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Studies on the Effect of Temperature During the Reduction Division and the Grain Filling Stage in Rice Plants

II. Effect of Air Temperature at the Grain Filling Stage in Indica-Japonica Crosses

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水稻의 減数分裂期 및 登熟期에 있어서 温度反應에 관한 研究

第2報 水稻 Indica×Japonica 品種의 登熟期에 있어서의 温度反応

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ABSTRACT

The effects of air temperature on the grain filling stage of indica-japonica crosses were studied in artificial temperature-controlled cabinets, using Indica-Japonica crosses (Suweon 264, Suweon 258 and Milyang 29), *Indica* (IR 36 and Lengkwang) and a Japonica rice (Jinheung).

The optimum temperature to achieve maximum grain weight during the grain-filling stage was 26/18°C for all varieties. Within the temperature range of 13 to 28°C, the grain filling period was shorter as the temperature was increased.

At the highest temperature (32/24°) the upper-position grains ("special spikelets") of IR 36 required 13 days after flowering to reach the maximum weight, in Jinheung 23 days, in indica-japonica varieties (Suweon 264, Suweon 258, and Milyang 29) 18 days, and in Lengkwang, 23 days.

In the case of Lengkwang, at 32/24, 29/21°C and 26/18°C temperature range the upper-position grain also required same 23 days after flowering to reach the maximum weight.

At the lowest temperature range of 17/9°C, Jinheung required 68 days and Lengkwang 53 days after flowering to reach maximum grain weight.

The whole panicle took 10 to 15 days later than the special spikelets to reach the maximum weight. At lower-than-optimum temperature range (17/9°C and 20/12°C), all IR 36 plant died within 15 days after flowering. In the case of indica-japonica varieties all plants died within 15 days only at 17/9°C.

There were more chalky grains when the temperature was higher and lower than optimum. The highest and lowest temperature range produced dead rice (black and dark red rice).

Lower than optimum temperature ranges (17/9°C and 20/12°C) affected grain quality (length, width and depth) at these temperature ranges, grains were shorter, narrower, and thinner than grains at the optimum temperature of 26/18°C.

With regared and the effects of temperature on frequency of grain weight at grain filling stage of indica

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variety IR 36, the highest (32/24°C) and lowest (23/15°) temperature ranges matched the frequency of grain weight curves. In Japonica variety Jinheung, at the three temperature ranges, that is, lowest (17/9°C) highest (32/24°C) and optimum (26/18°C), the frequency of grain weight curve showed very different patterns, In the case of indicaj-aponica variety Suweon 258, the frequency of grain weight curve was midway between that of IR 36 and Jinheung.

INTRODUCTION

Air temperature is a very important ecological factor which may have a profound influence on the quality of rice grain and grain yield.

In rice, within the optimum temperature range (from 15°C-18°C to 30-33°C), higher temperatures, in general, favour the growth and development of the rice plant (Nishiyama 1974). The rice plant during this period carries on morphological differentiation as well as increasing dry matter. Grain yield is essentially determined through two processes, spikelet formation before heading and grain ripening after heading. Consequently, many studies have been done on the functional relationship between the related main factor and the reproductive growth of rice. In temperate zones, the rice crop is normally harvested before temperature drops below 13°C (YOSHIDA, 1978). In recent study, it was observed that the ripening grade, as expressed by grain yield per spikelet number, was mainly governed by the climatic factors at the two stage of 20 days before heading and 20 days after heading (MUNAKATA, 1974). The effect of solar radiation was positive through the reproductive stage, while the effect of temperature was not simple. The negative effect of low temperature on ripening grade was most severe at 20 days before heading stage, followed by that at 10 days after heading stage. Also, a negative effect of high temperature was observed around heading time. The optimum temperature for ripening grade was 26°C at heading, followed by 23°C at (−20) stage and 22°C at (+20) stage under normal solar radiation. In temperate zones, the crop is normally harvested before temperature drops below 13°C (Yoshida 1978). After flowering, temperature becomes the dominant factor affecting duration of the ripening period. Thus temperature dominate for about 30 days from flowering to maturity in the tropics. But for 65 days in South wales, Australia, and Hokkaido, Japan (Tanaka and vergara 1967). Variety slightly influences the duration of the ripening period; varieties with greater grain size require longer time to mature (Yoshida 1977).

In studies on Indica-Japonica variety "Tongil" at the ripening stage, it was found that as temperature decreased translocation of assimilate to grains was retarded more rapidly in Tongil compared to Jinheung (Heu 1978). There are many reports on Japonica varieties of rice in Japan which yielded evidence that the optimum air temperature for the ripening of rice is about 20° to 22°C and that higher or lower temperature than this optimum may impair the grain yield (Aimi et al, 1959; Matsushima et al, 1957; Murakai; 1973). Most studies on the effects of temperature at the grain ripening period have been done on Japonica and Indica varieties. But there is no report of detailed data on the effects of air temperature on the Indica-Japonica crosses at grain-filling stage. The objective of this study is to find out the effects of air temperature on the Indica-Japonica varieties at the grain-filling stage.

MATERIALS AND METHODS

Varieties

The varieties used were Indica-Japonica crosses (Suweon 264, Suweon 258, Milyang 29), Indica (IR36, Lengkwang), Japonica (Jinheung) rice.

Controlled environmental conditions

This experiment was conducted in the bioclimatic laboratory of the IRRI at Los Banos, Philipines. The plants were grown in the phytotron glasshouse room until 3 days after flowering, after which they were transferred to artificially temperature controlled cabinets, Koitotron KG-106 SHL-D cabinets. The relative humidity of the glasshouse room was maintained about 75 percent while the temperature was kept at 29°C between 09:00 and 17:00 hr and 21°C during the night. Daylength was according to natural conditions. In the artificially lighted cabinets, light was provided by 11 x 400 W Toshiba Yoko lamps DR 400/T and 12 x 40 W Mitsubishi white fluorescent lamps. The spectral composition of the radiation is similar in the visible region to that of sunlight. Daytime was from 06:00 to 18:00 hr. The relative humidity in the artificially lighted cabinets was maintained at 70 percent during daytime and 80 percent during the night.

Cultural methods

Each pot contained 3.5 kg Maahas clay soil fertilized with 1 g N, 0.5 g P_2O_5, and 0.5g K_2O and was put into a 4-liter plastic pot. For seed spacing, 20 sowing holes were made uniformly in size, depth and interval, in a circle by pressing the soil surface in pots. One pregerminated rice seed was placed in each hole. The sown seeds were covered by fine upland soil.

Temperature treatment

Each variety was subjected to air temperature treatment at the grain filling stage (3 days after heading to harvest).

The daily mean temperature varied from 13°C to 28°C with a constant day-night temperature difference of 8°C. Thus, at a daily mean temperature of 13°C, the day temperature was 17°C and the night temperature was 9°C; this is expressed as 20°/12°C. Thus, each temperature combination (day/night) may be expressed as follows: 17°/9°C, 20/12°C, 23/15°C, 26/18°C, 29/21°C, 32/24°C.

Grain sample and measuring procedures

Grain samples were collected from the panicles of the main culm at anthesis, 3 days later, and then every five days. To measure the length of the grain filling period, nine grains were sampled from the 3rd, 4th and 5th position from the top on three upper primary branches with the same flowering date. It was replicated three times. The panicles from which the nine grains were sampled were allowed to ripen to maturity and were used for measurement of yield components. The sampled grains and panicles were weighed immediately after harvest to record the fresh weight, then oven dried for 3 days at 70°C, and finally weighed for dry weight.

The grains were separated by hand into filled and unfilled grains. Unfilled grains were further divided by the iodine test into unfertilized and partially filled grains.

Grain quality and measuring

At maturity, 15 selected panicles were harvested for yield components and grain quality. In each of 300 randomly sampled grains the husk was removed and examined visually for chalky grains, green grains and dead grain (black rice).

Grain dimensions were determined as follows:

Grain length (mm): Longitudinal dimension measured from 10 well-developed grains as the distance from base to tip. A dial-type Vernier caliper was used.

Grain width (mm): diameter measured from 10 grains as the distance at the widest point (Fig. 1). A dial-type Vernier caliper was used.

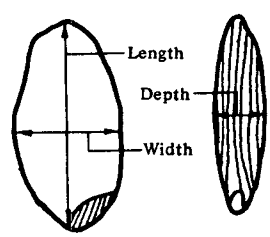

Fig. 1. Grain dimensions

Grain depth (mm): Lateral diameter measured from 10 grains as the largest distance between the two lateral sides in the middle part of the caryposis. A dial-type Vernier caliper was used.

RESULTS

1. Growth condition (leaf activity) during the temperature treatment.

At the lowest temperature 17/9°C, the leaves turned light yellow 1 day after treatment in all varieties. From 3-4 days after treatment, in IR36 and indica-japonica crosses the leaf tip (top part) turned light-red, and then 1 week after treatment the leaf tip was slowly wilting, but in Jinheung and Lengkwang, it only turned yellow. Only Jinheung had small brown spots on the leaf surface. About 2 weeks after treatment, IR36 and indica-japonica crosses died slowly, but in Jinheung and Lengkwang, the leaves turned yellow green and grain filling was very slow.

At 20/12°C, IR36 and indica-japonica varieties also had leaf discoloration 3 days after treatment. In Jinheung and Lengkwang, the leaves turned light yellow. In IR36, 2 weeks after treatment the leaf tip began to roll and then started dying. However, in indica-japonica crosses the leaves remained green and grain filling was much slower.

At 23/15°C, IR36 and indica-japonica crosses had only slight leaf discoloration 1 week after treatment. On the other hand, at the highest temperature 32/24°C, earlier leaf senescence was observed in IR36 and indica-japonica crosses.

2. Effects of temperature on grain filling

The grain filling period was shorter within the daily mean temperature range of 13 to 28°C, the higher the temperature for all varieties (Fig. 2 - 7). There is very high correlation between the day and night temperature and the grain weight in grain filling stage. The duration of the grain filling period is defined as the number of days required to reach the maximum weight ("special spikelets").

In indica variety IR36 the duration was 13 days at 32/24°C, 18 days at 29/21°C, 32 days at 26/18°C and 33 days at 23/15°C (Fig. 2).

In japonica variety Jinheung, it was 23 days at 32/24°C, 28 days at 29/21°C and 26/18°C, 38 days at 20/12°C and 68 days at 17/9°C (Fig. 3).

Indica-japonica varieties had grain filling periods as follows: Suweon 264, 18 days at 32/24°C and 29/21°C, 23 days at 26/18°C, 28 days at 23/15°C, and 38 days at 20/12°C (Fig. 4); Suweon 258, 18 days at 32/24°C, 23 days at 29/21°C and 26/18°C, 28 days at 23/15°C, 33 days at 20/12°C (Fig. 5); Milyang 29 also 18 days at 32/24°C, 23 days at 29/21°C, and 26/18°C, 28 days at 23/15°C, and 43 days at 20/12°C (Fig. 6). In indica variety Langkwang, a variety with high resistance to low tem-

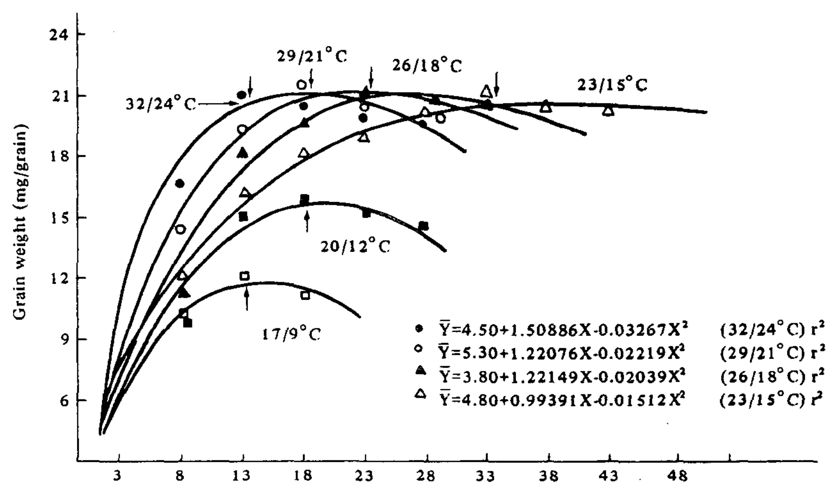

Fig. 2. Effects of temperature on grain filling in IR36.

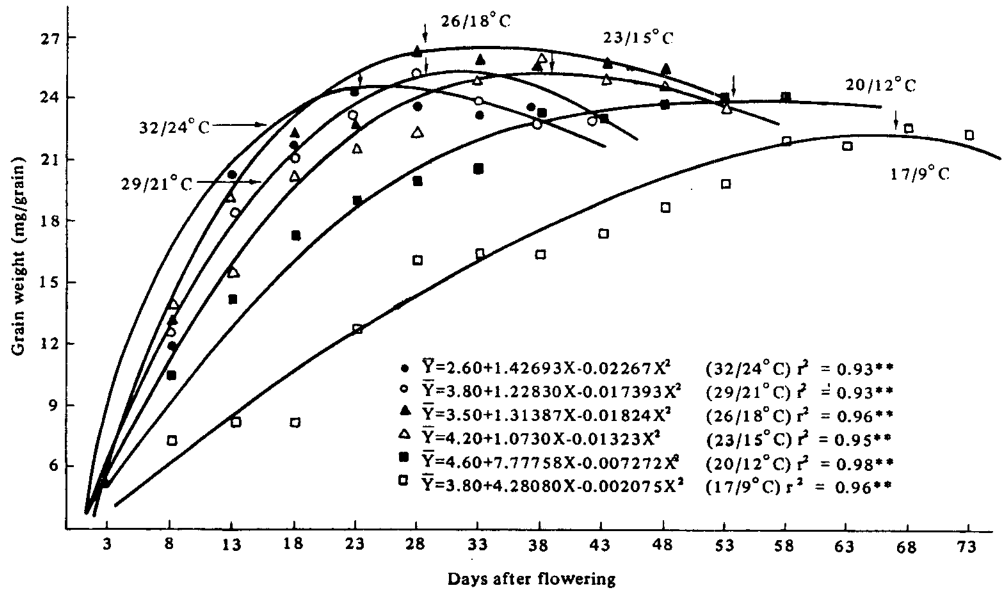

Fig. 3. Effects of temperature on grain filling in Jinheung.

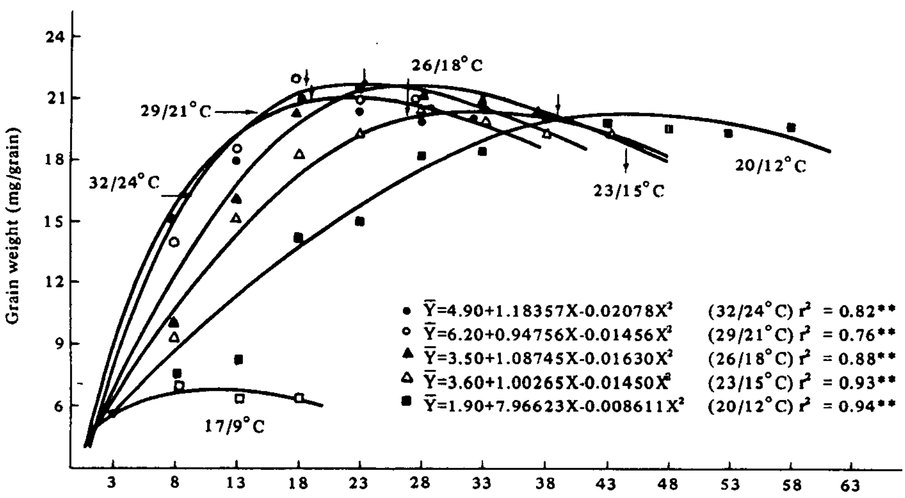

Fig. 4. Effects of temperature on grain filling in Suweon 264.

perature the duration was 23 days at 3 ranges of temperature (32/24°C, 29/21°C and 26/18°C), 28 days at 23/15°C, 33 days at 20/12°C, and 58 days at 17/9°C (Fig. 7).

In all varieties, the length of the grain filling period was very different at different temperature ranges.

In general, in IR36 and indica-japonica crosses the influence of air temperature on the grain filling stage was very similar. On the other hand japonica variety Jinheung at all the temperature ranges took more than 10 days later than IR36 and indica-japonica crosses after flowering to reach the maximum grain weight.

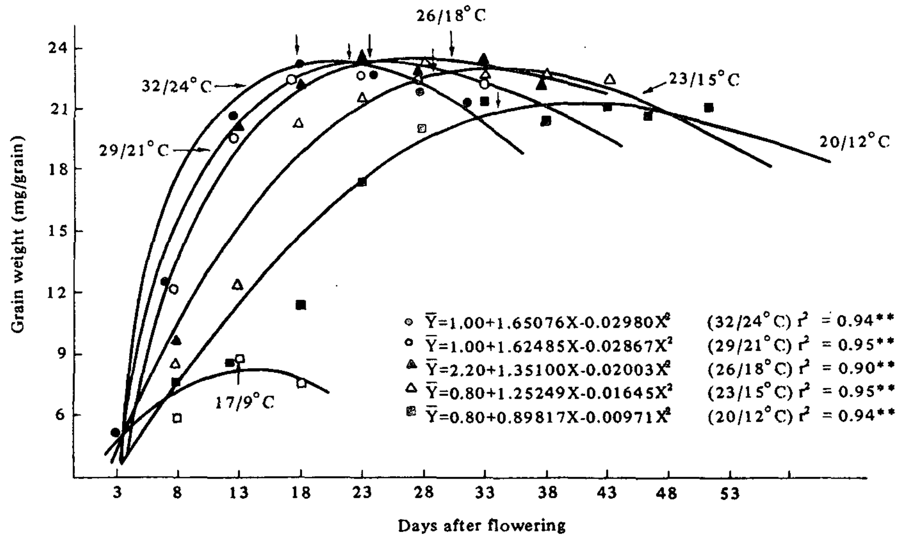

Fig. 5. Effects of temperature on grain filling in Suweon 258.

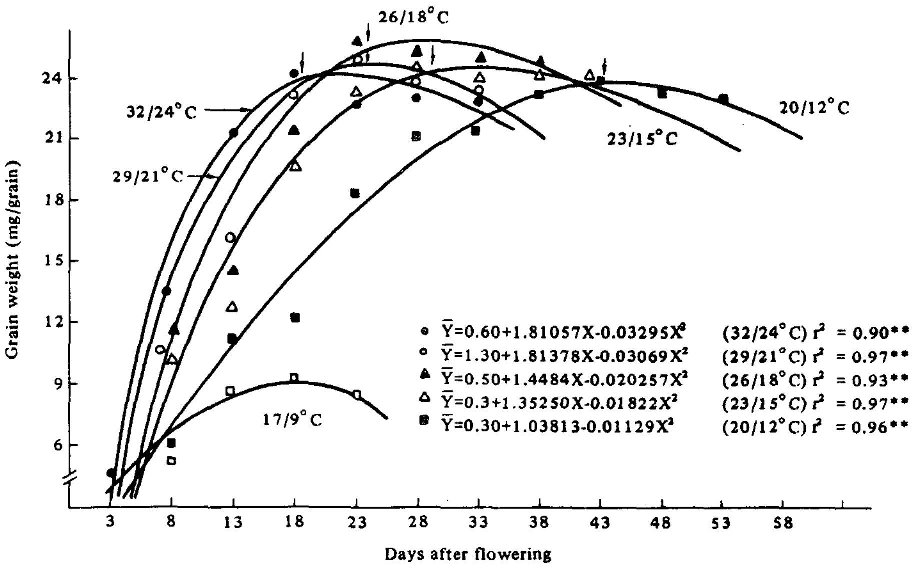

Fig. 6. Effects of temperature on grain filling in Milyang 29.

In Jinheung and Lengkwang, at lower temperature range (17/9°C and 20/12°C) the grain growth curve was characterized by a long lag-phase following a linear phase.

3. Effect of temperature on the grain filling period for the whole panicle.

The duration of grain filling period for the whole panicle, defined as number of days required to reach the maximum weight, in IR36 was 23 days at 32/24°C, 28 days at 29/21°C, 33 days at 26/18°C, and 38 days at 23/15°C (Fig. 8). In Jinheung, it was33 days at 32/24°C, 38 days at 29/21°C, 43 days at 26/18°C and 23/15°C, 58 days at 20/12°C, and 68 days at 17/9°C (Fig. 9).

In Suweon 264, it was 33 days at 32/24°C and

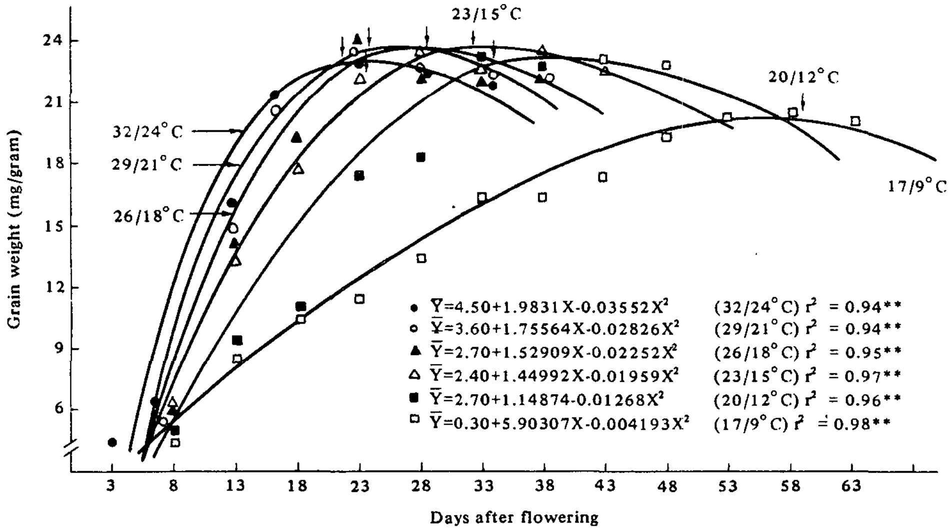

Fig. 7. Effects of temperature on grain filling in Lengkwang.

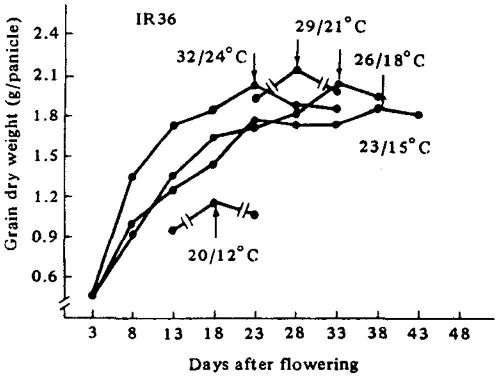

Fig. 8. Effects of temperature on grain filling in IR36.

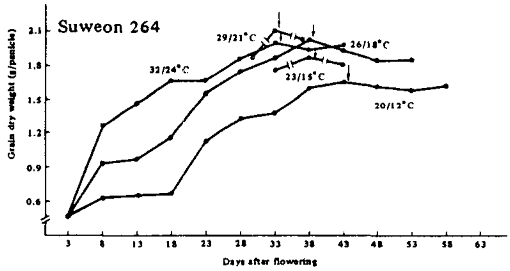

Fig. 10. Effects of temperature on grain filling in Suweon 264.

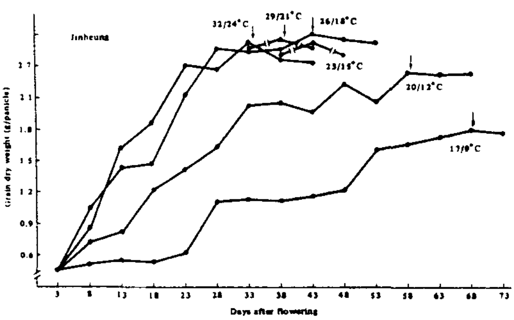

Fig. 9. Effects of temperature on grain filling in Jinheung.

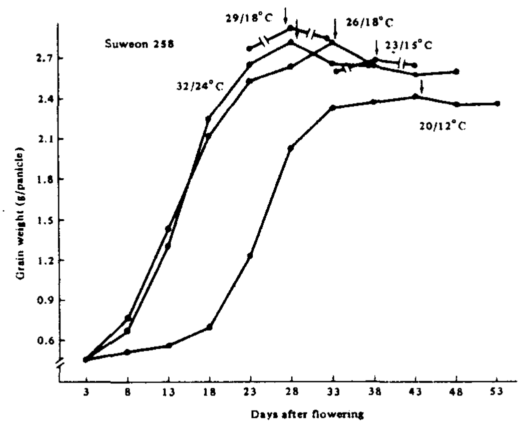

Fig. 11. Effects of temperature on grain filling in Suweon 258.

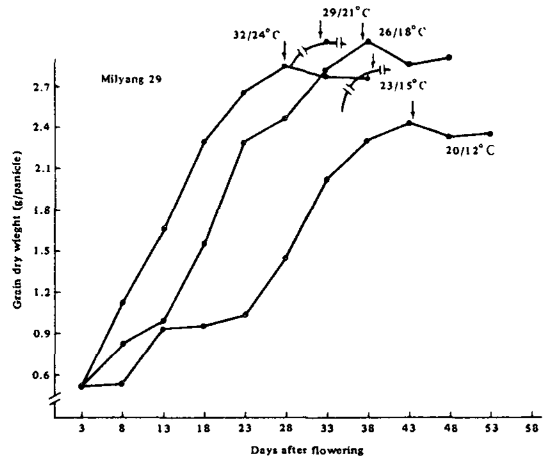

Fig. 12. Effects of temperature on grain filling in Milyang 29.

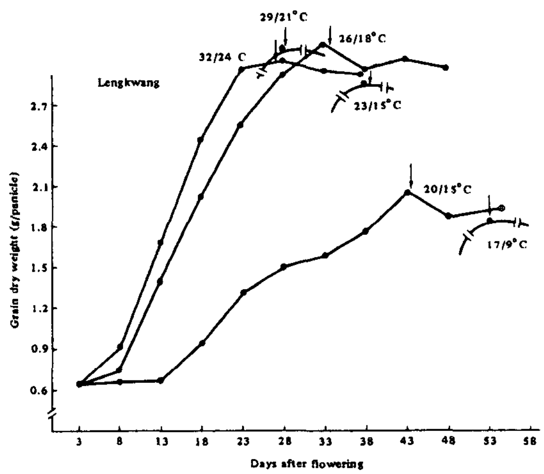

Fig. 13. Effects of temperature on grain filling in Lengkwang.

29/21°C, 38 days at 26/18°C to 23/15°C, and 43 days at 20/12°C (Fig. 10). In Suweon 258, it took 28 days at 32/24°C and 29/18°C, 33 days at 26/18°C, 38 days at 23/15°C, and 43 days at 20/12°C (Fig. 11).

In Milyang 29, it took 28 days at 32/24°C, 33 days at 29/21°C, 38 days at 26/18°C to 23/15°C, and 43 days at 20/12°C (Fig. 12).

In Lengkwang, it was 28 days at 32/24°C and 29/21°C, 33 days at 26/18°C, 43 days at 20/15°C, and 53 days at 17/9°C (Fig. 13).

These results show that the grain filling period for the whole panicle was 10 to 15 days longer than that for each grain ("special spikelets). However, in Jinheung and Lengkwang, at the lower temperature ranges (17/9°C and 20/12°C), the grain and the whole panicle required the same number of days to reach maximum grain weight.

4. Influence of different temperature ranges on grain filling rate.

Table 1 indicates the effects of different temperature ranges on grain filling rate (mg/day) after temperature treatment to reach maximum grain weight. In all varieties, the grain filling rate was high during the first 2 weeks after flowering at high temperature ranges.

At the optimum temperature range, the grain filling rate was high up to 4 weeks after flowering in Jinheung, and up to 3 weeks after flowering in indica-japonica crosses and IR36.

In the case of low temperature ranges, in Jinheung and Lengkwang at 17/9°C, the grain filling rate was lowest during the first 3 weeks after flowering, then increased slowly 4 to 5 weeks after flowering.

In indica-japonica varieties, at the low temperature range of 20/12°C, the grain filling rate increased slowly 2 to 4 weeks after flowering.

5. Influence of temperature on grain weight and grain quality

At the lower temperature ranges, the grain weight was almost the same after reaching the maximum grain weight, but at higher temperature ranges, the grain weight tended to decline after reaching the maximum grain weight (Fig. 2-7).

At each day-and-night temperature grade, the higher weights per grain were observed as follows (Table 12): in IR36, 26/18°C > 29/21°C > 32/24°C > 23/15°C; in Jinheung and Lengkwang, 26/18°C > 23/15°C ≧ 20/12°C > 29/21°C > 31/24°C > 17/9°C; in indica-japonica varieties, 29/21°C ≧ 26/18°C > 23/15°C > 32/24°C > 20/12°C.

The optimum day and night temperature for maximum weight per grain appeared to range

Table 1. Influence of different temperature on grain filling rate (mg/day) after temperature treatment to reach maximum grain weight.

Temp. (°C) day/night	8 days after flowering	13	18	23	28	33	38	43	48	53	58	63	68	73
							IR 36							
17/9	–													
20/12														
23/15	0.92	0.76	0.46	0.14	0.18	0.16 (20.9)	–							
26/18	1.02	1.26	0.34	0.72 (21.2)	–									
29/21	1.60	1.02	0.36 (21.6)											
32/24	1.92 (21.4)	1.02	–											
							Jinheung							
17/9	0.40	0.12	0.01	0.32	0.64	0.06	0.01	0.20	0.28	0.24	0.50	0.01	0.22 (21.3)	–
20/12	1.02	0.72	0.62	0.34	0.24	0.12		0.01	0.20	0.16 (25.6)	–			
23/15	1.70	0.50	0.65	0.62	0.14	0.67	0.10 (26.2)	–						
26/18	1.64	1.04	0.64	0.08	0.78 (26.5)	–								
29/21	1.48	1.22	0.32	0.34	0.06 (25.7)	–								
32/24	1.32	1.52	0.30	0.62 (24.4)	–									
							Suweon 264							
17/9	–													
20/12	0.18	0.30	0.62	0.14	0.80	0.40	0.32 (20.7)	–						
23/15	0.72	0.96	0.66	0.16	0.14 (20.9)	–								
26/18	0.76	1.26	0.80	0.24 (21.3)										
29/21	1.64	0.78	0.66 (21.4)											
32/24	1.76	0.56	0.80 (21.8)											
							Suweon 258							
17/9	–													
20/12	0.44	0.38	0.40	0.80	0.66	0.20 (21.4)	–							
23/15	0.70	0.78	1.60	0.38	0.26 (23.6)									
26/18	0.96	1.56	0.30	0.38 (23.4)	–									
29/21	1.28	1.56	0.54	0.16 (20.5)	–									
32/24	1.36	1.44	0.76 (22.8)											
							Milyang 29							
17/19	–													
20/12	0.30	0.52	0.16	1.02	0.48	0.12	0.28	0.08 (23.5)	–					
23/15	1.20	0.50	1.42	0.72	0.22 (24.5)	–								
26/18	1.38	0.62	1.46	0.82 (25.2)	–									
32/24	1.78	1.66	0.52 (24.0)	–										
							Lengkwang							
17/9	0.06	0.58	0.36	0.16	0.49	0.46	0.01	0.18	0.40	0.32 (20.8)				
20/12	0.28	1.16	0.20	1.30	0.62	0.62 (23.6)	–							
23/15	0.66	1.42	0.96	0.90	0.20 (23.4)	–								
26/18	0.52	1.74	1.00	0.74 (22.8)	–									
29/21	0.62	1.82	1.16	0.34 (23.2)	–									
32/24	0.64	2.00	1.02	0.42 (22.8)	–									

• (　　) : Maximum grain weight (mg)
Temperature treatment: 3 days after flowering.

Table 2. Influence of temperature on grain weight and grain quality in different varieties

Temperature (°C) day/night)	Daily mean temperature (°C)	Grain weight (mg/grain)	Filled grains (%)	Partially. filled grains (%)	Unfertilized grains (%)	Grain quality		
						Chalky grains (%)	Green grains (%)	Dead grains (%)
				IR 36				
16/ 9	13	–	–	–	–	–	–	–
20/12	16	–	–	–	–	–	–	–
23/15	19	20.1	76.8	15.4	12.3	8.1	9.6	6.7
26/18	22	22.1	82.8	8.7	8.4	4.5	4.0	1.8
29/21	25	21.7	78.9	11.2	9.9	10.3	3.4	2.7
32/24	28	21.4	81.0	11.5	7.5	14.9	1.5	1.1
				Jinheung				
17/ 9	13	23.3	52.6	27.7	19.7	7.8	23.8	27.7
20/12	16	25.3	79.5	8.3	16.1	3.2	8.9	1.1
23/15	19	25.2	84.9	3.4	11.6	2.1	1.3	0.9
26/18	22	25.7	85.7	2.2	12.9	2.5	1.0	–
29/21	25	24.1	89.8	1.5	8.3	5.9	–	–
32/24	28	23.8	88.6	2.1	9.3	16.6	–	–
				Suweon 264				
17/ 9	13	–	–	–	–	–	–	–
20/12	16	19.7	73.1	11.0	15.9	9.4	10.8	2.9
23/15	19	20.6	80.4	10.6	8.9	5.5	4.3	–
26/18	22	20.3	82.3	10.5	7.2	5.4	2.3	–
29/21	25	20.5	81.8	9.7	8.4	4.6	2.7	–
32/24	28	19.4	81.7	10.2	8.1	13.4	2.3	–
				Suweon 258				
17/ 9	13	–	–	–	–	–	–	–
20/12	16	21.4	71.6	16.9	15.5	10.5	13.4	2.2
23/15	19	22.1	78.5	10.9	10.5	4.9	8.0	1.1
26/18	22	22.5	81.2	10.3	8.5	5.0	3.8	–
29/21	25	22.6	79.6	11.3	9.0	6.7	2.6	–
32/24	28	21.7	80.3	10.9	8.8	14.5	3.0	1.2
				Milyang 29				
17/ 9	13	–	–	–	–	–	–	–
20/12	16	22.8	70.5	16.4	13.1	11.5	14.3	2.6
23/15	19	24.1	78.7	9.8	11.4	5.3	9.0	1.2
26/18	22	25.1	81.1	7.5	11.0	4.2	4.5	–
29/21	25	23.8	80.4	10.6	8.9	2.3	3.4	0.8
32/24	28	23.3	76.4	12.6	11.0	32.1	3.7	3.5
				Lengkwang				
17/ 9	13	20.5	58.3	25.2	16.5	14.2	30.5	12.2
20/12	16	22.5	77.3	13.2	11.5	5.6	24.8	–
23/15	19	23.8	86.7	7.1	6.2	2.0	14.7	–
26/18	22	23.3	87.6	6.0	6.4	–	4.5	–
29/21	25	23.1	88.1	7.9	6.0	4.0	3.3	1.9
32/24	28	22.8	86.8	8.0	5.2	18.3	3.5	1.0

* Chalky grain : White belly and white center grain
Dead grain : Black and dark red grain

between 26/18°C and 29/21°C for IR36 and indica-japonica varieties and 26/18°C to 23/15°C in Jinheung and Lengkwang. IR36 and indica-japonica varieties appeared to be sensitive to low temperature range compared to japonica variety Jinheung.

The percentage of chalky grains for all varieties was higher in high temperature ranges than in lower temperature ranges (Table 2). At 32/24°C Milyang 29 had 32.1%; Lengkwang, 18.3%; Jinheung 16.6%; IR36 and Suweon 258, 14.5%; and Suweon 264, 13.4%.

A high percentage of dead grains (black and dark red grain) was found at the lowest temperature regime (17/9°C) in Jinheung and Lengkwang (Table 2).

Higher percentages of green grains were found at the low temperature ranges than those at high temperature ranges. At the lowest temperature, the percentage of green grain was in IR36, 9.6% at 23/15°C; in Jinheung, 23.8% and Lengkwang, 30.5% at 17/9°C; in indica-japonica crosses Suweon 264, 10.8% Suweon 258, 13.4%; and Milyang 29, 14.3% at 20/12°C.

6. Effects of temperature on frequency of grain weight

The day and night temperature was found to be the most meaningful expression for describing the effect of temperature on grain filling.

In this study, the weight of grains was lowest

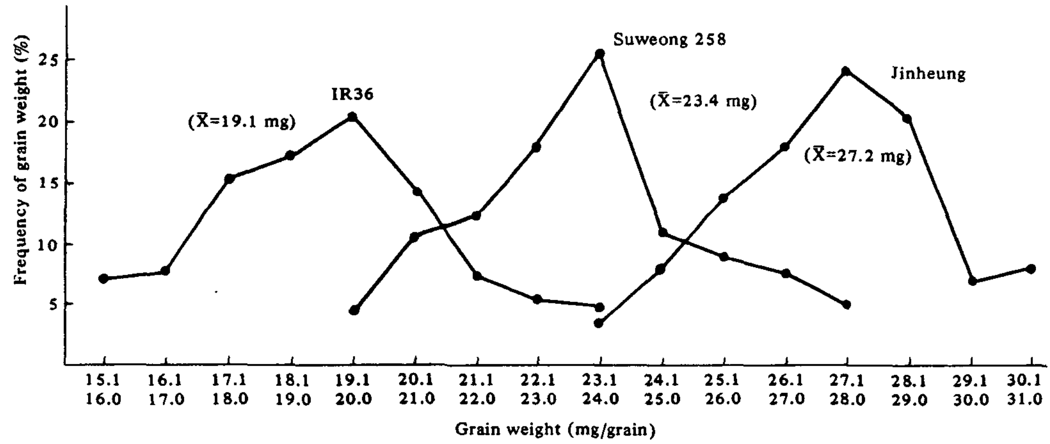

Fig. 14. Effect of temperature (26/18°C) on frequency of grain weight at grain filling stage in different *varieties.*

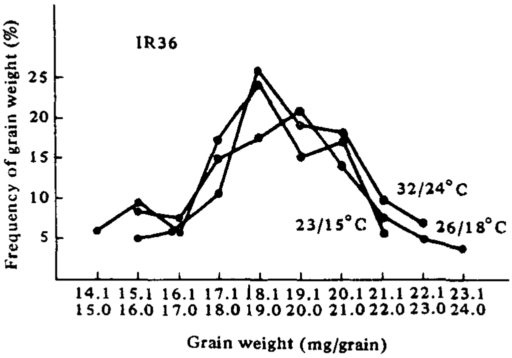

Fig. 15. Effects of temperature on frequency of grain weight at grain filling stage in IR36.

when the day and night temperature was at lower ranges, in Jinheung and Lengkwang at 17/9°C, in indica-japonica crosses at 20/12°C and in IR36 at 23/15°C.

At higher temperature ranges the grain weight was lower than the optimum temperature of 26/18°C (Fig. 15-17). Figure 14 shows the effect of temperature on frequency of grain weight at grain filling stage in different varieties. This figure shows that only at optimum temperature ranges, all varieties followed an almost normal distribution curve on the grain weight in different grain weight

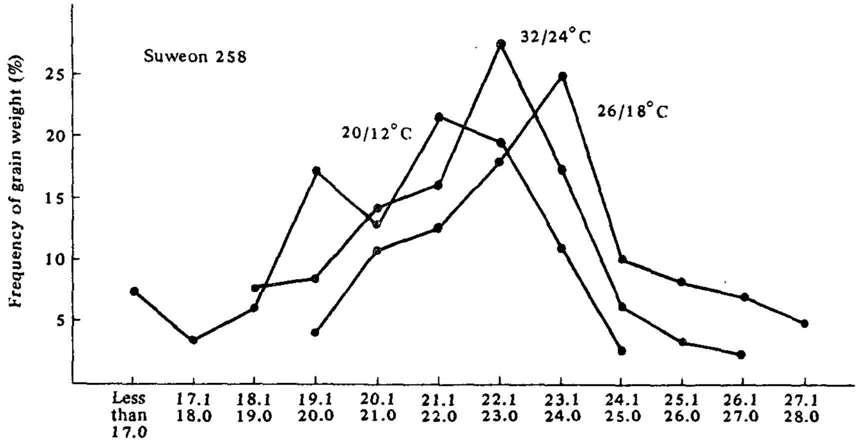

Fig. 16. Effects of temperature on frequency of grain weight at the grain filling stage in Suweon 258.

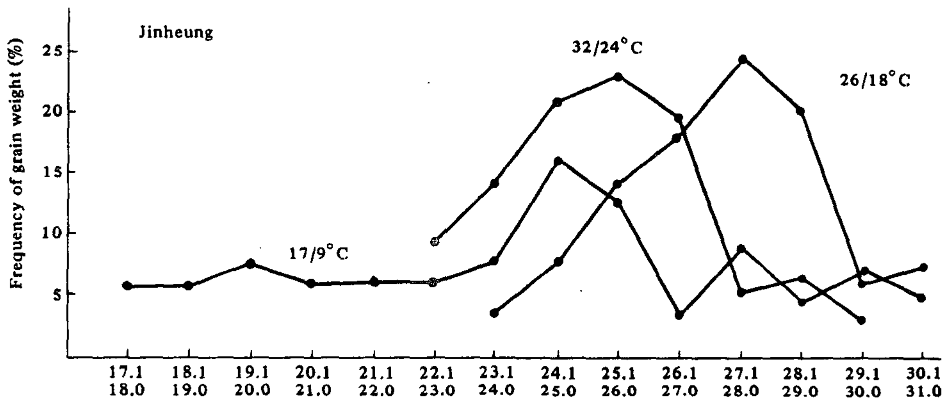

Fig. 17. Effects of temperature on frequency of grain weight at grain filling stage in Jinheung.

ranges.

Therefore, a comparison of grain weight distribution among the three temperature ranges (lowest, highest and optimum temperature) shows a very different pattern in each variety.

In indica variety IR36, the highest (32/24°C) and lowest (23/15°C) temperature ranges matched the frequency of grain weight curves (Fig. 15). In japonica variety Jinheung, at the three temperature ranges, that is, lowest (17/9°C), highest (32/24°C), and optimum (26/18°C), the frequency of grain weight curve showed very different patterns (Fig. 17). But in indica-japonica crosses Suweon 258, the frequency of grain weight curve was in (medium area) between that of IR36 and Jinheung variety (Fig. 16).

7. Influence of temperature on grain length, width and depth.

The lower-than-optimum temperature ranges (17/9°C and 20/12°C) affected grain length, width and depth. At these temperature ranges, grains were shorter, narrower, and thinner than grains at the optimum temperature of 26/18°C (Table 3).

At the lowest temperature, the effect on grain

Table 3. Influence of temperature on grain length, width and depth in different varieties.

Varieties	Grain growth (mm)	Temperature (day/night °C)					
		17/9	20/12	23/15	26/18	29/21	32/34
Jinheung	Length	5.26	5.35	5.33	5.33	5.30	5.27
	Width	2.77	2.99	3.00	3.01	2.96	2.94
	Depth	2.09	2.14	2.12	2.13	2.15	2.14
IR36	Length	–	–	6.19	6.36	6.29	6.31
	Width	–	–	2.06	2.15	2.18	2.15
	Depth	–	–	1.39	1.52	1.55	1.57
Suweon 264	Lenggh	–	5.32	5.37	5.42	5.36	5.35
	Width	–	2.49	2.59	2.61	2.60	2.57
	Depth	–	1.64	1.67	1.69	1.66	1.67
Suweon 258	Length	–	5.18	5.31	5.32	5.30	5.31
	Width	–	2.63	2.77	2.82	2.79	2.83
	Depth	–	1.81	1.83	1.92	1.89	1.91
Milyang 29	Length	–	6.31	6.43	6.37	6.38	6.30
	Width	–	2.57	2.61	2.65	2.64	2.61
	Depth	–	1.85	1.89	1.88	1.87	1.85
Lengkwang	Length	5.40	5.52	5.49	5.58	5.57	5.58
	Width	2.43	2.49	2.60	2.61	2.56	2.54
	Depth	1.85	1.89	1.92	1.90	1.91	1.90

length, width and depth was very clear. On the other hand, the highest temperature (32/24°C) seemed to have little effect on grain length, width and depth, although it progressed differences among the varieties.

DISCUSSION

The reproductive growth of a rice plant goes on for a lengthy period of about 60 days from initiation of panicle formation to grain maturity (Munakata, 1974). The rice plant during this period carries on morphological differentiation as well as increasing dry matter. Grain yield is essentially determined through two processes, spikelet formation before heading and grain ripening after heading. Consequently, many studies have been done on the functional relationship between the related main factor and the reproductive growth of rice. Air temperature is a very important ecological factor which many have a profound influence on the quality of rice grain and grain yield.

In rice, within the optimal temperature range (from 15-18° to 30-33°C), higher temperatures, in general, favour the growth and development of the rice plant (Nishiyama, 1974). In temperate zones, the rice crop is normally harvested before temperature drops below 13°C (Yoshida, 1978).

In recent study, it was observed that the ripening grade, as expressed by grain yield per spikelet number, was mainly governed by the climatic factors at the two stages of 20 days before heading and 20 days after heading (Munakata, 1974). The effect of solar radiation was positive through the reproductive stages, while the effect of temperature was not simple. The negative effect of low temperature on ripening grade was most severe at 20 days before heading stage, followed by that at 10 days after heading stage. Also, a negative effect of high temperature was observed around heading time. The optimum temperature for ripening grade was 26°C at heading, followed by 23°C at (-20) stage and 22°C at (+20) stage under normal solar radiation.

The critical temperature for seed ripening is in a range from 12°C to 18°C (Kondo *et al.*, 1948; Tanaka, 1962; Toriyama, 1962; Sinitsyna and Chan, 1972). High air temperatures averaging approximately 30eC are not favorable for ripening (Nagato *et al.*, 1961; Matsushima *et al.*, 1964).

Matsushima *et al.*,(1974) reported that in lowland rice, during the period from just before the heading stage to the early ripening stage and the most active ripening stage, only air temperature has a remarkable effect, while water temperature has no effect on yield, an air-temperature of 21°C having the most favourable effect on yield. At the time from just before the heading stage to the early ripening stage a remarkable detrimental effect of a high temperature of 36°C as well as that of a low temperature of 16°C is found on yield but at the most active ripening stage temperature as low as 16°C has a beneficial effect on yield and high temperatures such as 36°C and 31°C have remarkable detrimental effect on yield.

Nagato and Chaudhry(1969) studied that in the preliminary developmental stages of the kernel, the multiplication of endosperm cells is quicker in indicas than in japonicas.

Filling of starch grains is also faster. These two factors influence the ripening, in a way, that the total length, breadth, thickness and weight of kernel were achieved earlier and consequently maturity was also reached earlier in indicas.

Indica and japonica varieties gained 30-40 percent and 25-30 percent weight, respectively, till the time of translucency at center of kernel was reached. Similarly, 80 percent and 70 percent weight was achieved by indicas and japonicas, respectively, till the time of translucency at apical portion.

Aimi *et al.*,(1959) reported that while the grain filling of a japonica rice was completed in about 25 days after anthesis at a daily mean temperature of 25°C, it took much longer when the daily mean temperature was 21°C, and was not complete even after 75 days from anthesis when the daily mean temperature was 17°C. Yamakawa (1962) planted 12 rice varieties in the field in Japan at different times so that these rice crop would be exposed to different daily mean temperatures during the ripening period, he showed that japonica rice ripened over 30 days when the daily mean temperature was about 29°C, while ripening took 53 days when the daily mean temperature was 18°C.

In this study, the optimum temperature to achieve maximum weight per grain during the grain filling stage was 26/18°C for all varieties. At the highest temperature (32/24°C), the upper position grains ("special" spikelets) of IR36 required 13 days after flowering to reach the maximum weight; those of Jinheung and Lengkwang, 23 days, and those of indica-japonica crosses (Suweon 265, Suweon 258, Milyang 29), 18 days.

At the lowest temperature range of 17/9°C, Jinheung required 68 days and Lengkwang 53 days after flowering to reach the maximum grain weight. Yoshida and Hara(1977) reported that the optimum daily mean temperature range to achieve maximum weight per grain was 19 to 25°C for IR20 and 16° to 22°C for Fujisaka 5. At 28°C, the upper grains of IR20 took 13 days to reach the maximum weight, whereas those of Fujisaka 5 took 18 days. These data are in partial agreement with those of the present study. Similar results were obtained by Nagato *et al.*,(1961), Matsushima *et al.*,(1974), and Aimi *et al.*, (1959).

Table 1 shows the influence of different temperature on grain filling rate Img/day) after temperature treatment to reach maximum grain weight. At the optimum temperature range, the grain filling rate was high up to 4 weeks after flowering in japonica variety Jinheung, and up to 3 weeks after flowering in indica-japonica crosses and indica variety IR36. At high temperature ranges, the grain filling rate was high during the first 2 weeks after flowering. However, at the low temperature range of 17/9°C, the grain filling rate of Jinheung and Lengkwang was lowest during the first 3 weeks after flowering, then increased slowly 4 to 5 weeks after flowering. At 20/12°C, the grain filling rate of indica-japonica varieties increased slowly 2 to 4 weeks after flowering. In general, the grain filling rate of indica-japonica was faster than that of japonica variety. Similar tendency was found by Nagato *et al.*,(1969).

In this study, at the lower-than-optimum temperature ranges (17/9°C and 20/21°C), all IR36 plants died within 15 days after flowering. However, all indica-japonica plants died within 15 days only at 17/9°C. This means that the resistance of indica-japonica crosses to low-temperature stress was better than that of IR36. These results suggest that in the case of indica-japonica crosses, in the low temperature ranges, the grain filling stage is more stable at temperature above 23/15°C.

The optimal day-night temperature combinations for various maturity traits were 15-20°C for grain weight, 30-20°C for the percentage of fully matured grains and 30-20°C for width of brown rice (Chen, 1974). Nagato *et al.*,(1965) reported that high temperatures throughout the ripening period accelerated starch accumulation into the kernels and kernel development during the early phase of the ripening period, but depressed them in the later phase, thus the ripening period was remarkably shortened and the weight of the matured kernel was somewhat reduced.

Under high temperature, the rate of ripening was found to be much higher at an early ripening period, but the inflow of assimilates into grain ended earlier (2 to 3 weeks after flowering) resulting in lower 1000-kernel weight than that of normal out-door temperature (Sato and Inaba, 1976). Sato *et al.*,(1976) also observed that phosphorylase activity reached a maximum on the 10th day and then gradually decreased at high and normal temperature, being lower at high temperature. Yellowing of spikelet was first recognized at rachilla protein and occurred earlier at high temperature. Succinic-dehydrogenase activity at rachilla disappeared on the 16th day and soon yellowing started. Kernel enzyme activities seemed to decline earlier than disappearance of succinic-dehydrogenase activity at rachilla.

Aimi *et al.*,(1959) reported that the activity of enzymes (amylase, phosphorylase, investase, and hexokinase) in respect of each part of the plant which ripened at the low temperature, was not so much low on the after flowering, the dry weight and the starch content of the ear were respectively highest at 21°C and were almost equal between 25°C and 17°C were quite different from each other.

At 25°C, the dry weight and the starch content of the ear increased rapidly and then ceased accumulating at an early stage of ripening. On the contrary, at 17°C it increased slowly but steadily and it continued until the 75th day after flowering.

In the present study, the optimum day and night temperature for maximum weight per grain appeared to range from 26/18°C to 29/21°C for indica-japonica crosses and IR36, and from 26/18°C to 23/15°C for Jinheung and Leng-kwang. These results, also, indicate that indica-japonica varieties appeared to be more sensitive to low temperature range than japonica variety Jinheung.

Heu(1978) reported that at the ripening stage, as temperature decreased translocation of assimilates to grain was retarded more rapidly in Tongil compared to Jinheung. In contrast, at a high temperature of 35/24°C, translocation of assimilates to grains was greater in Tongil than in Jinheung. These results are similar to those in the present study.

The percentage of chalky grains in all varieties was higher in high temperature ranges than low temperature ranges (Table 2). Especially, in Milyang 29, the percentage of chalky grains was very high (32/1%) at grain filling stage at 32/24°C. This result suggests that among indica-indica-japonica crosses, high temperature adversely affects grain weight and grain quality at the grain-filling period. It must be considered that in Korea the heading stage of rice occurs during a high-temperature period (late July to early August), which is not favourable to grain weight and grain quality.

On the other hand, dead grains (black and dark red grain) were observed at the lowest temperature regime (17/9°C) in Jinheung and Lengkwang (Table 2). Green grain also appeared more at the low temperature ranges than at high temperature ranges. In many studies, high and low temperature have been shown to have deleterious effect on ripening of rice (*Nagato et al., 1960*; *Matsushima et al.*, 1957; Ebata, 1961).

In this study, figure 26-28 shows the effects of temperature on frequency of grain weight at grain filling stage. In indica variety IR36, the highest (32/24°C) and lowest (23/15°C) temperature range matched the frequency of grain weight curves (Fig. 16). In japonica variety Jinheung, at the three temperature ranges, that is, lowest (17/9°C) highest (32/24°C) and optimum (26/18°C), the frequency of grain weight curve showed very different patterns (Fig. 17). But in indica-japonica cross Suweon 258, the frequency of grain weight curve was in (medium area) between that of IR36 and Jinheung (Fig. 16). These data also shows that the weight of grain never increased beyond that at the optimum temperature.

The ventral radius which grows in the early period of ripening is lengthened and the dorsal radius which grows until the late period is shortened by high temperature, with the consequence that the ratio of the dorsal radius to the ventral radius (dorso-ventral ratio caused by high temperature) is greater in the varieties assumed to be less adaptable to high temperature than in the more adaptable varieties (Nagato, 1965). In the present study, at the lowest temperature, the effect on grain length, width and depth was very clear. On the other hand, the highest temperature (32/24°C) seemed to have little effect on grain length, width and depth, although it produced intervarietal differences (Table 3). This results indicates that the effect of temperature on the grain length, width and depth is more serious in low temperature ranges than in high temperature ranges.

摘 要

Indica×Japonica品種에 있어서 溫度處理가 登熟에 미치는 影響을 究明하고자 phytotron을 이용하여 Indica×Japonica品種(水原 264, 水原 258, 密陽 29) Indica品種(IR 36, Lengkwang) Japonica 品種(振興)을 供試 試驗한 結果를 要約하면 다음과 같다.

1. 登熟期에 있어서 粒重增加를 爲한 最適溫度는 晝夜溫度 26／18℃였고, 日平均溫度 13℃에서 28℃까지의 範圍에서는 溫度를 높임에 따라 登熟期間이 짧아졌다.

2. 高溫條件(32／24℃)에서의 上位部 穎花(Special)의 開花後 粒重이 最大가 되기까지에는 IR36 13日, 振興 23日, Indica×Japonica品種(水原264, 水原 258, 密陽 29) 18日 및 Lengkwang 23日이 要求되었다.

3. Lengkwang의 경우 晝夜溫度 32／24℃, 29／21℃, 26／18℃의 3個 處理溫度 範圍에서는 開花後 粒重의 最大時期가 同時에 나타났다.

4. 低溫條件(17／9℃)에서 登熟期間이 振興 68日, Lengkwang 53日의 長期間이 所要되었다.

5. 一穗가 完全히 登熟하는데는 上位部 穎花들의 登熟보다 下位部 穎花의 登熟은 15日程度 늦어졌다.

6. 低溫條件下에서(17／9℃, 20／12℃) IR36은 開花後 15日 以內에 枯死되었으나 Indica×Japonica 品種들은 17／9℃에서만 枯死되고 20／12℃에서는 初期登熟이 停滯되었다가 2週日後부터 登熟이 서서히 始作되었다.

7. 溫度條件에 따른 腹白米의 形成은 最適溫度(26／18℃)로부터 最低나 最高條件에서 많았고 死米 및 赤米도 같은 傾向으로 나타났다.

8. 玄米粒의 길이 및 두께 幅에 대한 영향을 보면 低溫條件(17／9℃, 20／12℃)에서 짧거나, 얇고, 좁은 편이었다.

9. 溫度別 粒重分布의 頻度를 보면 IR 36은 最高溫度條件이나(32／24℃) 最低溫度(23／13℃)에서 同一한 粒重分布를 보였고 最適溫度條件에서는(26／18℃) 높은 粒重分布를 보였고 振興은 最高, 最低, 最適溫度 順으로 粒重增加의 頻度를 보였으며 Indica×Japonica品種들은 振興과 IR36品種의 中間 領域에 머물고 있었다.

REFERENCES CITED

1. AHN, S.B.(1973) Studies on the varietal difference in the physiology of ripening in rice with special reference to raising the percentage of ripened grains. J. Korean Soc. Crop Sci. 14: 1-40.
2. AIMI, R. and H. SAWAMURA(1959) The effects of temperature on translocation of 32P in rice plant. Physiological investigation of the mechanism of ripening of crop plants. Proc. Crop Sci. Soc. Jpn. 28: 41-43.
3. AIMI, R., H. SAWAMURA and S. KONNO (1959) Physiological studies on the mechanism of ripening of crop plants. The effect of the temperature upon the behaviour of carbohydrates and some related enzymes during the ripening of rice plant. Proc. Crop Sci. Soc. Jpn. 27:405-416.
4. CHAUDHARY, T.N. and B.P. GHILDYAL (1970) Influence of submerged soil temperature regimes on growth, yield and nutrient composition of rice plant. Agron. J. 62(2):281-285.
5. CHEN, C.C.(1976) Studies on the anther culture of rice: pollen stage and low-temperature treatment. Natl. Sci. Counc. Mon. 4(2):49-52.
6. CHEN, C.S., L.C. CHANG and H. SU.(1974) Effect of alternating day-night temperatures on maturity of rice grains. Mem. Coll. Agric. Natl. Taiwan Univ. 15(2): 28-37.
7. DE DATTA, S.K. and P.M. ZARATE(1970) Environmental conditions affecting the growth characteristics, nitrogen response and grain yield of tropical rice. Biometeorol. 4(1):71-84.
8. EBATA, M.(1961) Studies on white-core rice kernel. IV. Effects of night temperature in ripening time upon the occurrence and types of whitecore kernels. Proc. Crop Sci. Soc. Jpn. 29:409-411.
9. HEU, M.H. and S.H. BAE.(1972) Selection for lines of rice tolerant to low temperature in Korea. In Rice Breeding, p. 533-534. IRRI, Los Banos, Philippines.
10. Heu, H.(1978) Studies on physiological and econological characteristics of indica x japonica rice varieties. Res. Rep. of ORD., Korea 20 (Crops); 1-47.
11. Kondo. Y., Y. Otani, Y. Doi, and S. Izumi (1948) Physiological studies on the injuries of cool weather in rice plant. Effect and varietal differences of the low temperature after heading on the ripening. Proc. Crop Sci. Soc. Jpn. 16-8.
12. Kim, K.C., M.Y. Eun, H.I. Cho, and Y.S. Ham (1978) Effect of climatic condition on yield of rice in different growing seasons. Res. Rep. ORD., Korea 19(Crop): 71-77.
13. Matsushima, S., T. Manaka, and K. Tsunoda (1967) Analysis of developmental factors determining yield and yield predication in lowland rice. XXXIX-XI. On the mechanism of ripening. 5. Effects of temperatures and light intensities and their compound conditions in different stage in growth upon the ripening of rice plants. 6. Effect of the daily temperature in different stages in growth upon the ripening of rice plants. Proc. Crop Sci. Jpn. 25: 203-206.
14. Matsushima, S., T. Tanaka, and T. Hoshino (1964) Analysis of yield-determinign process and it application to yield prediction and culture improvement of lowland rice. LXX. Proc. Crop Sci. Soc. Jpn. 33-53-58.
15. Munakata, K.(1976) Effects of temperature and light on the reproductive growth and irpening of rice. P 187-210. In Climate and Rice. IRRI, Los Banos, Philippines.
16. Munakata, K., I. Kawasaki, and K. Kariya (1967) Quartitative studies on the effects of the climatic factors on the productivity of rice. Bull. Chugoku Agric Exp. Stn. A. 14: 59-96.
17. Murakami, T.(1973) Paddy rice ripening and temperature, Japan Agr. Reso Stn. A. 14:59-96.
18. Nagato, K., and M. Ebata(1960) Effects of temperature in the ipening periods upon the development and qualities of lowland rice kernels. Proc. Crop Sci. Soc. Jpn. 28: 275-279.
19. MURATA, Y.(1964) On the influence of solar radiation and air temperature upon the local

differences in the productivity of paddy rice in Japan. Proc. Crop Sci. Soc. Jpn. 35: 59-63.

20. Nagato. K., M. Ebata, and Y. Kono(1961) On the adaptability of rice varieties to high temperature in the ripering periods. Proc. Crop Sci. Soc. Jpn. 29: 337-340.
21. Nagato, K., and M. Ebata(1965) Effects of temperatures during the ripening period on the development and the quality of rice kernels. Proc. Crop Sci. Soc. Jpn. 34: 59-66.
22. Nagato, K. M., and F. M. Chavdury(1969) Repening of japonica and indica type rice as imfluenced by temperature during ripening period. Proc. Crop Sci. Soc. Jpn. 38: 657-667.
23. Nishiyama, I.(1976) Effects of temperature on the vegetative growth of rice plants. P. 159-185. In Climate and Rice. IRRI, Los Banos, Philippines.
24. Ota. T., and Ebata(1974) Effect of temperature on ripening and quality of rice. Rep. Tokai Br. Crop Sci. Soc. Jpn. 69: 39-43.
25. Stao, K., and K. Imaba(1976) High temperature injury of ripening in rice plant. V. On the early decline of assimilate storiong ability of grains at high temperature. Proc. Crop Sci. Soc. Jpn. 45(1): 156-161.
26. Sinitsyna, N.I., and D. Chan(1972) The temperature conditions of rice in S. Ukraine. Meteorol. Klimatol. Gidrol. Mezhved. Nauchn. Sb. 8:83-87. Field Crop Abstr. 26:432.
27. Tanka, Y.(1962) Studies on the growth injuries of lowland rice induced by cool water irrigation and delayed heading. Bull. Aomori. Agri. Exp. Stm. 7:1-107.
28. Tanaka, A., and B.S. Vergara(1967) Growth babit and ripening of rice plants in relation to the environmental conditions in the Far East, Irc Newl. Spec. Issue. 26-42.
29. Toryama, K.(1962) Studies on the cool-tolerance of rice varieties, with special reference to testing methods and its inheritance. Bull. Amori Agric, Exp. Stm. 7:109-153.
30. Yamakawa, Y.(1962) Studies on the ecological varieties of the growth of rice plant caused by the shifting of cultivation season in warm region in Japan. Agr. Bull. Saga. Univ. 14, 23-159.
31. Yoshida, S., and I. Hara(1977) Effects of air temperature and light on grain filling of an indica and japonica rice under controlled environmental conditions. Soil Sci. Plant Nutr. 23(1): 93-107.
32. Ysohida, S.(1978) Tropical climate and its influance on rice. IRRI, Res. Paperseries 20, Banos, Philippines.