Photoperiodic Responses of the Cultivated Rice Collected in Fiji

Tadao C. KATAYAMA*

In the 1982 academic year, the Kagoshima University Research Center for the South Pacific carried out the second-year's research in Fiji and Solomon Islands. This project examined the ecological, ethnological and bio-productive feature of the natural environment, as well as the resources in Fiji and Solomon Islands. The present author was attended for research the agricultural sciences, *i.e.,* agricultural productivity, cultural patterns, pathological and physiological condition, land-use practices in tropical areas.

As a part of the project, 20 strains of cultivated rice, *Oryza sativa* L., using in Fiji were collected. The most of them were delivered him through the kindness of Dr. S. A. Haque, and some of them were directly collected in the field by the members of the party. These strains were used for the research on photoperiodic responses. The main purposes are to clarify the fundamental characters of photoperiodism and varietal variations, which are unknown at the present time.

Acknowledgement : The writer wishes to express his hearty thanks to Dr. S. A. Haque, Soil Chemist, Fiji Agricultural Department, Fiji, who helped to accomplish his work.

Materials and Methods

Twenty strains were collected. The most of them were delivered by Dr. Haque and some ones were collected by the members of the party. They were carried back to Kagoshima, Japan, and were used for the physiological investigations. They are listed up in Table 1. In this table, strain number, ordinary sowing and harvesting times and remarks are shown.

Seeds of the strains were all husked in order to get uniform germination and were sterilized with 70% EtOH solution for 10 minutes on May 17, 1983. Then they were washed twice and incubated at 30°C in Petri-dishes on filter paper. After 2-3 days after germination, young seedlings were planted in plastic boxes and kept in upland condition. The seedlings were transplanted in paddy field on June 16. Plants were grown under natural day light before and after the short day treatment, in which one half were subjected under short day condition [(10^h l+14^h d) x 21 days] during the

* Faculty of Agriculture, Kagoshima University, Kagoshima, Japan 890

Table 1. Ordinary sowing and harvesting times of cultivated rice, *Oryza sativa* L., collected in Fiji

Strain No.	Ordinary sowing time	Harvesting time	Remarks
1	Oct/Nov	Feb	Traditional
2	Non-seasonal	Non-seasonal	Improved
3	Oct/Nov	May/April	Traditional
4	Non-seasonal	Non-seasonal	Traditional
5	Oct/Nov	May/April	Traditional
6	Oct/Nov	May/April	Traditional
7	Oct/Nov	April/May	Traditional
8	Oct/Nov	April/May	Traditional
9	Oct/Nov	April/May	Traditional
10	Oct/Nov	April/May	Traditional
11	Oct/Nov	April/May	Traditional
12	Non-seasonal	Non-seasonal	Improved
13	Non-seasonal	Non-seasonal	Traditional
14	Non-seasonal	Non-seasonal	Traditional
15	Oct/Nov	April/May	Traditional
16	Non-seasonal	Non-seasonal	Improved
17	—	—	Traditional
18	—	—	Traditional
19	—	—	Traditional
20	—	—	Traditional

period from July 8 to July 28, and the other half were kept under the natural day length. The growing periods observed in those two plots were compared.

Heading date was referred to the time, when the tip of the first ear in a plant was emerging from the leaf sheath of the respective flag leaf.

Suitable temperature was provided for the growth of the plants. Civil twilight, natural day length, the average maximum and the minimum temperatures in Kagoshima are shown in Table 2. Those in Koronivia Research Station in Fiji are shown in Table 3. Civil twilight and natural day length during a year in Suva, Fiji are given in Table 4.

Results

Heading dates of 20 strains of rice are shown in Table 5. Growing period and the difference from those of the respective control plot in days are given in Table 6.

1. Heading dates of 20 strains of rice subjected under the natural condition ranged from

Table 2. Day length and temperature of the experimental paddy field in Kagoshima

Date		Civil twilight	Natural day length	Average maximum temperature	Average minimum temperature
		m	h m	°C	°C
May	11	26	13 38	23.9	15.1
	21	27	53	25.1	15.9
	31	27	14 04	25.9	17.1
June	10	28	11	26.5	18.4
	20	28	13	27.3	20.4
	30	28	12	29.0	22.3
July	10	27	08	30.6	23.5
	20	27	13 57	32.0	24.2
	30	26	44	32.4	24.3
August	09	25	30	32.5	24.2
	19	25	13	32.2	24.2
	29	24	12 56	31.7	23.4
September	08	24	37	30.7	22.4
	18	24	18	29.3	20.7
	28	24	11 59	27.7	18.7

Table 3. Meteorological records in Koronivia Research Station, 1981

Month	Mean maximum temperature (°C)	Mean minimum temperature (°C)	Total		Average rainfall 1949-1977 (mm)	Average sunshine 1971-1980 (hrs/month)
			rainfall (mm)	rainy days (No.)		
January	31.0	23.2	507.9	24	354	173
February	31.1	23.4	380.6	25	310	164
March	31.3	22.8	162.9	21	396	150
April	29.8	22.3	463.8	21	360	139
May	28.5	21.0	228.0	16	235	141
June	28.0	19.7	77.7	10	184	129
July	26.5	18.7	24.6	14	175	126
August	26.5	18.4	211.7	14	154	143
September	25.5	18.9	124.5	19	207	123
October	26.9	20.3	169.9	19	217	154
November	28.8	21.7	555.3	19	311	148
December	30.7	23.6	134.7	21	296	172
Total	—	—	3,041.6	223	3,199	1,762

Table 4. Astronomical day length, twilight length in Suva, Fiji (18°30'S)

Date		Civil twilight	Natural day length	Date		Civil twilight	Natural day length
January	01	24 m	11 h 03 m	July	10 h	24 m	13 h 12 m
	11	24	07		20	24	06
	21	23	13		30	23	12 h 59 m
	31	23	20	August	09	23	52
February	10	22	28		19	22	42
	20	22	38		29	22	33
March	02	22	49	September	08	22	23
	12	22	58		18	22	13
	22	22	12 h 09 m		28	22	03
April	01	22	19	October	08	22	11 h 52 m
	11	22	30		18	22	42
	21	22	39		28	22	32
May	01	23	49	November	07	23	24
	11	23	57		17	23	16
	21	24	13 h 05 m		27	24	09
	31	24	10	December	07	24	05
June	10	24	14		17	24	02
	20	25	15		27	24	02
	30	24	15				

204 days (strain Nos.7 and 15) to 95 days (No.20). In strain level, the longest (203.3 days) was obtained in No.15, followed by No.7 (199.3 days) and No.19 (186.3 days). The shortest (95.3 days) was noted in No.20, followed by No.13 (108.3 days) and No. 16 (110.3 days). It was noted that the value was peculiarly small in No.20. Average and its standard deviations through the whole strains were found to be 152.2 ± 32.2. The standard deviations in each strain, *i.e.*, showing intra-population's variations were found to be 1.82 ± 1.13.

2. Heading dated of 20 strains of rice subjected under the short day condition ranged from 195 days (No.7) to 81 days (No.20). In strain level, the longest (192.7 days) was obtained in No.7, followed by No.9 (177.7 days) and No.10 (175.0 days). The shortest (81.3 days) was noted in No.20, which was the same as in case of the control plot, followed by No.15 (88.0 days) and No.16 (93.0 days). Average and its standard deviations through the whole strains were found to be 113.7 ± 31.4. Standard deviations of each strain were found to be 1.88 ± 1.72. It was noted that the average value was the larger than those of the control plot.

3. In intra-population's variation in view of the control plots, the largest (5.1) was obtained in No.1, followed by No. 7 (3.4) and No.3 (2.9). The smallest (0.5) was noted in Nos. 4, 12 and 20. Average and its standard deviations through the whole strains were found to be 1.82 ± 1.13.

Table 5. Heading date of 20 strains of rice collected in Fiji, sown on May 17

Strain No.	Control				Treated			
	1	2	3	Mean	1	2	3	Mean
1	10-08*	9-26	9-29	10-01	9-03	8-25	8-28	8-29
2	9-16	9-17	9-15	9-16	8-18	8-18	8-19	8-18
3	10-01	10-08	10-05	10-05	9-08	9-05	9-02	9-05
4	10-09	10-09	10-10	10-09	10-10	10-10	10-07	10-09
5	11-08	11-09	11-12	11-10	8-20	8-21	8-19	8-20
6	11-18	11-18	11-15	11-17	8-25	8-22	8-23	8-23
7	12-07	12-01	11-29	12-02	11-27	11-22	11-28	11-26
8	11-08	11-12	11-13	11-11	8-23	8-19	8-20	8-21
9	11-08	11-14	11-10	11-11	11-08	11-12	11-12	11-11
10	11-15	11-13	11-09	11-12	11-08	11-07	11-09	11-08
11	11-14	11-13	11-16	11-14	8-16	9- 1	8-20	8-23
12	9-27	9-27	9-27	9-27	8-24	8-27	8-24	8-26
13	8-31	9-05	9-02	9-02	8-21	8-27	8-23	8-24
14	9-18	9-20	9-21	9-20	9-12	9-11	9-10	9-11
15	12-07	12-07	12-05	12-06	8-12	8-13	8-14	8-13
16	9-03	9-06	9-04	9-04	8-18	8-19	8-17	8-18
17	9-27	9-24	9-22	9-24	8-18	9-01	8-22	8-24
18	9-26	9-24	9-25	9-25	9-03	9-05	9-03	9-04
19	11-18	11-17	11-23	11-19	8-27	8-27	8-28	8-27
20	8-21	8-20	8-20	8-20	8-06	8-06	8-07	8-06

* : October 8

In view of the treated plots, the largest (6.8) was obtained in No.11, followed by No.17 (5.9) and No.1 (3.7). The smallest (0.5) was noted in Nos.2 and 20. The latter strain was the same as in case of the control plot. Average and its standard deviations through the whole strains were found to be 1.88 ± 1.72.

It may said that the larger is the standard deviations in the control plot, the larger is the standard deviations in the treated plot. Moreover, the smaller is the standard deviations, the more advanced is the strain statuses and its stability in genetic background.

4. Intra-specific variation in regard to acceleration of heading by short day treatment was recognized. The largest acceleration effect (115.3 days) was obtained in No.15, followed by No.6 (85.7 days) and No.19 (84.0 days). It was noticeable that the value was peculiarly large in No.15. The smallest acceleration effect (0.0 day) was noted in No.9, followed by No.4 (0.3 day) and No.10 (4.3 days). Average and its standard deviations through the whole strains were found to be 38.5 ± 35.0.

5. Intra-specific variations in regard to acceleration of heading by short day treatment is discontinuous with gaps somewhere between acceleration by 81.6 days to 33.1 days

Table 6. Growing period and difference from those of the respective control plot in days, sown on May 17

Strain No.	Control				Treated				Difference
	1	2	3	Average	1	2	3	Average	
1	144	132	135	137.0	109	100	103	104.0	33.0
2	122	123	121	122.0	93	93	94	93.3	28.7
3	137	144	141	140.7	114	111	108	111.0	29.7
4	145	145	146	145.3	146	146	143	145.0	0.3
5	175	176	179	176.7	95	96	94	95.0	81.7
6	185	185	182	184.0	100	97	98	98.3	85.7
7	204	198	196	199.3	194	189	195	192.7	6.6
8	175	179	180	178.0	98	94	95	95.7	82.3
9	175	181	177	177.7	175	179	179	177.7	0.0
10	182	180	176	179.3	175	174	176	175.0	4.3
11	181	180	183	181.3	91	107	95	97.7	83.6
12	133	132	133	132.7	99	101	99	99.7	33.0
13	106	111	108	108.3	96	102	98	98.7	9.6
14	124	126	127	125.7	118	117	116	117.0	8.7
15	204	204	202	203.3	87	88	89	88.0	115.3
16	109	112	110	110.3	93	94	92	93.0	17.3
17	133	130	128	130.3	93	107	97	99.0	31.3
18	132	130	131	131.0	109	111	109	109.7	21.3
19	185	184	190	186.3	102	102	103	102.3	84.0
20	96	95	95	95.3	81	81	82	81.3	14.0

and by 13.9 days to 9.7 days. Based on these facts, all strains so far tested could be easily divided into three groups, *i.e.*, the high, the medium and the low sensitivities. It was noticeable that the former gap, *i.e.*, 81.6 − 33.1 = 48.5 days, was remarkably large.

According to those results mentioned above, it may be concluded that they were clearly divided into three groups. Six (strain Nos.5, 6, 8, 11, 15 and 19), 8 (Nos.1, 2, 3, 12, 16, 17, 18 and 20) and the remaining 6 (Nos.4, 7, 9, 10, 13 and 14) strains were belonged to the high, the medium and the low sensitive groups, respectively. In view of grouping method, the following facts were found. 1) Heading dates of plants subjected under the natural condition ranged from 203.3 days (high), 140.7 days (medium) and 199.3 days (low) to 176.7 days (high), 95.3 days (medium) and 108.3 days (low), respectively. Those averages and the standard deviations were found to be 184.9 ± 8.8 (high), 124.9 ± 14.2 (medium) and 155.9 ± 32.1 (low), respectively. 2) Those of the short day condition ranged from 102.3 days (high), 111.0 days (medium) and 192.7 days (low) to 88.0 days (high), 81.3 days (medium) and 117.0 (low), respectively. Those averages and the standard deviations were found to be 96.2 ± 4.3 (high),

100.1 ± 7.1 (medium) and 151.0 ± 34.1 (low), respectively. 3) The acceleration effects ranged from 115.3 days (high), 33.0 days (medium) and 9.6 days (low) to 81.7 days (high), 14.0 days (medium) and 0.0 day (low), respectively. Those averages and the standard deviations were found to be 88.8 ± 11.9 (high), 26.0 ± 7.0 (medium) and 4.9 ± 3.8 (low), respectively. 4) In comparison with the group-average-values, the values were found in the order of high > low > average > medium, low > average > medium > high, and high > average > medium > low is the control plots, the treated plots and the differences, respectively. 5) In view of the intra-population's variations, the group-average-values and its standard deviations were found as in the order of 2.05 ± 0.93 (low) > 1.82 ± 1.13 (average) > 1.75 ± 1.49 (medium) > 1.68 ± 0.57 (high), and 1.98 ± 2.19 (high) > 1.96 ± 1.83 (medium) > 1.88 ± 1.72 (average) > 1.67 ± 0.73 (low), in the control and the treated plots, respectively.

6. In view of the strain specificity, the following facts were ascertained. 1) All of the improved varieties (strain Nos.2, 12 and 16) were belonging to the medium group. 2) All of the non-seasonal varieties (strain Nos.2, 4, 12, 13, 14 and 16) were belonging to the medium and the low groups, but not to the high group. 3) All of the strains showing high sensitivities were belonging to the traditional varieties.

7. Flower bud formation occurs thirty days before the heading, if plants are kept under suitable temperature during their growth period[3]. It was also proved that the influence of different day lengths on the number of days between bud formation and heading is negligible[4]. Based on such informations, a critical day lengths were estimated from a day length at the time when the flower bud formation took place, namely, 30 days before heading[6]. Of course, suitable temperature was provided for the growth of the plants (Table 2), even if compared with those of the original places (Table 3). It was presumed that the critical day lengths of the high sensitive groups ranged from $11^h\ 25^m$ to $11^h\ 50^m$.

Discussion

In the tropical regions (0° to 10°), only the insensitive strains are cultivated, while in Tropical India (10° to 20° N), sensitive strains are mainly used. In Formosa (22° to 25° N), insensitive strains are used in the first crop season and the sensitive ones in the second crop season. In the middle part of Japan (30° to 35° N), insensitive strains are used as early varieties, while the sensitive strains serve as middle or late varieties. In the northern part of Japan, only insensitive strains are used.

Those pattern of selection fit well the natural conditions, especially, seasonally photoperiodic conditions in the respective areas[6]. In the equatorial region, there is no remarkable annual periodicity of the natural day length. Differences in day length at 3° N or 3° S is only 22 minutes through the year. Therefore, rice growing there can initiate flower buds independently of natural day length. In fact, all the strains used in equatorial area of New Guinea (0° to 8° S), are apparently insensitive, since their

heading time changes parallel with the advancement or delay of sowing[5]. Rice is sown there in December to February and harvested in May to June, allowing about 180 days for completing the life cycle irrespective of the sowing date. This perieod is, of course, more or less variable depending upon rainfall. This fact suggests that no sensitive variety will succeed in those areas, and that only insensitive strains can be used.

In tropical countries in relatively higher latitudes, the main crop varieties are sown just before the monsoon and harvested at the end of it. They are called "seasonal blossomers", since the heading date is characteristic of each strain regardless of the time of sowing. They are all photoperiodically sensitive. Some strains grown there as "additional crops" are insensitive. They might have originated by spontaneous mutations, but seem not to be superior to sensitive strains, when grown in the "main crop-season".

In Fiji, differences in day length is $2^h\ 13^m$ throughout a year (Table 4). Then, growing pattern of rice in Fiji belongs to these categories.

In temperate countries, the insensitive strains are used for the first crop. Long day or neutral plants can be cultivated in this crop season, because its natural day length becomes longer day by day. The sensitive strains are used in this district as the second crop, because natural day length becomes then shorter day by day.

Considering from the agronomic standpoint, photoperiodically sensitive or insensitive strains seem to have been favored and adapted according to agronomic requirements.

Before the advent of Europeans, cereals and their use as a food were unknown in the islands of the Pacific, except in Guam, where the first European discoverers found some rice growing. Rice, *Oryza sativa* L., was introduced into the area in the early days of European colonization, as early as 1852 in New Caledonia. Attempts made so far to develop rice-growing in Pacific islands have met with little success, except in New Guinea and Papua and also Fiji[8].

Rice cultivation in Fiji had started in Navua areas in late 19th century by Indo-Fijians. Cultivation area was increased from year by year. In 1952, rice cultivation area was already counted as about 700 ha. Recently, total estimated rice consumption was increased from year by year[1,7]. Government aimed at achievement of self-sufficiency on rice consumption by increasing cultivation area and production per unit area. In 1981, there are 9,600 ha for rice cultivation in the whole Fiji. The several items are considered to be counterplan to advance of rice production, in which selection of adaptive varieties is included[2]. In this technique, the physiological characters should be fundamentally considered, especially photoperiodic sensitivities. Because it will be entertained to say a hopeful view of enlargement of cultivation area and of production per unit area of rice. This view depends mainly on the facts of high temperature during a year and abundant rainfall throughout a year (Table 3).

Summary

In 1982, the writer was sent to Fiji for agronomical research. In this opportunity, 20 strains of rice, *Oryza sativa* L., were collected. They have been brought back to Japan and used for physiological investigations, especially photoperiodic sensitivities. The main results obtained here were summarized as follows :

They were divided into 3 groups in regard to acceleration effect of heading by short day treatment [(10^h l + 14^h d) x 21],*i.e.*, the high (6 strains), the medium (8 strains) and the low (6 strains) sensitive groups. In view of "group-average-value", the growing periods of the plants subjected under the natural condition were found to be 152.2 days, 184.9 days, 124.9 days and 155.9 days in the average, the high, the medium and the low sensitive groups, respectively. Those of the treated plants were found to be in the same order as 113.7 days, 96.2 days, 100.1 days and 151.0 days, respectively. The differences from those of the respective control plots were found in the same order as 38.5 days, 88.8 days, 26.0 days and 4.9 days, respectively.

The standard deviations of each strain were found in the same order as 1.82, 1.68, 1.75 and 2.05 in the control plots, and 1.88, 1.98, 1.96 and 1.67 in the treated plots, respectively.

Several strain specificities were recognized. All of the improved varieties belonged to the medium sensitive group. All of the non-seasonal varieties belonged to the medium and the low sensitive groups. All of the strains showing the high sensitivities belonged to the traditional varieties. For extension of the adequate varieties and new technique, the photoperiodical characters of the respective strains should be primarily considered.

References

1) Annual Report for the year 1979, 1981. Parliamentary Report No. 14 of 1981. Ministry of Agriculture and Fisheries, Fiji.
2) Annual Research Report, 1981. Department of Agriculture, Fiji.
3) Asakuma, S. 1958. Ecological studies of heading of rice (in Japanese with English Summary). Proc. Crop Sci. Soc., Japan, **27** : 61-66.
4) Eguchi, Y. 1941. Studies on photperiodism (in Japanese). Agric. & Hort., **16** : 212-218.
5) Katayama, T. C. 1962. Some considerations on rice cultivation in New Guinea. Japan. Jour. Trop. Agr., **5** : 80-86.
6) Katayama, T. C. 1964. Photoperiodism in the genus *Oryza*. I. Japan. Jour. Bot., **18** : 309-348.
7) Katayama, T. C. 1983. Some aspects on rice cultivation in Fiji and Solomon Islands. Prompt Rep. 2nd Sci. Survey of South Pacific, 39-41.

8) Massal, E. and J. Barrau, 1973. Food plants of the south sea islands. South Pacific Commission Noumea, New Caledonia, Technical Paper, **94**: 1-51.