Effects of Temperature and Day-Length on Heading Habit of Recently Developed Korean Rice Cultivars

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ABSTRACT : To understand the heading habit of recently developed 20 Korean rice cultivars, rice plants in a phytotron were exposed to different temperature: 22.5°C (day 27°C / night 18°C), 27.5°C (day 32°C / night 23°C), and day-length conditions: 10, 12, 13, 14, 15 hours. Four rice cultivars (Sobibyeo, Juanbyeo, Ilpumbyeo and Shindongjinbyeo) showed relatively short Basic Vegetative Phase (BVP) of 17 to 18 days, while Dasanbyeo showed the longest (35 days) BVP, compared to other remaining 15 tested cultivars which exhibited 24 to 31 days of BVP. In this experiment, it was tried out to separate the eliminable vegetative phase into photosensitivity and thermo-sensitivity with two different pathways. Many tested cultivars, however, exhibited quite different responses under low temperature and / or long day-length conditions. Especially, Surabyeo and Juanbyeo were the most difficult cultivars to separate into photo- or thermo-sensitivity in that the eliminable vegetative phase of these two cultivars increased greatly only under low temperature (22.5°C) and long day-length (15 hr.) conditions. Regarding the heading response to temperatures, tested cultivars could be categorized into 2 groups. In 1st group of rice cultivars, the eliminable vegetative phase decreased almost equally as the temperature changed from 20.0°C → 22.5°C → 25.0°C → 27.5°C. In contrast, the 2nd group of rice cultivars exhibited eliminable vegetative phase slowly decreasing when the temperature changed from 22.5°C → 25.0°C → 27.5°C, but rapidly decreasing when the mean temperature changed from 20.0°C to 22.5°C. All the cultivars belonged to 2nd group, the heading date would be very delayed if cool summer comes.

Keywords: rice, temperature, day-length, heading date, thermo-sensitivity, photosensitivity

In biological terms, duration from sowing or emergency to floral initiation is called as "Vegetative growth stage" in plants. And also, vegetative growth stage can be divide into (1) "Basic vegetative Phase (BVP)" during which floral initiation cannot be made under any environmental conditions and (2) "Eliminable Vegetative Phase" during which floral induction is affected easily by temperature or day-length conditions. Regarding the variations in heading date, we call 'Photosensitivity' or 'Thermo-sensitivity' based upon relative impacts of day-length or temperature on floral initiation, respectively.

Vergara *et al.* (1965) classified the rice varieties as insensitive when the eliminable vegetative phase ranged 0 to 30 days, and as sensitive when it was longer than 31 days. Inouye (1965) insisted BVP was affected by leaf numbers, and BVP was disappeared after 5th leaf. But, BVP of most Korean rice varieties has been reported to range between 15 days and 36 days (Ahn & Vergara, 1969; Choi *et al.*, 1983).

Although the rice plant belongs to short-day plant, all rice varieties under 24 hours' day-length conditions headed between 114 days and 200 days (Asakuma & Kaneda, 1967), and heading dates of rice plants were delayed by the extended- or shortened- day-length more than suitable day-length conditions (Venkataraman, 1964). The optimum day-length inducing rapid young panicle initiation was 10 hours and the optimum day-length of most Korean rice varieties were close to 10 hours (Ahn & Vergara, 1969).

In general, most early maturity varieties are known to be mainly affected by temperatures, while late maturity varieties are mainly affected by day-length (Yoon, 1986). Although temperature does not so important factor to make floral initiation (Noguchi & Kamata, 1965) rare reports, however, on thermo-sensitivity and photosensitivity of recently developed Korean rice cultivars have been published, which are the major objectives of this report. Our experimental results in this report may offer an important information to the rice breeders in developing new rice varieties suitable to different agricultural regions in Korea.

MATERIALS AND METHODS

Treatments such as temperatures and day-lengths conditions were made in a phytotron of National Institute of Crop Science (NICS), Korea in 2001. For experimental purpose, 20 recently developed Korean rice cultivars of different maturity type were selected: Odaebyeo, Daejinbyeo, Sobaekbyeo, Georubyeo as the early maturing type; Hasungbyeo,

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Seoanbyeo, Juanbyeo, Sobibyeo, Kwanganbyeo, Surabyeo, Sampyeongbyeo as the mid-maturing type; Ilpumbyeo, Daeanbyeo, Saechucheongbyeo, Ilmibyeo, Donganbyeo, Sindongjinbyeo as the mid-late maturing type; and Andabyeo, Dasanbyeo, Areumbyeo as Tongil type.

Artificial lighting chambers were also used to clarify the heading responses of rice cultivars corresponding to day-length. Plants were exposed to two different mean temperature conditions: 22.5 °C (max. 27.0 °C ~ min. 18.0 °C) and 27.5 °C (max. 32.0 °C ~ min. 23.0 °C). To mimic the natural conditions, the temperature were changed each hour, while the day-length treatments were established as 10, 12, 13, 14, and 15 hours and the lighting intensity during the day time was maintained as 1,200 $\mu m/s/m^2$.

Precision glass room was used to clarify the temperature-dependent heading response of rice cultivars and the mean temperature conditions were 20.0, 22.5, 25.0, and 27.5 °C. The daily temperature range was ± 4.5 °C, and each temperature condition was changed every hour similar to natural conditions as it was in upper artificial lighting chambers' experiment case. The day-length was followed by natural condition.

Seeding date was April 20 for day-length response experiment and was April 21 for temperature response experiment. On seeding day, 12 germinated rice seeds were placed in a 1/5,000a size wagner pot, and after thinning only 3 rice plants in a pot were cultivated up to heading stage. Additional experiment was conducted in paddy fields. Twenty rice cultivars as same of phytotron tests were sowed on April 20th and transplanted on May 25th to calculate the growth duration to heading under natural conditions in Suwon city.

All the cultivation methods of rice plants were conducted following the standard growing method of Rural Development Administration (RDA).

RESULTS AND DISCUSSION

Thermo-sensitivity and photosensitivity of rice cultivars

Heading date of rice plants were reduced in high temperature and short day-length (10 to 12 hours). To know the BVP of rice cultivars, high temperature 27.5 °C (day 32.0/night 23.0 °C) and short day-length (10 hr.) conditions were applied from sowing to heading stage. Mean temperature 27.5 °C would be enough high to make minimize the BVP of rice as the report of Roberts (Roberts & Carpenter, 1965).

Table 1 shows the BVP of tested cultivars. Among total duration from sowing to heading, BVP were calculated by subtracting 32 days from total duration, which were the days from floral initiation to heading. The shortest BVPs among tested cultivars were 17 to 18days in Juanbyeo, Sobibyeo, Ilpumbyeo, Sindongjinbyeo, and the longest BVP was 35 days in Dasanyeo. Another 15 cultivars showed BVP from 24 to 30 days similar to previous reports of Ahn & Vergara (1969) and Choi *et al.* (1983). The BVPs of all tested cultivars distributed from 17 to 35 days.

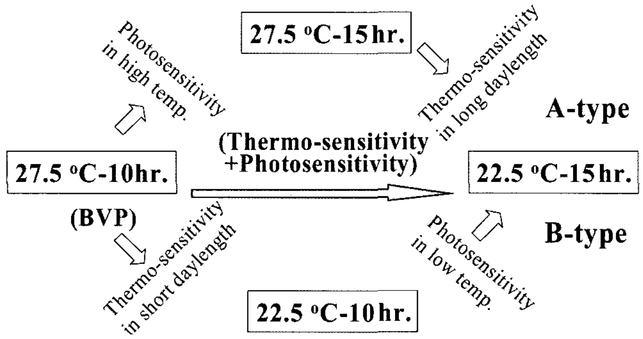


Fig. 1. Diagram for separating Vegetative Growth Period to thermo-sensitivity and photosensitivity.
A-Type : Separating to photosensitivity in high temperature and thermo-sensitivity in long day-length.
B-Type : Separating to thermo-sensitivity in short day-length and photosensitivity in low temperature.

Table 1. Basic vegetative phase (BVP) of 20 tested rice cultivars.

Eco type	Culivar	BVP† (days)	Eco type	Culivar	BVP (days)	Eco type	Culivar	BVP (days)	Eco type	Culivar	BVP (days)
Early maturity	Odaebyeo	30	Mid maturity	Hasungbyeo	24	Mid-late maturity	**Ilpumbyeo**	17	Tongil type	Andabyeo	30
	Daejinbyeo	29		Seoanbyeo	25		Daeanbyeo	29		**Dasanbyeo**	35
	Sobaekbyeo	26		**Juanbyeo**	18		Saechucheongbyeo	24		Areumbyeo	28
	Georubyeo	31		**Sobibyeo**	17		Ilmibyeo	27			
				Kwanganbyeo	30		Donganbyeo	30			
				Surabyeo	24		**Sindongjinbyeo**	18			
				Sampyeongbyeo	25						

†BVP was estimated under the condition of mean temperature 27.5 °C and day-length 10 hr.

Vegetative growth stage can be separated into BVP (Basic Vegetative Phase) and Eliminable Vegetative Phase. The former cannot be changed by any environmental conditions, while the latter can be changed easily by temperatures and day-lengths. In general, early maturity group is very sensitive to temperature conditions and mid-late maturity group is very sensitive to day-length, while both thermo-sensitivity and photosensitivity are complicated in any maturity group during vegetative growth stages.

In this report, the thermo-sensitivity and photosensitivity of tested rice cultivars during vegetative period were classified into two different types as shown in Fig. 1. The first class, named by A-type showed photosensitivity under high temperature and thermo-sensitivity under long day-length conditions, while the second B-type showed thermo-sensitivity under short day-length and photosensitivity under low temperature conditions during the eliminable vegetative phase.

The analysis results for A-type is shown in Fig. 2. The early maturity group of rice cultivars such as Georubyeo, Odaebyeo and Sobaekbyeo appeared high thermo-sensitivity in long day-length and very low photosensitivity in high temperature. In contrast, very high photosensitivity in high temperature and very low thermo-sensitivity in long day-length could be observed in mid-late maturity group such as Ilpumbyeo and Saechucheongbyeo. So these two cultivars were considered to have as strong degree of photosensitivity (Noguchi & Kamata, 1959). Tongil type rice cultivars such as Areumbyeo, Andabyeo and Dasanbyeo showed mid level of thermo-sensitivity and photosensitivity among tested 20 rice cultivars. Kwanganbyeo, however, appeared similar to Tongil type group, and Daejinbyeo showed unique independent group. Surabyeo and Juanbyeo specially showed low photo-sensibility under high temperature and the highest thermo-sensibility under long day-length condition.

The results analyzed for B-type is shown in Fig. 3. The 4 rice cultivars of early maturity including Daejinbyeo showed somewhat little different response in thermo-sensitivity under short day-length condition, but appeared very low photosensitivity under low temperature condition. Tongil type rice cultivars were proved as a mid photosensitivity group as the same trend of A-type, but thermo-sensitivities under short day-length were the highest. Between A- and B-type analysis, the results of Tongil type cultivars analyzed by B-type were very similar with Yoon's report (1986) that heading dates were much delayed by short day-length and low temperature in all Tongil type cultivars. Considering that Tongil type rice cultivars were developed as a medium type between Indica and Japonica by crossing so that they may need higher temperature condition than typical Japonica type rice cultivars. So Tongil type rice cultivars could be adapt easily in wide agricultural area except low temperature region (Lim, 1981). Other cultivars could be plotted as a middle thermo-sensitivity group except for Saechucheongbyeo, which showed the highest photosensitivity under low temperature conditions.

Changes in thermo-sensitivity and photosensitivity from A-type to B-type of rice cultivars are shown in Fig. 4. In general, most cultivars located high or low thermo-sensitivity and photosensitivity by A-type classification moved to

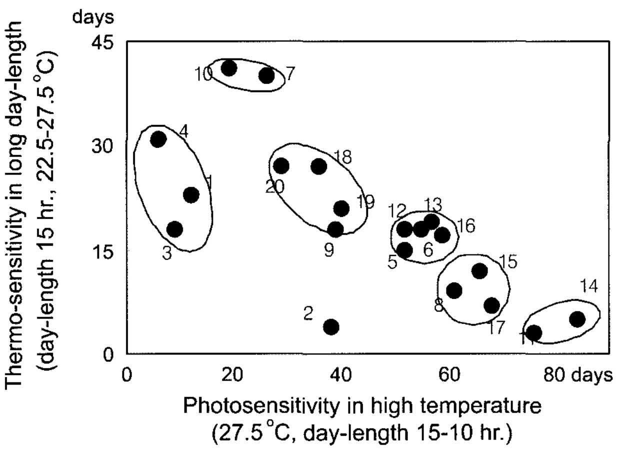


Fig. 2. Thermo-sensitivity and photosensitivity of 20 tested cultivars showed with classified A-type diagram.

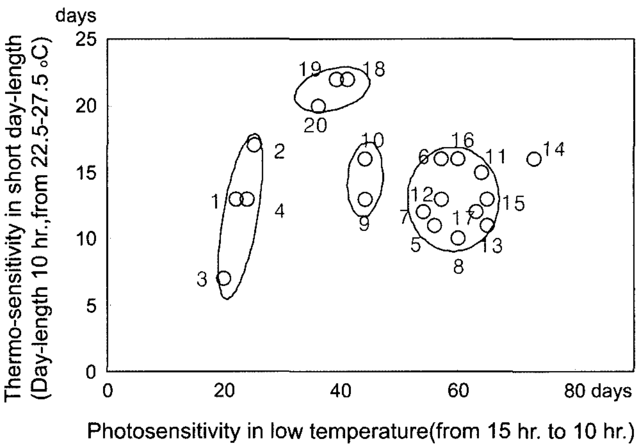


Fig. 3. Thermo-sensitivity and photosensitivity of 20 tested cultivars showed with classified B-type diagram.

1. Odaebyeo	2. Daejinbyeo	3. Sobaekbyeo	4. Georu-byeo	5. Hwasungbyeo	6. Seoanbyeo
7. Juanbyeo	8. Sobibyeo	9. Kwanganbyeo	10. Surabyeo	11. Ilpum-byeo	12. Daeanbyeo
13. Sampyeongbyeo	14. Saechu-cheongbyeo	15. Ilmibyeo	16. Donganbyeo	17. Sin-dongjinbyeo	18. Andabyeo
19. Dasanbyeo	20. Areumbyeo				

central area by B-type classification. Especially, arrowed marks represent greatly moved cultivars from A- to B-type classification. Lee (1994) reported that heading date of rice varieties could be calculate with some coefficients of temperature and day-length, but the change of heading date in this experiment were so complicate to analyze. For example, Surabyeo and Juanbyeo which showed the highest thermo-sensitivity by A-type classification moved into central area by B-type classification, and Georubyeo, Odaebyeo, Sobaekbyeo, the early maturity cultivars which appeared very low photosensitivity increased photosensitivity, and which was appeared very low photosensitivity cultivar, Daejinbyeo, combined to early maturity group by B-type classification. Most of low thermo-sensitivity cultivars such as Ilpumbyeo and Saechucheongbyeo increased their thermo-sensitivity. The other cultivars also showed slight movement by the change from A-type to B-type classification.

Fig. 5 shows the changes of heading date according to different day-length in some special cultivars which moved greatly in thermo-sensitivity and photosensitivity from A- to B-type classification. In Juanbyeo and Surabyeo which showed greatly decreased thermo-sensitivity and increased photosensitivity by changing from A-type to B-type classification, the heading dates gradually increased according to longer day-length in case of 27.5 °C. Heading date, however, exhibited sharp increase between 14 to 15 hours of day-length in case of low temperature (22.5 °C) conditions. These data suggest that these two cultivars have special characteristics of maintaining longer vegetative growth period under both low temperature and long day-length conditions.

In contrast, in case of Ilpumbyeo and Saechucheongbyeo which showed increased thermo-sensitivity and decreased photosensitivity by changing from A-type to B-type classification, the heading date gradually increased according to increasing day-length from 10 to 14 hours, but it sharply increased between 14 to 15 hours of day-length under both 22.5 and 27.5 °C conditions, and especially the slope was more steep in 27.5 °C condition.

The eliminable vegetative phase in natural field condition was calculated by subtracting BVP (Table 1) and 32 days from total growth duration to heading. In this experiment, 32 days were equally applied to all tested cultivars as a common value representing the duration from floral initiation to flowering.

As shown in Table 2, the eliminable vegetative phase under natural field condition in Suwon-city were 27 to 33 days in early maturity group, 44 to 57 days in middle maturity group, 47 to 66 days in mid-late maturity group, and 36 to 46 days in Tongil type rice cultivars. Especially, the eliminable vegetative phase of Sindongjinbyeo (65 days) and Ilpumbyeo (66 days) were the longest ones among tested cultivars under natural field conditions.

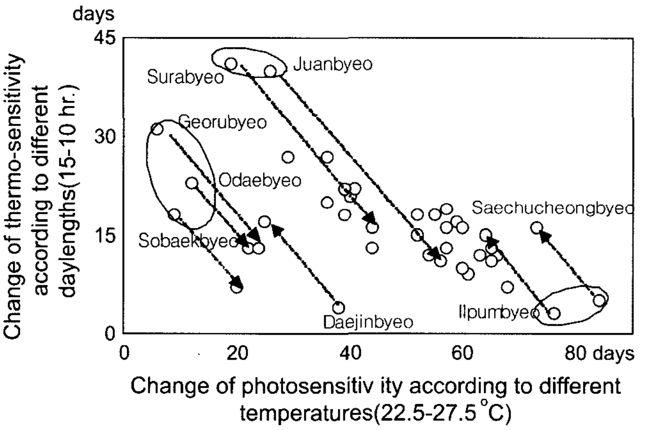


Fig. 4. Changes of thermo-sensitivity and photosensitivity according to classified type A and B in tested rice cultivars.

Temperature-dependent heading response under natural day-length conditions

Changes in thermo-sensitivity according to temperature

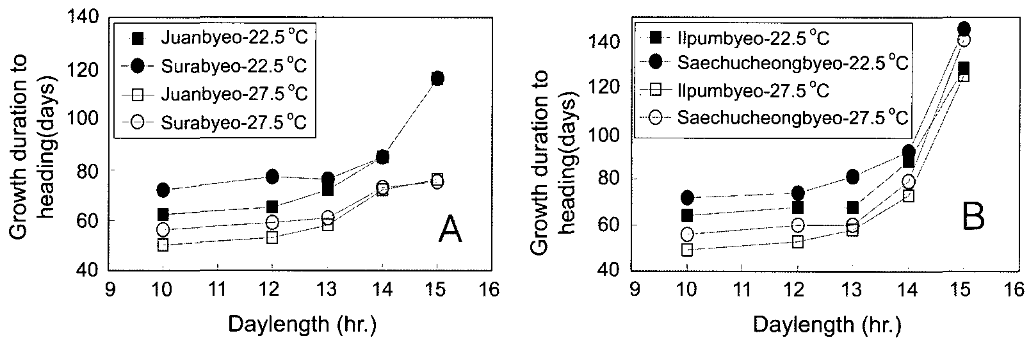


Fig. 5. Decreased thermo-sensitivity and increased photosensitivity in Juanbyeo and Surabyeo (A) and increased thermo-sensitivity and decreased photosensitivity in Ilpumbyeo and Saechucheongbyeo (B) by changing classification from A-type to B-type.

Table 2. Eliminable vegetative periods and heading dates of 20 rice cultivars in paddy field condition in Suwon city.[†]

Cultivars	BVP[‡]	Eliminable vegetative phase in field	Days from panicle initiation to heading	Growth duration to heading	Heading date
			Days		
1. Odaebyeo	30	31	32	93	July 22
2. Daejinbyeo	29	33	32	94	July 23
3. Sobaekbyeo	26	29	32	87	July 16
4. Georubyeo	31	27	32	90	July 19
5. Hwasungbyeo	24	46	32	102	Aug. 1
6. Seoanbyeo	25	50	32	107	Aug. 5
7. Juanbyeo	18	56	32	106	Aug. 4
8. Sobibyeo	17	57	32	106	Aug. 4
9. Kwanganbyeo	30	44	32	106	Aug. 4
10. Surabyeo	24	50	32	106	Aug. 4
11. Ilpumbyeo	17	66	32	115	Aug. 13
12. Daeanbyeo	29	47	32	108	Aug. 6
13. Sampyeongbyeo	25	50	32	107	Aug. 5
14. Saechucheongbyeo	24	60	32	116	Aug. 14
15. Ilmibyeo	27	58	32	117	Aug. 15
16. Donganbyeo	30	52	32	114	Aug. 12
17. Sindongjinbyeo	18	65	32	115	Aug. 13
18. Andabyeo	30	42	32	104	Aug. 2
19. Dasanbyeo	35	36	32	103	Aug. 1
20. Areumbyeo	28	46	32	106	Aug. 4

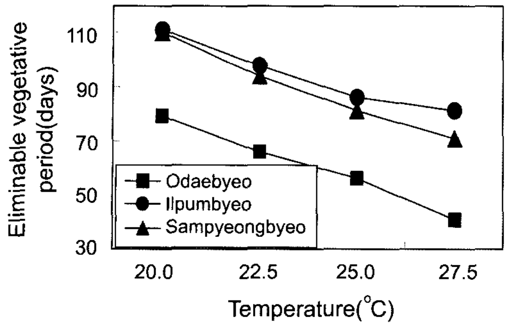
[†]Sowing : Apr. 20, Transplanting : May 25.
[‡]BVP was estimated under mean temperature 27.5 °C and 10hr.' day-length in phytotron.

Table 3. Vegetative growth periods divided into BVP, panicle growth duration to heading, and eliminable growth phase of rice cultivars under different temperature conditions.

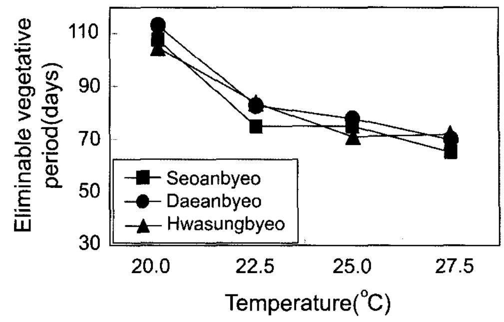
Cultivar	BVP	From panicle initiation to heading(days)	Thermo-sensitivity and photosensitivity(days)				
			20.0	22.5	25.0	27.5	Thermo-sensitivity from 20.0 to 27.5
1. Odaebyeo	30	32	47	34	24	9	38(25)†
2. Daejinbyeo	29	32	-	38	38	21	- (17)
3. Sobaekbyeo	26	32	41	24	13	7	34(17)
4. Georubyeo	31	32	51	32	16	7	44(25)
5. Hwasungbyeo	24	32	73	52	39	40	33(12)
6. Seoanbyeo	25	32	76	43	43	33	43(10)
7. Juanbyeo	18	32	82	61	52	47	35(14)
8. Sobibyeo	17	32	76	59	40	47	29(12)
9. Kwanganbyeo	30	32	67	45	43	36	31(9)
10. Surabyeo	24	32	75	57	48	41	34(16)
11. Ilpumbyeo	17	32	79	66	54	49	30(17)
12. Daeanbyeo	29	32	81	51	46	38	43(13)
13. Sampyeongbyeo	25	32	78	62	49	39	39(23)
14. Saechucheongbyeo	24	32	81	65	55	48	33(17)
15. Ilmibyeo	27	32	76	61	54	45	31(16)
16. Donganbyeo	30	32	72	53	51	38	34(15)
17. Sindongjinbyeo	18	32	83	68	58	55	28(13)
18. Andabyeo	30	32	82	56	54	39	43(17)
19. Dasanbyeo	35	32	59	52	52	30	29(22)
20. Areumbyeo	28	32	68	45	37	31	37(14)
Average	25.9	32	70.9	51.2	43.3	35.0	

[†]The data in parenthesis mean the days of thermo-sensitivity from 22.5 °C to 27.5 °C.

conditions are shown in Table 3. Vegetative periods of all tested cultivars were shortened by the increasing temperature. Most vegetative periods of early maturing cultivars such as Odaebyeo, Sobaekbyeo, Georubyeo were thermo-



(Type-I)



(Type-II)

Fig. 6. Cultivar groups appeared different thermo-sensitivity from 20.0 to 22.5 °C (Type-I: equally decreasing, Type-II: decreasing rapidly between 20.0~22.5 °C).

Table 4. Cultivar groups classified by delayed degree of heading date in 20.0 °C.

Cultivars	Correlation coefficients (Changes of vegetative period according to temperatures)			A-B†
	A (20.0~27.5 °C)	B (22.5~27.5 °C)	A-B (delayed degree in 20 °C)	
1. Odaebyeo	-4.96	-5.00	-0.04	×
2. Daejinbyeo	-	-	-	-
3. Sobaekbyeo	-4.52	-3.40	1.12	△
4. Georubyeo	-5.92	-5.00	0.92	×
5. Hwasungbyeo	-4.48	-2.40	2.08	○
6. Seoanbyeo	-5.16	-2.00	3.16	○
7. Juanbyeo	-4.56	-2.80	1.76	△
8. Sobibyeo	-4.24	-2.40	1.84	△
9. Kwanganbyeo	-3.80	-1.80	2.00	○
10. Surabyeo	-4.44	-3.20	1.24	△
11. Ilpumbyeo	-4.08	-3.40	0.68	×
12. Daeanbyeo	-5.36	-2.60	2.76	○
13. Sampyeongbyeo	-5.20	-4.60	0.60	×
14. Saechucheongbyeo	-4.36	-3.40	0.96	×
15. Ilmibyeo	-4.00	-3.20	0.80	×
16. Donganbyeo	-4.16	-3.00	1.16	△
17. Sindongjinbyeo	-3.76	-2.60	1.16	△
18. Andabyeo	-5.24	-3.40	1.84	△
19. Dasanbyeo	-3.48	-4.40	-0.92	×
20. Areumbyeo	-4.76	-2.80	1.96	△

† ○ : A-B > 2.0, △ : 1.0 < A-B < 2.0, ×: A-B < ±1.0.

sensitivity, and the remaining days except for thermo-sensitivity from vegetative period were only each 9, 7 and 7 days, respectively. The shortened vegetative periods were 28 to 30 days in Sobibyeo, Ilpumbyeo, Sindongjinbyeo, 43 to 44 days in Dasanbyeo, Georubyeo, Daeanbyeo, Andabyeo and 31 to 39 days in other cultivars by temperature differences from 20 to 27.5 °C.

The changes of thermo-sensitivity were divided into two different groups as shown in Table 3. The decreasing vegetative periods were almost equal when the temperature changed from 20.0 °C → 22.5 °C → 25.0 °C → 27.5 °C in 1st group (Type-I). In case of 2nd group (Type-II) cultivars, the vegetative periods slowly decreased only when temperature changed from 22.5 °C → 25.0 °C → 27.5 °C, but decreased rapidly when mean temperature changed from 20.0 °C to 22.5 °C Fig. 6 shows that cultivars Odaebyeo, Ilpumbyeo, Sampyeongbyeo belong to Type-I, while Seoanbyeo, Daeanbyeo, Hwasungbyeo belong to Type-II.

So, based upon the results in Table 3 and Fig. 6, all the tested cultivars were analyzed by comparing the decreased vegetative growth period from 20.0 ~ 27.5 °C to 22.5 ~ 27.5 °C (Table 4). Changes of vegetative period in each temperature difference from 20.0 to 27.5 °C and from 22.5 to 27.5 °C were calculated with regression equations. The difference in regression coefficients between vegetative periods in each temperature conditions from 20.0 to 27.5 °C (A) and from 22.5 to 27.5 °C (B) showed the degree of delayed heading date between 20.0 and 22.5 °C. Delayed heading dates degree from 22.5 °C to 20.0 °C were very small ($< \pm 1.0$) in Odaebyeo, Georubyeo, Ilpumbyeo, Sampyeongbyeo, Chucheongbyeo, Ilmibyeo and Dasanbyeo. Heading date, however, were delayed very much (> 2.0) in case of cultivars Hwasungbyeo, Seoanbyeo, Kwanganbyeo and Daeanbyeo, while the other cultivars were midium types. Therefore, all the cultivars which exhibited heading date delayed greatly only in 20.0 °C could be considered as the cultivars very dangerous in cool summer by late heading.

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