

High Temperature Damage to Ripening in Rice Plant

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It has been experienced that the ripening of rice plant might suffer from some damage by unusually high temperature. Matsushima et al. (1959), Nagato et al. (1965) and Sato et al. (1971) reported that the temperature of 30°C or a little higher kept during the ripening period hastened the ripening but get it stopped at the second to third week after anthesis, resulting in lower 1000-kernel weight. The present author has further continued to carry out several experiments to clarify the processes or mechanisms of such ripening damages caused by high temperature to which plants were exposed not only during the ripening period but also at earlier growth stages. The high temperature here used is day/night temperature 35/30°C, kept constant during each treatment period. The temperature-controlled phytotrons composed of many small cabinets were used for the experiments, all receiving natural light. The air-humidity was maintained at 60 to 70% R.H. For special purpose, temperature and humidity were changed in different regimes.

Effects of high temperature at different stages of panicle development on ripening

A japonica rice variety, Norin-17, was used. Results of temperature treatment each for 7 days are shown in Fig. 1. Grain number per panicle was changed only slightly by the treatment, but grain sterility as high as 24% occurred when treated just before flowering. The rate of sterility was decreased as the time of treatments delayed from the flowering stage, although the rate was more or less

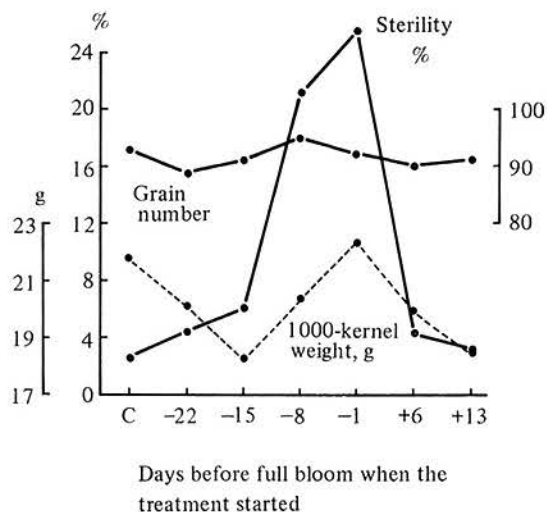


Fig. 1. Effects of high temperature treatments of 7 days on the grain number per head, occurrence of sterility, and weight of 1000 kernels ripened
C : outdoors with no treatment

higher than that of untreated plants. Leaves and stems of the plant which exhibited a higher sterility contained a larger amount of carbohydrate and nitrogen.

Plants treated two to one week before flowering produced grains of very small 1000-kernel weight due to a depressed glume growth. In such a plant more nitrogen and TAC (total sugar + crude starch) remained in the straw. Treatments given during the ripening period generally decreased the 1000-kernel weight, especially the treatment started from two weeks after flowering caused a remarkable decrease in 1000-kernel weight due to a reduced kernel thickness. In general, TAC content per culm including panicle decreased by the treatment, but the amount remained

in the straw increased as the 1000-kernel weight decreased.

The cause of sterility occurred at flowering stage

To know more precisely the time which may be related to the occurrence of sterility, the treatment for 3-day period was given to the plant which was just flowering. Fig. 2 shows

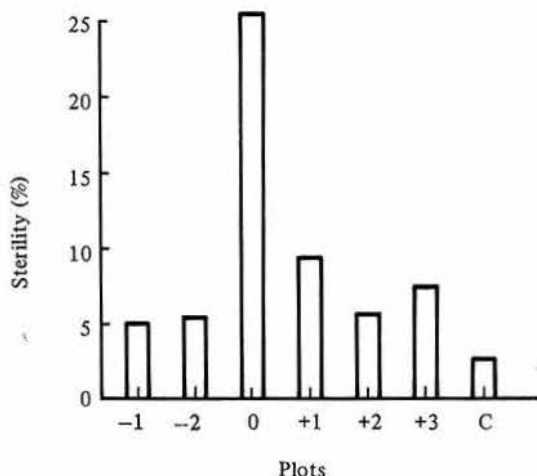


Fig. 2. Effects of high temperature treatment for 3-days started just before flowering on the occurrence of sterility in flowers bloomed during or after the treatment

Note: -2, -1; Flowers bloomed at the 1st and 2nd day of the treatment, respectively.

0; Flowers bloomed at the 3rd day of the treatment.

+1~+3; Flowers bloomed outdoors at the 1st to 3rd day after the treatment finished.

that the sterility higher than 25% occurred with the flowers which opened in the high temperature cabinet at the 3rd day of the treatment, while the rate of sterility was low with the flowers opened earlier or later than that, being only 2 to 3 times over the outdoor control. This great sterility over 25% was due to functional disorder in stamens rather than pistils. High temperature applied just before

the pollen maturation decreased the pollen number, pollen size, starch deposition in pollen and induced the dehiscence-incompetent anther. An occurrence of empty grains attributable to high temperature at flowering stage in rice was confirmed by Osada et al. (1973) in Thailand and by Satake (1977) at IRRI.

Varietal difference

Six japonica varieties and an indica rice (IR-8) were used to compare the varietal difference in responses to high temperature treatments each for 7 days started at A-stage (about 2 weeks before flowering when distances between auricles of the last two leaves of most stems reached zero), B-stage (3 days before heading) and C-stage (one week after flowering). In general, varietal difference in high temperature injuries was very small. The 1000-kernel weight of the plants treated at the A-stage decreased 10 to 15% in all varieties and the sterility was increased slightly compared with those of the control. By the B-stage treatment, all varieties produced many empty grains reaching 44% in an average, but IR-8 behaved more resistant than japonica varieties. In this case, all varieties increased their 1000-kernel weight slightly. By the C-stage treatment all varieties decreased 1000-kernel weight by 14% in an average without any change in sterility. The grain/straw ratios were 0.8, 0.6 and 0.8 at A, B and C, respectively, suggesting a much more carbohydrates and nitrogen remained in the straw comparing with the control plant the ratio of which was 1.2.

Effects of high temperature during ripening period

1) Effects of air-temperature, its daily range and photoperiod¹⁾

Norin-17 and IR-8 were exposed, after anthesis to maturity, to day-temperature from 20 to 35°C and night-temperature from 10 to 35°C at 5°C intervals, and to two levels of photoperiod; 8-hr natural daylight (SD) and

16-hr photoperiod (LD) which is SD plus 8-hr supplemental artificial light. Under the higher temperature except 35/35°C, the ripening proceeds faster, but it ceased earlier resulting in greater sterility and smaller 1000-kernel weight. At 35/35°C the 1000-kernel weight was smallest, 47% and 43% to that of 20/20°C grains in Norin-17 and IR-8, respectively. Lowering of night temperature by 5°C significantly improved ripening. The optimum day temperature seems to be 20°C or a little higher combined with a range of 5 to 10°C lower night temperature, so that the optimum mean temperature seems to be 20°C or a little lower. The two varieties did not differ significantly in their response. Short-day was inferior to long-day for ripening.

2) *Effects of air-temperature combined with air-humidity and light-intensity²⁾*

Treatments of H-H (high humidity, 70-80% R.H.), L-H (low humidity, 60-70% R.H.), S-L (strong light, i.e., natural light being supplemented with a 5000 f.c. special lamp), W-L (weak light, being covered by a vinyl blind) were combined with 4 day/night temperatures; 35/30, 30/25, 25/20 and 20/15°C. As shown in Fig. 3, the ripening proceeds faster but it ceased earlier with the increase of temperature, resulting in smaller 1000-kernel weight and smaller grain/straw ratio. At high

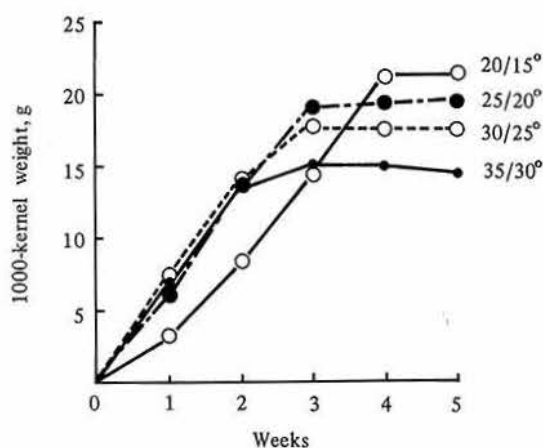


Fig. 3. Trend of 1000-kernel weight as affected by day/night temperature. Means of 4 replications (Norin-17)

temperatures, L-H was favorable for ripening, but at lower temperatures humidity had little effect, W-L depressed markedly ripening and caused a higher N % in both grains and straw (Fig.4). The N absorption was not significantly influenced by the treatments, but the TAC accumulation was progressively greater as temperature decreased, as air-humidity decreased at higher temperature and as light-intensity increased at all temperatures. At high temperatures much variation in weight was found among grains. There was a strong correlation between grain DW/straw DW and grain N content/straw N content, suggesting a parallel translocation of N and carbohydrates to grains. However at higher temperatures relatively less TAC accumulated in grains making N % of both grains and straw higher. As far as the final grain weight is concerned, IR-8 seemed to be more tolerant to high temperatures than Norin-17.

The protein properties and amino acid composition of the kernels obtained in this experiment were determined³⁾. IR-8 had a greater 1000-kernel weight and a higher concentration of crude protein (CP) than Norin-17. In both varieties, CP concentration increased with increase of ripening temperature and weaker light intensity and higher air-humidity. CP contents per kernel tended to increase under weak light or high humidity. A strong negative correlation was found between CP concentration and 1000-kernel weight. Glutelin constituted about 60% of the total protein, followed by insoluble nitrogen, albumin, globulin and prolamine in that order. Kernels ripened at 35/30°C contained more albumin-globulin but less glutelin than the others. The individual amino acid content increased in direct proportion to ripening temperature, air-humidity and in inverse proportion to light intensity, although its ratio to total amino acids changed little.

3) *Ripening when the panicle and straw were separately treated by different temperatures⁵⁾*

With 3 varieties used (Norin-17, IR-8 and Boshito, an indicate rice), it was found that

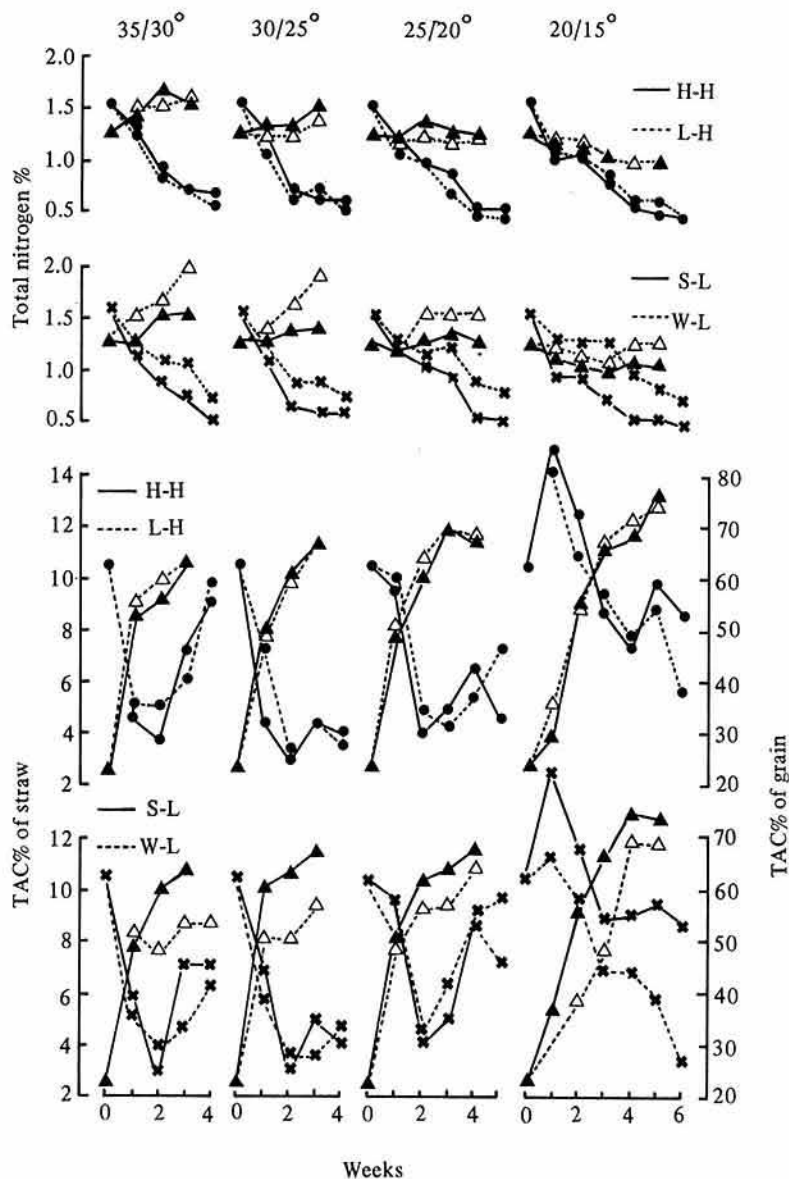


Fig. 4. Trend of total nitrogen and total available carbohydrate concentrations during repening period in grains and straw as affected by temperature, air-humidity and light intensity (Norin-17) ▲△ Grains ●× Straw H-H High humidity L-H Low humidity S-L Strong light W-L Weak light

the 1000-kernel weight was markedly decreased by high panicle temperature, although it was only slightly influenced by high straw temperature. The kernels ripened at high temperature were inferior in quality with much opaque, chalky and milky-white kernels. Soluble-N/protein-N ratio and total sugar/

crude starch ratio in the straw or often in the panicle too increased by treating the panicle or straw or both by high temperature, suggesting a physiological abnormality occurred in the plant. The amount of TAC stored per tiller was greatest at 35/35°C, followed by 35/25, 25/35 and 35/35°C in that

order. Relatively less TAC was stored in the panicle with more amount remained in the straw when the panicle was treated by high temperature. On the contrary, the total-N accumulation per tiller was greatest at 35/35, followed by 25/35, 35/25, and 25/25°C in that order. This high N accumulation at 35/35°C was partly attributable to new tillers with new roots emerged from higher nodes. However, high temperature applied around panicle accumulated relatively more N in the straw. The leading factor causing the decreased 1000-kernel weight by high panicle temperature seems to be an early termination of the ability of panicles to receive assimilates.

The cause of the decline of 1000-kernel weight

1) Respiration⁶⁾

Since the trend of respiration rate of grains and leaves during ripening period was found to have a close relation with the ripening processes when grown at high temperature, it is suggested that the plant, especially its panicle grown at high temperature decreased its physiological activity more rapidly than that grown at lower temperatures.

2) Photosynthesis and translocation⁷⁾

¹⁴CO₂ was applied to the whole plant grown at high and normal temperatures at several different stages of ripening and ¹⁴C distribution in plant parts was counted one and two days later. The ¹⁴C distribution to the panicle was greater in the plant grown at high temperature at an early ripening period, but thereafter it decreased rapidly. There was little difference in apparent photosynthesis between the plants grown at different temperatures as far as deduced from ¹⁴C assimilation.

3) Sink and source relations⁸⁾

Treatments to increase or decrease the TAC amount per grain were given at the beginning of ripening as shown in Fig. 5 with the purpose of changing the sink and source rela-

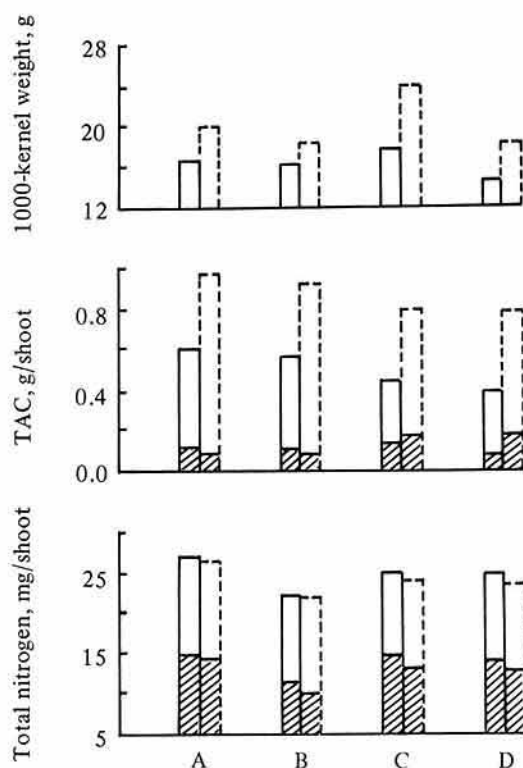


Fig. 5. Effects of sink and source relation during ripening period on the 1000-kernel weight, TAC and total nitrogen content of shoot, as influenced by temperature
 A : No treatment B : Fertilizer deficiency
 C : Panicle with primary branches thinned to a half number
 D : 2nd and 3rd leaf-blades from top were removed
 Solid line : 35/30°C, Broken line : outdoor
 hatched portion : straw, unhatched portion : panicle
 TAC : Total sugar+crude starch

tions at different temperature conditions. The result suggested that the early termination of ripening at high temperature was caused by the early decline of assimilate-storing ability of panicles rather than an assimilate deficiency in the plant.

4) Enzyme activities of kernel⁹⁾

The enzyme activities which may be concerned with the assimilate-storing ability were compared between kernels grown at high and normal temperatures with the progress of maturation. As shown in Fig. 6, the respira-

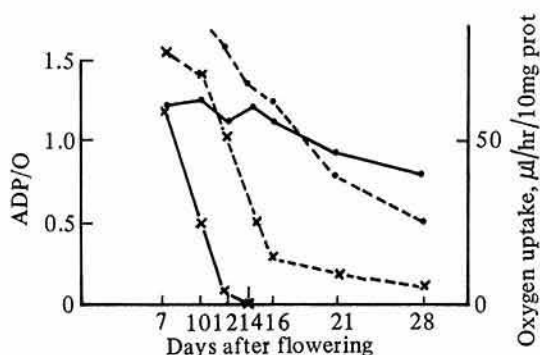


Fig. 6. Effect of high temperature during ripening period on the mitochondrial oxidative phosphorylation of kernels.

• Outdoor — ADP/O
 × 35/30°C O₂-uptake

tion rate of kernel declined with the progress of ripening more rapidly at high temperature, reaching the lowest level at about two weeks after anthesis. Oxygen uptake by kernel mitochondria followed a similar pattern as kernel respiration and ADP/O ratio at high temperature reached zero at the 14th day. Phosphorylase activity reached a maximum at the 10th day and then gradually decreased at both temperatures, but it was lower at high temperature. Yellowing of spikelet was first recognized at rachilla portion and occurred earlier at high temperature. Succinic-dehydrogenase activity at rachilla disappeared at the 16th day and soon yellowing began. Activities of kernel enzymes seemed to decline earlier than the disappearance of succinic-dehydrogenase activity at rachilla. Thus, the early decline of assimilate-storing ability of grains at high temperature had a close relation to the early decline of physiological activities of kernel cells.

Methods to diminish the injuries

It was shown in our simple experiments that the injuries during ripening period were diminished by the application of well-decomposed compost, appropriate drainage and proper fertilization, but accelerated by a marked decrease of redox-potential of the soil and fertilizer deficiency. On this matter, however, further experiments are needed.

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