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Photoperiodism in the Genus *Oryza*

VII. Accumulation effect (1)

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Photoperiod influences several aspects of plant growth. Some of its effects on rice have been reviewed by VERGARA *et al.*[6] Several factors have been accounted for different photoperiodic sensitivity of various rice strains, among which the aging effect, dosage effect and others were already considered[2,3].

Accumulation effect in rice plant have been reported using strains of *O. sativa*, cultivated species[4,5]. However, such investigations have been limited to only *O. sativa*. The author's aim of this investigation was consistently to study photoperiodism of cultivated and wild species and its variation among them in the hope to get useful information on phylogenetic differentiation of the genus. In addition, the emphasis has been put on the analysis of photoperiodic responses and its evolutional processes in rice. Then, in order to clarify the accumulation effect produced by short day condition, the present experiment was conducted using 24 strains belong to 5 species in the genus *Oryza*.

Materials and Methods

Twenty four strains belonging to 5 species of the genus *Oryza* were used in the present investigation, among which 17 strains belong to *O. sativa* (1 of Japan, 1 of India, 5 of North Borneo, 8 of Brunei, 2 of Sarawak), 1 to *O. glaberrima* (Sierra Leone), 1 to *O. sativa* var. *spontanea* (India), 1 to *O. perennis* (India) and 4 to *O. officinalis* (1 of Brunei, 2 of Sarawak, 1 of Java). Most of them are distributing relatively in low latitudinal areas. Procedures of cultivation and detection of heading date were the same with those mentioned in the previous paper[3].

Sowing was done on June 17. Plants were exposed to natural day length until the start of short day treatment, during the interruption by long day condition and after the treatment. At the beginning of the treatment, they were 45 days old counted from the date of sowing. Plants were divided into 8 plots, 3 plants in each, and 1 plot was exposed to natural day length as control. Plants in the other 7 plots were subjected to the short day condition, 12.5 hours light and 11.5 hours dark cycles. Design of an experiment for studying accumulation effect was shown in Fig. 1. Number of short day treatment given to the 7 plots were 20 (=5 days ×4 terms) for II, III, IV and V plots, 25 (=5×5) for VI and VII plots, and 35 (=5×7) for I plot. Number of interruption inserted between short day conditions were 5 (III and VI plots), 10 (IV and VII plots) and 15 (V plot). Suitable temperature (25° to 30°C) in greenhouse was provided for the growth of plants.

Results and Discussion

1. As shown in Table 1, 24 strains used can be classified into 8 groups based on the patterns of accumulation effects. Group number are arranged in the order of values, which was illustrated by the efficiencies from those of respective control plot. In each group, strains are arranged in order of strain number and species order. Four strains responded steady during the whole treated plots (Group 1), while 2 strains did not respond in plot V (Group 2), 2 strains in plots IV and V (Group 3), 3 strains in plots III, IV and V (Group 4), 8 strains in plots III, IV, V and VII (Group 5), 2 strains in plots II, III, IV and V (Group 6), 2 strains in plots II, III, IV, V and VII

(Group 7), 1 strain in plots II, III, IV, V, VI and VII (Group 8), respectively. No strain required more than continuous 35 days treatment (plot I). This results indicated that the accumulation effects are significantly different among various species and strains, and that this phenomenon can be used as an index of photoperiodic sensitivity. Theoretically, 2 groups other than 8 groups mentioned above will be found, *i.e.*, one group in which plant does not head in plots IV, V and VII, and another in which plant does not respond in plots III, IV, V, VI and VII. It is not clear whether those groups could be found or not if the materials are used more than 24 strains, or those groups do not essentially exist in the genus *Oryza*.

Group 1 means that any insertion of long day condition between two series of short day conditions seems to be nonsense for eliminating the effect produced by the first 10 short day cycles, *i.e.*, accumulation effect was gotten in the whole plots (II∼VII). Group 2 means that 5 and 10 days insertions seems to be nonsense, but 15 days insertion seems to be enough to eliminate completely the latent potentiality to floral induction produced by the first short day cycle (10 days), and those plant headed at nearly the same time with natural flowering. Group 3 means that 5 days insertion seems to be nonsense, but more than 10 days insertion seems to be enough to eliminate

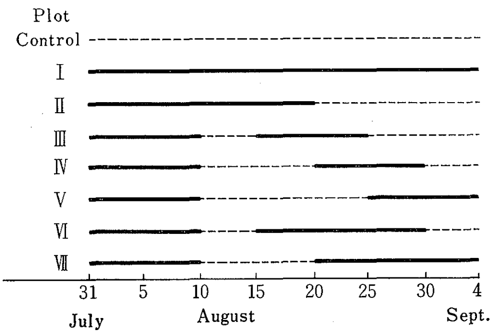

Fig. 1. Design of an experiment for studying accumulation effect. Solid and dotted lines indicate the periods during which a plant was subjected to the short day condition (12^h30^m l + 11^h30^m d) and natural day length, respectively.

completely the potentiality. Group 4 means that 5 days insertion seems to be enough to eliminate completely the potentiality. In addition to the effects found in group 4, plants in group 5 means that 15 additional short day cycles after 10 days insertion were of no use in inducing floral development, even though the experimental plants received the total of 25 short day cycles, which usually led to normal flowering eventually (presumed from the data in plot II). Groups 6, 7 and 8 means that 20 short day cycles seems to be insufficient for floral induction, even though the treatment were given continuously. In group 6, it was clear that 15 short day cycles after 10 days insertion can compensate the efficiency for floral induction, in comparison with the data obtained in plots IV and VII.

In comparison with the data obtained in the plots II, III, IV, V, in which the plants were subjected to the 20 day cycles in the total, the followings may be mentioned. In general, the smaller was the insertion, the larger was the efficiency of accumulation effect.

In comparison with the data obtained in the plots II, III, IV, V and in another plots VI and VII, in which the plants were subjected to the 20 (the former) and 25 (the latter) short day cycles in the total, respectively, the followings were ascertained. The eliminating effect by 5 days insertion was held in groups 4, 5, 6, 7 and 8, even though the plants were subjected to 10 post-short day cycles; these effects were recovered by 15 days post-short day cycles in groups 4, 5, 6 and 7, but not in group 8. The eliminating effect by 10 days insertion was held in groups 3, 4, 5, 6, 7 and 8, even though the plants were subjected to 10 days post-short day cycles; these effects were recovered by 15 days post-short day cycles in groups 3, 4 and 6. Continuous 20 short day cycles was superior to discontinuous 25 short day cycles for the accumulation effect in view of the values compared with the respective control plot. In some cases, however, the former was inferior to the latter (groups 6 and 7 in plot VI and group 6 in plot VII), in which the effect was eliminat-

Table 1. Heading dates of 45 days old plants of 24 strains treated under different periods of short day treatments; heading dates of treated plants are expressed by the difference (in days) from those of respective control plot, and heading dates of control plots are expressed by the growing period (from sowing to heading).

Plot	Strain											
	KA	124	W0106	W0120	C7695	W1289	C8461	C8463	C8464	C8465	C8470	C8475
Control	92.3	123.3	139.0	135.0	140.0	137.7	152.3	127.7	134.3	124.3	122.0	118.3
I	20.7	39.3	26.3	18.0	20.3	19.0	30.0	18.0	27.3	24.3	19.7	21.3
II	21.0	39.0	22.0	18.0	20.0	17.3	29.7	16.3	27.0	24.3	18.3	19.7
III	20.3	29.7	11.3	12.0	17.7	15.0	25.0	15.7	2.0	2.0	1.3	2.3
IV	20.3	21.3	8.7	10.7	8.3	9.3	2.0	1.7	1.7	1.7	0.7	1.7
V	16.7	21.7	5.3	5.3	1.0	0.3	0.7	1.0	0.3	0.7	0.3	1.7
VI	22.0	27.0	21.0	11.3	17.7	16.0	25.0	16.3	27.0	18.0	18.0	19.0
VII	17.3	21.7	19.7	11.0	15.0	14.7	19.3	14.0	19.7	17.3	14.7	2.0
5 % l.s.d.	1.9	2.4	3.5	2.9	2.0	1.7	2.4	2.6	2.4	1.9	2.3	2.5
Group	1	1	1	1	2	2	3	3	4	4	4	5

Plot	Strain											
	C8481	C8491	C8492	C8495	C8500	C8505	C8510	C8515	C8516	W1269	W1282	W1280
Control	117.3	121.7	110.0	117.0	115.7	114.7	156.7	147.3	145.0	165.0	155.3	156.7
I	22.7	22.7	21.3	22.0	27.3	20.3	27.7	26.7	26.0	27.7	25.0	32.8
II	19.0	21.0	17.5	21.7	19.0	20.0	25.0	1.3	2.0	1.7	2.0	1.0
III	1.7	2.0	1.0	2.3	2.3	1.7	1.7	1.3	2.0	1.7	2.0	0.0
IV	1.7	1.7	0.7	1.7	2.0	0.7	1.7	1.3	2.0	1.7	2.0	0.0
V	0.3	0.7	0.7	1.3	2.0	0.3	1.7	0.7	1.3	0.3	0.3	0.0
VI	19.0	18.7	12.3	14.7	15.0	20.0	23.7	26.0	24.3	24.0	24.7	0.3
VII	1.7	2.0	1.0	2.0	2.0	1.7	1.7	24.7	20.7	1.7	2.0	0.0
5 % l.s.d.	1.9	2.2	1.7	3.1	2.5	2.1	1.9	1.7	2.1	2.0	2.8	1.6
Group	5	5	5	5	5	5	5	6	6	7	7	8

ed in the former but not in the latter.

Post-15 short day cycles after 5 days insertion was superior to post-10 short day cycles after 10 days insertion. Accumulation effects expected in plot V were almost inferior to that of plot VI. Accumulation effects expected in plot V were almost the same to that of the plot VII (groups 5, 7 and 8), and inferior to that of the latter (groups 2, 3, 4 and 6). Accumulation effect expected in plot VI were almost the same with that of the plot VII (groups 1, 2, 3, 4 and 6), and superior to that of the latter (groups 5 and 7). The latter case means that post-15 short day cycles can supply the eliminating effect after 5 days insertion, but not supply the eliminating effect after 10 days insertion.

2. Since in this experiment, the number of strains available were rather limited, 24 strains, any precise conclusion may not be drawn in regard to the geographical distributions. However, the followings may be mentioned. In *O. sativa,* strains of Japan and India belong to group 1, strains of North Borneo (4°-7°N) belong to groups 3 and 4, strains of Brunei (5°N) to group 5, and strains of Sarawak (2°–5°N) to group 6, respectively, strain of *O. glaberrima* (8°N) belongs to group 2. Strains of *O. sativa* var. *spontanea* and *O. perennis* (20°N) belong to group 1. In *O. officinalis,* strain of Java (7°S) belongs to group 2, strain of Brunei (5°N) and one of Sarawak (4°N) belong to group 7, and one strain of Sarawak (3°N) belongs to group 8, respectively. In comparison with the data obtained in the strains of *O. sativa* and *O. officinalis* distributing in Brunei and Sarawak, it may be said that the accumulation effect shown by strains of *O. sativa* were clearly larger than that of *O. officinalis* in the same latitude. In the previous paper[2], it was found that *O. officinalis* has extremely many insensitive strains. Consequently, it may be possible that C genome, which constitutes *O. officinalis*, lackes several factors responsible for photoperiodic sensitivity, not only in aging or accelerating effect but also in accumulation effect. On the other hand, strain of Java showed significant accumulation effect. Then in general, strains distributing in relatively high latitude showed significant accumulation effect among the all treated plots. On the contrary, strains distributing in relatively low latitude showed rare accumulation effect from plot to plot.

3. It is supposed that stimulus produced by repeated treatment is cumulative and floral induction can take place when it has reached to a certain threshold value[2]. Basing on the data shown in Table 1, the grades and largeness of the values of accumulation effect should be discussed. The differences of growing periods from those of the respective control plot were converted using the 5% l.s.d. For example, the converted values of strain W0106 in plots I, II, III, IV, V, VI and VII, were 7.5, 6.3, 3.2, 2.5, 1.5, 6.0 and 5.6, respectively. These values are the quotients of 26.3/3.5, 22.0/3.5, 11.3/3.5, 8.7/3.5, 5.3/3.5, 21.0/3.5 and 19.7/3.5, respectively. Values obtained by this method were plotted out in graph and compared from one another within and between groups. Several patterns were found in 24 strains used. For example, strain KA showed gradual changes from plot to plot. On the other hand, strain W0106 showed the gradual changes between plots I and II, VI and VII, but showed drastic changes between plots II and III. These problems have not been fully studied only in the present experiment, and remained to be investigated by the detailed experiment using as many materials and treated plots as possible. It was confirmed that the patterns shown by this method were significantly different among various strains and species, and that patterns can be used as an index of accumulation effect, *i.e.*, photoperiodic sensitivity.

4. Kondo *et al.*[4] had reported that continuous 8 hours short day cycles are more effective for accumulating effect than discontinuous 8 hours short day cycles. If the plants were subjected to alternately 8 hours short day and natural day conditions, the heading was accelerated and heading date was found intermediately between that of continuous 8 hours short day condition and continuous natural condition. This result means that stimulus of short day condition are remarkably accumulated. Although the design of present experiment was different from that of Kondo *et al.*, nearly the same results could be compared between plots II and IV in this experiment. In the present experiment, nearly the same accumulation effect was found only in strain KA, but the efficiencies produced by continuous short day cycles (plot II) are generally superior to that of plot IV. Then, in this strain, insertion of long day condition did not show complete elimination of effect produced by pre-short day treatment.

Using a variety that requires 10 photoinductive cycles to induce floral development, Noguchi *et al.*[5] interposed a long day in the middle of the 10 photoinductive cycles. No flowering occurred. They found that for the Zuihô variety, more than 16 hours of photoperiod eliminated the latent potentiality to floral induction previously produced by the 5 photoinductive cycles, and less than 14 hours day length had hardly any effect on elimination. In the present experiment, the accumulation effect were found in many strains, and this fact may be suited to the latter case of Noguchi *et al.*' experiment (the day length is 13^h42^m on July 31 in the present experiment).

It is generally believed that day length causes no variation in the development of flower buds in rice varieties[1]. The results obtained in the present experiment, however, in some strains, showed otherwise, namely that insertion of long day condition affected slightly the flower bud development. In these points, further experiment would be required using many strains and experimental plots.

Summary

In order to investigate photoperiodic sensitivity of rice strains and species and its changes according to a insertion of long day conditions during short day condition, an experiment was done using 24 strains. They belong to 5 species of the genus *Oryza,* including 2 cultivated and 3 wild species, in which the most of them were distributing relatively in low latitudinal areas. The results obtained are summarized as follows:

1) Accumulation effect of floral induction were tested by using natural day length and 7 plots, in which the plants were subjected to short day condition, 12.5 hours light and 11.5 hours dark, having several combinations short day and long day insertions. They can be classified into 8 groups in regard to the behaviour found in the accumulation effect.

2) Generally, strains distributing in relatively high latitude showed significant accumulation effect among the all plots treated. On the contrary, strains distributing in relatively low latitude showed rare accumulation effect.

3) It was confirmed that the patterns shown by this method were significantly different among various strains and species, and that the patterns can be used as an index of accumulation effect, *i.e.,* photoperiodic sensitivity, in the genus *Oryza.*

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〔和 文 摘 要〕

稲 属 の 感 光 性

第7報 累 積 効 果（1）

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短日処理回数とその累積効果及びその種間と種内変異を調査する目的で，低緯度地方に分布する材料を主として稲属5種24系統を用いて実験を行った．45日令に達した時，自然日長区及び短日処理7区合計8区を設け，短日条件として12時間30分明期を用いた．その期間中に種々の程度に自然日長条件を挿入して短日条件の効果とその累積効果を調査した．

全系統は累積効果の程度に応じて8群に分類された．一般に高緯度地方に分布する系統では短日条件の効果は累積し易く，低緯度地方に分布する系統ではその累積効果が少ない傾向が見い出された．

この様な方法で示された結果は，種や系統によって著しく異なる事実から，短日処理の累積効果，換言すればこれらの因子は感光性を表示する方法として有効である事が分かった．