Phenological Development in Relation to Temperature of Winter Wheat Iwainodaichi Seeded Early in Southwestern Japan

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Abstract: The phenological development of winter wheat Iwainodaichi seeded early was compared with that of spring wheat Chikugoizumi based on the temperature. In this paper, the developmental phase from the sowing to double ridge is referred to phase 1, that from double ridge to anthesis phase 2 and that from the anthesis to maturity phase 3. The duration of phase 1 in Iwainodaichi was almost constant independent of the mean temperature in this phase, but that in Chikugoizumi decreased as the mean temperature in this phase increased. When seeded early, the duration of phase 1 was obviously longer in Iwainodaichi than in Chikugoizumi since the mean temperature in this phase was higher when seeded early. The duration of phase 2 decreased in both varieties as the mean temperature and photoperiod in this phase increased. When seeded early, phase 2 was shorter in Iwainodaichi than in Chikugoizumi, since the mean temperature was higher and photoperiod longer in this phase in Iwainodaichi than in Chikugoizumi. The duration of phase 3 decreased as the mean temperature in this phase increased in both varieties and was shorter in Iwainodaichi than in Chikugoizumi at the same mean temperature. Consequently, Iwainodaichi reached the double ridge stage later but reached maturity at about the same time as Chikugoizumi when seeded early.

Key words: Early sowing, Phenological development, Photoperiod, Spring wheat, Temperature, Winter wheat.

Early maturity is the most important trait for wheat cultivation in southwestern Japan since rainfall during the late ripening stage often degrades grain quality. Early sowing facilitates early maturity. However, early sowing of conventional spring wheat causes the stem to elongate rapidly during winter, resulting in frost injury. Winter wheat is less prone to suffer frost injury than spring wheat, since the stem elongation is not accelerated even if it is sown early (Inamura et al., 1958). A winter wheat, “Iwainodaichi” recently developed in the National Agricultural Research Center for Kyushu Okinawa Region, is a prospect for early sowing (Fujita, 1997; Taya et al., 2003). However, the specific characteristics suitable when seeded early are not fully understood except for the tolerance to frost injury (Fukushima et al., 2003).

In order to develop cultivation technology suitable for early sowing, it is necessary to understand the phenological development of wheat plant. Winter wheat Iwainodaichi reaches the double ridge stage later than, but matures at almost the same time as spring wheat Chikugoizumi when seeded early (Fukushima et al., 2001). However, the effects of environmental factors such as temperature and photoperiod on each developmental stage are not fully understood. Phenological development of the wheat plant can be divided by several stages, depending on the research objective. Early stem elongation and heading are often used since these stages can easily be distinguished (Yoshida et al., 1985). In the present study, the double ridge stage and anthesis, which are the starting points of reproductive growth and grain filling, were used. In this paper, the developmental stage from sowing to double ridge is called phase 1, that from double ridge to anthesis phase 2 and that from anthesis to maturity phase 3. Each phase responds to environmental factors differently (Slafer and Rawson, 1994). Among the environmental factors, temperature is considered to be the most important and universal one. The objectives of this study is to clarify the effects of temperature on each developmental phase of winter wheat Iwainodaichi when seeded early. The effects of the photoperiod are also discussed when temperature alone cannot fully explain the phenological development of wheat plants.

Materials and Methods

Fifteen field experiments were conducted over a five-year period (1998/1999 to 2002/2003) in a paddy field (gray lowland soil) at the National Agricultural Research Center for Kyushu Okinawa Region (Chikugo City, Japan; 33°11’ N latitude, 130°31’ E longitude). Sowing dates ranged from late October to early December (Table 1). Winter wheat Iwainodaichi (Taya et al., 2003) and spring wheat Chikugoizumi (Ujihara et al., 1995) were used in the present experiments.

A randomized complete block design with three replications was used in all experiments. The plots were approximately 20 m², each consisting of a 1.3 m wide ridge with four rows 22 cm apart. The sowing rate was 160 grains m⁻². Chemical fertilizer was applied as a basal dressing at a rate of 5.0 g m⁻² for N, P₂O₅, and...
When the fifth leaf was fully emerged and the eighth leaf was half emerged, chemical fertilizer was applied as topdressing at a rate of 3.0g m\(^{-2}\) for N, P\(_2\)O\(_5\), and K\(_2\)O.

The six main shoots were randomly sampled every three to seven days and the double ridge stage was judged under a stereoscopic microscope by the method of Porter et al. (1987). Date of anthesis was scored when half or more of the shoots flowered. Date of maturity was recorded when the grain moisture content decreased to 25%. Daily mean temperature was obtained from the meteorological equipment installed in the research center. The photoperiod was calculated using the function described by Jones (1992). Fig. 1 presents the seasonal changes of mean temperature and calculated photoperiod in Chikugo City, Japan.

### Table 1. Phenological development of two wheat varieties with different sowing dates.

| Year of sowing | Sowing | Varieties  | Double ridge stage | Anthesis | Maturity |
|----------------|--------|-----------|---------------------|----------|---------|
| 1998           | 10/26 (verly early) | Iwashidaichi | 1/2 | 4/8 | 5/22 |
|                |        | Chikugoizumi | 12/4 | 3/26 | 5/17 |
|                | 11/5 (early) | Iwashidaichi | 1/13 | 4/9 | 5/23 |
|                |        | Chikugoizumi | 12/18 | 4/4 | 5/21 |
|                | 11/24 (standard) | Iwashidaichi | 2/4 | 4/18 | 5/27 |
|                |        | Chikugoizumi | 1/31 | 4/17 | 5/28 |
| 1999           | 10/25 (verly early) | Iwashidaichi | 1/8 | 4/14 | 5/25 |
|                |        | Chikugoizumi | 12/8 | 4/11 | 5/23 |
|                | 11/5 (early) | Iwashidaichi | 1/15 | 4/18 | 5/26 |
|                |        | Chikugoizumi | 12/26 | 4/16 | 5/27 |
|                | 11/30 (standard) | Iwashidaichi | 2/11 | 4/25 | 5/31 |
|                |        | Chikugoizumi | 2/11 | 4/24 | 6/1 |
| 2000           | 10/27 (verly early) | Iwashidaichi | 1/7 | 4/7 | 5/21 |
|                |        | Chikugoizumi | 12/12 | 4/5 | 5/20 |
|                | 11/7 (early) | Iwashidaichi | 1/13 | 4/11 | 5/22 |
|                |        | Chikugoizumi | 12/24 | 4/9 | 5/22 |
|                | 11/27 (standard) | Iwashidaichi | 2/12 | 4/16 | 5/27 |
|                |        | Chikugoizumi | 2/12 | 4/15 | 5/26 |
| 2001           | 11/8 (early) | Iwashidaichi | 1/16 | 4/5 | 5/18 |
|                |        | Chikugoizumi | 12/27 | 4/1 | 5/19 |
|                | 11/22 (standard) | Iwashidaichi | 2/3 | 4/11 | 5/21 |
|                |        | Chikugoizumi | 1/28 | 4/8 | 5/21 |
|                | 12/5 (late) | Iwashidaichi | 2/13 | 4/16 | 5/24 |
|                |        | Chikugoizumi | 2/10 | 4/14 | 5/24 |
| 2002           | 11/6 (early) | Iwashidaichi | 1/17 | 4/14 | 5/22 |
|                |        | Chikugoizumi | 12/26 | 4/11 | 5/22 |
|                | 11/20 (standard) | Iwashidaichi | 2/7 | 4/19 | 5/25 |
|                |        | Chikugoizumi | 1/30 | 4/18 | 5/26 |
|                | 12/10 (late) | Iwashidaichi | 2/21 | 4/23 | 5/29 |
|                |        | Chikugoizumi | 2/23 | 4/21 | 5/29 |
| Average        | 11/5 (early) | Iwashidaichi | 1/14 | 4/11 | 5/22 |
|                |        | Chikugoizumi | 12/23 | 4/8 | 5/22 |
|                | 11/24 (standard) | Iwashidaichi | 2/7 | 4/17 | 5/26 |
|                |        | Chikugoizumi | 2/3 | 4/16 | 5/26 |

Date (month/day).
Results and Discussion

In both varieties, the earlier the sowing date, the earlier the date of double ridge stage, anthesis and maturity. The differences in the date of each developmental stages between different sowing dates decreased as the developmental stage progressed (Table 1). The date of the double ridge stage when seeded early was clearly later in Iwainodaichi than in Chikugoizumi, although it did not differ significantly when seeded on the standard date. Phase 2 was prolonged by early sowing compared with standard sowing and was shorter in Iwainodaichi than in Chikugoizumi when seeded early (Table 2). Accordingly, the date of anthesis was hastened six to eight days by early sowing compared with standard sowing and was three days later in Iwainodaichi than in Chikugoizumi when seeded early. Phase 3 was prolonged by early sowing compared with standard sowing and was longer in Chikugoizumi than in Iwainodaichi. Consequently the date of maturity was May 22 for both varieties when seeded early and was May 26 for both varieties when seeded at standard date. These results show that the early sowing enabled both Iwainodaichi and Chikugoizumi to mature four days earlier compared with standard sowing. In addition, our study revealed that Iwainodaichi had a longer phase 1 but shorter phases 2 and 3 compared with Chikugoizumi when seeded early (Table 2). We analyzed these varietal differences in relation to the response to temperature.

Although the duration from sowing to anthesis (phases 1 + 2) was independent of the mean temperature in phase 1 + 2 in both varieties (Fig. 2a), the durations of phase 1 and phase 2 seemed to vary with the mean temperature. The duration of phase 1 in Iwainodaichi was almost constant independent of the mean temperature, but that in Chikugoizumi decreased linearly as the mean temperature increased (Fig. 2b). Porter et al. (1987) reported that winter wheat did not exhibit a clear relationship between the duration of phase 1 and the mean temperature in this phase because of the vernalization requirement. In spring wheat, however, the duration of phase 1 decreased as the mean temperature increased (Takahashi and Nakaseko, 1992; Eguchi and Shimada, 2000). In our study, the double ridge stage of winter wheat Iwainodaichi was delayed by early sowing compared with spring wheat Chikugoizumi (Table 2) because the mean temperature of phase 1 in early sowing was high and the winter wheat required vernalization. The effect of the mean photoperiod on the duration of phase 1 was not clear since the photoperiod in phase 1 varied less with the change in sowing date compared with that in phase 2 (Fig. 3).

The duration of phase 2 decreased linearly as the mean temperature increased in Iwainodaichi as well as in Chikugoizumi (Fig. 2c), probably because phase 2 has little or no vernalization requirement (Flood and Halloran, 1986; Porter et al., 1987). The duration of phase 2 was also closely related to the mean photoperiod in both varieties (Fig. 3b). These results suggest that a high temperature and/or long photoperiod accelerated the development of young spikes. However, it was difficult to evaluate the response to temperature and photoperiod separately since the mean temperature and photoperiod in phase 2 increased similarly as the date of double ridge stage became delayed (Fig. 1). When seeded early, the temperature was higher and photoperiod longer in Iwainodaichi than in Chikugoizumi (Table 2). The higher temperature and/or longer photoperiod seemed to be responsible for the shorter

| Table 2. Duration, temperature and photoperiod for each developmental phase for early and standard sowing. |
|---------------------------------------------------------------|
| **sowing** | **variety** | **Duration** | **Mean temperature** | **Mean photoperiod** |
| date | | Phase 1 (days) | Phase 2 (days) | Phase 3 (days) | Phase 1 (°C) | Phase 2 (°C) | Phase 3 (°C) | Phase 1 (hour) | Phase 2 (hour) | Phase 3 (hour) |
| early | Iwainodaichi | 70 | 87 | 41 | 8.7 | 8.4 | 17.7 | 9.99 | 11.22 | 13.31 |
| | Chikugoizumi | 48 | 106 | 44 | 10.0 | 7.8 | 17.4 | 10.04 | 10.91 | 13.26 |
| standard | Iwainodaichi | 75 | 70 | 38 | 6.8 | 10.0 | 18.5 | 10.00 | 11.60 | 13.46 |
| | Chikugoizumi | 71 | 70 | 40 | 6.9 | 9.7 | 18.4 | 9.98 | 11.61 | 13.44 |

Phase 1: From sowing to double ridge. Phase 2: From double ridge to anthesis. Phase 3: From anthesis to maturity. *: Significant at the 0.05 level. **: Significant at the 0.01 level. NS: Not significant.
duration of phase 2 in Iwainodaichi when seeded early. The duration of phase 3 decreased as the mean temperature increased in both varieties and was shorter in Iwainodaichi than in Chikugoizumi at the same mean temperature (Fig. 2d). Phase 3 is simplest to analyze because temperature appears to be the only major factor affecting its duration (Slafer and Rawson, 1994). Our results showed that phase 3 was three days shorter in Iwainodaichi than in Chikugoizumi when seeded early (Table 2). This short phase 3 in Iwainodaichi is a desirable trait for early maturity, although a short phase 3 could reduce the grain yield (Yoshida et al., 1985).

In conclusion, Iwainodaichi developed to the double ridge stage later than but reached maturity at about the same time as Chikugoizumi when seeded early. These varietal differences in phenological development seemed to be attributed to the differential response in phases 1 and 3.

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