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Summer-Sown Cultivation of Forage Oats and Breeding in Japan

Masaaki KATSURA

Department of Grassland, Kyushu National Agricultural Experiment Station (Nishigoshi, Kikuchi, Kumamoto, 861-1192 Japan)

Abstract

Oats are mainly used as forage in Japan. A new cultivation type, in which oats are sown in late summer and *harvested* as silage or hay in December or later, has been adopted in the warm region of Japan. This type which is referred to as "summer-sown cultivation" enables to make good use of the field from late summer to early winter. However, this system is not satisfactory for oats, because high temperatures persist until mid-September, the day-length shifts from long to short, and the temperature from high to low. We have been engaged in the breeding of oats for summer-sown cultivation to overcome such adverse conditions. Therefore we focused on early heading habit in fall. Based on the evaluation of introduced varieties and lines for heading habit, we observed that some Mexican varieties headed early in summer-sown cultivation. Then we released 'Haeibuki' which is a progeny from a cross between a Mexican cultivar, 'Guelatao' and an old Japanese one, 'Hayate'. Haeibuki is characterized by very early heading in summer-sown cultivation and a high dry matter percentage at harvest. Through field trials in the breeding process, we observed differences among cultivars in germination under summer-sown conditions, presumably associated with high temperature.

Discipline: Plant breeding
Additional key words: *Avena sativa* L., heading, germination

Introduction

Oats, *Avena sativa* L., are mainly used as forage in Japan, while as grain and for grazing in other countries. The total area of forage crops in Japan was estimated at 980,200 ha in 1995, of which the seeding area covers 188,582 ha. The seeding area of oats is estimated at 10,500 ha and oats rank third after maize and sorghum except for grasses, including Italian ryegrass. Oats are mainly distributed in Kyushu, which is located in the southwestern part of Japan, with an area accounting for about 65% of the total oat area.

Oats have been sown in fall in the southwestern part of Japan and harvested in the next spring for many years. This system is referred to as "fall-sown cultivation". When oats are used as forage, another cultivation type has been adopted in the warm region of Japan, which is referred to as "summer-sown cultivation". In this type, oats are sown in late summer and harvested as silage or hay in December or later. We have been engaged in the breeding of forage oats for summer-sown cultivation since 1988. In this review, various aspects relating to the breeding of oats for summer-sown cultivation will be described along with the characteristics observed through our breeding process.

Summer-sown cultivation of oats and breeding objectives

The main forage crops in Japan are summer crops such as corn and sorghum. They are sown in spring and harvested in summer and fall. Farmers try to get high yield with high nutritive value by growing them. Therefore, some farmers implement double cropping of corn. In this case, since the interval between the first harvest and second seeding is very short, the system is very laborious.

In the warm region of Japan, corn tends to be sown earlier for avoiding typhoons in late summer while paddy rice is transplanted in early spring. Therefore, it is necessary to make good use of the field from late summer to early spring after harvesting rice or corn by mid-August because the area of arable land in Japan is small. Oats are an important crop for producing feed in early winter and next spring as well as Italian ryegrass. In the case of summer-sown cultivation of oats, in which oats are sown in late summer and harvested in early winter, farmers have enough time to make preparations for the growth of the next crops. As stated above, to save labor and avoid risk, summer-sown cultivation of oats is an important alternative. Then, the weather from fall to early winter is mild in the southwestern part of Japan, particularly in southern Kyushu, i.e. Miyazaki and Kagoshima (Fig. 1). There is enough rain and the weather is mild in fall. Therefore, this cultivation type enables to make the best use of the climatic conditions.

However, the conditions of summer-sown cultivation are not favorable for oats which are a long-day plant. High temperature persists until mid-September, and this period corresponds to the germination stage. The day-length shifts from long to short and the temperature from high to low (Figs. 1 and 2). These conditions influence panicle emergence

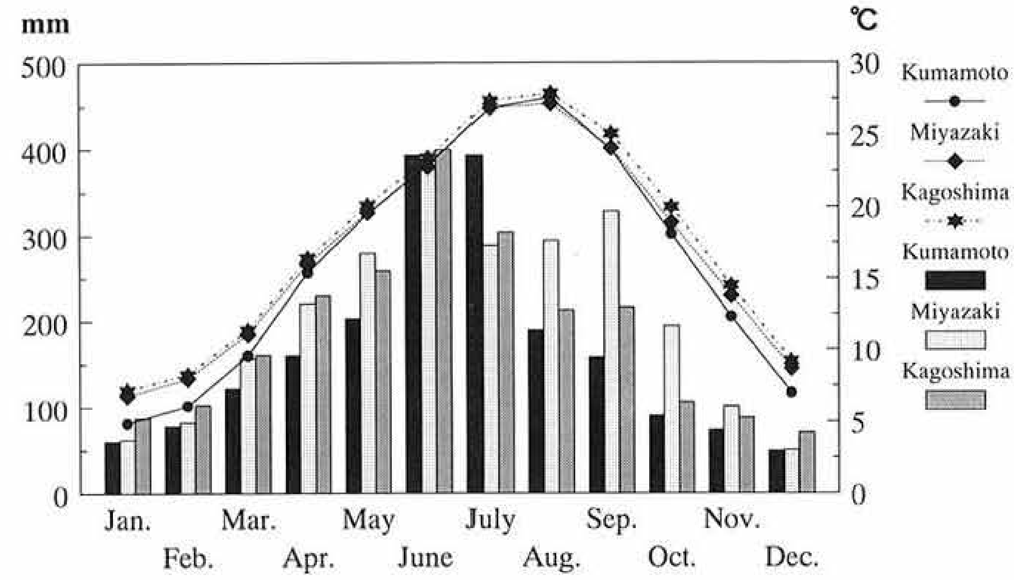


Fig. 1. Monthly total precipitation and average temperature

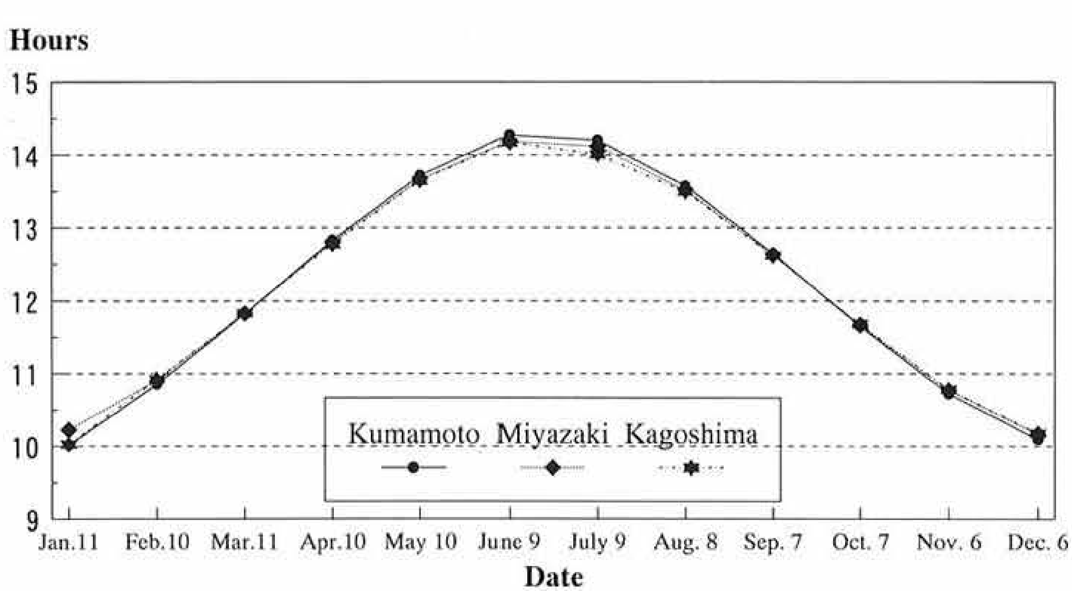


Fig. 2. Daylight in Kyushu, Japan (hours)

and subsequent growth. In order to overcome such shortcomings, we developed the following breeding objectives: (1) stable germination under high temperature conditions, and (2) early heading in fall to reach a stage beyond the milky stage at harvest. Particularly, we focused on early heading in fall to obtain a high dry matter percentage at harvest. Then the high dry matter percentage may decrease the labor for prewilting in the field before harvesting at a low temperature.

Evaluation of germplasm for heading habit

Many studies on heading habit have been performed. Peterson[5] pointed out in his review that the time required for inflorescence development and emergence is affected by the temperature and photoperiod in oats. While the optimal temperature for the most rapid development varies among studies, both warmer and cooler temperatures were found to delay heading. Griffiths[3] reported that panicle emergence was entirely suppressed under photoperiods of 12 h and less in some varieties. In addition, he dissected the growing points of plants which failed to emerge under short days. As a result, he observed that floral differentiation had not been inhibited by short days, but that the full elongation of the internodes, especially the upper internodes, had been suppressed.

As stated above, the day-length shifts from long to short, and the temperature from high to low in summer-sown cultivation (Figs. 1 and 2). Con-

Table 1. Days to heading of introduced cultivars and lines in summer- and fall-sown field tests

Group	Cultivar, line	Summer-sown		Fall-sown	
		Aug. 29, 1988	Aug. 29, 1989	Oct. 27, 1988	Oct. 25, 1989
I	Irwin	67	60	162	156
	Hayate	65	65	159	156
	West	71	68	160	159
	Early Queen	72	66	160	160
II	Diamante R31	58	51	161	163
	Paramo	58	60	168	167
	Akiwase	62	62	166	169
	Tarahumara	61	64	166	161
	Guelatao	65	66	169	168
	Hokkai-45	68	69	168	168
III	Gokuwase Sprinter	85	70	163	159
	Enducks	84	71	162	161
	Hayabusa	83	74	163	160
	Swan	87	73	163	160
IV	Satsukei-63	74	68	170	166
	M. D. Dolphin	77	79	171	170
	Pacsun	77	80	172	170
	Donald	80	71	168	169
	Huamantla	83	75	167	166
	Coker 820	80	72	165	162
	Chihuahua	79	77	175	172
V	Kairyo Grainoats	87	–	174	171
	Coker 87-9	95	–	174	171
	Mametank	–	73	165	163
	S-1	–	–	165	161
	Kagoshima 1	–	–	164	163
	Hyugakairyokuro	–	–	171	171
	Honkei-998	–	–	173	170

Cited from Ueyama[8].
These tests were performed under spaced planting. Heading date was based on the date when the first panicle emerged from the flag leaf per plant until December (summer-sown) and the second panicle in spring (fall-sown).
–: No heading.

sidering the climatic conditions and the results mentioned above, panicle emergence may be affected. In order to head under such unfavorable conditions, cultivars should be characterized by a low chilling requirement and low sensitivity to day-length. Ueyama[8] evaluated 28 introduced cultivars and lines for heading habit in summer-sown and fall-sown cultivation (Table 1). He divided these cultivars and lines into 5 groups. The panicle emergence of group I was early in summer-sown cultivation and very early in fall-sown cultivation. Heading in group II was earlier than that in group I in summer-sown cultivation and later than that in group I in fall-sown cultivation. Heading in group III was later than that in group I and as early as that in group I, respectively. Heading in group IV was later than that in group I in both types of cultivation. Group V did not reach the heading stage within a year in summer-sown cultivation. Many Japanese commercial varieties belonged to group I and group III. Group II included Mexican cultivars and their progenies. As a result, he pointed out that the characteristics of group II were important to develop a new cultivar for summer-sown cultivation.

Development of a new cultivar 'Haeibuki'

We released a new cultivar 'Haeibuki' for summer-sown cultivation in 1996[4]. Haeibuki is a progeny from a cross between 'Guelatao' and 'Hayate'. Guelatao, released by the National Institute of Agriculture Research in Mexico, is able to head in early fall. Hayate, introduced from Australia, has been used in summer-sown cultivation for many years. The cross, Guelatao × Hayate, was made in the greenhouse in 1988. The F_1, F_2 and F_3 were advanced in the greenhouse without selection. The F_4 plants were grown from late summer to winter in 1989, and individual selection was performed for early heading in fall. The F_5 lines derived from the selected F_4 plants were selected for early heading in fall again in 1990. The F_6 plants were multiplied by removing abnormal plants in the spring of 1991. The F_7 lines were evaluated for yield and the other agronomic characteristics in summer-sown cultivation in 1991. As a result, 2 lines were selected, and named Kyushu-1 and Kyushu-2. After the F_8 generation, Kyushu-1 and Kyushu-2 were examined in the local adaptability tests. Lastly, we chose Kyushu-2, and it was registered as Haeibuki. The characteristics of Haeibuki are shown in Table 2. The significant characteristics were early heading in summer-sown cultivation and high dry matter percentage at harvest. Moreover, the dry matter yield was slightly higher than that of other leading cultivars.

Germination habit of oat cultivars for summer-sown cultivation

Throughout the breeding process, we observed differences among cultivars and lines in germination in the summer-sown field test. Our experimental lines showed good germination, while some cultivars displayed poor germination. Then we carried out the germination test using the seeds harvested in 1994 and 1995 at constant temperatures of 20 and 30°C on the date corresponding to the seeding time in summer-sown cultivation, because we considered that poor germination was due to high soil temperature. Mean maximum/minimum soil temperatures in the fields in Kumamoto at a depth of 2 cm were 32/23°C in 1995 during the seeding and germination period from August 31 to September 10, and at a depth of 5 cm in 1996 the values were 30/22°C.

Table 3 shows the results of the germination test. There was a significant difference among cultivars at 30°C, while all of them showed a germination percentage of more than 80% at 20°C. The germination percentages of Haeibuki and Guelatao were very high, and those of 'Enducks' and 'Super

Table 2. Characteristics of Haeibuki in summer-sown field test[a)]

Cultivar	Days to heading[b)]	Plant height[c)] (cm)	Dry matter yield (t/ha)	Dry matter percentage (%)
Haeibuki	44	102.2	4.47	30.4
Guelatao	48	124.2	4.44	26.7
Hayate[d)]	54	99.8	4.02	21.5
Akiwase[d)]	45	113.7	3.53	26.1

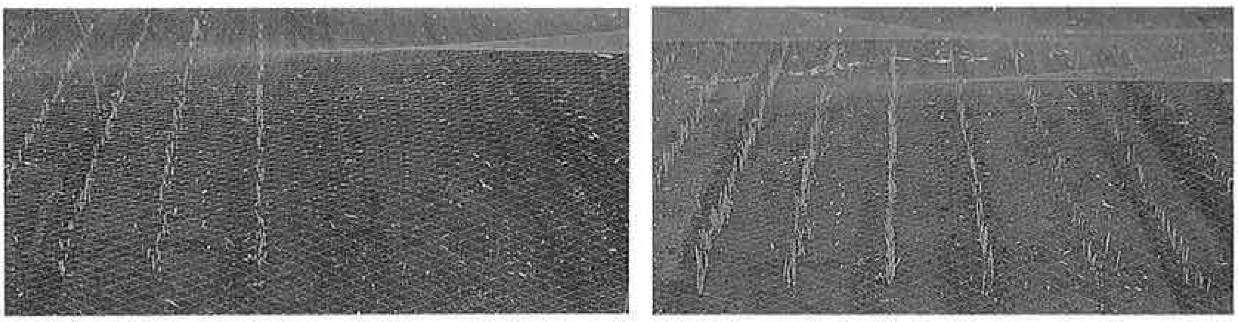
a): Average of 1992–1944. b): The date when 3 panicles emerged from the flag leaf per 1 m^2.
c): At harvest. d): Japanese leading cultivars.

Hayate Hayabusa' were very low. Radford and Key[6] determined how the temperature affects germination, mesocotyl length and coleoptile length in 16 oat (*Avena* spp.) genotypes. They defined germination as the emergence of the shoot from the seed, and observed that the critical temperature for the differentiation of genotypic effects on germination was 30°C. Our results were in agreement with those findings. Observation of the state of germination in the field test of summer-sown cultivation in 1995, revealed a difference similar to the results mentioned above. That is, cultivars except for Super Hayate Hayabusa and Enducks reached the germination stage within 5 days after seeding, while in the former 2 germination was delayed. Fig. 3 shows the state of germination of Haeibuki and Super Hayate Hayabusa in the test in summer-sown cultivation in 1997. Apparently the germination of Super Hayate Hayabusa was delayed compared with that of Haeibuki. Then, we performed germination tests at a constant

Table 3. Influence of temperature on the germination percentage on the date corresponding to the seeding time in summer-sown cultivation

Cultivar	Year when harvested	Temperature (°C)	
		20	30
Haeibuki	1994	98	100
	1995	95	94
Guelatao	1994	94	88
	1995	96	89
Hayate	1994	88	62
	1995	84	21
Early Queen	1994	90	45
	1995	93	24
Enducks	1994	84	6
	1995	85	0
Super Hayate Hayabusa	1994	86	46
	1995	89	0
Sabitsuyoshi	1994	89	60
	1995	97	78

Germination test was started on September 12, 1994 and August 29, 1995. Seeds were harvested in the spring 1994 and 1995, and stored at room temperature after threshing and cleaning. Seeds of Super Hayate Hayabusa and Sabitsuyoshi in 1994 were bought from a seed company. Fifty seeds were placed in a petri dish (9 cm in diameter) with 2 sheets of filter paper imbibed with distilled water at the constant temperatures of 20 and 30°C. A seed was considered to have germinated when the radicle protruded through the seed coat. Germination counts were performed for 7 days. The results in 1995 were expressed as mean germination percentage obtained from 2 replications.



Haeibuki Super Hayate Hayabusa Haeibuki Super Hayate Hayabusa

Fig. 3. Conditions of germination in summer-sown cultivation in 1997
Seeds were harvested in spring, 1997 and stored at 30°C after threshing and cleaning. Seeding date was August 29.
Left: The conditions on September 5, 7 days after seeding. Right: The conditions on September 8, 10 days after seeding. Germinating date of Haeibuki was September 4, and that of Super Hayate Hayabusa September 7.

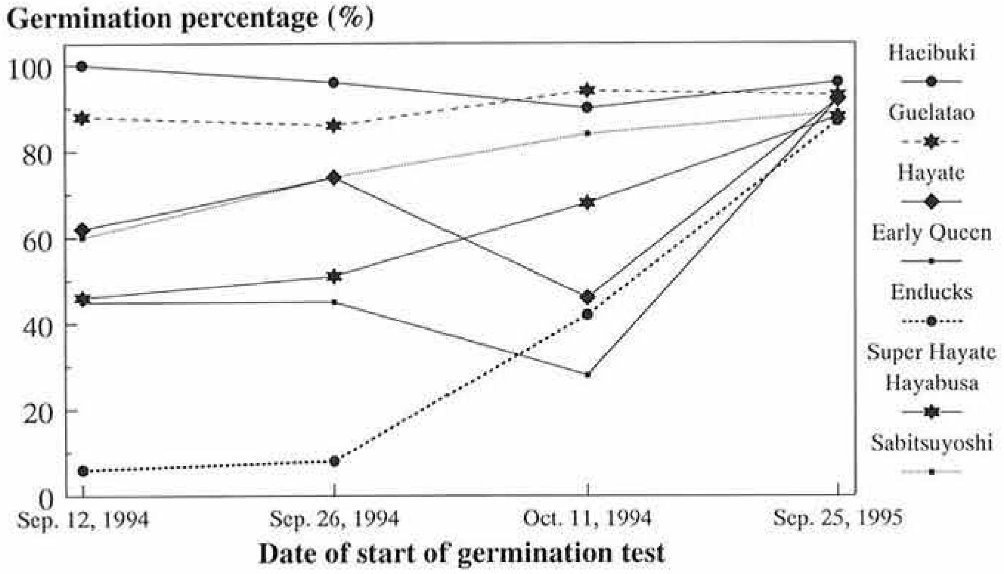


Fig. 4. Effect of storage period on the germination percentage at constant 30°C
Germination tests were conducted in the same way as shown in Table 3.

temperature of 30°C in 1995 using the seeds stored at room temperature, which were harvested in 1994 (Fig. 4). As a result, all the cultivars germinated with a percentage of more than 80%, because the non-germination habit decreased during the storage, as stated by Corbineau et al.[1]. They examined the dormancy of cultivated oat (*Avena sativa*) seeds, and its elimination during dry storage at 30°C. They showed that the longer the dry storage at 30°C, the more easily the coated caryopses germinated at high temperatures. Therefore, the new cultivar Haeibuki was able to germinate at high temperatures better than the other cultivars and the non-germination habit at high temperature could be removed more rapidly than in the other cultivars. In addition, regarding the relation between germination and high temperature in oats, Radford and Key[6] reported that high temperature induced a temporary dormancy or state of "suspended animation". Corbineau et al.[2] also studied the induction of thermodormancy using dormant seeds and non-dormant ones in oats, and showed that the incubation of imbibed dormant seeds at 30°C induced a thermodormancy. The results obtained and observations may be related to the induction of a temporary dormancy or a thermodormancy and studies on this phenomenon are currently in progress.

Perspectives

In the breeding of forage oats for summer-sown cultivation, we focused on early heading in fall. We were able to develop Haeibuki and other very early heading lines. However, new problems related to early heading should be addressed. Nagatani (pers. comm.) observed that some diseases spread after heading stage in the field tests, suggesting that the early type may be readily affected, and special attention was paid to crown rust and Helminthosporium leaf blotch. There are many descriptions about crown rust resistance, but very few about Helminthosporium leaf blotch resistance. Tsukiboshi et al.[7] evaluated 56 cultivars and lines including *A. strigosa* and *A. byzantina* for their resistance to Helminthosporium leaf blotch based on seedling tests using spore spray inoculation, and they examined the mechanism of plant reaction. They could not detect any cultivars with true resistance. However, they classified the cultivars into 4 categories according to the level of susceptibility to the disease. Therefore we plan to introduce the seedling test of Helminthosporium leaf blotch into individual selection schemes.

Lodging resistance is also an important characteristic for summer-sown cultivation. Lodging leads to damage of growing plants and consequently the quality and yield decrease. Actually, we developed an experimental line with a strong lodging resistance which is currently undergoing local adaptability tests.

In this way, in order to make the best use of the period from late summer to early winter, oat cultivars can be improved. The major purpose of summer-sown cultivation is to achieve stable yield every year. However, the yield of forage oats in summer-sown cultivation seems to be largely affected by the weather conditions. Breeding work can play a very important role in stabilizing the yield of forage oats.

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