PHOTOPERIODIC STUDIES ON RICE

I. The turning point between the short-day effect and the long-day effect in certain short-day varieties of rice

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Introduction

It has been recognized that there is a critical daylength for short-day plants. Floral bud differentiation is not supposed to take place when the day length exceeds a certain limit (Garner, 1933). However, results of experiments conducted in Taiwan with certain short-day rice varieties have indicated that the daylength-sensitive varieties grown as first crop did head even under long day conditions and in continuous light, although their heading dates were markedly delayed. Grown as a second crop, some varieties failed to head under long-day conditions, but flower primordia were invariably initiated. Hence it appears that a critical daylength does not exist in the short-day varieties of rice in Taiwan. From the results of different daylength treatments, the authors have been able to determine the turning point between the short-day and long-day effect. This report will deal with some studies on turning points in several short-day varieties of rice.

Materials and Methods

The rice varieties used in the present studies include three native varieties cultivated as second crop in Taiwan, Shuang-Chiang (霜降), Hsia-Chiao-Ko-Tze (下脚格仔) and Wan-Tze (蔓仔), all of which belong to the subspecies Indica, and two Japanese varieties, Iwata-Asahi (磐田朝日) and Shinriki (神力), both of which belong to the subspecies Japonica. These five varieties have been definitely proven to be short-day varieties by a number of preliminary tests.

According to natural circumstances and recovery of plant growth, daylength

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treatments were begun within 10 days of transplantation or seeding. Each treatment provided 8 hours of natural sunlight and additional hours of artificial light was provided by using 200 W tungsten lamps as supplementary light in the dark room when a photoperiod of more than 8 hours was required. The light intensity averaged 15.77±4.62 and 11.90±1.91 foot-candles to the apex and the base of the plants respectively. The pots were set on the railing-carts to facilitate movement out of the controlled daylength room at 8:00 a.m. and back into the room at 4 p.m. each day.

For each treatment, one or two pots with three plants each was used, hence each figure in the following tables represents the average of three to six plants.

The methods of culture followed the general cultural practices for rice in Taiwan. The site of the studies was Taipei, Taiwan.

Least significant difference was used as a criterion to determine the turning points between the short-day and long-day effect. Hartley's sequential method of testing (Snedecor, 1957) was also calculated lately for comparisons and discussion.

Results and Discussion

During the second crop season of 1950, two varieties, Shuang-Chiang and Hsia-Chiao-Ko-Tze, were placed under daylengths of 8, 12 and 16 hours. A control plot of each variety was placed outdoor as an indicator of the effects of natural daylength. The experimental results are shown in Table 1.

Table 1. The number of days (average of six plants each) required from the beginning of treatment until heading for two short-day varieties of rice under different daylength during the second crop season, 1950.

Seeding	July 27
Transplantation	Aug. 7
Beginning of Treatment	Aug. 14

Variety \ Daylength (hrs.)	8	12	16	Control
Shuang-Chiang	27	30	>94	51
Hsia-Chiao-Ko-Tze	27	29	>94	52

L. S. D. $_{0.05}$ between photoperiods = 3.183
L. S. D. $_{0.01}$ between photoperiods = 5.841

The results presented in Table 1 indicate that photoperiods up to and including 12 hours were effective as short day in these two varieties. When the light period was extended to 16 hours, the heading of both varieties was markedly delayed.

The natural daylength of the second crop season in Taipei has a gradual change (Yü and Yao, 1957) starting from July 20 to December 31, and the light-period shortens from 13:32 hours to 10:36 hours day by day. The days from the beginning of treatment to heading of control pots, therefore, were apparently influenced by the natural daylength and intermediate between 12-hour's and 16-hour's.

As judged by least significant differences, the turning point between the short-day and long-day effects is somewhere between 12 and 16 hours.

Since the interval between photoperiods of 12 and 16 hours appeared to be too wide to allow an accurate determination of the turning point, the same experiment was repeated during the first crop season of 1951, using smaller intervals between photoperiods. The results obtained are presented in Table 2.

Table 2. The Number of days (average of six plants each) required from the beginning of treatment until heading of two short-day varieties of rice under different photoperiods during the first crop season, 1951.

Seeding	Mar. 27
Transplantation	Apr. 21
Beginning of Treatment	May. 1

Variety \ Daylength (hrs.)	8	12	13	14	15	16	Control
Shuang-Chiang	33	34	54	>90	>90	>90	>90
Hsia-Chiao-Ko-Tze	32	33	52	>90	>90	>90	>90

L. S. D. $_{0.05}$ between photoperiods= 1.324
L. S. D. $_{0.01}$ between photoperiods= 2.006

Table 2 shows that the same varieties again demonstrated a short-day effect under light periods of up to 12 hours for the first crop season of 1951. The heading dates were markedly delayed when the photoperiod was 13 hours. Heading time is even more delayed under light periods of 14 hours and longer. Judging by the least significant differences, the turning point between the short-day and long-day effect for the two varieties falls between 12 and 13 hours. As there is a gradual change from short-day to long-day conditions during the first crop season at Taipei, these two varieties demonstrated the long-day effect under natural conditions.

During the first crop season of 1954, the authors renewed the study of this problem, since the responses to daylength of the varieties Shuang-Chiang and Hsia-Chiao-Ko-Tze were rather similar, only one of them, Shuang-Chiang was used while two short-day Japanese varieties Iwata-Asahi and Shinriki were included for the first time. The experimental design and the results obtained are shown in Table 3 and Figure 1.

Table 3. The number of days (average of three plants each) required from the beginning of treatment until heading for three short-day varieties of rice under different photoperiods during the first crop season, 1954.

Seeding	Feb. 15
Transplantation	Mar. 20
Beginning of treatment	Mar. 26

Variety \ Daylength (hrs.)	8.0	12.0	12.5	13.0	13.5	14.0	Control	Mean squares for: Treatment means	Mean squares for: Individuals	F Value	D
Iwata-Asahi	48.3	49.0	54.0	57.0	70.3	84.0	61.3	579.94	2.19	264.96**	1.19
Shinriki	45.7	48.0	55.0	59.7	76.0	89.0	63.3	766.18	9.11	84.10**	2.49
Shuang-Chiang	53.7	57.0	81.5	77.0	104.0	147.0	137.0	3540.90	253.20	13.98**	12.94

L. S. D. $_{0.05}$ between photoperiods = 7.991
L. S. D. $_{0.01}$ between photoperiods = 10.718

** Significant at 1% level.

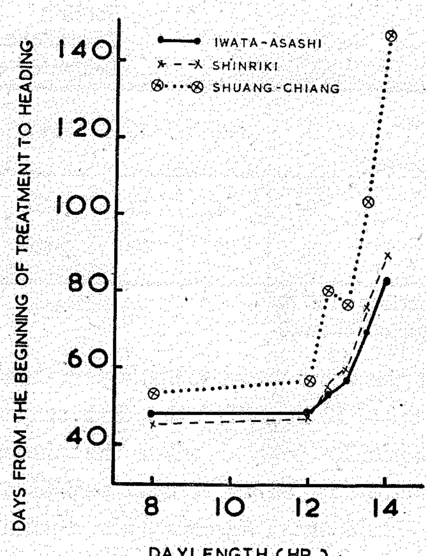

Fig. 1. The number of days required from the beginning of treatment until heading for three short-day varieties of rice under different photoperiods during the first crop season, 1954.

The data presented in Table 3 and Figure 1 show that photoperiods of 12 hours and shorter act as short-days in all three varieties. A photoperiod of 12.5 hours slightly delayed the heading of the two Japanese varieties in comparison with a 12-hour photoperiod, but the heading time of Shuang-Chiang, a native variety of Taiwan, was considerably delayed in a 12.5 hours photoperiod. As judged by the L. S. D. $_{0.05}$ and the L. S. D. $_{0.01}$, a 12.5 hours photoperiod is a short-day for the two Japanese varieties while it is a long-day for Shuang-Chiang. In other words the turning point between the short-day and long-day effect for Shuang-Chiang is between 12 and 12.5 hours. The two Japanese varieties headed slightly later under a 13-hour than under a 12.5-hour photoperiod but the difference is not significant. If the results obtained with photoperiods of 12 and 13 hours are compared directly, then the difference for variety Iwata-Asahi just exceeds the 5% level, while that for variety Shinriki exceeds the 1% level. Therefore, the turning point between the short-day and long-day effect for the Japanese varieties can be considered to lie between 12 and 13 hours.

It can be concluded from F and D values, excluding the results of natural daylength as shown in Table 3, that the turning point between short-day and long-day effect is between the light-periods of 12- and 12.5-hour for all three varieties. Apparently the testing hypothesis by computing a difference, D, which is significant at 5% level, is more powerful than the use of least significant difference.

Photoperiods of 13 hours and longer very markedly delay the heading of all three varieties.

During the second crop season of 1954, one more Taiwanese short-day variety, Wan-Tze, was included in the experiment along with the three varieties used during the first crop season. Direct seeding was used instead of transplanting to eliminate any possible effect of transplantation. Two photoperiods, 16 hours and continuous light, were added to the treatments. The experimental results are shown in Table 4.

Table 4. The number of days (average of three plants each) required from the beginning of treatment until heading of four short-day varieties of rice under different daylengths during the second crop season, 1954.

Seeding July. 22
Beginning of treatment Aug. 11

Variety \ Daylength (hrs.)	8.0	12.0	12.5	13.0	13.5	14.0	16.0	24.0	Control	Mean squares for: Treatment means	Mean squares for: Individuals	F Value	D
Iwata-Asahi	37.3	32.5	35.3	47.7	60.7	80.7	90.0	124.7	39.7	3,177.14	29.48	107.79**	3.08
Shinriki	34.7	29.7	36.7	47.0	72.3	90.5	*	*	42.0	1,997.50	7.93	251.89**	1.91
Shuang-Chiang	25.7	25.7	31.7	53.7	93.7	123.7	*	*	56.7	17,647.08	24.98	707.01**	3.36
Wan-Tze	25.5	24.7	38.7	113.3	*	*	*	*	77.0	5,152.30	94.08	54.76**	13.22

* Did not head until December 16, 1954, but the flower bud was differentiated.
** Significant at 1% level.
L. S. D. $_{0.05}$ between photoperiods = 8.465
L. S. D. $_{0.01}$ between photoperiods = 11.243

The results have been presented in graphical form in Figure. 2.

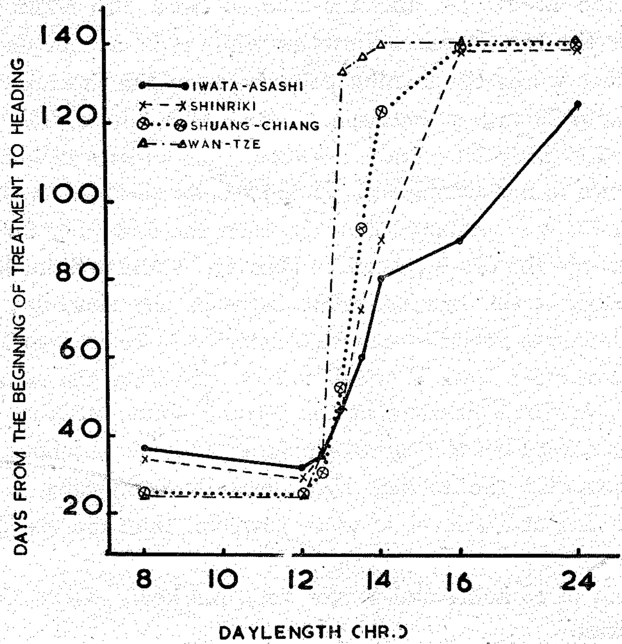

Fig. 2. The number of days required from the beginning of treatment until the heading of four short-day varieties of rice under different day-lengths during the second crop season, 1954.

The least significant difference for the testing of difference between treatment means obtained in the results of second crop, 1954, is 8.465 at 5% level or 11.243 at 1% level. Using these values as criteria, the turning point between the short-day and long-day effect for the three varieties, Iwata-Asahi, Shinriki and Shuang-Chiang, is found between 12.5 and 13 hours and the variety Wan-Tze lies between the light-periods of 12 and 12.5 hours.

Snedcor's F and D values have also been presented in Table 4. The results for natural day-length were again excluded from the calculations.

Based on these calculations, the turning point for variety Iwata-Asahi should be between 12.5 and 13 hours, while that for the other three varieties should be between 12 and 12.5 hours.

Using photoperiods longer than 13 hours, it was found that the longer the photoperiod, the more significant was the delay of the heading dates of all four varieties. Variety Wan-Tze did not head when the photoperiod was 13.5 hours or longer. A 16-hour photoperiod or continuous light prevented the heading of varieties Shinriki and Shuang-Chiang. Nevertheless, when the growing points of the three varieties which failed to head were examined, they were invariably found to have formed flower primordia. Among the three varieties the degree of differentiation was most advanced in variety Shinriki, in which differentiation had progressed as far as a complete ear. Differentiation was less advanced in variety Shuang-Chiang and least advanced in variety Wan-Tze. Thus, the failure of the three varieties to head during the second crop season may be attributed to the initial delay in the differentiation of flower primordia under long-day conditions and the subsequent low temperatures which prevented the further development of the inflorescence. In Eguti's (1937) words, "the ear emergence" of these varieties is suppressed in long-day conditions, but "the differentiation of flower primordia" is not completely inhibited. Cho (1930) has reported a similar phenomenon in short-day varieties of rice grown under long-day conditions.

On the basis of the number of days required from the beginning of treatment until heading under a 13.5-hour photoperiod during the first and second crop seasons of 1954 and the degree of differentiation of the apex of those varieties which failed to head, the four varieties can be arranged in the following order of decreasing sensitivity to long-day conditions (Photoperiods of 12.5 hours and longer): Wan-Tze is most sensitive, followed by Shuang-Chuang, Shinriki, and Iwata-Asashi in that order.

Supposedly the different response of the foregoing varieties to photoperiods longer than the daylength which constitutes the turning point may be attributed to genetic differences. There may be much variation in degree of sensitivity among rice varieties.

Two reports by Japanese workers dealt with similar studies, but neither one discussed the turning point. By exposing five varieties belonging to different Japanese geo-ecological districts to daylengths of 7, 9, 11, 12, 13, 14, 15 and 17 hours and natural day-length, Miyabayashi (1944) found that variety Bozu was day neutral, and that the optimal photoperiod of variety Kuhei No. 2 was 9 to 12 hours, while that of the varieties Ginbozu, Shinriki, and Kyushu No. 8 was 9 hours. According to the authors' calculation, the turning point for the variety Kuhei No. 2 is between 12 and 13 hours while that for the other three varieties is between 9 and 11 hours. Miyabayashi stated that for all varieties, with the exception of the day-neutral ones, the vegetative growth period was shortest when the photoperiod was optimal but that the vegetative growth period would gradually increase in length when the photoperiod is somewhat longer than the optimal one, and that the vegetative period would be greatly prolonged when that duration of the photoperiod exceeded a certain limit.

Morinaga and Kuriyama (1954) treated 20 varieties from different regions of Asia with photoperiods of 10.5, 11.5 and 12.5 hours. Their results are summarized in Table 5.

Table 5. The effect of photoperiod on the duration of the vegetative growth period of a number of different rice varieties (After Morinaga 1954).

Variety	Native place of the variety	Vegetative growth period in days under different photoperiod (hrs.)		
		10.5	11.5	12.5
Emata Yin A 31-32	Burma	52	51	84
Myac 104	Burma	73	78	148
Heenati	Ceylon	82	80	84
Kokumawi B-11	Ceylon	78	94	—
Fukoku	Japan	46	43	45
Norin No. 29	Japan	55	52	55
Norin No. 18	Japan	61	58	61
Ptb 16	India	83	118	—
T-100	India	54	58	83
GEB 24	India	57	75	144
Gendjah Ratgi	Indonesia	140	139	141
Baok	Indonesia	133	138	164
Brondol Putih 277	Indonesia	156	163	182
Tjina	Indonesia	106	122	144
Skrimankoti	Indonesia	75	77	114
Acheh Puteh	Malaya	116	130	149
Siam 29	Malaya	80	104	—
Ravang	Vietnam	83	107	—
Samo	Vietnam	61	73	108
Patnai	Pakistan	71	74	110

According to the authors' judgement, the turning point is between 10.5 and 11.5 hours for varieties Kokumawi B-11, Ptb 16, GEB 24, Tjina, Acheh Puteh, Siam 29, Ravang and Samo. The turning point is between 11.5 and 12.5 hours for varieties Emata Yin A31-32, Myac 104, T-100, Baok, Brondol Putih 277, Skrimankoti and Patnai, while for the other varieties, the turning point is over 12.5 hours or the varieties are day-neutral.

It seems that the turning points found by the Japanese workers have a tendency to be shorter than those obtained by the authors in Taiwan. The cause of such discrepancies has to be the subject of further studies.

Summary

1. In Taiwan, the vegetative growth period of short-day rice varieties planted under long-day condition during the first crop season was markedly prolonged, but all varieties flowered. When the same varieties were planted under long-day conditions during the second crop season, some failed to head,

but flower primordia were invariably differentiated. The authors concluded, therefore, that the short-day rice varieties cultivatied in Taiwan do not possess a critical day length, but that there is a turning point between the short-day and long-day effects.

2. The turning points determined for the varieties used in the experiments have been summarized as follows:

Variety	Daylength (hrs.)	
	First crop	Second crop
Shuang-Chiang	12.0–12.5	12.0–12.5
Hsia-Chiao-Ko-Tze	12.0–13.0	—
Wan-Tze	—	12.0–12.5
Shinriki	12.0–12.5	12.0–12.5
Iwata-Asahi	12.0–12.5	12.5–13.0

3. The experimental results obtained by the Japanese workers on short-day varieties from different regions of Japan and other parts of Asia have furnished turning points which in terms of photoperiod are generally shorter than those found by the authors in experiments conducted in Taiwan.

Acknowledgement

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Literature Cited

CHO, S. On the influence of day length and light intensity caused by obstruction and night illumination upon the growth of rice plants (1). (In Japanese). *Agr. & Hort.* 5: 1059–1066, 1930.

EGUCHI, T. On the effect of daylength before and after flower bud initiation (in Japanese). *Jour. Hort. Soc.* 8: 1–71, 1937.

GARNER, W. W. Comparative responses of long-day and short-day plants to relative length of day and night. *Plant Physiol.* 8: 347–356, 1933.

MIYABAYASHI, T. Earliness and lateness of rice varieties and their optimum and critical daylength (in Japanese). *Proc. Crop. Sci. Soc. Jap.* 15: 194–196, 1944.

MORINAGA, T. and H. KURIYAMA. Some experiments on the photoperiodism in rice. *Studies on Rice Breeding* (A separate volume of the *Jap. Jour. Breeding* 4): 35–63, 1954.

SNEDECOR, G. W. Statistical Methods, pp. 251–253, 1957.

YÜ, C. J. and Y. T. YAO. Ueber die Vererbung der Ausschusszeiten beim Reis. *Jap. Jour. Genet.* 32: 179–188, 1957.

水稻光週性的研究

I. 若干短日性水稻品種之短日效果與長日效果的轉捩點

于景讓　姚潤德

據 Garner 的報告 (1933)，凡對於日長 (Daylength) 有反應的植物，皆有一限界日長 (Critical daylength)。例如短日性植物 (Short day plant)，在日長超過一定長度的狀態下，即不能開花結實。惟作者等在臺灣第一季栽培水稻的季節中以短日性水稻品種置長日狀態下，見在 24 小時的長日狀態下，其抽穗雖極度延遲，而皆能抽穗。在第二季中，短日性水稻品種在長日狀態下，有一部分不抽穗，而其生長點已明白分化。故作者等以爲短日性水稻品種在臺灣，無 Garner 所說的嚴格的"限界日長"而祇有顯示短日效果與長日效果的轉捩點。

作者等在本文中指出霜降、下脚格仔、蔓仔等三臺灣土種與磐田朝日、神力等二日本品種的該一轉捩點，不問是在第一季或第二季，皆在 12 小時日長與 13 小時日長之間。

作者等又指出一部分日本人所作的結果，其轉捩點似是在 12 小時日長之前，故以爲需要擴大實驗範圍，對於這一點加以澄清。

作者等在比較各處理區的差別時，是並用 Least Significant Difference 和 Hartley's Sequential Method，應用結果，見後者是較前者爲敏銳。