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Timothy Breeding in Japan

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Abstract
The national breeding program and network system of timothy in Japan started at the Hokkaido Prefectural Kitami Agricultural Experiment Station in 1964. It is recognized that the station is located at a favorable site for timothy breeding from the viewpoint of its environmental conditions. The breeding resources have come from Hokkaido Local, a well-adapted ecotype, as well as from 97 exotic varieties from 19 countries. Evaluation on the breeding populations was made in relation to their diversifications of heading dates, yielding abilities, resistance to diseases, regrowth abilities, winter hardiness and others. During the past 25 years, four cultivars, i.e. Senpoku, Nosappu, Hokushu and Kunpu, were registered and recommended.

Discipline: Grassland
Additional key words: ecotype, exotic, variety, genetic resources, registered cultivar

Introduction

Timothy, *Phleum pratense* L., was introduced to Japan from the United States in 1874. The cultivation has spread in various parts of Hokkaido, the northernmost island, after the introduction, and a variety of Hokkaido Local has been developed during this period. At present, timothy is cultivated mainly in Hokkaido and low-temperature areas of Tohoku district, and partly in mountainous areas of the central region of Japan. Approximately 430,000 ha, or 80% of the total area of grassland in Hokkaido, are grown to timothy as the most important resources for hay and silage in general, and for hay-pasture dual use particularly in eastern Hokkaido. Such a wide use of timothy in Hokkaido is attributed to its cold tolerance and high resistance to snow mold (*Sclerotinia borealis*) as well as its stable productivity even under extensive cultivation. High persistency of plant growth and suited palatability are additional advantages of timothy[11,22].

As shown in Table 1, seed requirements of timothy are in the second rank among the grasses in Japan as of 1985. Consumption of timothy seed in Hokkaido, however, is the greatest in amount, which accounts for 65% of grass seeds and 47% of the total seed consumption of grasses and legumes. It is still increasing rapidly, and will further increase in future.

Organization for breeding

In accordance with the reorganization of the forage breeding system of Japan in 1964, the national breeding program for timothy and smooth bromegrass, *Bromus inermis*, was assigned to Hokkaido Prefectural Kitami Agricultural Experiment Station. Since then, no other stations have been engaged in timothy breeding program in Japan. However, five stations cooperate for testing adaptability and two stations for screening materials for cold tolerance and palatability. Climatic conditions in the Kitami area are characterized by several factors, including 5.1°C of annual mean temperature (AMT), 700 to 800 mm of precipitation and 50 cm in snow-depth, about 120 days of snow-covering, 30 to 60 cm in depth of soil freezing in winter and −16.5°C of minimum temperature in January which is the coldest region in Japan. In the summer season, however, an accumulated effective temperature during the period May to September accounts for 2,500°C, which is quite

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Table 1. Annual seed imports and estimated sown areas of main forage crops in Japan (1985)

Species	Imported (t)	Seeding rate (kg/ha)	Estimated sown area (1,000 ha)	Seed demand in Hokkaido (t)
Timothy	985.2	12	82.1	814
Orchardgrass	841.1	15	56.1	225
Meadow fescue	32.4	7.5	4.3	63
Tall fescue	350.1	7.5	46.7	38
Italian ryegrass	4,702.2	25	188.1	12
Kentucky bluegrass	416.2	10	41.6	75
Perennial ryegrass	118.3	7.5	15.8	25
White clover	444.0	3	148.0	279
Red clover	281.9	5	56.4	150
Alfalfa	220.3	5	44.1	62

favorable for the growth of timothy plants. These conditions provide a suitable environment for producing quality seeds of various varieties ranging from extreme early to late maturing materials and a highly favorable background for its breeding, accordingly.

Areas adapted for timothy

The areas adapted for growing timothy in Japan are presumed to be a region with less than 10°C of AMT. In particular, in the areas that are exposed to shallow snow-cover in winter with less than 6°C of AMT, other temperate grasses are not suited because of their limited resistance to cold and snow mold (*Sclerotinia borealis, Typhula* spp. etc.) as well, while timothy is the only grass to be grown for stable grass harvests. All the areas of Hokkaido are under less than 10°C and those of eastern Hokkaido are under less 6°C. The areas of Kushiro and Nemuro located in eastern Hokkaido are often called "Timothy Land" by dairymen, recognizing a high adaptability and productivity of timothy to those areas. In initiating a breeding program of timothy at the Hokkaido Prefectural Kitami Agricultural Experiment Station, those environmental conditions as mentioned above were fully taken into account (Fig. 1).

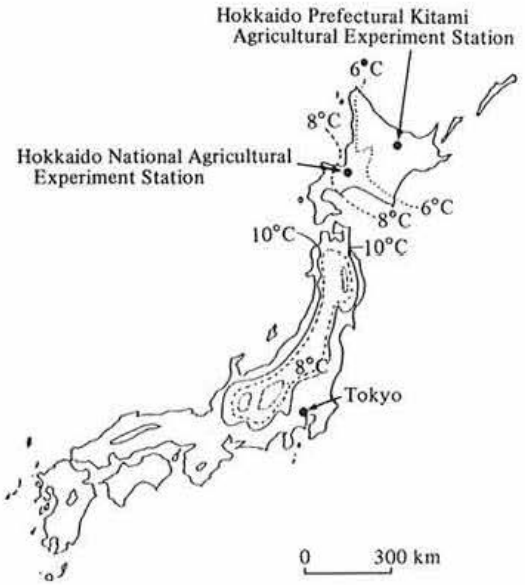

Fig. 1. Areas adapted for growing timothy in Japan The contour lines indicate the areas of annual mean temperatures of 6, 8 and 10°C, respectively.

Timothy breeding and its relevant research at the Kitami Agricultural Experiment Station

1) Importance of the variety of Hokkaido Local in the breeding program

Until 1965, most of timothy plants have been represented by only an exotic cultivar, i.e. Climax, and Hokkaido Local and "Common" types. The Common types are populations composed of miscellaneous cultivars and/or unknown ones. The variety, Hokkaido Local, was originally introduced from the United States by the Hokkaido Kaitakushi (Commission of Hokkaido Colonization) in 1874: it was eventually established as a variety after repeated natural selections on its self-propagated

populations for many years. Although those populations have never been subjected to any artificial selection for improvement, Hokkaido Local, an established ecotype, is highly adapted to climatic and cultural conditions in Hokkaido due to its early heading and stable grass production. It is recognized however that this variety has some shortcomings such as a low ratio of leaf-to-stem, susceptibility to several leaf diseases and low nutritional contents. Nevertheless, Hokkaido Local has been a valuable genetic resource because of its high winter hardiness and high resistance to snow mold. Hokkaido Local is composed of several groups, which are called Hidaka Line, Tsukisamu Line etc., depending on their original sites of seed production or conservation.

2) Breeding objectives

In the first stage of the breeding program, main efforts were directed toward the improvement of Hokkaido Local. Selections were made for priority objectives of the breeding: i.e. leafiness, resistance to diseases and high productivity. Following are the breeding objectives that are expected to be achieved by the introduction of genetic resources from abroad.

(1) Diversification of heading dates

Genetic resources newly introduced from abroad have been used extensively, since the materials maintained in Hokkaido Local were lacking in very early group. It is planned to cover a wider range from extremely early to late maturing to provide dairymen with a complete set of cultivars containing diversified heading dates.

(2) High yielding ability, especially increased digestible dry matter

Since 1969 selections for higher digestibility have been made using *in vitro* technique[13]. The one-step-cellulase method is presently used for this purpose.

(3) Resistance to selected diseases

In regard to damages in timothy caused by diseases in Hokkaido, 14 species of 12 genera have been reported. The breeding program on resistance to the

Table 2. Number of exotic timothy varieties and Hokkaido ecotypes tested and classified by source and year at Kitami Agr. Exp. Sta.

Source countries	No. of tested varieties by year					Total no. of varieties
	1964–'67	1965–'68	1968–'71	1971–'73	1973–'75	
Japan (1)	3		1			4
Japan (2)	1		4	4	2	11
Japan (3)	14	10		2		26
U.S.A.	2 (16)[a]	5	2	1		10 (16)
Canada	13	3	10	4	2	32
Sweden	3	3	6	4	3	19
Denmark	2	1	1	1	2	7
Netherlands	5	5	7	5	12	34
G. Britain	7	4	5	2	1	19
France	2			2		4
New Zealand	1	1			1	3
Ireland	2		1			3
Poland	1		1		5	7
U.S.S.R.	4					4
Finland		5	4			9
Belgium		1	1	1		3
W. Germany		5				5
E. Germany			4	1	9	14
Norway			5			5
Rumania					1	1
Italy					1	1
Iceland					1	1
Total	60	43	52	27	40	222

a): Wild types introduced from U.S.A. (diploid and tetraploid).

most serious diseases such as purple spot (*Cladosporium phlei*), stem rust (*Puccinia graminis*), and leaf streak (*Scolecotrichum graminis*) is now under way. Breeding materials are subjected to testing for screening on purple spot by inoculation at a seedling stage and by field infection as well. Resistance to stem rust is evaluated among the newly bred lines on the basis of percentages of the plants showing resistance to the rust race III C.

(4) Regrowth ability and less seasonal variation in yield

Timothy is not sufficient enough in its regrowth ability, which should receive high priority in the breeding program so that seasonal fluctuations in grass production of timothy could be reduced. In addition, suitable cultivars for delayed planting are also required.

(5) Winter hardiness and others

New cultivars should have the same level, at least, of winter hardiness and seed production with Hokkaido Local. They should also have good association with companion legume species and lodging resistance.

3) Evaluation of exotic varieties and collection of ecotypes in Hokkaido

Evaluation experiments were undertaken during the period 1964 to 1975 in a series of five sets of field testing programs. One hundred and ninty-seven varieties from 19 foreign countries were included in those tests, as shown in Table 2. The result shows that there are great genetic variations in the agronomically important characters and those foreign varieties are likely to be useful in breeding. Several varieties and strains were used in the breeding program, having resulted in the birth of new varieties. A few varieties among the introductions were recommended and distributed in Hokkaido for direct use.

4) Genetics in relation to breeding practices of timothy

On the way of the establishment of Hokkaido Local under repeated natural selections, the variety has resulted in a very wide genecological differentiation[8,9,11,20]. The first harvest of timothy gives the major component of annual production, which is closely correlated with stem number and leafiness. The leafiness was effectively estimated by a multiple regression formula[3,10]. Heritability of the characteristics directly related to production and correlation coefficients among them were calculated in exotic varieties and Hokkaido Local; these information may be useful in improving breeding efficiency[4]. In reference to the plant type, it was indicated that a selection for upright leaves would be effective in raising yielding ability of timothy[1]. Regarding the physiology of timothy plants, a report indicated that desirable plants with a high photosynthesis rate on a single leaf basis could be selected by an SLA (specific leaf area) method of the first crop[2]. In relation to seed propagation of timothy in breeding practices, the following components were identified, by the path coefficient analysis, to be directly relevant to effective seed production: kernel weight per panicle, average kernel weight, seeding date, seeding rate, amount of fertilizers and planting density[5,6]. A high positive correlation was observed between seed production and earliness, indicating that early varieties produced more seeds with a large size. The seed production of timothy could be further improved by utilizing its potentially large genetic variability[9].

In a breeding program for disease resistance, especially to purple spot, a quick and mass rearing method of conidia was developed and an effective technique of screening by inoculation at the seedling stage was established[12,14]. A screening method for stem rust resistance to the race III C is now made available[14]. A result of the study on the resistance of main Gramineae species to snow mold indicated that cultivars of timothy had the highest resistance[19]. The rates of winter survival plants of timothy showed that there were some differences in degree of resistance to snow mold among the cultivars.

In regard to forage quality, varietal differences in dry matter digestibility were identified. Heritabilities of forage quality and its correlations with crude protein contents were estimated[15–18,21]. These information as mentioned above have proved of effective use in breeding practices of timothy.

5) Registered cultivars under the national breeding program

(1) Senpoku (Timothy Norin 1)

This cultivar originated from 14 ecotype groups in eastern Hokkaido. The breeding objective was to improve leafiness and yielding ability, both of

Table 3. Characteristics of Senpoku at Kitami Agr. Exp. Sta.

Variety	Head emergence	Heading	Flowering	Plant type	Plant height (cm)	Disease resistance[a]			Leafiness	Regrowth	Lodging[a]
						PS	LS	SR			
Senpoku	6.15	6.22	7.17	Hay	108	MR	MR	MR	Medium	Good	R
Climax	6.18	6.25	7.19	Hay	109	M	M	MS	Low	Fair	M
Hokkaido Local	6.15	6.22	7.15	Hay	111	M	M	MS	Low	Fair	M

a): PS; Purple spot, LS; Leaf streak, SR; Stem rust, R; Resistant, MR; Moderately resistant, M; Medium, MS; Moderately susceptible.
Observation was mainly conducted in the 2nd year.

Table 4. Air-dry matter yield of crops of Nosappu: ratio to Senpoku (control variety)[a]

Area	Testing stations[b]	1st crop	2nd crop	3rd crop	Annual yield
Hokkaido	Tempoku Agr. Exp. Sta.	110	112	123	113
	Kitami Agr. Exp. Sta. (A)	109	118	123	113
	Kitami Agr. Exp. Sta. (B)	95	122	117	105
	Konsen Agr. Exp. Sta.	100	114	—	105
	Shintoku Ani. Hus. Exp. Sta.	110	115	111	111
	Average	103	115	117	108
Tohoku	Aomori Ani. Hus. Exp. Sta.	102	104	100	102
	Yamagata Ani. Hus. Exp. Sta.	100	105	94	99
	Average	101	105	96	101

a): Data obtained in 1975–1976.
b): Kitami (A); Nitrogen dressing 100 kg/ha/year, Kitami (B); Nitrogen dressing 200 kg/ha/year.

Table 5. Productivity of Hokushu and Senpoku

Area	1st crop			Final crop		
	Heidemij[a]	Hokushu	Senpoku	Heidemij[a]	Hokushu	Senpoku
	(cont.)	(% to the cont.)		(cont.)	(% to the cont.)	
Hokkaido	1.01[b]	130	170	1.04[b]	124	92
Tohoku	3.13	108	137	1.39	105	104

a): A variety introduced from overseas.
b): Average yield of air-dry matter (t/ha).

which were achieved through mass selection. In 1969, a registered name, i.e. Timothy Norin 1, was given. The variety is early in heading, leafy and high yielding with a wide adaptability. Other characteristics resemble those of Hokkaido Local. Main characteristics are shown in Table 3[22]. It is a leading variety as of 1990. The statistics show that 32% of the total requirement of timothy in a seed market of Hokkaido has been covered by this variety since 1980.

(2) Nosappu (Timothy Norin Gou 2)

This cultivar originated from ecotype groups collected from eastern Hokkaido and Aomori Prefecture. They were planted in a mixed form with those materials introduced from Europe. The cultivar is a synthetic variety composed of four elite clonal lines. In 1977, a registered name, i.e. Timothy Norin Gou 2, was given. Nosappu has an early hay-type with a good regrowing ability. Its grass yields, particularly those of the second and third crops, are much

Table 6. Heading dates of Kunpu in 1978 and 1979

Area	Date of head emergence		Date of heading	
	Kunpu	Senpoku[a)]	Kunpu	Senpoku[a)]
Hokkaido[b)]	12 June	20 June	18 June	26 June
Tohoku[c)]	1 June	10 June	3 June	17 June

a): A check variety of early type. b): Average of five stations. c): Date of head emergence observed in a station, and date of heading in two stations in 1979, respectively.

higher than Senpoku, a control variety, providing a greater annual production accordingly. Nosappu shows a high resistance to stem rust race III C as well as to purple spot disease[2,3] (Table 4).

(3) Hokushu (Timothy Norin 3)

This cultivar was derived under a mass selection applied to Kitami-4021, one of the breeding materials of the Kitami Agricultural Experiment Station. A registered name, i.e. Timothy Norin 3, was given in 1977. It has a late and prostrate type with a later heading date by two weeks than the early varieties. Hokushu is highly resistant to stem rust, but moderately resistant to purple spot disease. It shows a good regrowth and high yielding ability in late autumn. Compared with Senpoku, Hokushu shows a slightly higher annual grass production but lower winter hardiness[2,4] (Table 5).

(4) Kunpu (Timothy Norin 4)

A registered name, Timothy Norin 4, was given in 1980. The original breeding materials consisted of Hidaka and Kitami Strains of Hokkaido Local and Clair which had been introduced from the United States. Maternal line selections were employed. The most distinctive characteristic of this cultivar is its extremely early heading date, which is 8 to 10 days earlier than the early cultivar Senpoku and 2 days earlier than Clair. It has the same level of annual production as Senpoku but higher in later harvest. The heading date of the second crop is also early. In regard to winter hardiness and disease resistances, Kunpu is similar or slightly inferior to Senpoku. It is recommended for use as part of a group comprising several varieties in order to extend the harvesting period[7] (Table 6).

Conclusion

Genetic resources of timothy introduced from abroad have greatly contributed to the breeding program in Japan. Firstly, the genetic resources brought over from the United States many years ago served as the origin of Hokkaido Local. They supplied a valuable genetic basis for the subsequent timothy breeding. Those materials introduced rather recently have played an important role in the breeding of Kunpu. Secondly, the resources introduced from Europe were also effectively utilized in breeding late varieties. Thus, the timothy improvement in Japan has benefited from the materials provided by the United States in breeding early to extremely early varieties, while those from the European countries in developing late varieties. Diversification of genetic resources of timothy has therefore been achieved by introduction efforts from abroad. There exist very large differences in agronomic characteristics among Hokkaido Local, Clair and other timothy varieties. This fact implies that a considerable amount of genetic variations could be further made available by mutual exchange of genetic resources molded under various ecological conditions around the world.

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