresses to assess the potential consequences of stratospheric ozone depletion. With respect to rice plants, Teramura *et al.* (1991) found in greenhouses that, among 16 rice cultivars from 7 different geographical regions, Kurukaruppan (Sri Lanka), Himali(Nepal) and Tetep (Vietnam) cultivars were more tolerant to the effects of elebated UV-B radiation, and suggested that geographical location might influence sensitivity to UV-B radiation. Recently, Dai *et al.* (1992) examined the effects of UV-B radiation on the growth of four lowland rice cultivars (IR line) in a phytotron

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We have been studying for several years to know how the expansion of the UV region of the spectrum, especially UV-B, influences growth and development of microorganism and plant, interactions between microorganism and plant and plant and plant. We are also thinking of understanding the mechanism of resistance to UV radiation of rice, which would help breeding rice having more resistance to UV radiation. In this lecture, I introduce our studies conucted in Sendai as follows: (1) inhibitory effects of elevated UV-radiation containing a large amount of UV-B and a small amount of UV-C on growth and development of Japanese rice cultivars (*Oryza sativa* L.) in a phytotron and paddy field; (2) effects of high quality UV-B radiation on growth of Japanese rice cultivars; (3) cultivar differences in resistance to the inhibitory effects of UV radiation among Asin ecotypes and Japanese lowland and upland cultivars of rice; (4) recovery of UV radiation-caused injuries by elevated visible radiation or elevated CO_2 environment and (5) genetic analysis of resistance to the inhibitory effects of UV-radiation.

1. Inhibitory effects of elevated UV-radiation on growth and development of Japanese rice cultivars (*Oryza sativa* L.)

In our early experiments, unfiltered UV-B lamps were used instead of high quality UV-B radiation. We considered that cultivars showing resistance to the inhibitory effects of UV radiation, containing a large amount of UV-B with a small amount of UV-C, would exhibit higher tolerance to high quality UV-B radiation, too, because various biologial phenomena having action peaks in the UV-C region also utilize the UV-A and UV-B regions of the spectrum to a lesser degree. For instance, an absolute action spectrum for cyclobutyl pyrimidine dimer induction in DNA in intact alfalfa seedings peaks around 280 nm in a wave range as long as 365 nm (Quaite *et al.*, 1992).

The effect of UV radiation on the increase in plant height of 4 Japanese rice cultivars (Norin 20, Zosan 1, Sasanishiki and NOrin 1) was first examined in a phytotron (Kumagai and Sato, 1992). When these cultivars were grown under irradiation with visible light supplemented with or without UV radiation, the increase in plant height of each rice cultivar was inhibited by supplementary UV radiation. Blazing appeared in Norin 20, Norin 1 and Zosan 1, 3 days after the transfer of the plants to the UV irradiated conditions, and then browning gradually spread from older leaves to younger ones with the prolongation of the duration of cultivation. About 1.5 months later, Norin 1 became severely damaged. It was observed that Sasanishiki was most resistant to the damaging effect of UV radiation, while Norin 1 was the least resistant. We further analyzed more precisely the mechanism whereby UV radiation affected biomass production and photosynthesis Norin 1 and Sasanishiki. The experimental conditions were as follows; the photoperiod consisted of 12 h of light and 12 h of dark, and the temperature was maintained at 27℃ during the day and 17℃ at night. Fluence rate of photosynthetically active radiation (PAR) was about 115 $\mu mol/m^2/sec$. The irradiance of UV-radiation was varied at 4 different levels "control" "low" "medium", and "high" levels. The fluence rate (W/m^2) in UV region was 0.022 for the "control", 0.133 for the "low" level; 0.294 for the "medium" level; and 0.573 for the "high" level. Both the biomass production and photosynthetic activity in Borin 1 remarkably decreased with the increase in the irradiance of UV radiation: the degree of inhibition of biomass production in the plants grown for 2 weeks under the "medium" and"high"irradiance level of UV radiation was 58 and 64%, respectively. The degree of inhibition of photosynthesis determined in the 5th leaf of the plants grown for 2 weeks under the "high" irradiance level of UV radiation was about 90%. A remarkable reduction was observed in particular in the biomass production and photosynthesis determined in the 7th leaf of plants grown for 4 weeks under the"high" irradiance level of UV radiation: the degree of inhibition of biomass production amounted to almost 80% and that of photosynthesis exceeded 90%. The extent of biomass production and photosynthesis in Sasanishidi also decreased with the increase in the irradiance of UV radiation. However, the degree of inhibition and photosynthesis in this cultivar was much lower than that of Norin 1.

We have been studying the effects of UV radiation on growth of Sasanishiki and Norin 1 in the paddy field since four years ago. According to 1992's data,the develoment of tiller in Norin 1 was markedly inhibited by elevated UV radiation in the early stage of growth compared with that of Sasainshiki. This was not the case concerning the increase in plant height. With lenghening the duration of growth, the degree of reduction in tiller formation was gradually recobered. Number of sterile seed sincreased in both cultivars grown under elevated UV radiation: percentage of sterility was about 10% higher than that of non-elevated UV irrdiated control. Grain size became a little smaller. About 35% yield reduction was observed. Protein content of grain increased by ca. 10%, indicating the lowering of rice quality. It was totally evaluated that Norin 1 was less resistant to elevated UV radiation than Sasanishiki.

In this way, it was evident that there cultivar differences among cultivars in the dehree of among cultivars in the degree of resistance to UV radiation in rice plants, and that Sasanishiki was the most resistant to UV radiation among the tested cultivars.

According to the data base of Hokuriku Agricultural Experiment Station in Japan (1977; 1980), Norin 20 is an early maturing variety requiring approximately 79 days for ear emergence, while the others require about 110 days. The plant height of this cultivar is as short as 70 cm; it has a large number of ears per plant but a small number of grains per ear. Zosan 1 is a variety with a tall plant height (102 cm) with long ears, a small number of ears per plant but a large number of grains per ear. The plant height of Sasanishiki, a leaking variety in Miyagi prefecture of Japan is 77 cm; the size of the ear and number of grains are intermdiate between those of Norin 20 and Zosan 1. The plant height of Norin 1 is 89 cm, and its ears and grains are similar to those of Sasanishiki. Hence, the results described above indicated that the degree of resistance to UV radiation was independent of the plant shape.

2. Effects of elevated UV-B radiation on growth and development of rice cultivars

Effect of high quality UV-B (containing no UV-region below 290 nm) on growth and development of rice was examined in a phytotron. The radiation emitted from Toshiba 20 SE fluorescent lamps (emitting a large amount of UV-C) was filtered through either cellulose acetate film or glass cut-filter UV 31 in order to eliminate radiation below 290 nm. The development of tiller, the increase in fresh weight and dry weiht and dry weight, the chlorophyll content and total leaf nitrogen were decreased by elevated UV-B radiation, while accumulation of UV-absorbing compound (flavonoids) increased.

3. Cultivsar differences in resistance to the inhibitory effects of UV radiation among Asian ecotypes and Japanese lowland and upland cultivars

of rice

As described above, a possibility that the rice cultivars having more resistance to UV radiation could be screened by examining the effect of various irradiance of UV-radiation supplemented to visible radiation in a phytotron was indicated. We (Sato and Kumagai, 1993) therefore examined cultivar differences in resistance to the inhibitory effects of UV radiation among 5 Asian rice ecotypes (*aus, aman, boro, bulu, tjereh*) and the Japanese lowland (*j.j.r.*) and upland rice groups (*j.u.r.*; *Oryza satiua* L.). The *aus, aman, boro* ecotypes, from Bengal region, and the *tjereh* ecotype, from Indonesia, belong to *indica*. The *bulu* ecotype, from Indonesia, belongs to the tropical *japonica*, and Japanese lowland and upland rice groups belong to the temperate *japonica*. When experimental plants were grown under the "low" irradiance level, a wide range in the freguency distribution was observed in every ecotype and group, but remarkable differences among ecotypes and groups were observed neither in the pattern of the distribution nor in the mean of the ratio of FW of sample/control (open columns in Fig. 1). Different sensitivities to the effects of UV radiation were involved in the same ecotype and in the same group; one type was promoted by UV radiation i.e. "resistance". while the other type was inhibited by UV radiation i.e "sensitive". The proportion of cultivars resistant to the "low" irradiance level in individual ecotypes or groups differed; 79% for the *boro*; 69% for the *aman*; 57% for the *bulu* and 58% for the *tjerch*, respectively. As for the Japanese rice cultivars 75% of the *j.l.r.* and 54% of the *j.u.r.* wre resistant, respectively. With an increase in the irradiance level of UV light to the "medium" level, the pattern of the frequency distribution of the ratio of FW of sample/control significantly shifted towards the lower values and the mean decreased markedly (columns in Fig. 1). However, it should be noted that *j.l.r.* maintained a mean of 83%, which was the highest value, and the *boro* ecotype showed 67%, while that the others showed a mean below 58%. Furthermore, the proportion of cultivars resistant to the "medium" irradiance level was 21% for the *j.l.r.* and 14% for the *boro* ecotype, respectively, while that of others was below 4%. With an increase in the irradiance level of UV light to the "high" level, the pattern of the frequency distribution of the ratio of FW of sample/control in all ecotypes and groups was similar to that as seen in plants grown under the "medium" irradiance level, except that the mean of each ecotypes somewhat decreased. Even in cultivars grown under the "high" irradiance level, 2 cultivars of *j.l.r.* and 1 cultivar of each of *boro, bulu* and *tjereh* exhibited resistance to the UV radiation. Similar results were observed concerning the effects of elevated UV radiation on the increase in plant height and chlorophyll content in the 3rd leaf. Overall, it was clear that the *j.l.r.* group and the *boro* ecotype were more resistant to the inhibitory effects of UV radiation: Sasanishiki belonged to the most resistant group while Norin 1 did to the less resistant one. The data suggested that the differences in resistance to UV radiation was not related to the geographical origins of the rice cultivars examined.

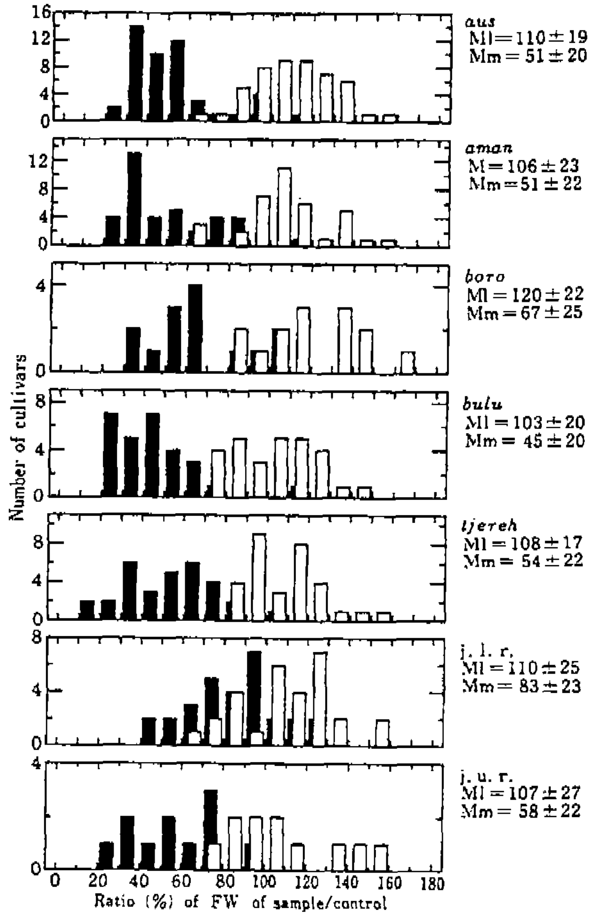

Fig. 1. Frequency distribution of the ratio (%) of FW of the sample to that of the control. Open and black columns show the results of plants grown under the "low" and "medium" irradiance levels of supplemental near-UV radiation, respectively. Ml and Mm are mean±SD of ratio of FW in plants grown under the "low" and "medium" near-UV radiation, respectively. from Jpn. J. Breed. 43: 61-88, 1992

4. Recovery of UV radiation caused-injuries by elevated visible radiation or elevated CO_2 environment

Experimental plants were grown for 4 weeks under two different levels of visible radiation, i.e. "low" and "high" irradiance levels. The irradiance of the "high" level was about 2 times higher than that of the "low" level. The irradiance of UV radiation was varied at 4 different levels as described as described previously. The growth components such as plant height, leaf formation, fresh weight (FW) and dry weight (DW) of biomass and total chlorophyll content in Norin 1 and Sasanixhidi grown under "low" irradiance level of visible radiation also decreased with the irradiance of UV radiation (Kumagai and Sato, 1992). When both cultivars were grown under the "high" irradiance level of visble radiation, the increase of the irradiance of UV radiation resulted in the reduction of each growth component as well. However, the degree of reduction of all the parameters decreased as compared with the "low" irradiance level of visible radiation. It was thus indicated that the parameters in both cultivars grown under "low" irradiance level of visible radiation were more inhibited by UV radiation than those of the cultivars grown under the "high" irradiance level of viaible radiation. The degree of inhibition in all the parameters of Norin 1 was higher than that of Sasanishiki irrespective of the amount of visible radiation applied. It should be noted that the degree of inhibition of each growth component caused by UV radiation was alternated by the increase of the amount of visible radiation, and that such reductions in inhibition in "Sasanishiki" were more pronounced than those of "Norin 1". These results suggested that the capacity to recover from the inhibitory effects of UV radiation through the exposure to visible radiation was greater in "Sasanishiki" than "Norin 1". It is therefore considered that the difference in the resistance to UV radiation between "Norin 1" and "Sasanishiki" may be attributed either to the sensitivity to UV radiation or to the capacity to recover from the injury caused by UV radiation through the exposure to visible radiation".

Cultivars Sasanishidi and Norin, *japonica*, and Marith-bati and Surjamkhi, *indica*, were grown in 12 h light (27℃). Cvs. Sasanishiki and Marithbati have more resistance to UV radiation, while the other two have less resistance. CO_2 concentration in the growth cabinet was adjusted to about 350 ppm all day for the ambient CO_2 environment. In elevated CO_2 environment, CO_2 concentration was kept at 700 ppm during the day alone, and returned to about 350 ppm at night. Growth components such as fresh weight, tiller number and plant height were significantly increased by elevating CO_2 concentration in the two types of cultivars. Elevation of CO_2 concentration alleviated the inhibitory effect of UV radiation. However, there was no specific correlation between the degree of enhancement of growth by elevating CO_2 concentration and the degree of reduction in inhibitory of UV radiation by elevating CO_2 concentration (unpublished).

5. Genetic analysis of resistance to the inhibitory effects of UV-radiation

Some experimental plants were grown in visible radiation supplemented with UV radiation containing a large amount of UV-B and a small amount of UV-C in a phytotron, while others were grown without UV radiation. The degree of resistance to UV radiation was estimated in terms of the degree of reduction caused by supplemental UV radiation in the fresh weight of the aboveground plant parts and the chlorophyll content per unit fresh weight. Fresh weight and chlorophyll content in F_2 plants generated by reciprocally crossing cv. Sasanishiki, a cultivar more resistant to UV radiation, and Norin 1, a cultivar less resistant to such radiation, exhibited a normal frequency distribution. The heritabilitirs of these two propertise in F_2 plants were low under condition of non-supplemental UV radiation.

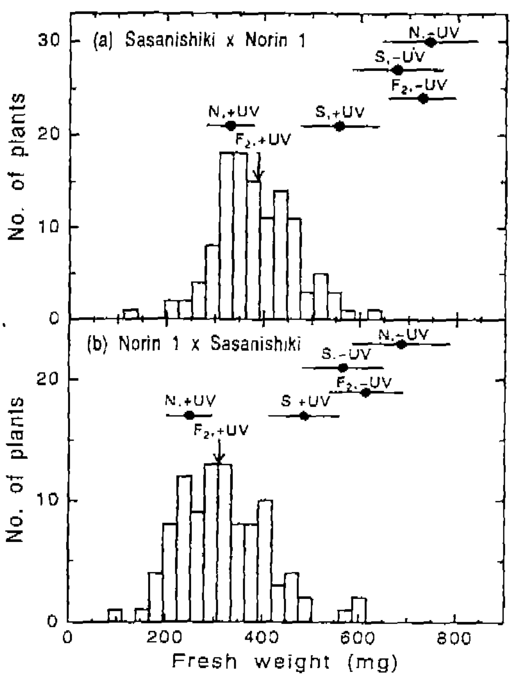

Fig. 2. Frequency distribution of fresh weight per plant. Symbols in the figures: N, −UV, N, +UV, S, −UV, S, +UV, F_2 plants of cross between Norin 1 and Sasanishiki grown without or with supplemental UV radiation. The bars indicate the mean±DS. from *Physiol Plant.* 91: 234-238, 1994.

Under elevated UV radiation, the F_2 population shifted to the lower range of fresh weight and chlorophyll content, and the means were close to those of Norin 1 (Fig. 2). The heritabilities of these two properties were the same in the reciprocal crosses, indicating that maternal inheritance was not involved. Inheritance of chlorophyll content per unit fresh weight was further determined in F_3 lines generated by self-fertilizing F_2 plants of Sasanishki and Narin 1. The results showed that F_3 population was segregated into three genotypes, namely, resistant homozygotes, segregated heterozygotes and sensitive homozygotes, with a ratio of 1:65:16. These values did not fit with the segregation ratio of 1:2:1 (x^2 Ns 1:2:1=33.58; difference signeficant with $p < 0.01$).

It was thus evident that the resistance to the inhibitory elevated UV radiation in these rice plants was controlled by recessive polygenes. These results indicated that cv. Sasanishiki, which was bred to be resistant to cool summer damage, must have acquired resistance from some progenitor during breeding. However, it is still obscure why Sasanishiki has strong resistance to UV radiation and it might be impossible to trace back the process of breeding. Consequently, it is indispensable that the relationship between the genetic mechanism and physiological mechanism of the resistance to the inhibitory effects of UV radiation should be solved (Sato, Kang and Kumagai, 1884).

II. In Conclusion

This report has introduced fundamental physiological and genetic aspects of the effects of UV radiation on growth and development of rice and of resistance to the inhibitory effects of UV radiation on growth of rice. We are now progressing biochemical and molecular biological studies regarding the mechanism of resistance to the inhibitory effects of UV radiation on growth and development of rice. I am hoping to have a chance again to introduce our further studies in the near future.

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