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Combination Effects of Sowing and Transplanting Time on Harvest Time in Some Onion (*Allium cepa* L.) Cultivars with Different Photoperiod Requirements in Hokkaido

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The combination effect of sowing and transplanting time on harvest time, yield, and external bulb quality was investigated to achieve earlier shipment of onions in northeastern Hokkaido, Japan. A total of five cultivars with different levels of photoperiodic responses for bulb formation were used in both the 1996/97 and 1997/98 trials. The seeds were sown on a monthly basis in a soil bed in an unheated plastic greenhouse from December to March, and the seedlings were transplanted outdoors from late April to mid-May. The daily minimum soil temperature was kept at almost 0°C, even when the air temperature in the plastic tunnel inside the greenhouse fell to −14.4°C in mid-winter. Seedling emergence took approximately 20 and 35 days in the 1996/97 and 1997/98 trials, respectively, when the seeds were sown in December and January. However, these seedlings grew slowly, and the leaf length, fresh leaf number, and leaf sheath diameter of the seedlings at transplanting time were all greater when the onion seeds were sown earlier. In addition, the bulb ripening time advanced with earlier transplanting. The cultivars, 'Kitawase No. 3' and 'Kitahayate', with an intermediate photoperiodic response, were harvested in early August if they were sown in December and January and transplanted from late April to early May. Moreover, with this combination of sowing and transplanting time, these cultivars produced an acceptable yield and bulb appearance in terms of marketable quality. The cultivar, 'Sonic', a typical short-day cultivar, had the earliest harvest time. However, the yield was very low due to the short period of leaf growth. On the other hand, for the cultivars 'Okhotsk No. 1' and 'Kitamomiji 86', which belong to a long-day photoperiodic response group, although the yields tended to increase under early sowing or early transplanting, they were not harvested by early August. On the basis of these observations, a new cropping type for early sowing and early transplanting will be adopted in northeastern Hokkaido by using the 'Kitawase No. 3' and 'Kitahayate' cultivars for early shipment in the domestic fresh onion market.

Key Words: cropping type, intermediate-day cultivar, onion nursery, photoperiodic responses.

Introduction

In Japan, onion is one of the leading vegetables in agricultural production, as it is an essential ingredient in many dishes. There are two onion cropping types: an autumn transplanting and spring harvest system in the western region of Honshu and Kyushu islands, and a spring transplanting and autumn harvest system in Hokkaido.

Onion production in Hokkaido accounts for more than 60% of total domestic production (Ministry of Agriculture, Forestry and Fisheries, 2019). In particular, more than 30% of domestic onions are produced in the Kitami region, which is located in the northeastern part of Hokkaido.

It is well known that the day length affects bulb formation in onions (Comin, 1946; Abe et al., 1955; Kato, 1964; Lancaster et al., 1996). In the catalogs of seed companies, onion cultivars are frequently classified as 'short-day' (SD), 'intermediate-day' (ID), and 'long-day' (LD) types (Brewster, 2008). The minimum day lengths for stimulating bulb formation are 11–12 h for SD, 13–14 h for ID, and up to 16 h for LD cultivars.

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SD and ID cultivars are primarily produced in the western region of Japan (Kojima, 2013). For SD cultivars, the bulb begins to grow in size even if the day length is less than 13 h, and the temperature is approximately 10°C. In ID cultivars, the bulb does not enlarge when the temperature is low, even if the day length is sufficiently long. LD cultivars, which are produced on the Hokkaido Island and in the Tohoku region of Honshu, need a longer day length and a higher temperature of approximately 15–20°C for bulbing (Miyaura, 2001).

From July to August, there is a shortage in the domestic onion market as a result of the off-season harvest, which is between the end of the shipping of autumn-sown onions and the beginning of the harvest of spring-sown onions. Continuous provision of domestic onions to the market requires controlling the harvest time of domestic onions: extending the harvest period of the autumn-sowing type and expediting the harvest of the spring-sown type.

Some trials have been conducted regarding the early shipping of Hokkaido onions. However, farmers experienced unseasonable bolting if they transplanted LD cultivars too early.

There was an attempt to introduce the SD cultivars used in the western region of Japan into the standard cropping system of spring sowing in Hokkaido. When SD cultivars were transplanted in spring in the same manner as LD cultivars in Hokkaido, the SD cultivars matured earlier compared with the LD cultivars. However, many issues arose, such as low yield, small bulbs, and a poor, yellowish skin color. The reasons for this low marketability were thought to be the limited performance of SD cultivars in the case of spring transplanting, and early bulb formation under the long day condition.

Shiga (1998) succeeded in autumn-sown cropping of SD and ID cultivars in central Hokkaido in regions with no soil freezing. The bulbs of some ID cultivars, such as 'Kitawase No. 3' (KW3), could be harvested before the harvest season for standard LD cultivars in Hokkaido. However, the autumn-sown cropping system was not applied in the northeastern area of Hokkaido due to the incidence of soil freezing in winter. Therefore, other options must be explored to establish earlier and stabler shipments.

In North America, provided the seeds are sown early in either a greenhouse or a hotbed, large transplants are secured for transplanting and they provide a good yield of bulbs after the plants are moved to the field (Comin, 1946). Hamashima (1953) found that larger plants formed bulbs earlier than smaller plants. Iwama and Hamashima (1953) pointed out that it may be possible to increase the yields of spring-sown onions by raising seedlings in hotbeds to enable them to begin forming bulbs earlier in the season.

Typically, onion farmers in Hokkaido have plastic film-covered greenhouses to enable the growth of an onion nursery throughout winter. From the examples of out-of-date technology described above, we conducted early sowing trials to raise large seedlings for transplanting in spring. We hypothesized that (1) early transplanting of large seedlings would promote leaf growth in early summer and create a large plant through the lodging time, and (2) ID cultivars would be effective for early harvest as they are likely to start bulbing earlier compared with the leading LD cultivars in Hokkaido.

In the present study, field trials with early sowing and early transplanting were conducted by comparing SD, ID, and LD cultivars in northeastern Hokkaido, near the Kitami region, for early shipment to the market. The study aimed (1) to clarify the effectiveness of early sowing and early transplanting on the harvesting time for each cultivar and (2) to select suitable cultivars for early harvest through the evaluation of yield and bulb quality.

Materials and Methods

Location

All experiments were conducted at the Kitami Agricultural Experiment Station, Hokkaido Research Organization, Kunneppu, Hokkaido Japan (43°73'N, 143°74'E), in the harvest years of 1997 and 1998. The soil in the experimental field was classified as brown lowland soil.

Experimental design and cultivars

The factors to be compared were the sowing date and transplanting date (Table 1). In the 1996/97 trial, four sowing dates and three transplanting dates were set, and 12 factorial treatments were established by combining them with a randomized block design. The 1997/98 trial, which was modified based on the previous year's results, had five sowing dates and three transplanting dates. All treatments were replicated twice.

The cultivars used in this study are presented in

Table 1. Sowing and transplanting dates for the two years of experiments.

Trial year	Sowing date	Transplanting date[z]
1996/97	Dec. 19 in 1996, Jan. 16, Feb. 19, Mar. 11 in 1997	Apr. 25, May 2, 13 in 1997
1997/98	Dec. 19 in 1997, Jan. 16, 30, Feb. 19, Mar. 11 in 1998	Apr. 21, May 1, 12 in 1998

[z] The seedlings were covered for approximately one month by unwoven fabric sheets (Paopao 90) after transplanting except for the plots transplanted on May 13 in 1997 and May 12 in 1998.

Table 2. Effect of sowing date on required days for seedling emergence in five cultivars used in the 1996/97 and 1997/98 trials.

Trial year	Sowing date	Cultivar[z]				
		SON	KHT	KW3	OK1	KM86
1996/97	Dec. 19[y]	24	—	21	21	19
	Jan. 16	25	—	18	18	22
	Feb. 19	18	—	16	16	16
	Mar. 11	15	—	14	13	14
	cultivar			*[x]		
	sowing date			***		
1997/98	Dec. 19[y]	—	36	36	36	34
	Jan. 16	—	31	26	22	22
	Jan. 30	—	22	22	20	—
	Feb. 19	—	17	17	12	14
	Mar. 11	—	13	13	13	15
	cultivar			NS		
	sowing date			***		

[z] Cultivar: SON, 'Sonic'; KHT, 'Kitahayate'; KW3, 'Kitawase No. 3'; OK1, 'Okhotsk No. 1'; KM86, 'Kitamomiji 86'.
[y] Previous December.
[x] ANOVA. ***, *, and NS indicate significant difference at $P<0.001$, 0.05, and non-significant, respectively.

Table 2. 'Sonic' (SON) and 'Kitahayate' (KHT) were obtained from Takii & Co., Ltd., Kyoto, Japan and KW3, 'Okhotsk No. 1' (OK1), and 'Kitamomiji 86' (KM86) were obtained from Shippo Co., Ltd., Mitoyo, Japan. SON is an SD cultivar, whereas KW3 and KHT are classified as ID cultivars and OK1 and KM86 as LD cultivars. The cultivars KW3, OK1, and KM86 were used in both trial years. However, SON was only used in the 1996/97 trial, and KHT was only used in the 1997/98 trial. The following treatment combinations of the time of sowing and transplanting could not be achieved due to a lack of onion seedlings: the sowing on December 19 and January 16, and transplanting on May 13 for SON in the 1996/97 trial. The same procedure was followed for sowing on January 16 and transplanting on May 1 for KHT and KW3 in the 1997/98 trial. In addition, no plot was assigned for the March 11 sowing or May 12 transplanting of KHT.

Sowing and temperature conditions in a plastic greenhouse

In the 1996/97 trial, seeds of the four cultivars were sown in a soil bed inside a plastic greenhouse, which was 5.4 m wide and 18 m long, with no artificial heating. The sowing dates were December 19 in 1996 and January 16, February 19, and March 11 in 1997 (Table 1). In the Kitami region, the standard sowing date was around March 11.

The distances between plants and lines were approximately 1 and 5 cm, respectively. The surface of the soil bed was directly covered with plastic film, 0.1 mm thickness, and a small tunnel with polyethylene film, 0.05 mm thickness, was placed over the soil bed. The plastic film cover of the soil surface remained until the end of February to avoid injury to the seedlings from freezing. The plastic tunnel cover was opened in the daytime and closed at nighttime. During cloudy days, the tunnel remained closed all day.

The 1997/98 trial was conducted in the same way as the 1996/97 trial. In 1997, the sowing date was December 19, and in 1998, the sowing dates were January 16, January 30, February 19, and March 11 (Table 1).

In both trials, inside the tunnel, the air temperature at 30 cm above the soil surface and the soil temperature at 5 cm depth from the soil surface was measured every 10 min using the KADEC-U model II (KONA System Co., Ltd., Sapporo, Japan). However, a bimetallic recording thermometer (Sato Keiryoki Mfg. Co., Ltd., Tokyo, Japan) was only used from mid-December 1997 to mid-January 1998.

Transplanting of seedlings

In the 1996/97 trial, the seedlings grown from the four different sowing dates were manually transplanted into an open field on April 25, May 2, and May 13, 1997 (Table 1), as May 13 is the standard transplanting date in the Kitami region. The seedlings were transplanted into a plot (1.2×2.7 m, 3.24 m^2) with four lines, with 30 cm between each line and 10.5 cm between each plant. The plant density was 3,174 plants·a^{-1}. In the 1997/98 trial, the seedlings were transplanted on April 21, May 1, and May 12 in the same field as in the 1996/97 trial. The seedlings transplanted in April and early May were covered with an unwoven fabric sheet (Paopao 90; Mitsubishi Chemical Agri Dream Co., Ltd., Tokyo, Japan) for approximately one month in the field, but the seedlings transplanted in mid-May were uncovered in both trial years.

A compound chemical fertilizer, 12 kg of nitrogen, 22 kg of phosphate, and 14 kg of potassium, was applied as a basal dressing per 10 a several days prior to the transplanting, and no side dressing was applied in either trial year. Two tons of compost per 10 a had also been applied in the trial field the previous autumn.

Onion growth and yield

Growth characteristics, such as leaf number, leaf length, and leaf sheath diameter, were measured for at least 10 plants in each plot, without a border area. In each plot, the dates of bulbing, leaf lodging, and bulb ripening were recorded through visual observations. The lodging date was recognized as the date when half of the plants' leaves had fallen to the ground. Approximately 10 days after lodging, the root was manually cut by lifting the bulb and then returning it to the ground to continue the drying process. According to our observations, the time in which the onion leaves and outer skin dried was defined as the ripening time, near the harvesting time. After harvest, onion yield and external appearances, such as the skin color and skin retention, were noted. The skin retention score indicated the strength of skin attachment and the thickness of the outer dry leaves, and this was determined through visual observation and physical touch.

The meteorological data related to growth were obtained based on the Automated Meteorological Data Acquisition System (AMeDAS, Sakaino station), located 7 km west southwest of the trial site.

Statistical analysis

Data on 1) the sowing dates, cultivars and seedling growth in the plastic greenhouse, and 2) the sowing dates and transplanting dates of each cultivar in the field, were analyzed by a two-way analysis of variance (ANOVA). In addition, statistical analyses were conducted using EZR version 1.36 (Kanda, 2013).

Results

Temperature trends in the plastic greenhouse without artificial heating

At the AMeDAS Sakaino point, the outside daily minimum temperature between late December and late February was recorded from −2.4°C to −20.9 °C in the 1996/97 trial, and from −4.6°C to −26.1°C in the 1997/97 trial. The outside temperature affected the air temperature in the plastic greenhouse in both trial years. The minimum air temperature recorded between late December and late February in the 1996/97 trial was −1.1°C to −5.4°C (Fig. 1). In the 1997/98 trial, the minimum air temperature recorded was from −6.7°C to −14.4°C in the same period. However, the minimum soil temperature was recorded from 1.8°C to 4.8°C in the 1996/97 trial and from −0.2°C to 2.0°C in the 1997/98 trial. The surface of the soil bed was lightly frozen early in the morning, but melted throughout the day. From visual observations, the juvenile onion seedlings exhibited no damage.

The average air temperatures in the plastic tunnel were from 6.3°C to 10.5°C in January and from 7.4°C to 14.9°C between late February and late April in the 1996/97 trial. In the 1997/98 trial, the average air temperatures for same periods were from 2.8°C to 7.4°C and from 11.5°C to 19.5°C, respectively (Fig. 2). The temperatures were higher in the 1996/97 trial than in the 1997/98 trial in January. However, the opposite trend was observed between late February to late April. On the other hand, the average temperature trends of the soil in both trial years were similar.

Seedling emergence

The tested cultivars took approximately 20 days to emerge in the 1996/97 trial following the December and January sowings (Table 2). However, the time required for seedling emergence reduced to approximately 15 days in the February and March sowings.

The same tendency seen in the 1996/97 trial was observed in the 1997/98 trial. In the 1997/98 trial, seedling emergence occurred after 34–36 days in the December sowing, and this time was reduced from the

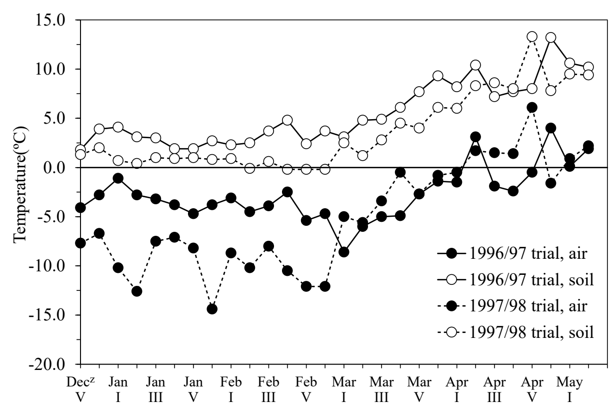

Fig. 1. The minimum temperature of air and soil in plastic greenhouses during nursery production in the 1996/97 and 1997/98 trials.
z Roman numerals indicate 5 days within a month.

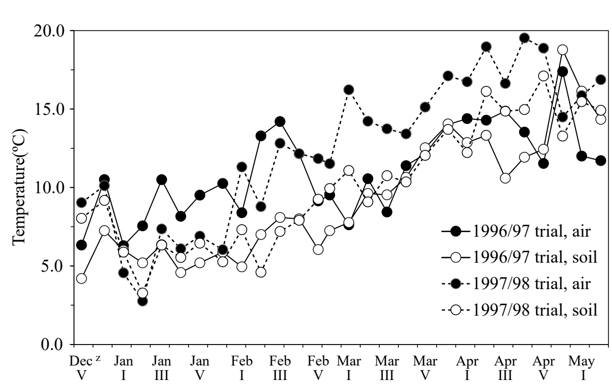

Fig. 2. The mean temperature of air and soil in plastic greenhouses during nursery production in the 1996/97 and 1997/98 trials.
z Roman numerals indicate 5 days within a month.

January sowings. Moreover, after the February and March sowings, these times were reduced to approximately 15 days.

A significant difference in the required amount of time for seedling emergence among cultivars was observed in the 1996/97 trial. From the December 19 sowing, the earliest seedling emergence occurred in KM86 and the latest occurred in SON (Table 2).

Seedling growth in the plastic greenhouse

In the 1996/97 trial, the seedlings grew slowly due to cold temperatures that lasted until late February. After March, warmer temperatures accelerated seedling growth. In SON, the leaf length of the seedlings sown in December and January was longer than that of the seedlings sown in February and March on April 25 and May 2 (Table 3).

In KW3, leaf length, fresh leaf number and leaf sheath diameter clearly differed due to the combinations of sowing and transplanting dates. The seedlings sown in December and January, and transplanted on May 13 were larger. The same trend was observed in OK1 and KM86 as in KW3, except for the fresh leaf number of the two cultivars by sowing dates.

In the 1997/98 trial, the same trend for the above three characteristics was observed in all cultivars, except for the fresh leaf number of KHT (data not shown). Moreover, KW3 exhibited stable seedling growth characteristics in both trial years.

Onion growth in the field

In the 1996/97 trial, the daily mean temperature in late April was 1.8°C higher than usual, 1.6°C lower from May to mid-June and, 3.5°C higher in late July (Fig. 3). On the other hand, in the 1997/98 trial, the mean temperature in late April was as high as 4°C above the usual temperature, 1.7°C lower in June, and 2.3°C lower in mid-July.

Onion leaf growth in the open field in the 1996/97 trial was measured on July 30. However, bulbing and leaf lodging had already occurred in all cultivars at that time (Table 4). On June 30 in the 1997/98 trial, in the standard cropping including March sowing and mid-May transplanting, leaf length of the onion plants was

Table 3. Effect of sowing date and transplanting date on seedling growth at transplanting time in four cultivars in the 1996/97 trial.

Cultivar	Sowing date	Leaf length (cm)			Fresh leaf number			Leaf sheath diameter (mm)		
		Transplanting date			Transplanting date			Transplanting date		
		Apr. 25	May 2	May 13	Apr. 25	May 2	May 13	Apr. 25	May 2	May 13
SON	Dec. 19	33.1	34.9	—[z]	3.1	2.8	—	4.5	4.3	—
	Jan. 16	28.1	33.6	—	2.8	3.4	—	3.4	4.2	—
	Feb. 19	17.0	21.1	32.0	2.0	2.4	3.1	3.2	3.2	3.9
	Mar. 11	16.8	17.9	22.2	2.0	2.5	2.6	1.6	3.0	3.3
	Sowing date[y]		**			NS			+	
	Transplanting date		*			+			*	
KW3	Dec. 19	28.0	28.2	38.1	2.2	2.6	3.2	3.5	3.9	4.7
	Jan. 16	23.2	26.0	31.3	2.7	2.9	2.9	2.9	3.3	4.0
	Feb. 19	16.6	18.7	25.6	2.1	2.4	2.8	2.2	3.1	3.3
	Mar. 11	13.6	15.4	22.7	1.6	2.2	2.5	1.4	2.7	3.0
	Sowing date		***			*			***	
	Transplanting date		***			***			***	
OK1	Dec. 19	25.9	31.4	35.6	3.0	2.7	3.0	3.6	4.0	4.7
	Jan. 16	22.4	22.2	32.5	2.9	3.3	2.9	2.9	3.3	4.3
	Feb. 19	21.8	23.8	28.6	2.3	2.7	3.4	2.8	3.0	3.8
	Mar. 11	16.4	17.9	26.8	2.2	2.6	3.1	2.4	3.0	3.4
	Sowing date		**			NS			***	
	Transplanting date		***			NS			***	
KM86	Dec. 19	24.4	27.3	29.6	2.7	2.6	3.4	3.4	3.9	4.8
	Jan. 16	26.7	28.4	38.5	3.0	2.8	3.3	3.4	4.5	4.9
	Feb. 19	18.2	21.9	29.3	1.8	2.5	3.1	2.4	2.7	3.5
	Mar. 11	14.4	17.8	26.4	2.0	2.4	3.1	2.2	2.9	3.2
	Sowing date		**			+			***	
	Transplanting date		***			**			***	

[z] A dash means that plots could not be prepared due to an insufficient number of seedlings.
[y] ANOVA. ***, **, *, +, and NS indicate significant difference at $P<0.001$, 0.01, 0.05, 0.1 and non-significant, respectively.

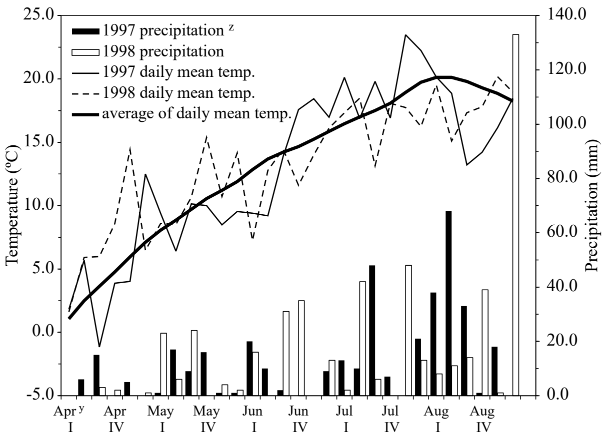

Fig. 3. Temperature and precipitation during the growth period in the 1996/97 and 1997/98 trials.
[z] Daily mean temperature is the average of 5 days within a month and precipitation is shown as a total of 5 days. Average of daily mean temperature was calculated from the values of AMeDAS Sakaino Station in 1966–1996.
[y] Roman numerals indicate 5 days within a month.

61–65 cm, with eight fresh leaves, and 14–15 mm leaf sheath diameter in KW3, OK1, and KM86 (Table 5). Early sowing from December to February and early transplanting in April and early May promoted leaf growth, especially for OK1 and KM86. Leaf length and leaf sheath diameter of OK1 and KM86 grew to approximately 80 cm and more than 20 mm in the December and January sowings, respectively. Similarly, for KW3 sown from December to February and transplanted in April, the leaf length and leaf sheath diameter were over 70 cm and 17 mm, respectively, and were greater than those of standard cropping with March sowing and mid-May transplanting.

Bulbing, leaf lodging, and bulb ripening time

Transplanting in April and early May accelerated the bulbing date. Bulbing began in late June in KW3 and OK1 and early July in KM86 in the 1996/97 trial (Table 4). Furthermore, the bulbing began in mid-June in KHT and KW3 and in late June in OK1 in the 1997/98 trial (Table 5).

The acceleration of the bulbing date influenced the lodging time. In the combination of the December and January sowings of KW3, OK1, and KM86, along with the April and early May transplanting, the lodging date was 5–10 days earlier than that of the March sowing and mid-May transplanting for each cultivar. Particularly, in the 1996/97 trial, the lodging date in KW3 was 18–23 days earlier compared with that of standard cropping in OK1 and KM86, which occurred on July 31 and August 5, respectively (Table 4). A similar tendency was observed in the acceleration of the lodging date in the 1997/98 trial, although lodging time was delayed because of cooler summer temperatures. Namely, in the case of KHT, the lodging time was 24–31 days earlier than that of OK1 (standard cropping) and 32–39 days earlier than that of KM86 (standard cropping).

In addition to the lodging date, the ripening date was accelerated in the December and January sowings and April and early May transplanting, compared with standard cropping, March sowing and mid-May transplanting in all cultivars used in the 1996/97 trial (Table 4). The SON seedlings ripened in mid-July. The ripening date for KW3 extended from July 28 to August 6 in April and early May transplantings. On the other hand, the ripening dates in OK1 and KM86 were in mid- and late August, respectively.

In the 1997/98 trial, the ripening date was delayed for all cultivars as a result of leaf growth having been extended by irregular weather, which was warmer in mid-May and cooler in late June and mid-July (Fig. 3). Nevertheless, KHT ripened from July 30 to August 2 in the December 19 and January 16 sowings and April 21 and May 1 transplantings. Moreover, KW3 also ripened on August 7 in the December sowing (Table 5).

Bolting

The frequency of unseasonable bolting was 0.6%–3.3% only in KM86 under the combination of sowing in either December or January and transplanting in April or the beginning of May in the 1996/97 trial (Table 6). This did not occur in the other cultivars. In addition, KM86 also showed bolting in the 1997/98 trial (Table 7).

Bulb weight and yield

There was a difference in bulb weight among the cultivars used, and bulb weight tended to increase in the order of KW3, OK1, and KM86 in both trial years (Tables 6 and 7). In the 1996/97 trial, the mean bulb weight of SON in all plots was nearly always less than 100 g, and early sowing and late transplanting led to a lower bulb weight (Table 6). The ratio of unmarketable small bulbs was 2.6%–74.1%. This ratio was affected by the sowing date and the transplanting date. In KW3, the mean bulb weight was greater than 100 g in all plots. For seedlings that were transplanted up to May 2, the bulb weight reached approximately 130 g in almost treatments (Table 6). In OK1, the bulb weight was more than 150 g, reaching a maximum of 172 g, in all plots, particularly when seedlings were transplanted up to May 2. KM86 produced larger bulbs compared with the other three cultivars, except for the combination of sowing on February 19 and transplanting on May 13. The bulb weight from the December or January sowing was more than 200 g. However, the bulb weight from the February or March sowing was less than 200 g.

As for the onion yield in the 1996/97 trial, SON had the lowest yield of 102–297 $kg{\cdot}a^{-1}$ because of its low bulb weight (Table 6). In KW3, the yield of onions sown in December and January was more than 500 $kg{\cdot}a^{-1}$ for the April transplanting. However, this

Table 4. Effect of sowing date and transplanting date on plant growth in the 1996/97 trial.

Cultivar	Sowing date	Transplanting date	Growth on Jul. 30			Bulbing date[z]	Lodging date[y]	Ripening date[x]
			Leaf length (cm)	Fresh leaf no.	Leaf sheath diameter (mm)			
SON	Dec. 19	Apr. 25	—[w]	—	—	—	Jun. 17	Jul. 12
		May 2	—	—	—	—	Jun. 15	Jul. 11
	Jan. 16	Apr. 25	—	—	—	Jun. 15	Jun. 29	Jul. 18
		May 2	—	—	—	Jun. 15	Jun. 25	Jul. 11
	Feb. 19	May 2	55.0	6.0	10.0	Jun. 18	Jul. 1	Jul. 21
		May 13	—	—	—	Jun. 24	Jul. 9	Jul. 25
	Mar. 11	May 2	50.0	6.0	10.0	Jun. 20	Jul. 6	Jul. 25
		May 13	—	—	—	Jun. 26	Jul. 10	Jul. 25
	Sowing date[v]		—	—	—	*	***	***
	Transplanting date		—	—	—	**	***	*
	Sowing d. × Transplanting d.		—	—	—	NS	NS	NS
KW3	Dec. 19	Apr. 25	63.5	6.5	10.5	Jun. 24	Jul. 13	Jul. 31
		May 2	69.5	6.5	15.0	Jun. 27	Jul. 13	Jul. 28
		May 13	64.0	7.8	15.0	Jul. 3	Jul. 20	Aug. 6
	Jan. 16	Apr. 25	68.5	6.3	13.0	Jun. 26	Jul. 14	Aug. 6
		May 2	69.0	6.5	14.5	Jun. 28	Jul. 13	Aug. 1
		May 13	63.0	10.5	7.5	Jul. 5	Jul. 23	Aug. 8
	Feb. 19	May 2	61.5	6.5	16.0	Jun. 30	Jul. 20	Aug. 11
		May 13	61.5	5.5	13.0	Jul. 4	Jul. 24	Aug. 11
	Mar. 11	May 2	66.5	6.4	14.0	Jul. 3	Jul. 22	Aug. 11
		May13	62.0	5.5	10.0	Jul. 4	Jul. 24	Aug. 12
	Sowing date		NS	NS	NS	NS	***	**
	Transplanting date		NS	NS	*	***	***	+
	Sowing d. × Transplanting d.		NS	NS	NS	NS	*	NS
OK1	Dec. 19	Apr. 25	76.5	7.5	16.5	Jun. 28	Jul. 20	Aug. 11
		May 2	65.0	7.7	17.0	Jul. 1	Jul. 21	Aug. 13
		May 13	67.0	8.0	16.0	Jul. 4	Jul. 26	Aug. 16
	Jan. 16	Apr. 25	69.5	8.0	17.5	Jun. 29	Jul. 23	Aug. 18
		May 2	68.5	7.5	17.5	Jul. 2	Jul. 24	Aug. 16
		May 13	69.0	9.0	17.0	Jul. 8	Jul. 28	Aug. 19
	Feb. 19	May 2	71.5	7.3	19.0	Jul. 2	Jul. 25	Aug. 18
		May 13	65.5	9.3	16.5	Jul. 11	Aug. 4	Aug. 26
	Mar. 11	May 2	66.5	7.9	17.5	Jul. 4	Jul. 25	Aug. 20
		May 13	66.5	7.5	15.5	Jul. 7	Jul. 31	Aug. 22
	Sowing date		NS	NS	NS	**	***	*
	Transplanting date		NS	+	NS	***	***	NS
	Sowing d. × Transplanting d.		NS	NS	NS	+	NS	NS
KM86	Dec. 19	Apr. 25	78.5	7.6	21.0	Jul. 5	Jul. 25	Aug. 23
		May 2	72.0	6.8	15.5	Jul. 6	Jul. 26	Aug. 23
		May 13	80.5	10.5	20.0	Jul. 10	Aug. 3	Aug. 28
	Jan. 16	Apr. 25	80.0	8.5	21.0	Jul. 5	Jul. 26	Aug. 24
		May 2	80.0	9.3	20.0	Jul. 6	Jul. 27	Aug. 23
		May 13	71.5	9.5	16.0	Jul. 12	Aug. 1	Aug. 28
	Feb. 19	May 2	74.5	8.7	20.0	Jul. 8	Jul. 29	Aug. 24
		May 13	63.0	8.3	15.5	Jul. 9	Jul. 28	Aug. 24
	Mar. 11	May 2	74.5	7.9	18.5	Jul. 7	Aug. 1	Aug. 26
		May 13	67.0	9.3	17.5	Jul. 12	Aug. 5	Aug. 30
	Sowing date		+	NS	NS	NS	*	NS
	Transplanting date		+	**	+	***	**	**
	Sowing d. × Transplanting d.		**	NS	+	NS	NS	NS

[z] Date on which the bulb diameter was twice that of the leaf sheath diameter in 40–50% of plants observed. The hyphen symbol indicates that onion plants already started bulbing when observed.

[y] Date on which 40–50% of plants had lodged.

[x] Date on which 40–50% of plants' leaves had dried.

[w] The hyphen in the sowing on December 19 and January 16 indicate no data because onion leaves were already dried. Those of sowing on February 19 and March 11 indicate data lacking.

[v] ANOVA. ***, **, *, +, and NS indicate significant difference at $P < 0.001$, 0.01, 0.05, 0.1, and non-significant, respectively.

Table 5. Effect of sowing date and transplanting date on plant growth in the 1997/98 trial.

Cultivar	Sowing date	Transplanting date[z]	Growth on Jun. 30 Leaf length (cm)	Fresh leaf no.	Leaf sheath diameter (mm)	Bulbing date[y]	Lodging date[x]	Ripening date[w]
KHT	Dec. 19	Apr. 21	71.2	8.1	15.8	Jun. 10	Jul. 10	Jul. 30
		May 1	72.7	8.9	15.4	Jun. 16	Jul. 13	Aug. 3
	Jan. 16	Apr. 21	70.8	8.5	15.9	Jun. 12	Jul. 13	Aug. 2
	Jan. 30	Apr. 21	69.6	8.3	15.7	Jun. 16	Jul. 17	Aug. 6
		May 1	72.8	9.5	15.8	Jun. 18	Jul. 17	Aug. 8
	Feb. 19	Apr. 21	69.9	8.6	14.9	Jun. 14	Jul. 16	Aug. 5
		May 1	62.9	8.8	14.6	Jun. 20	Jul. 18	Aug. 10
	Mar. 11	Apr. 21	65.3	6.8	14.4	Jun. 22	Jul. 23	Aug. 12
		May 1	65.9	7.9	14.5	Jun. 27	Jul. 22	Aug. 12
	Sowing date[v]		NS	**	NS	***	***	*
	Transplanting date		NS	**	NS	***	NS	NS
	Sowing d. × Transplanting d.		NS	NS	NS	NS	NS	NS
KW3	Dec. 19	Apr. 21	74.2	8.8	18.2	Jun. 12	Jul. 17	Aug. 7
		May 1	74.8	9.3	17.7	Jun. 18	Jul. 20	Aug. 13
	Jan. 16	Apr. 21	73.2	9.0	17.7	Jun. 13	Jul. 20	Aug. 14
	Jan. 30	Apr. 21	70.6	8.8	17.0	Jun. 15	Jul. 22	Aug. 15
		May 1	74.9	9.4	17.1	Jun. 23	Jul. 24	Aug. 18
	Feb. 19	Apr. 21	71.1	8.5	17.3	Jun. 17	Jul. 23	Aug. 15
		May 1	65.3	8.6	15.8	Jun. 22	Jul. 24	Aug. 17
	Mar. 11	Apr. 21	63.8	6.8	15.4	Jun. 23	Jul. 31	Aug. 20
		May 1	66.6	7.9	14.9	Jun. 28	Jul. 28	Aug. 19
		May 12	64.7	7.7	14.3	Jul. 6	Jul. 28	Aug. 18
	Sowing date		*	***	+	**	***	***
	Transplanting date		NS	*	NS	***	NS	+
	Sowing d. × Transplanting d.		NS	NS	NS	NS	NS	+
OK1	Dec. 19	Apr. 21	79.2	9.2	21.6	Jun. 16	Jul. 24	Aug. 17
		May 1	77.8	9.5	20.2	Jun. 21	Jul. 26	Aug. 20
	Jan. 16	Apr. 21	78.4	9.7	21.1	Jun. 24	Jul. 29	Aug. 22
		May 1	88.0	10.7	22.4	Jun. 29	Jul. 30	Aug. 21
	Jan. 30	Apr. 21	77.2	9.1	20.5	Jun. 24	Aug. 1	Aug. 23
		May 1	78.1	9.4	18.8	Jul. 4	Aug. 1	Aug. 24
	Feb. 19	Apr. 21	73.6	8.6	20.2	Jun. 27	Aug. 4	Aug. 25
		May 1	70.0	9.5	19.4	Jul. 2	Aug. 3	Aug. 25
	Mar. 11	Apr. 21	63.1	7.1	16.3	Jul. 7	Aug. 15	Sep. 4
		May 1	67.7	8.7	18.3	Jul. 4	Aug. 6	Aug. 27
		May 12	64.0	7.9	14.9	Jul. 13	Aug. 10	Aug. 30
	Sowing date		***	***	+	***	***	***
	Transplanting date		NS	***	NS	***	NS	***
	Sowing d. × Transplanting d.		NS	NS	NS	*	NS	**
KM86	Dec. 19	Apr. 21	80.1	8.7	22.5	Jul. 3	Aug. 7	Sep. 1
		May 1	83.6	9.6	21.3	Jul. 3	Aug. 6	Aug. 31
	Jan. 16	Apr. 21	75.0	9.1	21.2	Jul. 1	Aug. 10	Sep. 5
		May 1	77.9	9.5	21.0	Jul. 9	Aug. 12	Sep. 5
	Feb. 19	Apr. 21	73.1	8.4	19.2	Jul. 1	Aug. 13	Sep. 6
		May 1	73.9	8.6	19.5	Jul. 12	Aug. 12	Sep. 3
	Mar. 11	Apr. 21	50.7	6.3	13.4	Jul. 14	Aug. 26	Sep. 10
		May 1	64.5	7.8	16.9	Jul. 12	Aug. 19	Sep. 7
		May 12	61.5	8.1	15.0	Jul. 18	Aug. 18	Sep. 6
	Sowing date		***	***	***	*	***	*
	Transplanting date		NS	***	NS	+	NS	NS
	Sowing d. × Transplanting d.		NS	*	NS	+	NS	NS

[z] No plots were designed for combination of sowing on January 16 and planting on May 1 for KHT and KW3 in the 1997/98 trial due to the insufficiency of seedlings.
[y] Date on which the bulb diameter of 40–50% of plants was twice that of the leaf sheath diameter.
[x] Date on which 40–50% of plants had lodged.
[w] Date on which 40–50% of plants' leaves had dried.
[v] ANOVA. ***, **, *, +, and NS indicate significant difference at $P < 0.001$, 0.01, 0.05, 0.1, and non-significant, respectively.

Table 6. Effect of sowing date and transplanting date on yield and bulb quality in the 1996/97 trial.

Cultivar	Sowing date	Transplanting date	Bolting (%)	Unmarketable small bulb (%)[z]	Bulb weight (g)	Yield ($kg \cdot a^{-1}$)	Skin color (1–9)[y]	Skin retention (1–9)[x]
SON	Dec. 19	Apr. 25	0	58.0	63	181	2.5	2.0
		May 2	0	74.1	35	102	3.5	2.0
	Jan. 16	Apr. 25	0	10.4	104	290	3.0	3.0
		May 2	0	52.3	54	156	3.5	3.0
	Feb. 19	May 2	0	8.9	95	297	2.5	3.0
		May 13	0	25.7	69	201	3.0	4.0
	Mar. 11	May 2	0	2.6	98	291	3.0	4.0
		May 13	0	24.9	73	214	3.5	3.5
	Sowing date[w]		—	***	***	***	NS	NS
	Transplanting date		—	***	**	**	NS	NS
	Sowing d. × Transplanting d.		—	+	NS	NS	NS	NS
KW3	Dec. 19	Apr. 25	0	0.0	178	524	4.0	4.0
		May 2	0	0.0	145	425	5.5	5.0
		May 13	0	0.5	129	380	4.5	4.5
	Jan. 16	Apr. 25	0	0.0	174	509	5.0	4.5
		May 2	0	0.0	135	384	4.0	4.0
		May 13	0	1.0	124	364	4.0	4.5
	Feb. 19	May 2	0	0.6	147	449	4.5	4.5
		May 13	0	1.5	105	321	3.5	5.5
	Mar. 11	May 2	0	2.7	133	393	4.0	4.5
		May 13	0	1.0	114	332	3.5	4.0
	Sowing date		—	NS	NS	NS	NS	NS
	Transplanting date		—	NS	**	**	+	NS
	Sowing d. × Transplanting d.		—	NS	NS	NS	+	NS
OK1	Dec. 19	Apr. 25	0	0.0	239	684	7.0	6.5
		May 2	0	0.0	182	533	5.5	6.0
		May 13	0	0.5	158	443	5.5	5.5
	Jan. 16	Apr. 25	0	0.0	210	629	7.0	6.5
		May 2	0	0.0	175	539	5.5	6.0
		May 13	0	0.5	166	500	5.5	5.5
	Feb. 19	May 2	0	0.0	174	503	6.0	6.0
		May 13	0	0.0	183	567	6.5	4.5
	Mar. 11	May 2	0	0.0	172	535	5.5	5.5
		May 13	0	0.6	169	507	5.5	6.0
	Sowing date		—	NS	NS	NS	NS	NS
	Transplanting date		—	NS	**	*	**	*
	Sowing d. × Transplanting d.		—	NS	NS	NS	NS	NS
KM86	Dec. 19	Apr. 25	3.3	0.0	260	697	7.0	6.0
		May 2	0.6	0.0	216	661	5.5	6.0
		May 13	0	0.0	203	568	6.5	6.0
	Jan. 16	Apr. 25	2.2	0.0	249	713	7.0	5.5
		May 2	0	0.6	213	640	5.5	6.0
		May 13	0	0.0	202	591	6.5	6.0
	Feb. 19	May 2	0	0.0	194	605	6.0	5.5
		May 13	0	0.6	169	523	5.5	6.0
	Mar. 11	May 2	0	0.6	196	621	5.5	6.0
		May 13	0	0.0	193	596	6.5	6.0
	Sowing date		NS	NS	NS	NS	NS	NS
	Transplanting date		*	NS	NS	NS	*	NS
	Sowing d. × Transplanting d.		NS	NS	NS	NS	NS	NS

[z] The percentage of onion bulbs less than 5 cm in diameter.
[y] Scores mean as follows: 1: poor light yellow, 3: light brown, 5: brown (standard), 7: dark brown, 9: excellent dark brown.
[x] Scores mean as follows: 1: skin missing, 3: skin missing slightly, 5: standard, 7: thick skin, 9: thick skin, intact.
[w] ANOVA. ***, **, *, +, and NS indicate significant difference at $P < 0.001$, 0.01, 0.05, 0.1, and non-significant, respectively.

Table 7. Effect of sowing date and transplanting date on yield and bulb quality in the 1997/98 trial.

Cultivar	Sowing date	Transplanting date	Bolting (%)	Unmarketable small bulb (%)[z]	Bulb weight (g)	Yield ($kg\cdot a^{-1}$)	Skin color (1–9)[y]	Skin retention (1–9)[x]
KHT	Dec. 19	Apr. 21	0.0	0.0	227	694	5.0	4.0
		May 1	0.0	0.5	244	737	5.5	5.0
	Jan. 16	Apr. 21	0.0	1.0	251	762	6.0	5.0
	Jan. 30	Apr. 21	0.0	0.7	268	833	6.0	5.0
		May 1	0.0	0.5	235	718	5.5	5.0
	Feb. 19	Apr. 21	0.0	0.0	256	712	5.0	5.0
		May 1	0.0	0.5	216	671	5.5	5.0
	Mar. 11	Apr. 21	0.0	2.2	226	521	5.5	5.0
		May 1	0.0	0.5	209	655	5.5	5.5
	Sowing date[w]		—	NS	NS	NS	NS	*
	Transplanting date		—	NS	NS	NS	NS	*
	Sowing d. × Transplanting d.		—	NS	NS	NS	NS	*
KW3	Dec. 19	Apr. 21	0.0	0.0	271	841	6.0	5.0
		May 1	0.0	0.0	288	914	6.5	5.5
	Jan. 16	Apr. 21	0.0	0.0	286	890	6.0	6.0
	Jan. 30	Apr. 21	0.0	0.0	280	875	5.5	4.5
		May 1	0.0	0.0	273	861	6.0	6.0
	Feb.19	Apr. 21	0.0	0.0	259	778	5.5	4.5
		May 1	0.5	0.0	250	735	6.0	5.5
	Mar. 11	Apr. 21	0.0	0.0	250	679	5.5	5.5
		May 1	0.0	0.0	221	684	5.5	6.0
		May 12	0.0	0.0	207	627	4.0	4.0
	Sowing date		—	—	*	**	NS	+
	Transplanting date		—	—	NS	NS	*	**
	Sowing d. × Transplanting d.		—	—	NS	NS	NS	NS
OK1	Dec. 19	Apr. 21	0.0	0.0	301	928	7.0	7.0
		May 1	0.0	0.0	354	1102	7.5	7.0
	Jan. 16	Apr. 21	0.0	0.0	322	1007	7.0	7.0
		May 1	0.0	0.0	306	836	6.5	7.0
	Jan. 30	Apr. 21	0.0	0.0	316	959	7.0	7.0
		May 1	0.0	0.0	304	946	7.0	6.5
	Feb. 19	Apr. 21	0.0	0.0	327	951	7.0	7.0
		May 1	0.0	0.0	273	854	6.0	6.0
	Mar. 11	Apr. 21	0.0	0.0	335	623	6.5	6.5
		May 1	0.0	0.0	276	835	6.5	6.5
		May 12	0.0	0.0	275	816	4.5	5.0
	Sowing date		—	—	NS	*	NS	NS
	Transplanting date		—	—	+	NS	**	**
	Sowing d. × Transplanting d.		—	—	*	+	NS	NS
KM86	Dec. 19	Apr. 21	3.2	0.0	348	970	7.0	7.0
		May 1	9.2	0.0	319	650	6.5	6.0
	Jan. 16	Apr. 21	3.5	0.0	339	963	7.0	7.0
		May 1	2.8	0.0	355	829	7.0	6.0
	Feb. 19	Apr. 21	0.7	0.0	344	915	6.5	6.5
		May 1	0.0	0.0	296	835	6.0	6.0
	Mar. 11	Apr. 21	0.0	0.0	336	619	6.5	6.0
		May 1	0.0	0.0	316	821	6.5	6.0
		May 12	0.0	0.0	308	895	5.5	6.0
	Sowing date		**	—	NS	NS	NS	NS
	Transplanting date		NS	—	NS	NS	NS	NS
	Sowing d. × Transplanting d.		+	—	NS	NS	NS	NS

[z] The percentage of onion bulbs less than 5 cm in diameter.
[y] Scores mean as follows: 1: poor light yellow, 3: light brown, 5: brown (standard), 7: dark brown, 9: excellent dark brown.
[x] Scores mean as follows: 1: skin missing, 3: skin missing slightly, 5: standard, 7: thick skin, 9: thick skin, intact.
[w] ANOVA. ***, **, *, +, and NS indicate significant difference at $P<0.001$, 0.01, 0.05, 0.1, and non-significant, respectively.

number was reduced when they were transplanted in mid-May. In OK1, the yield was more than 500 kg·a^{-1}, except for the combination of sowing in December and transplanting in mid-May. In KM86, all plots exhibited sizeable yields of around 600 kg·a^{-1}, excluding the mid-May transplanting. All four cultivars showed a tendency to have a lower bulb weight and yield when the seedlings were transplanted later.

In the 1997/98 trial, there were no clear differences in bulb weight or yield from the combination of the time of sowing and transplanting for all cultivars used (Table 7). In the early harvest, through a combination of the December and January sowings and April 21 and May 1 transplanting in KHT, the bulbs grew to be more than 230 g and yielded more than 700 kg·a^{-1}. In KW3, the bulbs grew to be 270 g and yielded 841 kg·a^{-1} in the early harvest through a combination of the December sowing and April 21 transplanting.

External appearance of bulbs

The effect of the sowing date and transplanting date on the skin color score and skin retention score was unclear in the 1996/97 trial (Table 6). The skin color score in OK1 and KM86 was more than 5, which is the standard color (Tables 6 and 7). Moreover, SON had a score of approximately 3 with a light yellowish-brown skin color. The skin retention score observed in SON was less than 4, as a little skin was missing from the outer leaves (Table 6). The skin color and skin retention in KW3 were near the standard level. Both scores in KW3 improved in the 1997/98 trial, especially in the transplanting before early May, and its skin color and skin retention scores were more than 5.5 (Table 7).

Discussion

Seedling growth in winter

The onion seedlings raised in a plastic greenhouse exhibited no freezing damage even in mid-winter. Seedling emergence took a long time in all cultivars sown in December and January, especially in the 1997/98 trial. Aoba (1967) reported that the germination rate of onion seeds reached 91% after 50 days even if the temperature was 2–4°C. The germination rate under low-temperature conditions (5°C) was higher in the spring-sowing type cultivars than in the autumn-sowing type cultivars (Mori et al., 1987). In a freezing tolerance test at −2.5°C, nearly all of the onion seedlings survived regardless of leaf age and exposure duration (1–3 h) (Tanaka, 1978). In addition, this treatment at the first leaf stage promoted seedling height. The findings of the present examination and the reports above have shown that onion seeds can germinate and grow in a non-heated plastic greenhouse during winter.

Initially, soil water potential influenced seed germination, and the seedling emergence time was largely determined by temperature (Finch-Savage and Phelps, 1993). In the current study, the soil surface was covered with plastic film to maintain soil moisture, and the seeds were able to germinate in the soil bed. However, germination and seedling emergence were delayed by the low soil temperature. Onion germination increased linearly, ranging from 5°C to 25°C (Brewster, 1990). In the early sowing, it was important that the cultivars could germinate under 5°C.

With each transplanting date in spring, the number and size of emerged leaves in the seedlings sown in December and January were larger than those of emerged leaves in the seedlings sown in March, except for the leaf numbers in SON and OK1. In particular, the leaf number doubled when transplanting in April in KW3. Even if seedlings were grown in mid-winter, early sowing contributed to the production of large seedlings.

Cultivar differences in bulb formation

Accelerating the harvest time was the most important aim of the present research. Leaf lodging is caused by bulb formation, and the subsequent development of internal leaf scales and the ceased production of long leaf blades. As undercutting of roots is generally carried out after leaf lodging for smooth drying of enlarged bulbs in Hokkaido, bulb harvest was performed almost three weeks after the leaf lodging in the standard cropping types, and the lodging date is an indicator of maturity in Hokkaido onions.

The interactions between temperature and photoperiod are known to induce bulbing (Brewster, 1990). Lancaster et al. (1996) reported that bulbing only occurred when dual thresholds held a minimum thermal time of 600 degree days, and a photoperiod of 13.75 h was reached in an experiment with two cultivars and different transplanting times from May to August in New Zealand. In their observations, the thermal time of onion seedlings, which were transplanted late and grew under relatively higher air temperatures and longer day lengths, reached 600 degrees sooner than it did from early transplanting. The bulb size in late transplanting was smaller than that in early transplanting as a lower number of leaves emerged. In addition, a cultivar difference in leaf emergence in the trial was recognized, and cultivar selection was important when the transplanting date was changed from the conventional one.

In the present experiment, the lodging and ripening dates were earlier when sowing and transplanting were earlier in all cultivars used compared with standard cropping with sowing in mid-March and transplanting in mid-May.

Cultivar differences in the time of bulbing, leaf lodging, and ripening (harvest) were observed in the 1996/97 trial. SON grew rapidly after transplanting and began to form bulbs by mid- and late June in the longest day-length period. SON is a typical SD cultivar, and its critical day length for bulbing is estimated to be 12.5 h (Miyaura, 2001). The bulbing in KW3 was observed late in June in the combination treatment of December and January sowing and transplanting in April and early May. Subsequently, leaf lodging occurred in the middle of July, and onion bulbs were harvested in early August. However, the bulbing in OK1 and KM86 began in early July, even with the combination treatment of early seeding and transplanting, and the harvest time was moved to mid- or late August.

Returning to the purpose of the research, KW3 and KHT were proven to be suitable cultivars for early shipping. They are considered to be ID cultivars that begin bulb formation under intermediate day lengths of 13–14 h (Miyaura, 2001). The day length reached 13 h in early April and 14 h in late April in Hokkaido. In general, the optimal temperature for onion growth was 15–25°C (Kato, 2019). The average temperature in northeastern Hokkaido increased to 15°C after late June (Fig. 3). The small seedlings of KW3 and KHT were fully exposed to long day lengths in the field, but they did not start bulbing in May and early June because of the low temperatures in northeastern Hokkaido. KW3 and KHT began to form bulbs in either late June or early July, and these bulbs were harvested from late July to early August.

In the 1997/98 trial, the growth tendencies of KHT and KW3 were similar to those of KW3 in the 1996/97 trial. However, the lodging times of these cultivars were delayed, and they were harvested in early August in KHT and in mid-August in KW3. In KW3, the average duration from bulbing to lodging was 18 days in the 1996/97 trial, and 31 days in the 1997/98 trial, since the growth period was extended as a result of cool weather in June and July (Fig. 3).

The harvest times of OK1 and KM86 were earlier with sowings in December, January, and February. However, the harvest times were from mid- to late August and were not suited to early shipping. Since LD varieties require long day lengths (14.25 h or more) and high temperatures (20°C) (Miyaura, 2001), the start of bulbing was delayed, and the lodging time was not accelerated.

Yield and quality of harvested bulbs

As for the harvest time for early shipping, the yield and bulb quality are also significant traits. SON must be excluded from the promising cultivars due to its low yield. KW3 exhibited sufficient yield in the mid-January sowing and late April transplanting in the 1996/97 trial. Although the combined effect of the time of sowing and transplanting was unclear, KHT also exhibited a sufficient yield until the mid-February sowing and early May transplanting. Wright and Grant (1997) stated that skin color, skin staining, and skin retention were the main factors of visual quality for the export of onions from New Zealand. In Hokkaido, it is essential that onion bulbs have a pleasing appearance for the fresh market, such as an attractive dark brown color, and should not have lost skin to peeling (JA Hokkaido Chuokai and HOKUREN Federation of Agricultural Cooperatives, 2019). As for the external appearance of the bulbs produced under the early sowing and early transplanting method, the external bulb color was slightly brown in KW3 in the 1996/97 trial (Table 6), the outer dry skin remained and the bulb quality was marketable. In the 1997/98 trial, both scores in KW3 were 4 in the standard cropping type, but early transplanting improved this to a score of 4.5 or higher (Table 7). Onions lifted to 10% top-down and topped after curing had a higher proportion of bulbs with three or more intact skins than onions lifted at 90% top-down and topped after curing (Wright and Grant, 1997). In the present study, the onion root was cut 10 days after the lodging time. As it was a complete lodging period, if the roots were cut a little earlier, skin retention could improve.

Regarding the time of harvest, bulb yield and bulb quality, KW3 and KHT were suitable ID cultivars for the cropping type that combined early sowing and early transplanting.

Technical improvements for practical application

Some technical problems to solve will be examined to establish a cropping type with early sowing and early transplanting. Firstly, farmers must care for the onion seedlings for almost two months after germination in either January or February. Maintaining a nursery for a long period in winter involves the risk of plastic greenhouses collapsing from heavy snowfall. Farmers must continuously remove snow from plastic greenhouses to avoid such risks. Secondly, is field preparation for transplanting. In the Kitami region, the average date of snowmelt in spring is April 7, and farmers must use a snow-melting agent to accelerate the preparation of onion fields until late April. Thirdly, is the senescence of seedlings. Transplanting of aged seedlings sometimes contributes to a yield reduction, such as that experienced with KW3 with early sowing and late transplanting in the present study. Onodera et al. (2018) showed the combined effect of the split application of nitrogen in fields and either a foliar spray or a spot supply of phosphate in nurseries. These fertilization techniques were effective for early cropping type in this study. Fourthly, is the use of plastic trays in nursery production. Recently, plastic trays such as the Minoru system (Minoru Industrial Co., Ltd., Akaiwa, Japan) have been used for mechanical transplanting of seedlings, and the trays are put on the soil surface after sowing. When plastic trays are used in early sowing, seedlings must be protected from exposure to severe cold temperatures.

Significance of the cropping type with early sowing and early transplanting

Nowadays, the leading cultivars, such as ‘Okhotsk

222' and 'Kitamomiji 2000', belong to the LD group. In addition, the share of LD cultivars in the production area is approximately 90% in Hokkaido (JA Hokkaido Chuokai and HOKUREN Federation of Agricultural Cooperatives, 2019). However, in the last 10 years, unstable climate conditions in the transplanting period have affected the onion yield as small seedlings were affected by problems such as continuous rainfall and drought at the time of transplanting (Huang et al., 2017). New cropping types or cultivars are necessary to avoid weather damage in the future, and cropping with early sowing and early transplanting will be one of the solutions.

In conclusion, a cropping type that combines early sowing with early transplanting was introduced in northeastern Hokkaido using ID cultivars including KW3 and KHT. This new cropping type will contribute to the early shipment of Hokkaido onions.

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