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Photoperiodism in the Genus *Oryza*

VIII. Accumulation effect (2)

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Photoperiod influences several aspects of plant growth. Some factors have been accounted for different photoperiodic sensitivity of rice species and strains, among which the aging effect, dosage effect, critical day length and others were already considered[1,2].

On an accumulation effect, it had been reported that continuous 8 hours short day cycles are more effective for accumulation effect than discontinuous 8 hours short day cycles[4], and some variety shows also accumulation effect[6]. Light interruption during the dark period (=light break) had been reported[5,7]. However, such investigations have been limited to only a few strains and to *O. sativa*, cultivated species. The author's aim of this investigation was consistently to study photoperiodism of cultivated and wild species in hope to get useful information on phylogenetic differentiation and to get universal validity of the genus. Then, succeeding to the previous paper[3], in order to clarify the accumulation effect produced by short day condition, the present experiment was conducted using different designs in several points from the previous experiment[3].

Materials and Methods

Twenty strains belonging to 5 species of the genus *Oryza* were used in the present investigation, among which 4 strains belong to *O. sativa* (1 of Japan, 2 of India, 1 of Sarawak), 4 to *O. glaberrima* (Sierra Leone), 5 to *O. sativa* var. *spontanea* (1 of India, 2 of Burma, 1 of Malaya, 1 of New Guinea), 5 to *O. perennis* (2 of India, 1 of Philippines, 1 of Kalimantan, 1 of Brazil) and 2 to *O. officinalis* (1 of Brunei, 1 of Sarawak). Procedures of cultivation and detection of heading date were the same with those mentioned in the previous paper[2].

Sowing was done on May 2. 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, the plants were 80 and 85 days old counted from the date of sowing. Plants were divided into 21 plots, 3 plants in each, and 1 plot was exposed to natural day length as control. Plants in the other 20 plots were subjected to the short day conditions, 12.5 hours light and 11.5 hours dark cycles. Design of an experiment for studying accumulation effect was shown in Fig. 1. Suitable temperature (25° to 30°C) in greenhouse was provided for the growth of plants.

In the present experiment, the following points differed from the previous experiment[3] for magnifying the examination on the response; a few strains distributing in relatively high latitude were used in addition to those distributing in low latitudinal areas (mainly low latitude strains in the previous one); number of plots was 21 (8 in the previous one); at the beginning of the treatment, the plants were 80 and 85 days old counted from the date of sowing (45 days old in the previous one).

Results and Discussion

1. As shown in Table 1, 20 strains used can be classified into 11 groups based on the patterns of accumulation effects. Group number are arranged in the order of efficiencies, which was illustrated by the values from those of respective control plot. In each group, strains are arranged in the order of species and strain number. Four strains responded steady during the whole treated plots (Group 1), while 3 strains did not respond in plot X (Group 2), 1 strain in plots IV, VIII and X (Group 3), 2 strains in plots III, IV, VIII and X (Group 4), respectively. Two strains responded in plots V, VI, IX, XII, XIII, XV, XVII, XIX and XX (Group 5), while 1 strain in plots VI, XII, XIII, XVII, XIX and XX (Group 6), 1 strain in plots VI, XII, XIII, XV, XIX and XX (Group 7), 2 strains in plots VI, XII, XIII, XIX and XX (Group 8), 1 strain in plots VI, XIII, XIX and XX (Group 9), 2 strains in plots VI and XIII (Group 10), respectively. One strain did not respond in the whole plots treated (Group 11). This results indicated that accumulation effects are significantly different among various species and strains, and that this phenomenon can be used as an index of photoperiodic sensitivity. Theoretically, 10 groups other than 11 groups mentioned above will be found, *e.g.*, one group in which plant responds in plots VI, XII, XIII, XV, XVII, XIX and XX. It is not clear whether such groups could be found or not if the materials are used more than 21 strains, whether or not such groups do not essentially exist in the genus *Oryza*.

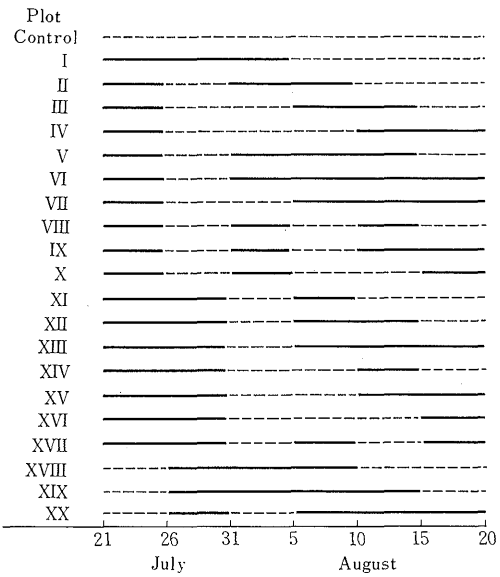

Fig. 1. Design of an experiment for studying accumulation effect. Solid and dotted lines indicate the periods during which a plant was subjected to the short day condition ($12^h30^m l+11^h30^m d$) and natural day length, respectively.

2. Group 1 means that any insertion of long day condition between two or three series of short day conditions seems to be nonsence for eliminating the effect produced by the first or the second 5 to 10 day cycles; *i.e.*, accumulation effect was gotten in the whole plots treated. In the Group 2, insertion of long day cycles after the second short day cycles seems to be enough to eliminate completely the latent potentiality to floral induction produced by the first and the second short day cycles (10 cycles in the total), and those plant headed at nearly the same time with natural flowering. In comparison with the data obtained in plots IV and X, it was clear that continuous 10 short day cycles was superior to discontinuous ones. Group 3 means that 15 days insertions after the first 5 short day cycles and 10 days insertions before and after the second short day cycles seems to be enough to eliminate completely the potentiality. In comparison with the data obtained in plots III and IV, and VIII and IX, it was clear that 10 short day cycles after 10 days insertion can compensate the efficiency, but not after 15 days insertion, and 10 short day cycles after the second 5 days insertion can compensate the efficiency, but 5 short day cycles can not compensate it, respectively. Group 4 means that 10 additional short day cycles after 10 days insertion were of no use in inducing floral development. In comparison with the data obtained in plots II and III, it was clear that 10 short day cycles after 5 days insertion can compensate the efficiency, but not after 10 days insertion. Group 5 means that 15 short day cycles in the total were of no use in inducing floral development, and 15 short day cycles after 10 days insertion seems to be not enough. In other words, any plots, in which the plants were subjected to the 15 short day cycles in the total, could not be weighed, and the plots, in which the plants were subjected to the short day cycles more than 20, should be

Table 1. Heading dates of 80 and 85 days old plants of 20 strains treated under different periods of short day treatment; heading dates of treated plants are expressed by the difference (in days) from those of the 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	421	W0629	W0149	C7482	W0039	W0623	W0027	W1294	W0026	W0598	W1235	W1292	W0612	C8515	W1269	W1282
Control	123.3	169.7	170.3	194.7	176.3	181.7	180.7	176.0	170.3	174.7	175.0	119.0	173.0	174.3	185.3	187.3	184.3	175.0	185.3	186.7
I	7.6	24.4	24.3	26.0	7.0	21.0	20.0	10.7	13.3	10.0	0.0	1.3	1.3	1.0	1.7	0.0	1.7	1.0	0.0	0.0
II	6.0	23.7	22.3	24.7	6.0	19.0	18.7	8.0	8.0	9.0	1.0	1.0	1.3	0.7	1.3	0.7	1.7	0.0	0.0	0.3
III	5.6	23.0	22.0	24.3	6.0	18.3	18.7	8.3	0.0	1.0	1.3	0.3	1.0	1.0	1.3	1.0	0.0	1.0	0.0	0.0
IV	3.6	22.4	20.7	18.3	5.7	18.3	18.7	0.0	0.7	0.7	0.0	0.7	0.7	0.3	0.0	0.3	0.7	0.7	0.0	0.0
V	7.6	23.7	23.7	42.3	7.7	31.0	22.0	14.3	23.3	12.0	12.3	21.7	1.7	1.0	0.3	0.3	0.0	0.0	0.3	0.0
VI	9.6	36.4	24.3	43.0	30.0	50.0	41.1	27.0	38.0	24.7	27.3	25.7	36.0	22.7	28.0	28.0	27.0	22.0	27.0	0.0
VII	6.0	23.0	12.7	24.7	7.0	27.7	20.3	13.7	21.7	10.7	0.3	1.3	1.3	0.0	1.0	1.0	0.3	1.0	0.0	—0.3
VIII	7.6	15.0	7.3	27.0	5.7	15.7	17.3	0.7	0.3	0.3	0.0	0.3	0.7	0.3	0.7	0.0	0.7	1.3	0.0	0.0
IX	8.0	21.4	22.3	29.7	7.0	28.0	20.3	13.7	22.3	12.0	10.7	21.3	0.0	0.0	0.3	0.3	1.0	0.0	0.0	0.0
X	6.6	14.0	2.0	24.7	1.0	1.0	0.7	0.0	0.0	0.0	0.3	0.7	0.3	0.0	0.3	0.3	0.7	0.3	—0.3	0.0
XI	9.0	24.0	7.0	14.0	6.7	19.7	20.0	10.7	13.3	9.4	1.0	0.0	1.3	0.3	1.0	1.7	0.3	0.0	0.0	0.0
XII	8.6	27.7	24.0	14.7	15.7	47.7	27.7	21.7	35.0	15.7	24.7	25.7	31.0	22.0	21.0	21.3	2.7	1.0	0.0	0.0
XIII	9.3	36.4	24.7	17.7	31.0	55.7	55.7	28.7	38.3	26.0	29.7	26.0	51.0	27.0	28.0	30.0	27.3	22.7	27.3	0.3
XIV	8.3	21.4	13.7	25.3	6.7	19.7	19.3	9.0	13.0	9.3	1.7	0.0	0.7	1.0	0.3	1.0	2.0	1.3	—0.3	0.0
XV	9.3	23.4	13.7	29.0	7.7	33.7	23.0	16.0	23.7	13.4	13.3	21.7	1.7	21.7	0.3	0.3	1.0	1.0	0.3	—0.3
XVI	8.6	17.7	10.0	20.7	6.4	19.0	18.7	8.7	8.3	9.0	1.0	1.7	0.3	0.3	0.0	0.7	0.3	1.0	0.0	0.0
XVII	9.3	27.0	21.7	31.0	7.7	34.0	24.0	20.3	29.3	15.0	16.0	24.3	21.0	0.0	1.0	0.3	0.7	1.0	0.7	0.0
XVIII	12.3	25.4	26.0	26.3	7.0	21.7	20.0	11.0	16.7	10.0	1.7	1.7	0.0	0.0	1.7	0.0	2.3	0.7	0.0	0.0
XIX	13.6	36.4	34.7	34.3	23.0	48.7	39.7	25.7	38.0	16.7	26.0	25.7	31.0	22.0	21.3	25.3	27.0	0.7	0.0	0.0
XX	8.6	24.0	24.7	20.3	9.0	43.7	27.7	20.7	34.7	14.0	21.3	25.0	30.7	21.7	20.0	21.3	20.3	0.3	0.0	0.0
5% l.s.d.	1.7	2.7	1.8	3.2	1.6	1.5	1.0	2.1	1.5	1.9	1.8	3.4	2.4	1.1	2.0	2.2	3.1	1.7	2.0	1.6
Group	1	1	1	1	2	2	2	3	4	4	5	5	6	7	8	8	9	10	10	11
Species*	1	1	3	4	1	3	4	2	2	3	2	4	2	3	3	4	4	1	5	5
Origin**	1	2	2	2	2	3	2	4	4	3	4	5	4	6	7	8	9	10	11	10

*: 1—*O. sativa*, 2—*O. glaberrima*, 3—*O. sativa* var. *spontanea*, 4—*O. perennis*, 5—*O. officinalis*.

**: 1—Japan, 2—India, 3—Burma, 4—Sierra Leone, 5—Philippines, 6—Malaya, 7—New Guinea, 8—Kalimantan, 9—Brazil, 10—Sarawak, 11—Brunei.

weighed up. In comparison with the data obtained in plots V and VII, and VII and IX, it was clear that 15 short day cycles after 5 days insertion can compensate the efficiency, but not after 10 days insertion, and the earlier was the second short day cycles, larger was the efficiency, even though the second short day cycles were discontinuously given. Moreover, it was ascertained that the first continuous short day cycles was superior to the post continuous short day cycles in comparison with the data obtained in plots VII and XV, in which the both plants were subjected to 10 days insertion. Group 6 means that continuous 20 short day cycles seems to be enough, but continuous 10 days insertion during them eliminated completely the potentiality. In comparison with the data obtained in plots V and XII, and IX and XII, it was clear that the longer was the first short day cycles, the larger was the efficiency, even though the short day cycles were the same in the total. In comparison with the data obtained in plots XV and XVII, it was also found that the earlier was the second short day cycles, the larger was the efficiency, even though the second short day cycles were discontinuously given. On the contrary in Group 7, continuous 10 days insertion (plot XV) seems to be nonsence, but discontinuous 10 post-short day cycles (plot XVII) were of no use in inducing floral development, even though the plants received equally the total of 20 short day cycles. Group 8 shows characters shown in groups 6 and 7. Group 9 means that post-short day cycles more than 10 after 5 days insertion were required for floral induction. Group 10 means that short day cycles more than 20 were required for induction even though no long day insertion was given. In Group 11, plant required more than continuous 25 days treatment for floral induction.

Theoretically, aging effects were evidently examined by comparing with the data obtained in plots I and XVIII, in which the plants were subjected to continuous 15 days treatment; and in plots V and XX, in which the plants were subjected to discontinuous 20 days treatment. The former case was slightly found in the strains KA and W0039. The latter case was found in some groups. In groups 2, 3, 4 and 5, efficiencies found in plot V were clearly smaller than those found in plot XX. In groups 6, 7, 8 and 9, values found in plot V were not significantly large, but those found in plot XX were significantly large in comparison with the data obtained in control plot. Because the plants in plots V and XX, at the beginning of the treatment, were 80 and 85 days old counted from the date of sowing, respectively, differences of plant age (=5 days) meant clearly the aging effect.

3. Since in the present experiment, the number of strains available were rather limited, 20 strains, a precise conclusion may not be drawn in regard to the taxonomic status and the geographical distribution. However, the followings may be mentioned. In *O. sativa,* strains of Japan and India belong to groups 1 and 2, strain of Sarawak (4°N) belongs to group 10, respectively, strains of *O. glaberrima* (8°N) belong to groups 3, 4, 5 and 6. In *O. sativa* var. *spontanea,* strain of India belongs to group 1, strains of Burma to groups 2 and 4, strain of Malaya to group 7, and strain of New Guinea to group 8, respectively. In *O. perennis,* strains of India belong to groups 1 and 2, strain of Philippines to 5, strain of Kalimantan to 8, and strain of Brazil to 9, respectively. Strains of *O. officinalis* belong to groups 10 and 11. In comparison with the data obtained in the strains of *O. sativa* and *O. officinalis* distributing in Sarawak, it may be said that the accumulation effect shown by the former was clearly larger than that of the latter in the same latitude (plots VI and XIII). In the previous paper[1], it was found that *O. officinalis* has extremely many insensitive strains. Consequently, it may be possible that C genome, which constitutes *O. officinalis,* lacks several factors responsible for photoperiodic sensitivity, not only in aging of acceleration effect but also in accumulation effect. In comparison with the data obtained in the strains of *O. sativa, O. sativa* var. *spontanea* and *O. perennis* distributing in India, it may be also said that the accumulation effect shown by the strains of *O. sativa* were larger than that of *O. sativa* var. *spontanea* and *O. perennis*.

Then, in general, strains distributing in relatively high latitude showed significant accumulation effect among the most treated plots. On the contrary, strains distributing in relatively low latitude showed rare accumulation effect from plot to plot, in both north and south hemispheres.

4. It is supposed that stimulus produced by repeated treatment is cumulative and floral induction can take place when it reached to a certain threshold value[1]. 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 in the treated plots from those of the respective control plot were converted using the 5% l.s.d. For example, the converted values of strain W0106 were as follows in the order from plots I to XX; 13.5, 12.4, 12.2, 11.5, 13.2, 13.5, 7.1, 9.6, 12.4, 1.1, 3.9, 13.3, 13.7, 7.6, 7.6, 5.6, 12.1, 14.4, 19.3 and 13.7, respectively. Those values are the quotients of the respective value by 1.8 (=5% l.s.d.). Values obtained by this method were plotted out in graph and compared from one another within and between groups. Several patterns were found in 20 strains used. However, these problems have not been fully studied in the previous[3] and the present experiments, and remained to be investigated by the detailed experiment using as many materials and treated plots as possible. It was presumed that the patterns shown by this method were significantly different among various species and strains, and that patterns can be used as an index of accumulation effect, *i.e.*, photoperiodic sensitivity, in the future.

5. In comparison with the data obtained in groups 6 and 7, the reversed results were gotten in plots XV and XVII. The discontinuous (XVII) or continuous (XV) 10 post-short day cycles after long day insertions can supply the eliminating effect in groups 6 and 7, respectively. Nextly in comparison with the data obtained in groups 8 and 9, the different results were gotten in plots XII. In this sense, it may be possible that a reversed result was found in plots VII and IX (group 5), or plots IV and X (group 2), etc., at the time when many materials were used.

It does not necessarily follow that the values were larger in plots II, XIV and XX than those in III, XVI and XVIII, respectively. In addition to these unanswered points, several problems were still remained unsolved, that is, 1) whether or not these methods can be used with universal validity for more species and strains, 2) whether the values shown by these methods are stable or not year by year through different seasons, 3) whether or not the values shown by these methods are influenced by the insertion-interval, day-length, temperature. Those problems may be clarify by further investigation using as many materials and treatment plots as possible.

Summary

Succeeding to the previous paper, an experiment was done using 20 strains belonging to 5 species of the genus *Oryza* in order to investigate photoperiodic sensitivity and its changes according to insertion of long day conditions during short day condition. The results obtained are summarized as follows:

1. Accumulation effect of floral induction were tested by using natural day length and 20 plots, in which the plants were subjected to short day condition, 12.5 hours light and 11.5 hours dark, having several combinations of short day and long day insertions. They can be divided into 11 groups in regard to the behaviour found in the accumulation effect (Table 1).

2. Generally, strains distributing in relatively high latitude showed significant accumulation effect among the many plots treated. On the contrary, strains distributing in relatively low latitude, especially near the equatorial regions, showed rare accumulation effect.

3. In comparison with the data obtained in the 10 plots, in which the plants were subjected to the 15 day cycles in the total,

it was ascertained that the smaller was the insertion treatment, the larger was the efficiency of accumulation effect, and the longer was the pre-short day cycles, the larger was the efficiency.

4. It was confirmed that the patterns shown by this method were clearly different among various species and strains, and that the behaviour 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8報 累積効果 (2)

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前報に引き続き短日処理程度の出穂まで日数におよぼす影響について，種間と種内変異を調査する目的で，種々の緯度に分布する稲属5種20系統を用いて実験を行った．自然日長区および短日処理20区を設け，80日令と85日令に達した時，12時間30分明期の短日処理を行った．そのさい，短日処理期間中に種々の程度に自然日長条件を挿入し短日条件の累積効果を調査した．

累積効果の内容によって全系統は11群に分類された。一般に栽培種は野生種に比較して，また高緯度地方に分布している系統は低緯度地方に分布している系統に比較して，いずれも短日条件の効果は累積し易い事，および短日条件中の長日条件が短かい程，また短日前処理が長ければ長い程，いずれも累積効果が大きい事，などの傾向が認められた．

前報の結果と合わせ考えると，このような分析方法で示される短日処理の累積効果は，感光性を表示する場合の一つの指標として有効であると言える．