Artificial Control of Flower Opening Time during the Day in Rice Plants

I. Preliminary experiments*

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If the flower opening time during the day could be advanced by any artificial means, it would provide a basis to a method to secure rice plants from high temperature sterility, because air temperature is low enough in the early morning even in high-temperature damage-prone areas (IRRI Ann Rep. for 1977; NISHIYAMA & BLANCO, 1980). From this viewpoint, we have conducted a series of preliminary experiments on the probability of controlling flower opening time during the day, and on the mechanism of flower opening in rice plants.

Materials and Methods

The rice variety IR36 was used throughout all experiments. Twenty seeds were seeded in a 1/5,000 a pot in a circle, and grown in a glasshouse room of the phytotron under a day/night temperature regime of 29/21°C.

At the flowering stage, the materials were transferred into artificially lit cabinets (Koitotron KG106 SHLD, Koito Kogyo Co., Ltd.) or to a screenhouse. The temperature of the cabinets was regulated at 25/25°C and 29/21°C; the light intensity was 40 klux, air humidity was 80/80 percent; the daytime was 0800–2000 h (12 hours) and night time was 2000–0800 h, unless otherwise stated.

The opening of flowers was checked every hour (or every 30 minutes) in the daytime.

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The time and the length of the dark or the light treatment for each experiment are indicated in the Results.

Results

Experiment 1. Flower opening time under standard conditions in the KG cabinets. The flower opening time of rice plants was estimated under standard conditions at 25/25°C and at 29/21°C in the KG growth cabinets. Nine trials were made for the 25/25°C treatment, and 5 for the 29/21°C treatment. Two representative examples of the treatments at 25/25°C and 29/21°C respectively are illustrated in Fig. 1 and the data on all the treatments are listed in Table 1. According to the figure and table, rice flowers in the cabinets open regularly in making a clear peak between 1300 to 1500 h for the 25/25°C treatment and between 1200 to 1300 h for the 29/21°C treatment, respectively.

Experiment 2. Effects of 1-hour and 30-minute dark treatments in the daytime. One-hour darkness was applied at 4 different times of the day, namely 0900–1000, 1000–1100, 1100–1200 and 1200–1300 h in the 25/25°C and 29/21°C treatments. The results are shown in Fig. 2 and 3.

One-hour dark treatment partially or entirely advanced the flower opening time which occurred at the time or just after the treatment. This advancement was more conspicuous in the 29/21°C treatment than in the 25/25°C one. Two-hour advancement could be obtained for practically all flowers by darkness applied at 1000 h in the 29/21°C treatment.

Thirty-minute dark treatments advanced

Fig. 1. Two representative examples of the flower opening time estimations at 25/25°C and at 29/21°C under standard conditions in the KG cabinets.

the opening time of a smaller portion of the flowers at 29/21°C, but not at 25/25°C.

Fig. 4 shows the results of 1-hour dark treatments in the screenhouse. The treatment applied at 0700 h did not affect the flower opening time, while that at 0800 h

Fig. 2. Effect of 1-hour dark treatment on the flower opening time at 25/25°C (average of 4 trials).

Table 1. Flower opening time under standard conditions in the KG cabinets.

Time (hours)	25/25°C*		29/21°C**	
	No. of flowers opened	Percentage	No. of flowers opened	Percentage
1700—0800	48	1.8	13	1.0
0800—0900	7	0.3	1	0.1
0900—1000	13	0.5	60	4.6
1000—1100	24	0.9	64	4.9
1100—1200	47	1.7	132	10.1
1200—1300	201	7.4	673	51.4
1300—1400	1026	37.8	353	27.0
1400—1500	1265	46.6	12	0.9
1500—1600	78	2.9	1	0.1
1600—1700	5	0.2	0	0.0
Total	2714		1309	

* 9 experiments.

** 5 experiments.

Fig. 3. Effect of 1-hour dark treatment on the flower opening time at 29/21°C (average of 4 trials).

clearly advanced it (sunrise: 0544 h). Thirty-minute dark treatment from 0830 h in the screenhouse was also effective. Thus, the advancement of opening time by dark treatment occurred also under natural conditions.

Observations showed that, in general, anthers did not dehisce in the flowers opened through dark treatment, but underwent dehiscence in the flowers opened after the treatment.

Experiment 3. Effects of the dark treatments of longer durations. One- to 4-hour dark treatments were applied from 0900 and 1000 h in both 25/25°C and 29/21°C regimes. At 25/25°C, the advancement was hardly observed, while at 29/21°C a clear peak in the opening time was observed just after the application of dark treatments either at 0900 or 1000 h. Fig. 5 illustrates the effect of the treatments applied at 0900 h.

Experiment 4. Flower opening under con-

Fig. 4. Effect of 1-hour dark treatment on the flower opening time in the screenhouse (average of 1-3 trials; sunrise: 0544 h).

Fig. 5. Effects of longer dark treatments (1-4 hours) for the flower opening time at 29/21°C (average of 4 trials).

tinuous light. Flower opening time was surveyed under continuous light at 25/25°C and at 29/21°C. Two kinds of trials were made for each of the temperature regimes: 1.

Rice plants were moved from a glasshouse room to a KG cabinet at 1700 h on the first day of the continuous light treatment. Thus in the daytime of the first day, the plants were kept under natural light at 29°C. 2. Rice plants were moved from a glasshouse room to a KG cabinet at 1700 h one day before the first day of the continuous light treatment. Thus the treatment was started at 0800 h in the KG cabinet.

The results are shown in Tables 2, 3, 4 and 5. The following observations were recorded throughout all trials:

1. Flower opening was strongly inhibited on the second day under continuous light treatment. Some inhibition was observed even on the third day at the constant temperature of 25/25°C.
2. Flowers opened throughout the day, but the peak of the opening was observed between 0900 and 1000 h even on the

Table 2. Flower opening under continuous light at 25/25°C (Trial 1).

Time (hours)	Number of flowers opened						
	1 st day*	2nd day**	3rd day	4 th day	5 th day	6 th day	7th day
1700—0800	1	0	36	38	35	42	45
0800—0900	4	0	2	21	24	16	12
0900—1000	8	0	4	20	27	37	32
1000—1100	85	0	15	11	14	10	3
1100—1200	55	1	6	9	6	6	6
1200—1300	12	0	6	12	3	3	0
1300—1400	0	0	1	4	4	4	2
1400—1500	0	0	3	3	6	6	0
1500—1600	0	0	1	7	5	4	2
1600—1700	0	1	4	1	1	5	4
Total	165	2	78	126	125	133	106

* 1 st day under continuous light in a glasshouse room with natural light at 29°C (0900—1700 h) and 21°C (1700—0900 h). Pots were moved into the KG cabinet at 1700 h on this day.

** KG cabinet at 25/25°C (Daytime is 0800—2000 h).

Table 3. Flower opening under continuous light at 25/25°C (Trial 2).

Time (hours)	Number of flowers opened						
	Glass- house room*	1 st day**	2 nd day	3 rd day	4 th day	5 th day	6 th day
1700—0800	1	0	3	28	61	44	38
0800—0900	1	154	0	5	11	19	19
0900—1000	7	35	0	8	14	19	25
1000—1100	135	22	0	3	5	7	11
1100—1200	5	6	4	3	8	6	6
1200—1300	0	6	0	4	5	8	8
1300—1400	1	2	0	3	3	2	5
1400—1500	0	2	1	6	7	6	2
1500—1600	0	2	0	4	1	3	3
1600—1700	0	1	0	5	9	9	3
Total	150	230	8	69	224	123	120

* Glasshouse room under natural light at 29° C (0900—1700 h) and 21°C (1700—0900 h). Pots were moved into the KG cabinet at 1700 h on this day.

** 1 st day under continuous light in a KG cabinet at 25/25°C (daytime: 0800—2000 h).

5th or 7th day after when the measurements were completed. This peak of opening was about 1 hour earlier than the original peak (1000–1100 h). (The peak on the day when the materials were moved into the KG cabinet tended to occur later except for the second trial at 25/25°C). Thus, the circadian rhythm was partially maintained under continuous light condition, and it was more distinctly observed at the tem-

perature diurnal cycle of 29/21°C.

Experiment 5. Flower opening under continuous very low light intensity. Flower opening time was estimated under continuous dim light (a 10 watt incandescent bulb about 1 m apart) at 25/25°C and at 29/21°C. The results are shown in Tables 6 and 7.

Flower opening was observed throughout the day, but a peak was clearly observed for both temperature regimes (the time of the peak was slightly advanced at 25/25°C).

Table 4. Flower opening under continuous light at 29/21°C (Trial 1).

Time (hours)	Number of flowers opened				
	1 st day*	2nd day**	3rd day	4 th day	5 th day
1700—0800	0	0	3	7	6
0800—0900	0	0	128	33	25
0900—1000	0	4	68	46	36
1000—1100	100	9	27	34	33
1100—1200	14	15	8	10	11
1200—1300	0	10	3	3	0
1300—1400	0	2	1	2	3
1400—1500	1	1	5	1	0
1500—1600	0	2	1	0	0
1600—1700	1	0	5	0	0
Total	116	43	249	136	114

* 1 st day under continuous light in a glasshouse room with natural light at 29°C (0900—1700 h) and 21°C (1700—0900 h). Pots were moved into the KG cabinets at 1700 h on this day.

** KG cabinet at 29/21°C (daytime: 0800—2000 h).

Table 5. Flower opening under continuous light at 29/21°C (Trial 2).

Time (hours)	Number of flowers opened						
	Glass- house room*	1 st day**	2 nd day	3 rd day	4 th day	5 th day	6 th day
1700—0800	0	1	0	0	7	4	2
0800—0900	0	0	0	10	111	44	16
0900—1000	2	9	0	44	63	71	46
1000—1100	93	14	28	40	35	44	42
1100—1200	18	27	16	31	14	13	17
1200—1300	1	179	1	19	3	5	8
1300—1400	0	12	2	4	3	4	9
1400—1500	0	3	0	10	0	1	1
1500—1600	0	1	0	1	0	1	3
1600—1700	0	1	0	1	0	0	0
Total	114	247	47	160	236	187	144

* Glasshouse room under natural light at 29°C (0900—1700 h) and 21°C (1700—0900 h). Pots were moved into the KG cabinet at 1700 h on this day.

** 1 st day under continuous light in a KG cabinet at 29/21°C (daytime: 0800—2000 h).

Table 6. Flower opening under continuous dim light at 25/25°C.

Time (hours)	Number of flowers opened					
	Glass- house room*	1 st day**	2nd day	3rd day	4 th day	5 th day
1600—0800	0	1	26	86	61	40
0800—1000	41	26	51	74	57	25
1000—1200	51	18	27	29	20	17
1200—1400	11	15	15	22	15	9
1400—1600	1	6	14	10	14	2
Total	104	66	133	221	167	93

* Glasshouse room with natural light at 29° C (0900—1700 h) and 21°C (1700—0900 h).

Pots were moved into the KG cabinet at 1700 h on this day.

** KG cabinet under a 10 watt incandescent lamp about 1 m apart at 25/25°C.

Table 7. Flower opening under continuous dim light at 29/21°C.

Time (hours)	Number of flowers opened					
	Glass- house room*	1 st day**	2nd day	3rd day	4 th day	5 th day
1600—0800	0	0	4	7	3	4
0800—1000	54	139	41	66	73	25
1000—1200	65	62	93	70	49	48
1200—1400	9	24	49	13	13	18
1400—1600	2	3	10	2	6	4
Total	130	228	197	158	144	99

* Glasshouse room with natural light at 29°C (0900—1700 h) and 21°C (1700—0900 h).

Pots were moved into the KG cabinet at 1700 h on this day.

** KG cabinet under a 10 watt incandescent lamp about 1 m apart at 29°C (0800—2000 h) and 21°C (2000—0800 h).

Discussion

Artificial devices to advance flower opening of rice plants, could contribute to the avoidance of the sterility induced by high temperature in the daytime, since rice flowers usually open after 1000 h, which coincides with the time when the air temperature rises rapidly.

We made a series of experiments to verify the possibility of inducing advancement of flower opening time in rice plants by the application of light-dark treatments in the phytotron.

The results showed that 1-hour dark treatment before the natural opening time clearly advanced the opening (Exp. 2). The advancement was 2 hours or more for almost all the flowers which opened, in some trials (Fig. 3). The day-night change of tem-

perature (29/21°C) was more effective in advancing the flower opening than the constant temperature regime of 25/25°C. Longer or shorter duration of dark treatment was less effective (Exps. 2 and 3).

About 40 years ago KAMO (1940) reported that flower opening was induced by transferring rice plants indoors where the light intensity is lower. In this experiment, flower opening was not accompanied by anther dehiscence, and hence all flowers were sterile. The same inability of anther dehiscence was observed during dark treatment in our experiments, but the flowers which opened after the treatments showed generally good dehiscence. Thus, light is important for anther dehiscence.

KAMO (1940) attributed the cause of the advancement to the change in light intensity and temperature. In our case, again, both

light and temperature affected the opening time. However, it was found that only the change in light intensity could advance the opening time at a constant temperature, though the percentage of flowers with earlier opening was lower following the application of different day-night temperature regimes (Figs. 2 and 3).

Two-hour advancement of flowering time is undoubtedly effective for rice plants in fields at high temperature to avoid the sterility. However, the 1-hour dark treatment does not look promising, because (1) some anthers do not dehisce in darkness, and (2) it is impractical in the field. KAMO (1940) reported that the rubbing of panicles with cloth advanced the flowering time. This method may not be practical in the fields either. We have made some experiments to seek the underlying mechanism of flower opening in rice plants, in expecting to be able to develop some other devices for controlling the opening time (Exps. 4 and 5).

Continuous light or continuous dim light disturbed the normal flower opening time (or circadian rhythm): 1. The peak of opening was lowered, the dispersion increased and flowers opened throughout a day; 2. The peak of opening was advanced or delayed a little; 3. The circadian rhythm was maintained much more regularly at temperatures which changed during the day than at a constant temperature. It is notable, however, that the circadian rhythm could be maintained for at least several days under continuous light or dim light (Tables 2 to 7). One-hour dark treatment modified it only temporarily. The circadian rhythm may be formed several days before heading.

Flower opening was markedly inhibited on the second day (and on the third day to a lesser extent) under continuous light (Tables 2 to 5) (In this case on the first day the plants were under normal conditions, whereas on the second day they were actually affected by continuous light). On the other hand, continuous dim light caused to a much lesser degree this inhibition (Tables 6 and 7). This observation suggests that light inhibits flower opening. The inhibition of flower opening by light

is supported also by the fact that 1-hour dark treatment advanced the opening time (the darkness might have removed light inhibition).

KAMO (1940) reported that normal flower opening time was well kept with comparatively large diurnal temperature changes under continuous light or even dark-day/light-night conditions, while with negligible temperature changes flower opening occurred evenly throughout the day under continuous light, and at night under dark-day/light-night conditions. These results are in agreement with our findings concerning the circadian rhythmicity. TOGARI et al. (1971) made a series of similar experiments and found that the indica variety, Tetep, was affected more by diurnal change in temperature, whereas the japonica variety, Fujisaka No. 5 was more affected by diurnal change in light.

All the data in our experiments indicate that flower opening time in rice plants is regulated by circadian rhythm which is caused by the diurnal changes of light and/or temperature and that it is modified by transitory changes in light or in temperature. However, we have not yet elucidated the underlying mechanism of the regulation, nor the measures required for the control of flower opening time.

Summary

A series of experiments were conducted to seek the probability of controlling flower opening time during the day in rice plants.

One-hour dark treatment before the natural flower opening clearly advanced the opening time (2 hours or more in some cases) (Figs. 2-4). This advancement was, however, accompanied by some anther indehiscence. The day-night change of temperature (29/21°C) was more effective in advancing the flower opening than the constant temperature (25/25°C). Longer (Fig. 5) or shorter duration of dark treatment was also effective but at a lesser extent.

Continuous light or continuous dim light disturbed the normal flower opening time (or circadian rhythm): 1. The peak of opening was lowered, the dispersion in-

creased and flowers opened throughout a day; 2. The peak of opening was advanced or delayed slightly; 3. The circadian rhythm was maintained much more regularly at the temperatures which changed during the day than at the constant temperature (Tables 2-7). The circadian rhythm was maintained for, at least, several days under the continuous light or dim light (Tables 2-7). Flower opening was markedly inhibited on the second day under the continuous light (Tables 2-5), while the continuous dim light caused to a much lesser degree this inhibition (Tables 6 and 7).

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〔和 文 摘 要〕

イネの開花時刻の人工制御

第1報 予備的実験

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イネの開花時刻を人工的に制御する目的で若干の予備的な実験をおこなった。

正常な開花時刻に先だつ1時間の暗黒処理はあきらかに開花時刻をはやめた(条件により2時間以上)(第2~4図)。しかし、この開花促進には若干の葯不裂開がともなっていた。昼夜変温条件(29/21°C)は恒温条件(25/25°C)よりも促進に有利であった。30分あるいは2時間以上の暗黒処理も促進効果があった(第5図)。

連続光あるいは連続微光条件はつぎのように開花時刻に影響した: 1. 開花のピークが低くなり、分散が増加して連続的に開花するようになった: 2. 開花時刻のピークが若干促進され、あるいは遅延した: 3. しかし日周リズムは部分的に維持され、ことに変温条件下で顕著であった(第2~7表)。この日周リズムはすくなくとも7日間維持された。開花は連続光の第2日目(ときには第3日目にも)につよく抑制された(第2~5表)。他方連続微光にはこの抑制がほとんどみられなかった(第6, 7表)。

以上の結果はイネの花の開花が、光および温度の日変化にもとづく日周性によって制御されていること、および光、温度の一時的変化は一時的にこの日周性を変化させうることをしめしている。しかし、この制御のメカニズムをあきらかにするにはいたらなかった。