Investigation of Yielding Ability of Wheat Cultivars for Early-Sowing Cultivation in Yamaguchi

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Abstract: The spring-type cultivar (Triticum aestivum L.) is usually sown in November. However, the sowing time is sometimes delayed considerably because of much rain in October, and the seed bed does not become suitably dry for sowing due to cold temperature. To find a solution to this problem, we compared the yielding ability of wheat sown early (early-sown group) with wheat sown at the standard date (standard group) in Yamaguchi. The grain yield for nine cultivars averaged for three growing seasons, 1999/2000, 2001/2002 and 2002/2003 was 230 gm⁻² in the early-sown group, and significantly lower than that in the standard group (334 gm⁻²). The spike number and grain number per spike were lower in the early-sown group than in the standard group. Akitakko, Iwainodaichi, Airakomugi had a higher grain yield, and Akitakko had a higher spikelet number per spike and higher grain number per spike than the other cultivars when sown earlier. Iwainodaichi showed higher spike number when sown earlier. Airakomugi showed higher grain number per spike and grain weight when sown earlier. Akitakko was the only cultivar that showed a higher grain yield by early sowing.

Key words: Early-sown, Grain number per spike, Grain weight, Grain yield, Spike number, Wheat cultivar, Winter habit.

In the conventional wheat cultivation, spring-type cultivar is sown in mid- or late-November and is harvested in early-June in Yamaguchi. November is sometimes too late to prepare the seed bed, because it is cold, and the soil is wet. If we have much rain, the sowing time is delayed considerably. A long rain in November 1997 caused poor emergence of wheat in Yamaguchi (Yamamoto et al., 1999). In the worst case, wheat cultivation is impossible in such a season.

Early sowing is a measure to avoid the influence of much rain in November. Because of the higher temperature, the soil after rain dries more quickly in October than in November. Moreover, earlier sowing usually results in earlier harvesting, which reduces the risk of harvesting during the rainy season and the season just before planting the rice. Based on the weather data in Fukuoka, 120 km from Yamaguchi, Kisakibaru et al. (1983) reported that if the sowing time were advanced to late-October we could do the sowing and the harvesting more easily.

The spring-type cultivars are not suitable for early sowing because the warm temperature at the juvenile phase stimulates the growth apex toward reproductive growth. Thus, too early growth causes frost damage (Fukushima et al., 2003a). Some researchers have looked for the way to spread the early sowing cultivation with spring-type cultivars, but they could not find any good cultivars for that (Kisakibaru et al., 1983; Manabe et al., 1983).

The winter-type cultivar was suggested to be suitable for early sowing in the western area in Japan (Taya, 1993; Fujita, 1995). Recently, a new cultivar “Iwainodaichi”, which is a winter-type and its jointing stage is not advanced by early sowing, was produced (Taya et al., 2003).

The objective of this study was to investigate the effect of sowing the seed early on the yielding ability of nine wheat cultivars with different degrees of winter habit and from different areas in Japan. We searched for cultivars showing higher yielding ability in the early-sown group in Yamaguchi.

Materials and methods

1. Cultivation of materials

Field experiments were conducted at the Experimental Farm of Faculty of Agriculture, Yamaguchi University in three growing seasons, 1999/2000, 2001/2002, and 2002/2003. The yielding ability and growth traits for early sowing cultivation of the nine wheat cultivars were compared with conventional cultivation, as we call standard group.

Table 1 shows the degree of winter habit and the cultivated district of the nine wheat cultivars. Hokushin, Akitakko and Nanbukomugi have a winter habit and are cultivated in northern Japan. Iwainodaichi and Airakomugi have an intermediate
habit and are cultivated in southern Japan. Norin 61, Haruyutaka and Harunoakebono have a spring habit and are cultivated throughout Japan. Selpek also has a spring habit, but is cultivated in Germany. Table 2 shows the dates of sowing early and the standard group in each season. Four hundred seeds per square meter were sown in rows with 20-cm row spacing, and the seedlings expanding two or three leaves were thinned to 200 plants per square meter. Fertilizer was applied only as basal dressing therein all growing seasons at a rate of 16 gm\(^{-2}\) of N, 10 gm\(^{-2}\) of P\(_2\)O\(_5\), and 8 gm\(^{-2}\) of K\(_2\)O.

2. Determination of the dates of anthesis and maturity

The date of anthesis was regarded as the date when half of the plants anthered, and the date of maturity as the date when grains had become hard enough not to be split easily with the fingernails.

3. Measurement of yielding ability

Grain yield, biomass yield, harvest index and yield components were measured in three replications of 0.6 m\(^2\) plots. These plots are arranged in a randomized block design. All plants in each plot were cut off at the ground level and their spike numbers were counted. Thirty of the spikes were randomly selected to determine spikelet number in 2001/2002 and 2002/2003. All the plants were dried for 48 hours at 80°C and weighed to determine the biomass yield. All spikes were hand-threshed to determine grain yield and 1000 grain weight. The harvest index was calculated as the grain yield divided by biomass yield. The number of grains per spike was also calculated from grain yield, spike number and 1000 grain weight.

Table 1. The degree of winter habit and site of cultivation for nine wheat cultivars.

| Cultivar       | Degree of winter habit | Raised place |
|----------------|------------------------|--------------|
| Hokushin       | Winter                 | Hokkaido     |
| Akitakko       | Winter                 | Tohoku       |
| Nanbukomugi    | Winter                 | Tohoku       |
| Iwainodaichi   | Intermediate           | Kyushu       |
| Airakomugi     | Intermediate           | Kanto        |
| Norin61        | Spring                 | Kyushu       |
| Haruyutaka     | Spring                 | Hokkaido     |
| Harunoakebono  | Spring                 | Hokkaido     |
| Selpek         | Spring                 | Germany      |

throughout the three growing seasons was 230 gm\(^2\) in the early-sown group, which was significantly lower than that (334 gm\(^2\)) in the standard group. Akitakko was the only cultivar with a higher grain yield in the early-sown group than in the standard group. Throughout the three growing seasons, Akitakko, Iwainodaichi and Airakomugi had a higher grain yield, than the other cultivars in the early-sown group, while Iwainodaichi, Airakomugi, and Norin 61 showed a higher one in the standard group. The 297 gm\(^2\) of Akitakko was the highest among all cultivars in the early-sown group, but it was lower than the average of 334 gm\(^2\) in the standard group. Norin 61 and Harunoakebono in the early-sown group were only 41% and 45% of those in the standard group, respectively, because many of spikes in main stems died of too-early heading and coldness in the early-sown group.

Table 4 shows the average biomass yield and harvest index for nine cultivars and three growing seasons in the early-sown group and the standard group. Biomass yield in the early-sown group did not significantly differ from that in the standard group, although only Akitakko in the early-sown group showed a 23% higher yield than in the standard group. There were significant differences in the biomass yield among cultivars both in the early-sown group and the standard group. The yield in Airakomugi, Haruyutaka and Selpek was higher than that in the other cultivars in the early-sown group, while that in Iwainodaichi, Airakomugi, Norin 61, Haruyutaka, Harunoakebono and Selpek was higher than that in the other cultivars in the standard group.

The harvest index was 26% lower in the early-sown group than in the standard group. There were also significant differences in the harvest index among cultivars both in the early-sown group and in the standard group. Akitakko and Iwainodaichi had a higher harvest index than that in the other cultivars in the early-sown group, while that in Iwainodaichi, Airakomugi and Norin 61 was higher in the standard group.

Table 5 shows the yield components in the early-sown group and the standard group for nine cultivars averaging three growing seasons. Spike number was significantly 16% fewer in the early-sown group than in the standard group. There was a significant difference

Table 2. Dates of sowing in the three growing seasons.

| Growing season | Early-sown group | Standard group |
|----------------|------------------|----------------|
| 1999/2000      | 11 Oct.          | 3 Dec.         |
| 2001/2002      | 4 Oct.           | 21 Nov.        |
| 2002/2003      | 1 Oct.           | 19 Nov.        |

Table 3 shows the grain yield in the nine cultivars sown earlier (early-sown group) and those sown at the standard date (standard group) in the three growing seasons. The average grain yield for all cultivars
among cultivars only in the early-sown group. Hokushin, Akitakko, Iwainodaichi and Selpek were more than the other cultivars in the early-sown group. The grain number per spike was 19% lower in the early-sown group than in the standard group. There were significant differences among cultivars both in the early-sown group and in the standard group. Akitakko, Iwainodaichi, Airakomugi and Haruyutaka

Table 3. Grain yield (gm$^{-2}$) in nine cultivars in the early-sown group and the standard group in the three growing seasons.

| Cultivar | 1999/2000 Early-sown group | Standard group | 2001/2002 Early-sown group | Standard group | 2002/2003 Early-sown group | Standard group | 3 seasons avg. Early-sown group | Standard group |
|----------|-----------------------------|----------------|-----------------------------|----------------|-----------------------------|----------------|-------------------------------|----------------|
| Hokushin | 190                          | 318            | 105                         | 127            | 297                         | 317            | 197                           | 254            |
| Akitakko | 366                          | 386            | 163                         | 151            | 362                         | 235            | 297                           | 257            |
| Nanbukomugi | 215                      | 376            | 114                         | 156            | 303                         | 437            | 211                           | 323            |
| Iwainodaichi | 347                     | 519            | 151                         | 256            | 338                         | 500            | 279                           | 445            |
| Airakomugi | 372                        | 554            | 176                         | 292            | 321                         | 444            | 290                           | 400            |
| Norin61   | 144                         | 515            | 147                         | 273            | 200                         | 419            | 164                           | 402            |
| Haruyutaka | 254                      | 404            | 137                         | 144            | 320                         | 398            | 237                           | 315            |
| Harunoakebono | 175                    | 371            | 91                          | 221            | 183                         | 398            | 150                           | 330            |
| Selpek    | 327                         | 307            | 114                         | 145            | 300                         | 388            | 247                           | 280            |
| Average   | 266                         | 417            | 133                         | 186            | 292                         | 400            | 230                           | 334            |

F-test

| Source | Cultivar | Sowing | Season | Cultivar x Season |
|--------|----------|--------|--------|-------------------|
|        | NS       | **     | NS     | NS                |
| Cultivar | *        | **     | NS     | **                |
| Sowing  | NS       | **     | NS     | **                |
| Season  | NS       | NS     | **     | **                |
| Cultivar x Season | MS       | NS     | NS     | **                |

**: Significant at the 1% level. *: Significant at the 5% level. NS: No significant.

Table 4. Biomass yield (gm$^{-2}$) and harvest index in nine cultivars in the early-sown group and the standard group averaged for three growing seasons.

| Cultivar       | Biomass yield Early-sown group | Standard group | Harvest index Early-sown group | Standard group |
|----------------|--------------------------------|----------------|--------------------------------|----------------|
| Hokushin       | 744                            | 735            | 26.0                           | 33.8           |
| Akitakko       | 986                            | 801            | 30.4                           | 32.0           |
| Nanbukomugi    | 783                            | 887            | 26.7                           | 36.0           |
| Iwainodaichi   | 880                            | 1055           | 32.1                           | 41.9           |
| Airakomugi     | 1049                           | 992            | 25.7                           | 39.3           |
| Norin61        | 764                            | 1036           | 24.1                           | 38.7           |
| Haruyutaka     | 1003                           | 1085           | 23.3                           | 27.9           |
| Harunoakebono  | 899                            | 1130           | 16.7                           | 28.9           |
| Selpek         | 1188                           | 1059           | 20.6                           | 25.9           |
| Average        | 922                            | 976            | 25.1                           | 33.8           |

F-test

| Source                | Cultivar | Sowing | Season | Cultivar x Season |
|-----------------------|----------|--------|--------|-------------------|
| Cultivar              | **       | NS     | **     | NS                |
| Sowing                | NS       | **     | NS     | NS                |
| Season                | NS       | NS     | **     | **                |
| Cultivar x Season     | MS       | NS     | NS     | **                |

**: Significant at the 1% level. *: Significant at the 5% level. NS: No significant.
were more than the other cultivars in the early-sown group. Hokushin and Selpek was much lower than that in the other cultivars in the standard group.

Although grain weight in the early-sown group did not significantly differ from that in the standard group, there were significant differences among cultivars both in the early-sown group and in the standard group. Haruyutaka had a markedly lighter weight than the other cultivars both in the early-sown group and in the standard group.

Table 6 shows the spikelet number per spike in the early-sown group and the standard group average of three growing seasons.

Table 5. Yield components in nine cultivars in the early-sown group and the standard group average of three growing seasons.

| Cultivar     | Spike number (m⁻²) | Grains per spike | 1000 grain weight |
|--------------|-------------------|-----------------|------------------|
|              | Early-sown group  | Standard group  | Early-sown group | Standard group  | Early-sown group | Standard group  |
| Hokushin     | 448               | 423             | 16.1             | 20.7            | 26.2             | 27.8             |
| Akitakko     | 420               | 411             | 22.4             | 25.0            | 30.5             | 24.7             |
| Nanbukomugi  | 334               | 389             | 18.0             | 24.5            | 33.4             | 32.2             |
| Iwainodaichi | 449               | 562             | 20.1             | 24.5            | 30.2             | 31.7             |
| Airakomugi   | 381               | 550             | 21.4             | 23.7            | 32.6             | 29.6             |
| Norin61      | 379               | 515             | 16.9             | 26.9            | 26.9             | 28.8             |
| Haruyutaka   | 372               | 527             | 28.2             | 24.5            | 20.8             | 22.8             |
| Harunoakebono| 356               | 441             | 14.0             | 24.0            | 31.0             | 30.8             |
| Selpek       | 24                | 426             | 16.8             | 20.2            | 33.9             | 31.7             |
| Average      | 396               | 471             | 19.3             | 23.8            | 29.5             | 28.9             |

Table 6. Spikelet number per spike in nine cultivars in the early-sown group and the standard group in 2001/2002 and 2002/2003.

| Cultivar     | 2001/2002 | T-test | 2002/2003 | T-test |
|--------------|-----------|--------|-----------|--------|
|              | Early-sown group | Standard group | Early-sown group | Standard group |
| Hokushin     | 18.6      | 20.5   | NS        | 19.3    | 23.1   | *        |
| Akitakko     | 18.7      | 19.7   | NS        | 20.2    | 21.8   | **       |
| Nanbukomugi  | 18.4      | 19.7   | NS        | 18.7    | 21.1   | NS       |
| Iwainodaichi | 18.0      | 17.0   | NS        | 19.7    | 18.8   | NS       |
| Airakomugi   | 18.0      | 16.7   | NS        | 15.9    | 19.2   | *        |
| Norin61      | 14.5      | 17.4   | NS        | 11.5    | 18.9   | *        |
| Haruyutaka   | 19.1      | 19.1   | NS        | 15.2    | 20.4   | **       |
| Harunoakebono| 15.8      | 22.7   | **        | 16.0    | 23.2   | **       |
| Selpek       | 20.4      | 21.0   | NS        | 18.6    | 26.2   | NS       |
| Average      | 17.9      | 19.3   | NS        | 17.2    | 21.4   | **       |

**: Significant at the 1% level. *: Significant at the 5% level. NS: No significant.
standard group in 2002/2003. The spikelet number per spike in Harunoakebono significantly (at 1% level) decreased by the early sowing both in 2001/2002 and 2002/2003, but that in Haruyutaka only in 2002/2003.

Table 7 shows the grain number per spikelet in the nine cultivars in the early-sown group and the standard group in 2001/2002 and 2002/2003. The grain number per spikelet did not significantly differ between the early-sown group and the standard group in either 2001/2002 or 2002/2003, although that in Airakomugi was 26% lower in the early-sown group than in the standard group in 2001/2002.

Table 8 shows the average dates of anthesis and maturity in the nine cultivars for three growing seasons in the early-sown group and the standard group. The anthesis date was more than seven days earlier in the early-sown group than in the standard group, and the maturity date was about a month after anthesis for all cultivars. Fig. 1 shows the precipitation and average temperature in the three growing seasons and in a common year. November in 1999/2000 had more precipitation than in a common year. Thus we could not sow the seeds in November. The temperature from late-October to mid-November was 2°C lower in 2002/2003 than in a common year.

**Discussion**

The average grain yield for three growing seasons was lower in the early-sown group than in the standard group in all cultivars except for Akitakko (Table 3). Iwainodaichi, Airakomugi and Akitakko seemed to be more appropriate than the other cultivars for early sowing, because they showed a higher spike number,
grain number per spike and grain yield than the others.

Norin 61 and Harunoakebono having a spring habit showed extremely lower grain yield because of an extremely low grain number per unit area. Most of their main stems died of winter coldness during the spike-developing stage. Therefore, the date of anthesis of those cultivars was recorded as the date when anthers developed after the death of main stem. As a result, they had an anthesis date close to the others (Table 8).

Winter-habit cultivars were vernalized earlier in 2002/2003 than in the other seasons, because the temperature was 2°C lower in 2002/2003 than in a common year (Fig. 1). This accelerated anthesis and maturity by 1-4 days in 2002/2003.

Fujita (1995) showed that there is an optimum sowing time for all wheat cultivars with a spring habit or winter habit, so that earlier or later sowing resulted in lower yield. He further showed that even the yield of winter wheat was reduced by earlier sowing because of fertilizer shortage during the vegetative growth. Manabe (1983) observed that too vigorous vegetative growth decreased the relative growth rate after anthesis and grain growth efficiency. In our experiments most cultivars, even a winter wheat, showed lower a harvest index and lower grain yield in the early-sown group, because biomass yield was not increased by early sowing. Nevertheless only Akitakko increased grain yield in the early-sown group increasing its biomass yield.

The spike number and grain number per spike, that is, the grain number per unit area was largely decreased by the early-sown group, and the grain yield was also decreased (Table 5). The spike number corresponds to the number of well-grown tillers. Longer vegetative growth in the early-sown group is expected to increase the tiller number in the early-sown group. However, too vigorous vegetative growth during autumn resulted in development of many non-productive tillers, which competed with each other and lowered the harvest index throughout the three growing seasons. The grain number per spike was 19% lower in the early-sown group than in the standard group. Taya (1993) reported that the earlier the maturation, the fewer the grain number per spike and the lower the grain yield in western Japan. The spring cultivars had a smaller leaf area index (LAI) under lower temperature, because the lower temperature could not give the developing leaf enough assimilate. In this experiment, all cultivars matured more than a week earlier (Table 8), and had a smaller number of spikelets per spike (Table 6) in the early-sown group than in the standard group. The LAI was higher in the early-sown group because it increased under a higher temperature condition in autumn, but rapid leaf expansion (high LAI) caused excessive competition for assimilate among developing spikes.

Winter wheat may not be damaged by cold temperature because spikes do not develop until the plant is exposed to an extremely cold temperature. Fukushima et al. (2003b) suggested that winter wheat was better for early sowing than spring wheat because winter wheat showed slow jointing following the coldest period, even though the seeds were sown in early autumn, and because the slow jointing of winter wheat resulted in many tillers even when sown early. Fukushima et al. (2003a) observed that Iwainodaichi sown early hardly suffered from cold damage while the spring-habit cultivar Chikugoizumi sometimes did. They also found that Iwainodaichi had a long period before anthesis when sown early, so it could have many spikes even if anthesis was early (Fukushima et al., 2001a). However, the spike number of Iwainodaichi and Airakomugi, intermediate winter-habit cultivars, was 20% and 31%, respectively, lower in the early-sown group than in the standard group, and that in Akitakko and Hokushin, winter-habit cultivars, was 2% and 6%, respectively, higher in the early-sown group than in the standard group (Table 5). These
intermediate-habit cultivars may have developed many non-productive tillers in the early-sown group.

Taya (1993) suggested that grain yield was mainly determined by spike number and grain number per spike in wheat. He showed that the cultivars matured early had a low grain yield due to decreased spikelet number and grain number. Fukushima et al. (2001b) also reported that too early sowing strongly inhibited leaf expanding or floret development because the plant were exposed to cold temperature, during the vegetative growth period, which lowered the LAI, and decreased sink size resulting in a smaller floret number per spikelet.

The spring wheat cultivar Haruyutaka had a higher grain number per unit area and per spike than the others in the early-sown group (Table 5). However, its grain yield was low because of the light grain weight. Haruyutaka is known to show a lighter grain weight than the local cultivars in western Japan every year (Takahashi et al., 2002). Even though its grain yield in Haruyutaka was low due to the light grain weight, the grain number per spike in this cultivar was about 30% higher than that in Akitakko, Iwainodaichi or Airakomugi. This may be due to the potential ability for high grain yield when sown early. Slafer et al. (1994) and Takahashi et al. (1994) found some cultivars with a high grain number per spike, but different growth habit or maturity earliness. Nerson et al. (1990) and Itoh et al. (1998) reported that spikelet number increased by applying a large amount of fertilizer and planting at a low density. We would be able to achieve a higher grain number per spike by improving the cultivation technique and using a good cultivar.

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