Factors Determining Varietal Differences of Heading Behavior of Wheats

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In southern and central Japan, wheats are usually grown in paddy fields alternately with rice. To make this type of double cropping easy, early ripening varieties of wheat are grown by farmers. Early maturity of wheats has become more and more important because the transplantation season of rice plants has recently been advanced a month or more due to the wide-spread application of transplanting machines. In southern and central Japan, the long rainy season usually starts just before the ripening of wheats, making harvesting works difficult and resulting in the reduced qualities. This is another reason for the predominant cultivation of early varieties of wheat in this part of Japan.

In the long history of wheat improvement in Japan, the early maturity has been the most important of all the breeding purposes. The development of an earlier variety of wheat is not an easy job because the prevailing cultivars in the district are the earliest in heading compared with the cultivars of foreign origin when tested in the climatic condition of the southern and central part of Japan.

In order to cope with this problem, it is necessary to make clear the mechanism which governs the varietal differences in heading of wheat, from the physiological and genetical point of view. As pointed out by Yasuda and Shimoyama,[9] heading behavior of a certain cultivar seems to be determined by three factors; vernalization requirement, response to day-length and response to temperature. The author's experimental results on these three factors will be briefly presented below.

Vernalization requirement

Winter wheats need to undergo a certain period of cold temperature to head normally, while spring wheats can head without encountering such temperature. This phenomenon was first reported by Lysenko[7], and designated as "Vernalization". Although some researchers noticed the presence of intermediate type between true winter and true spring, no foreign researcher classified varieties according to their degree of vernalization requirement. In Japan, Kakizaki and Suzuki[5] classified wheat varieties into 7 classes from the results of their experiment where plant materials were sown in outdoor successively from late winter (in non-heated glasshouse and transplanted in the fields) to early summer. This method was later adopted by Japanese wheat breeders to classify promising lines for the degrees of growth habit, and it was recognized as a reliable method for the evaluation of local adaptability. Certainly, the aim of this classification is to class plant materials by the degree of vernalization requirement, but the observed data are easily influenced by differences of photoperiod and temperature because of outdoor experiment. Taking these circumstances into consideration, the author has established a new method for classifying wheat cultivars by vernalization requirement, based on experiments under controlled conditions.

In the method, 1-leaf seedlings are given vernalization of a certain period at 8°C under continuous illumination of 400–600 lux from Vitalus A lamps. After vernalization, plants are raised at about 20°C under continuous illumination (day-length is supplemented by illumination of about 600 lux) till the main stem of each plant unfolds the flag leaf. If the duration between the end of vernalization and the flag-leaf unfolding is shorter than or equal to 34 days, the plant materials are judged as received a full vernalization. By this method, plants are classed into 7, the same number as of Kakizaki and Suzuki's[5] classification. In this classification, plants, which do not need vernalization, are classed into I and II. Class I plants usually attain flag-leaf unfolding within 30 days after 1-leaf stage without vernalization and do not show any acceleration of development by vernalization treatment, while class II plants usually take 31 to 34 days to attain flag-leaf unfolding without vernalization, but show some degree of acceleration in the development by vernalization treatment. Class III plants need 5 days of vernalization for complete satisfaction of vernalization requirement (as described above, plants are considered to be fully vernalized when they attain flag-leaf unfolding within 34 days after the vernalization treatment), and they need from 35 to 60 days to attain flag-leaf unfolding when they are not vernalized. Class IV plants need 10 to 30 days of vernalization and they need more than 61 days to attain flag-leaf unfolding without vernalization. Class V plants need 35 to 40 days of vernalization, and they need more than 90 days to attain flag-leaf unfolding when they are not vernalized. Class VI plants need vernalization of 45 to 55 days and Class VII plants need vernalization of more than 60 days. These results are shown in Table 1.

When winter is mild, wheat cultivars with high degree of vernalization requirement delay in heading and even fail to head due to the incomplete satisfaction of vernalization requirement. Therefore, in the southern and the central part of Japan, Class I to IV wheats are usually grown, whereas Class IV to VII wheats are usually grown in the northern part of Japan.

Since 1910, much effort has been concentrated on the studies of the inheritance of spring *vs.* winter habit of growth in wheat, and recently four spring habit genes, *Vrn* 1, *Vrn* 2, *Vrn* 3 and *Vrn* 4 have been established by Pugsley[8] and others. These genes are incompletely dominant over winter alleles, and winter wheats have been proved to have only recessive alleles at all these loci. Chromosomal localization of *Vrn* 1 and *Vrn* 3 were studied by Law[6] and others, and it was found that *Vrn* 1 located on Chromosome 5A and *Vrn* 3 located on Chromosome 5D.

Table 1. Criterion for classification of wheat cultivars for the degree of vernalization

Degree of vernalization requirement	Days to flag-leaf unfolding of non-vernalized plants at 20°C under continuous illumination	Necessary duration of cold treatment for the completion of vernalization (days)
I	≦30	
II	31～34	
III	35～60	5
IV	61≦	10～30
V	90≦	35～40
VI	90≦	45～55
VII	90≦	60≦

Genetic studies were made on Japanese spring wheats for growth habit by the author[3] and genes involved were estimated as shown in Table 2. From the result, it was assumed that the main spring habit gene for wheats indigeneous to Japan was *Vrn* 3, and *Vrn* 1 and *Vrn* 2 present in Japanese wheats were introduced into Japanese wheats from foreign wheats through hybridization.

Table 2. A list of spring habit genes of Japanese spring wheats

Cultivar	Spring habit gene involved			
Shinchunaga	*vrn* 1	*vrn* 2	***Vrn*** 3	*vrn* 4
Norin 61	*vrn* 1	*vrn* 2	***Vrn*** 3	*vrn* 4
Ushio Komugi	*vrn* 1	*vrn* 2	***Vrn*** 3	*vrn* 4
Shirasagi Komugi	*vrn* 1	*vrn* 2	***Vrn*** 3	*vrn* 4
Eshima Shinriki	*vrn* 1	*vrn* 2	***Vrn*** 3	*vrn* 4
Konosu 25	***Vrn*** 1	*vrn* 2	***Vrn*** 3	*vrn* 4
Saitama 27	***Vrn*** 1	*vrn* 2	*vrn* 3	*vrn* 4
Haruhikari	***Vrn*** 1	***Vrn*** 2	*vrn* 3	*vrn* 4

Response to day-length

The fact, that the response to day-length is an important factor determining heading behavior of wheats, has been pointed out by several researchers. Especially, in Japan, Hashimoto and Hirano[4] and Yasuda and Shimoyama[9] demonstrated that the early heading of wheats grown in the southern part of Japan largely depended upon their non-responsiveness to short days. To know the difference between the astronomical day-length and the day-length effective to wheats, the author[2] made some experiments. Spring wheat Norin 29, which was highly responsive to short days, was used in the experiments. Twelve hr-days were extended to 16 hr-days by adding 4 hr-illumination of various intensity before or after the high intensity illumination of 12 hrs. A distinctive retardation was noticed on the unfolding of flag-leaf when the intensity of additional 4 hr-light given ahead of 12 hr-illumination was lowered below 20 lux and that given after the 12 hr-illumination was lowered below 10 lux. Therefore, the minimum light intensity effective for wheat at the beginning of a day was estimated to be about 20 lux and that at the end of a day about 10 lux. From this result, and comparing with the transition of light intensity during twilight, the effective day-length for wheat at Fukuyama (34°30′ N) was estimated to be about 50 min. longer than the astronomical day-length. As the duration of twilight is approximately proportional to the peripheral velocity of the earth surface, the effective day-length for wheat at a certain place can be estimated from the latitude there. In this way, the effective day-length for wheat in southern and central Japan was estimated to be 12 hrs for two months before heading, 13 hrs for one month before heading and 14 hrs for the heading time.

Therefore, the responses of wheat varieties to 12, 13 and 14 hr day-length were compared at constant 20°C, with the heading date in outdoor conditions. The correlation coefficient with heading outdoors was the highest with 12 hr day-length (Table 3), which was the day-length when spike primordia began to grow. Thus the importance of non-responsiveness of early varieties to short days was ascertained.

Table 3. Correlation coefficients between days to flag-leaf unfolding of cultivars tested at different day-length and heading date outdoors

	12 hr-day	13 hr-day	14 hr-day
Heading date outdoors	+0.735**	+0.705**	+0.548**

Note) The average values of experiment 1966–67 and experiment 1967–68 are presented here.

Response to temperature

The correlation coefficient between days to flag-leaf unfolding under 12 hr-day at 20°C and days to heading under field condition was relatively high, but the agreement was not so good as expected. One more factor other than response to day-length, response to temperature seemed to be involved in the expression of varietal difference of heading date even after the completion of vernalization process. Therefore, the author carried out experiments to analyze the effect of temperature on the varietal

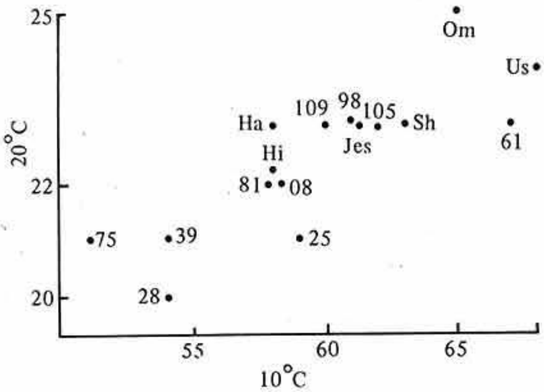

Fig. 1. Comparison of days to flag-leaf unfolding of cultivars tested at different temperatures.

Note) Names of cultivars are abbreviated as follows: 75: Kanto 75, 39: Himekei 1939, 28: Chukei 2028, 81: Chugoku 81, 08: Himekei 2008, 25: Konosu 25, Hi: Hiyoku Komugi, Ha: Hashiri Komugi 3, 109: Taichung 109, 98: Chugoku 98, Jes: Jessore, Sh: Shirasagi Komugi, 105: Chugoku 105, Om: Omasa Komugi, 61: Norin 61, Us: Ushio Komugi. Wheat plants vernalized for 40 days were tested in this experiment differences of days to flag-leaf unfolding. The experimental materials consisted of wheat cultivars grown in southern and central Japan. In these experiments, fully vernalized young plants were grown at three different temperature levels, 10°C, 15°C and 20°C with 12 hr day-length, and days to flag-leaf unfolding were compared among the three temperature levels. As shown in Fig. 1, varietal differences between the earliest cultivar and the latest cultivar was 17 days at 10°C, whereas, it was only 5 days at 20°C. In the field condition of southern and central Japan, heading of Chugoku 98 was about 6 days earlier than Norin 61 and at 10°C the unfolding of flag-leaf of Chugoku 98 was also 6 days earlier than Norin 61, but both cultivars attained the flag-leaf unfolding at almost the same date at 20°C. These data suggest that the physiological characteristic, through which the development can proceed even under relatively low temperature, is an important factor for early heading of wheat cultivars in southern and central Japan, in addition to the non-responsiveness to short day.

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