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Author(s)	田中, 静幸; Tanaka, Shizuyuki
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Studies on the onion cropping type for realizing the early shipment in northeastern Hokkaido

（北海道北東部におけるタマネギの早期出荷作型の確立に関する研究）

Shizuyuki Tanaka

Division of Biosphere Science

Graduate School of Environmental Science

Hokkaido University

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Studies on the onion cropping type for realizing the early shipment in northeastern Hokkaido

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Contents

Glossary

Bulbing date: Date on which the onion bulb diameter was twice the leaf sheath diameter in 40–50% of the plants observed.

Complete lodging date: Date on which 80% of the observed plants had onion leaves bent around the leaf sheath to the ground with maturity.

L-dai: "L-dai" size is the shipping standard for dry bulb onions in Hokkaido, and the bulb diameter is specified to be 8 cm or more and less than 9 cm. The unit price of this size is usually the best.

Lodging date: Date on which 40–50% of the observed plants had onion leaves that bent around the leaf sheath to the ground with near maturity.

Ripening date: Date on 40–50% of the observed plants had dried onion leaves, indicating readiness for harvest.

Root cut: Underground root cutting work to undried onions, which aims to unify ripening date by promoting the drying of the onion skin. This work makes mechanical harvesting easier to schedule and helps minimize unmarketable bulbs caused by, for example, bulb shape deformation or skin cracking and peeling that occurs when the bulb is overgrown.

List of Abbreviations

Terms

ANOVA	Analysis of variance
DM	Dry matter content
FBR	Fusarium basal rot caused by *Fusarium oxysporum* f. sp. *cepae*
ID	Intermediate-day

LD	Long-day
OP	Open-pollinated
PA	Pyruvic acid content
PCA	Principal Component Analysis
SS	Soluble solids content
SD	Short-day
SE	Standard error of the mean

Cultivar names

AMA2	‘Amagashi 2’
AUR	‘Aurora’
BB	‘Bullet bear’
KAR	‘KAR-004’
KHT	‘Kitahayate’
KHT2	‘Kitahayate No.2’
KM86	‘Kitamomiji86’
KW3	‘Kitawase No.3’
OK1	‘Okhotsk No.1’
OK222	‘Okhotsk222’
SJR	‘Sojiro’
SKMJ	‘Super kitamomiji’
SON	‘Sonic’
SPK	‘Sapporoki’
TSU2	‘Tsuritama 2 go’
YOK	‘YOK573’

Chapter 1

General Introduction

1. History of onion production in Hokkaido

Allium vegetables are an important and indispensable part of human diet. Onions are an edible *Allium* that have been cultivated for 4,700 years (Brewster, 2008) and is cultivated all over the world (Brewster, 2008), including tropical countries (Currah, 2002). The world's onion production area is 5.0 million hectares. In 2018, 96.8 million tons of onions were produced, which was the third highest production amount following tomatoes (182.3 million tons) and watermelons (103.9 million tons)(FAOSTAT, http://www.fao.org/faostat/en/#data/QC). Fresh and processed onions are consumed year-round. Onions contain both nutritional and functional components (Augsti, 1990; Fenwick and Hanley, 1990a, 1990b; Goldman et al., 1996; Keusgen, 2002; Lancaster and Boland, 1990; Tsushida, 1997).

The onion was introduced to Hokkaido island from the United States in 1871 when Horace Capron, an employed foreigner, ordered some vegetable seeds (Komochi, 2015). The imported vegetable seeds were planted in the Tokyo Government Garden in the spring of 1872, and were also sent to the Nanae Government Garden for trial production. By 1873, onion was also grown in the Sapporo Government Garden and Tobetsu Village.

Onions were first cultivated via direct sowing. In 1926, the transplanting system began (Sapporo Onion Sales Federation of Agricultural Cooperatives, 1970). Yamaki (1942) showed that the advantages of nursery production using hotbed and transplantation together lowered seed consumption, promoted plant growth, increased yield, and improved bulb quality. Despite these findings, with the intensification of World War II did not allow for the adoption of the new method, and onion production and sales reduced. The onion cultivation in the northeastern Hokkaido as Kitami region is believed to have been introduced in 1917, and the transplant cultivation system there began in 1948 (Kitami Onion Memorial Steering Committee, 1974).

2. Photoperiod requirement for bulb formation and cropping type

Onion cultivars are classified according to day length for bulbing requirements: short-day (SD, daylength 11−12 h required); intermediate-day (ID, 13−14 h); and long-day (LD, >16 h) types (Brewster, 2008). Temperature is an additional environmental factor for bulbing. In SD cultivars, if the day length requirement is met, the basal part of the leaf sheath will begin to enlarge, even at temperatures of approximately 10°C. In contrast, LD cultivars require longer day lengths and temperatures of approximately 15−20°C for bulb formation (Imazu et al., 1954; Miyaura, 2001). ID cultivars will not grow unless the temperature is met, even if the day length. Most Hokkaido cultivars belong to the LD group. On the islands of Honshu, Shikoku, and Kyushu, many cultivars were bred as SD cultivars to 11−13 h day length with the autumn sowing cropping type. It is difficult to obtain different cropping types in Hokkaido, because its short growing period only allows for spring sowing (Miyaura, 2001). In fact, only two cropping types are found in Hokkaido: standard cropping and standard cropping with non-woven fabric row covers (Natl. Res. Inst. Vegetables, Ornamental Plants and Tea. 1998).

3. Hokkaido onion breeding

Until the 1950s, vegetable breeding program by public institutions in Hokkaido was conducted by comparing and selecting imported and domestic cultivars from Honshu island (Hokkaido Natl. Agric. Exp. Stn. and Hokkaido Prefec. Agric. Exp. Stn., 1951). Before the F_1 hybrids were developed, the open-pollinated (OP) cultivars, ‘Kitamiki’ and ‘Sorachiki’, derived from ‘Sapporoki’ (SPK), suitable for each main production region (Kitami and Sorachi) were selected and cultivated (Arimura, 2018). Hanaoka and Ito (1959) compared the strains which had been individually developed in mass-selection of SPK from excellent growers, and found that each strain has differences in maturity and yield. They also found SPK male-sterile clonal lines by chance, which they propagated vegetatively (Hanaoka, 1961). It was shown that SPK was excellent as a parent of F_1 hybrids, regardless of whether it was used as a pollen parent or a seed parent. Hanaoka (1963) demonstrated the practical and effective method of crossing F_1 onion hybrids using the SPK-derived strains and cultivars from overseas or other regions of Japan.

An onion breeding program at the Hokkaido Prefectural Kitami Agricultural Experiment Station, was started in 1973 (Miyaura, 1998). Its primary goals were to obtain a highly marketable yield, long-term storability, and disease resistance, especially to Fusarium basal rot (FBR). The onion breeding programs in Hokkaido progressed with parental lines (Goldman,

1996) from the University of Wisconsin (Muro and Tanaka, 2002). Later, the Hokkaido government recommended ‘Furanui’ (Komochi, 1980), ‘Tsukihikari’ (Tanaka et al., 1987), ‘Sekihoku’ (Miyaura et al., 1985), ‘Tsukisappu’ (Sato et al., 1996) for their disease resistance, yield, and storability. In addition, excellent F_1 cultivars, such as ‘Kitamomiji86’ (KM86), ‘Super Kitamomiji’ (SKMJ), and ‘Okhotsk No.1’ (OK1) (Shippo Co., Ltd., Mitoyo, Japan), as well as ‘Higuma,’ ‘Leo’, ‘Wolf’ (Takii & Co., Ltd. Kyoto, Japan), were developed by seed companies. By combining these various cultivars, the introduction of F_1 cultivars with the FBR resistance trait, became possible, and contributed to stable yield. The development of mechanized growing system also expanded the cultivation area in Hokkaido (Murai, 2016).

Most Hokkaido cultivars were belonging to the LD type. Regarding for early shipment, even with 'Early Globe' (Muro et al., 2006), the lodging time of this cultivar was earlier than that of the LD leading cultivars, but the bulb was smaller in the trial test in the Kitami region. ‘Kitawase No.3’ (KW3, Shippo Co., Ltd. Mitoyo, Japan) and ‘Katahayate’ (KHT, Takii & Co., Ltd., Kyoto, Japan) were the few ID type commercial seeds for Hokkaido. The reason why only a limited number of early-maturing ID cultivars for Hokkaido is considered to be the following factors. According to seed company questionnaires, onion breeding was announced for the autumn-sown OP cultivar starting in 1951, while spring-sown cultivars started in 1975 (Tsunoda, 1996). In fact, 82 autumn-sown cultivars (SD or ID) were counted in 1996, whereas only 12 spring-sown cultivars were counted (LD). This may be due to the fact that there are many small seed companies on Honshu, Shikoku and Kyushu, where autumn-sown cultivars are more suitable, and the fact that it is difficult to breed the spring-sown cultivars needed on Hokkaido.

4. Early shipment for marketable demand

In 2019, the onion production area in Japan was 25,900 ha, of which 56% was the area of Hokkaido. Furthermore, approximately 30% of Japan was the area of the Kitami region (Statistics of Ministry of Agriculture, Forestry, and Fisheries, https://www.maff.go.jp/j/tokei/kouhyou/sakumotu/index.html). The Kitami region has the largest onion production area in Japan.

Onion production targets in the Kitami region in the 1970s were aimed at higher yields, fine quality onions without bulb rot diseases, and good storage ability for over winter shipping. At that time, the market demand for shipments to begin was from September 1st to 20th (Kitami Onion Memorial Steering Committee, 1974); early shipment was not as important as it is today.

In recent years, the decreased production area in Honshu, Shikoku and Kyushu (Fig. 1-1) and harvest loss due to weather disasters has driven the market to demand early shipment in late July from Hokkaido, especially from the Kitami region. These early shipments also need to be of a similar quality, such as external attractivity (uniformed global shape, skin retention, and bulb firmness), to ordinary Hokkaido onions. The first attempts for early onion shipments began in the early 1990's.

To reach this goal, some attempt were made to accelerate onion growth and increase yields in northeastern Hokkaido, where onion growth period is

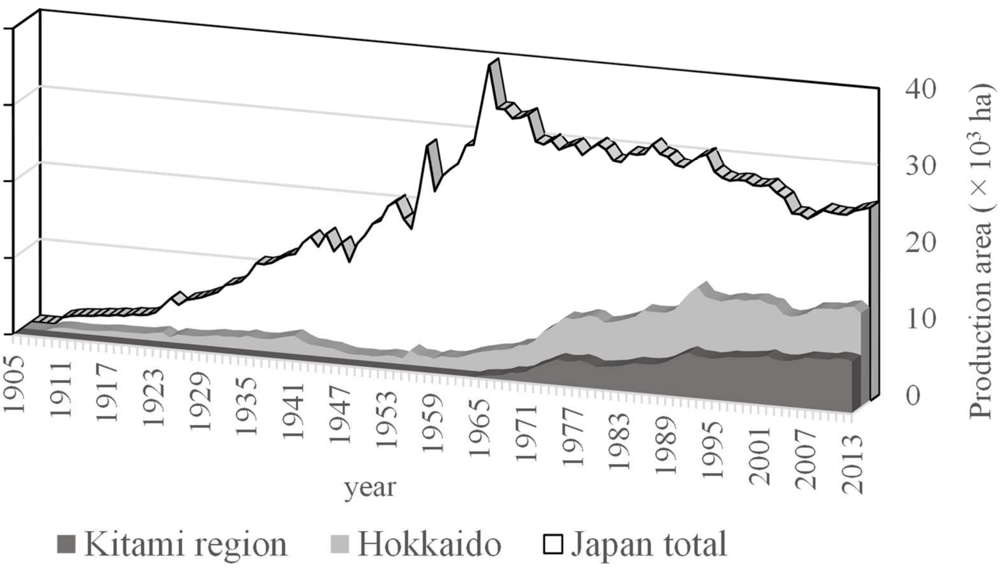


Fig. 1-1. Trend of onion production area in Hokkaido and Kitami region.

limited by freezing soil, low temperatures in early spring, and dropping temperatures starting in the middle of September. Kashida (1990) examined the effect of using row coverings with non-woven fabrics and was successfully able to accelerate bulbing and lodging time about 7 days earlier than the conventional system had allowed. He also obtained a larger yield due to the formation of larger bulbs, and concluded that if early cultivars were transplanted by May 10, then they could be shipped in August (Kashida, 1990). In another attempt, Tanaka et al. (1997) determined that OK1 could be harvested in mid-August if it was sown from late February to early March and transplanted from late April to early May.

Mori et al. (1993) determined that autumn sowing in Hokkaido would create large differences in the ability of the onions to overwinter and unseasonal bolting among cultivars. Autumn sowing became possible in Hokkaido by using autumn-sown cultivars from Honshu, Shikoku and Kyushu. For extra early shipping, Shiga (1998) succeeded in autumn-sown cropping in Central Hokkaido, which is a non-frozen soil area. This cropping type were used with SD or ID cultivars that could be harvested in late July. Currently, this cropping type is practiced only in Date City, located 80km southwest of Sapporo, with a mild climate and no late spring frosts. Autumn sowing was not used in northeastern Hokkaido, including the Kitami region, due to the presence of soils that severely freeze in winter (Ishikawa and Suzuki, 1964; Kinoshita et al., 1978).

5. Preliminary survey from farmers

In relation with this study, onion growers at Kitami region were asked to complete a questionnaire in 1999, regarding the actual conditions of their trial cultivation for early shipment.

The survey was answered by 179 onion growers, who had tried the new cultivation method for early shipment. The answers were analyzed using the type I quantification method (Yanai, 2011). Characteristics (see Table 1-1) included cultivar, irrigation, trial field area, sowing date, transplanting date, nursery duration, row cover duration by non-woven fabric, lodging date, root cut date, harvest date, yield, and rate of marketable bulb weight over "L-dai" (8−9 cm in bulb diameter) sized bulbs. Fifty-five cases were used analyzed; 124 cases were excluded due to a lack of item values.

The lodging time was examined based on five factors (Table 1-1). The multiple correlation coefficient was high (R = 0.830), and the contribution rate was 68.9%, which indicated that about 70% of the lodging date fluctuation could be explained by the selected five factors. The cultivar range was largest at 10.7. The range of row cover was 8.4 in duration. Irrigation was not related to lodging time. In the cultivar category, 'KTH' showed a negative value, indicating an earlier lodging date. There was a large difference among the cultivars in early and late lodging date. The row cover period was 26−35 days, which was the most negative characteristic. The row covering of about one month hastened the lodging time.

Six factors were examined regarding yield (Table 1-2). The large range value of root cut and sowing dates indicated that they had a large effect on

Table 1–1. Analysis result of factors affecting the lodging time of cultivars grown in Kitami region, the northeastern Hokkaido in 1999[z].

Item	Category	Case No.	Category score	Range	Partial correlation coefficient
1: Cultivar	1. Kitahayate	12	-5.6	10.7	0.721
	2. Kitawase No.3	22	-1.7		
	3. Okhotsk No.1	21	5.0		
2: Irrigation	1. Not irrigated	34	0.0	0.0	0.005
	2. Irrigated	21	0.0		
3: Sowing date	1. < Feb.16	3	0.5	3.0	0.305
	2. Feb.16–Feb.25	10	0.2		
	3. Feb. 26–Mar.5	27	-1.2		
	4. Feb. 6– Feb.15	15	1.9		
4: Transplanting date	1. < May 1	31	-1.1	2.7	0.300
	2. May 1–May 5	16	1.4		
	3. May 6–May 10	3	0.7		
	4. May 10 <	5	1.7		
5: Row cover period	1. None	37	0.7	8.4	0.388
	2. <26 days	7	-1.3		
	3. 26–35 days	9	-2.9		
	4. 36 days <	2	5.4		
Constant term			21.2		
Multiple correlation coefficient	R=0.830				
Contribution rate	R^2=0.689				

[z] Farmers' cultivation data (n=55) were analyzed by the qualification type I method.

onion yield. It was expected that a delay in root cutting would increase bulb weight and yield, and delay, the harvest; however the onion seeds were sown earlier than the conventional sowing period, larger seedlings could be transplanted into the open field in the spring. Transplanting times around May 6–10 seemed to have a positive effect on the yield, but only for three cases (1 KHT, 2 OK1). Non-cover and covering that was kept on too long had negative effects on yield.

The ratio of bulb yield of over "L-dai" size is desired due to its high-price, usually. The ratio of bulb yield to over “L-dai” size, was investigated for six criteria (Table 1-3). The largest range of values was found in the root cutting date and transplanting date. As outlined above, delayed root cutting allows the bulb to grow, but delays harvest time. Here, transplanting dates of May 6–10 were also appropriate for the same three cases. Although the partial correlation coefficient was lower, there was also a positive effect from KW3, earlier sowing dates, and irrigation to the amount of over “L-dai”-sized bulbs yielded. Thus, it was concluded that cultivar, sowing and transplanting times, and row coverage periods were the most important factors needed to attain early shipment from northeastern Hokkaido.

6. Scope of thesis

The LD cultivars currently used have high winter storage ability in large refrigerated warehouses that enable long-term shipment through late spring; however, market demand for the early summer shipment of newly harvested onions from northeastern Hokkaido (Fig. 1-2), has been increasing

Table 1–2. Analysis result of factors affecting the yield of cultivars grown in Kitami region, the northeastern Hokkaido in 1999[z].

Item	Category	Case No.	Category score	Range	Partial correlation coefficient
1: Cultivar	1. Kitahayate	12	-119.5	614.8	0.333
	2. Kitawase No.3	22	333.6		
	3. Okhotsk No.1	21	-281.2		
2: Irrigation	1. Not irrigated	34	-162.7	426.0	0.275
	2. Irrigated	21	263.4		
3: Sowing date	1. < Feb.16	3	846.1	1429.2	0.477
	2. Feb.16–Feb.25	10	497.4		
	3. Feb. 26–Mar.5	27	45.7		
	4. Feb. 6– Feb.15	15	-583.1		
4: Transplanting date	1. < May 1	31	58.3	718.3	0.226
	2. May 1–May 5	16	-198.2		
	3. May 6–May 10	3	520.2		
	4. May 10 <	5	-39.1		
5: Row cover period	1. None	37	-166.0	784.2	0.314
	2. <26 days	7	516.2		
	3. 26–35 days	9	340.5		
	4.36 days <	2	-268.0		
6: Root cut date	1. < Jul.26	22	-1028.0	4163.9	0.689
	2. Jul. 26–Jul. 31	11	465.1		
	3. Aug. 1–Aug. 5	11	608.2		
	4. Aug. 6–Aug. 10	10	767.5		
	5. Aug. 10<	1	3135.9		
Constant term			4739.3		
Multiple correlation coefficient	R=0.733				
Contribution rate	R^2=0.538				

[z] Farmers' cultivation data (n=55) were analyzed by the qualification type I method.

Table 1–3. Analysis result of factors affecting the L size-bulb, more than 8 cm in diameter, grown in Kitami region, the northeastern Hokkaido in 1999[z].

Item	Category	Case No.	Category score	Range	Partial correlation coefficient
1: Cultivar	1. Kitahayate	12	-9.3	17.5	0.465
	2. Kitawase No.3	22	8.9		
	3. Okhotsk No.1	21	-4.1		
2: Irrigation	1. Not irrigated	34	-3.9	9.2	0.323
	2. Irrigated	21	6.3		
3: Sowing date	1. < Feb.16	3	5.4	4.4	0.118
	2. Feb.16–Feb.25	10	0.5		
	3. Feb. 26–Mar.5	27	0.5		
	4. Feb. 6– Feb.15	15	-2.2		
4: Transplanting date	1. < May 1	31	0.3	29.0	0.316
	2. May 1–May 5	16	0.3		
	3. May 6–May 10	3	15.5		
	4. May 10 <	5	-10.0		
5: Row cover period	1. None	37	-0.6	17.5	0.276
	2. <26 days	7	6.5		
	3. 26–35 days	9	-5.8		
	4.36 days <	2	13.4		
6: Root cut date	1. < Jul.26	22	-13.2	35.6	0.614
	2. Jul. 26–Jul. 31	11	5.7		
	3. Aug. 1–Aug. 5	11	6.7		
	4. Aug. 6–Aug. 10	10	12.7		
	5. Aug. 10<	1	25.6		
Constant term			61.3		
Multiple correlation coefficient	R=0.736				
Contribution rate	R^2=0.542				

[z] Farmers' cultivation data (n=55) were analyzed by the qualification type I method.

to compensate for the decline in supply in rest of Japan. The soils of this region freeze thoroughly in winter and is not suitable for autumn sowing. Thus, this thesis aimed to enable a cultivation method for shipping new onions in early summer from regions where autumn sowing is not possible (Fig. 1-3).

Specifically, the first study investigated the effect that a combination of sowing and transplanting had on harvest time using SD, ID, and LD cultivars grown under unheated, ordinary plastic greenhouses. It was found that the ID cultivars would be most appropriate for early summer shipping from the new cropping type of early sowing and early transplanting. Then, a second study was conducted to understand how characteristics of ID cultivars compared to ordinary ordinary LD cultivar in northeastern Hokkaido.

Together, these studies clarified the cropping type and required characteristics of ID cultivars needed to enable the early shipment of onions from northeastern Hokkaido.

The attempts for the early shipment of onion have begun from late of 1990s. For carrying out the PhD research, the data obtained from 1996 and 1998 was examined. From the reexamination, cultivar selection was taken as topic for to realize the early shipment of Hokkaido onion. In the PhD thesis, the results of reexamination of the past data and cultivar selection were described in Chapter 2 and Chapter 3, respectively.

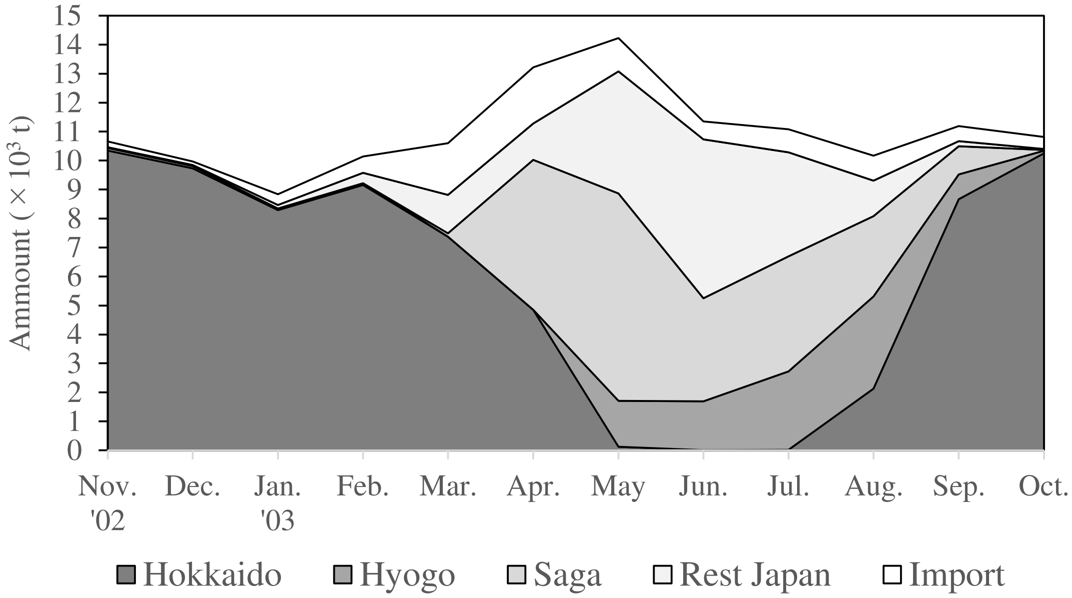
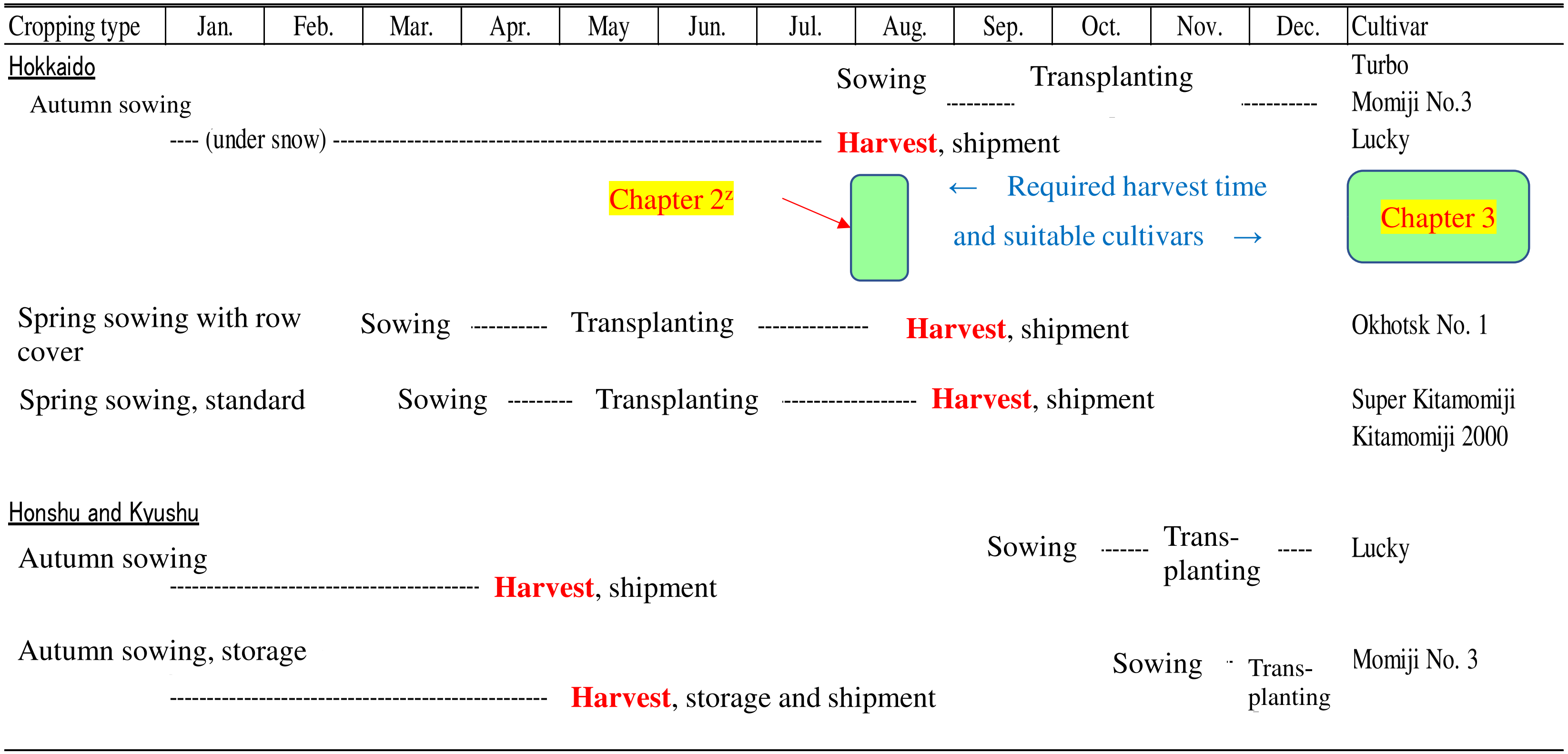


Fig. 1-2. Onion ammount sold in the Central Wholesale Market of Tokyo from November 2002 to October 2003.

Fig. 1-3. Onion cropping types in Japan and study areas in this paper.



z "Chapter 2" and "Chapter 3" refer to the chapters covered in this studies.

Chapter 2

Combination effects of sowing and transplanting time on harvest time in some onion (*Allium cepa* L.) cultivars with different photoperiod requirements in Hokkaido

2.1 Introduction

Day length affects onion bulb formation (Comin, 1946; Abe et al., 1955; Kato, 1964; Lancaster et al., 1996), which has led seed companies to classify their onion cultivars as short-day (SD), intermediate-day (ID), and long-day (LD) types (Brewster, 2008). SD and ID cultivars are primarily produced in the western region of Japan (Kojima, 2013).

From July to August, there is a shortage in the domestic onion market as a result of off-season harvesting between the end of autumn-sown onion shipments and the beginning of the spring-grown onion harvest. The continuous provision of domestic onions to the market would require further control of the domestic onion harvest, that is, extending the autumn-sown harvest period and expediting the spring-sown harvest. Some trials have already been conducted regarding the earlier shipment of Hokkaido onions, but farmers have experienced unseasonable bolting if LD cultivars were transplanted too early (Yoshikawa et al., 1984).

There was also an attempt to introduce the SD cultivars used in the western region of Japan to the standard spring sowing cropping system used in Hokkaido. When the SD cultivars were transplanted in the same manner as the spring-LD cultivars in Hokkaido, the SD cultivars matured earlier, but had many issues, such as low yield, small bulbs, and a poor, yellowish skin color. The reasons for this low marketability were thought to include the limited performance of the SD cultivars transplanted in the spring, and the early bulb formation under the LD condition found in the region.

Shiga (1998) succeeded in the autumn-sown cropping of SD and ID cultivars in central Hokkaido in regions where soil freezing does not occur. In these regions, the bulbs of some ID cultivars, such as ‘Kitawase No. 3’ (KW3), could be harvested earlier than standard LD cultivars. This success is not applicable to the northeastern area of Hokkaido given the region’s soil freezing in winter. Thus, other options must be explored to establish earlier, more stable shipments.

In North America, large transplants can be secured for transplanting provided their seeds are sown early in either a greenhouse or a hotbed, large and a good yield of bulbs after the plants are moved to the field can also be obtained (Comin, 1946). Hamashima (1953) found that larger plants formed bulbs earlier than smaller plants, while Iwama and Hamashima (1953) determined 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 use plastic film-covered greenhouses to establish an onion nursery through the winter. Given the above information, early sowing trials were performed to obtain large seedlings for spring transplanting. It was hypothesized that (1) early transplanting of large seedlings would promote leaf growth in early summer and create a large plant by lodging time, and (2) That ID cultivars would be most effective for early harvest since they are likely to start bulbing earlier compared to the leading LD cultivars in Hokkaido.

In this study, field trials were conducted using early sowing and early transplanting with SD, ID, and LD cultivars in northeastern Hokkaido, near the Kitami region. 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.

2.2 Materials and Methods

2.2.1 Location of experimental study

All experiments were conducted at the Kitami Agricultural Experiment Station, Hokkaido Research Organization, Kunneppu, Hokkaido Japan (43°73′ N, 143°74′E and 142 m a.s.l.) in the harvest years of 1997 and 1998. The soil in the experimental field was classified as brown lowland soil.

2.2.2 Experimental design and cultivars

The factors to be compared were sowing date and transplanting date (Table 2-1). In the 1996/97 trial, four sowing dates and three transplanting dates were set, with a total of 12 factorial treatments established by 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.

Table 2-1. 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.

The cultivars used in this study are presented in Table 2-2. ‘Sonic’ (SON) and ‘Kitahayate’ (KHT) were obtained from Takii & Co., Ltd., Kyoto, Japan, KW3, ‘Okhotsk No. 1’ (OK1), and ‘Kitamomiji 86’ (KM86) were obtained from Shippo Co., Ltd., Mitoyo, Japan. SON is an SD cultivar, KW3 and KHT are classified as ID cultivars, and OK1 and KM86 are LD cultivars. The cultivars KW3, OK1, and KM86 were used in both trial years, but, 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: 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.

2.2.3 Sowing and temperature conditions in a plastic greenhouse

In the 1996/97 trial, seeds from the four cultivars were sown in a soil bed inside a plastic greenhouse, that was 5.4 m wide and 18 m long with no artificial heating. Seeds were sown on December 19, 1996 and January 16, February 19, and March 11, 1997 (Table 2-1). The standard sowing date in the Kitami region is 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 thick), and a small tunnel of polyethylene film (0.05 mm

Table 2-2. 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.

thick) was placed over the soil bed. The plastic film on the soil surface remained until the end of February to avoid freezing injury to the seedlings. The plastic tunnel cover was opened in the day and closed at night. On cloudy days, the tunnel remained closed all day.

The 1997/98 trial using the same methods as the 1996/97 trial. The sowing dates were December 19, 1997 and January 16 and 30, February 19, and March 11, 1998 (Table 2-1).

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

2.2.4 Transplanting of seedlings

In the 1996/97 trial, the seedlings grown were manually transplanted into an open field on April 25, May 2, and May 13, 1997 (Table 2-1), since 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) in 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. 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 containing 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 transplanting. No side dressing was applied in either trial year. Two tons of compost per 10 a had also been applied to the trial field each previous autumn.

2.2.5 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 observation. 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 bulb was lifted and the root was manually cut, then was returned 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, which was near the harvesting time. After harvest, onion yield and external characteristics (e. g., skin color and retention) were noted. The skin retention score indicated the strength of skin attachment and the thickness of the outer dry leaves, which were determined through visual and physical observations. Meteorological data were obtained from the Automated Meteorological Data Acquisition System (AMeDAS, Sakaino station), located 7 km west southwest of the trial site.

2.2.6 Statistical analysis

Data on 1) the sowing dates, cultivars and seedling growth in the plastic greenhouse, and 2) the sowing dates and transplanting dates for 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).

2.3 Results

2.3.1 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 ranged from −2.4°C to −20.9°C during the 1996/97 trial, and from −4.6°C to −26.1°C during the 1997/98 trial. The outside temperature affected the air temperature in the plastic greenhouse in both trial years. The minimum air temperature in the greenhouse recorded between late December and late February in the 1996/97 trial was −1.1°C to −5.4°C (Fig. 2-1). In the 1997/98 trial, the minimum air temperature inside the greenhouse was from −6.7°C to −14.4°C during the same period. The minimum soil temperature was ranged 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.

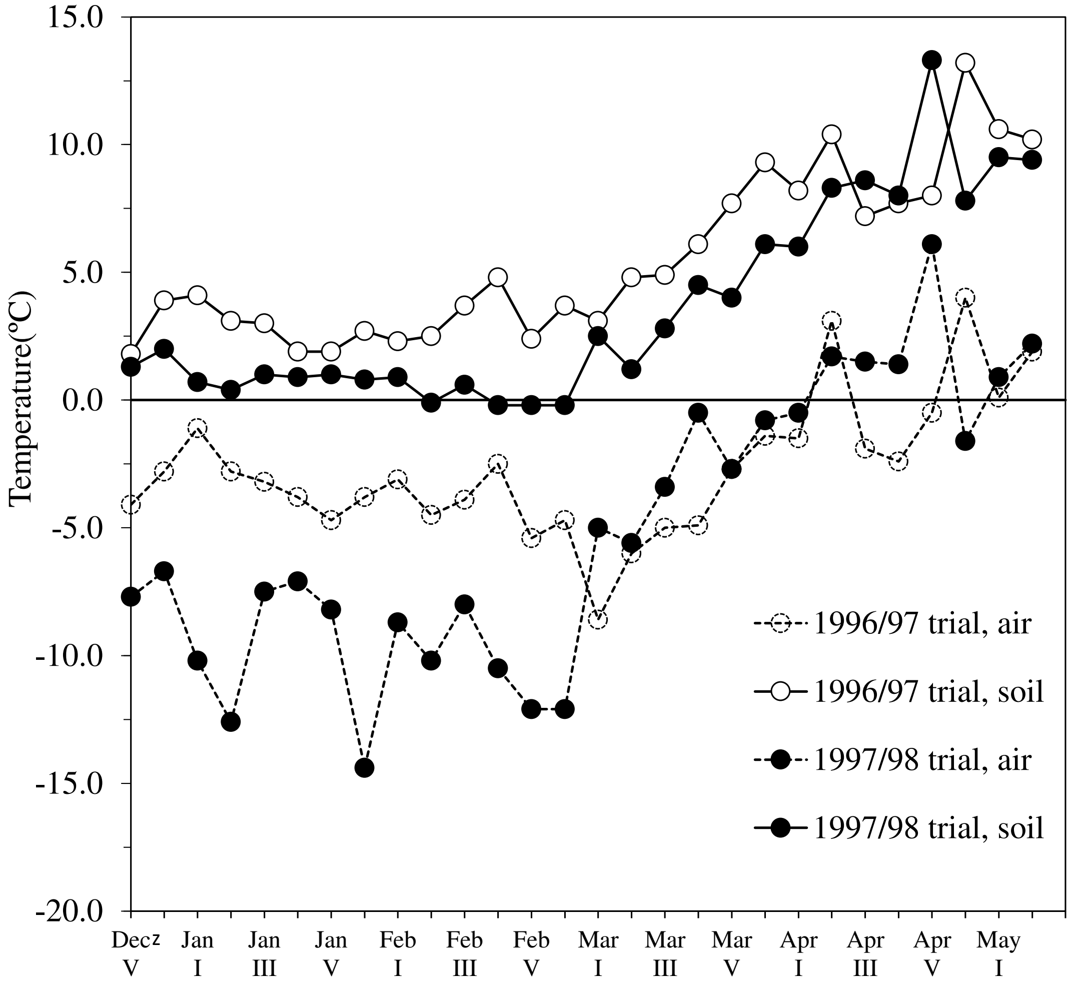


Fig. 2-1. The minimum temperature of air and soil in plastic greenhouses during nursery production in the 1996/97 and 1997/98 trials.

[z] Roman numerals indicate 5 days within a month.

The average air temperatures in the plastic tunnel ranged 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 the same periods were from 2.8°C to 7.4°C and from 11.5°C to 19.5°C, respectively (Fig. 2-2). 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 and late April. The average soil temperature trends in both trial years were similar.

2.3.2 Seedling emergence

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

The same tendency was observed in the 1997/98 trial, with seedling emergence after 34–36 days for the December sowing, which was further reduced after the January sowings. After the February and March sowings, these times were reduced to approximately 15 days.

A significant difference for seedling emergence among all tested cultivars was observed in the 1996/97 trial. Specifically, the earliest seedling emergence from the December 19 sowing occurred in KM86 and the latest occurred in SON (Table 2-2).

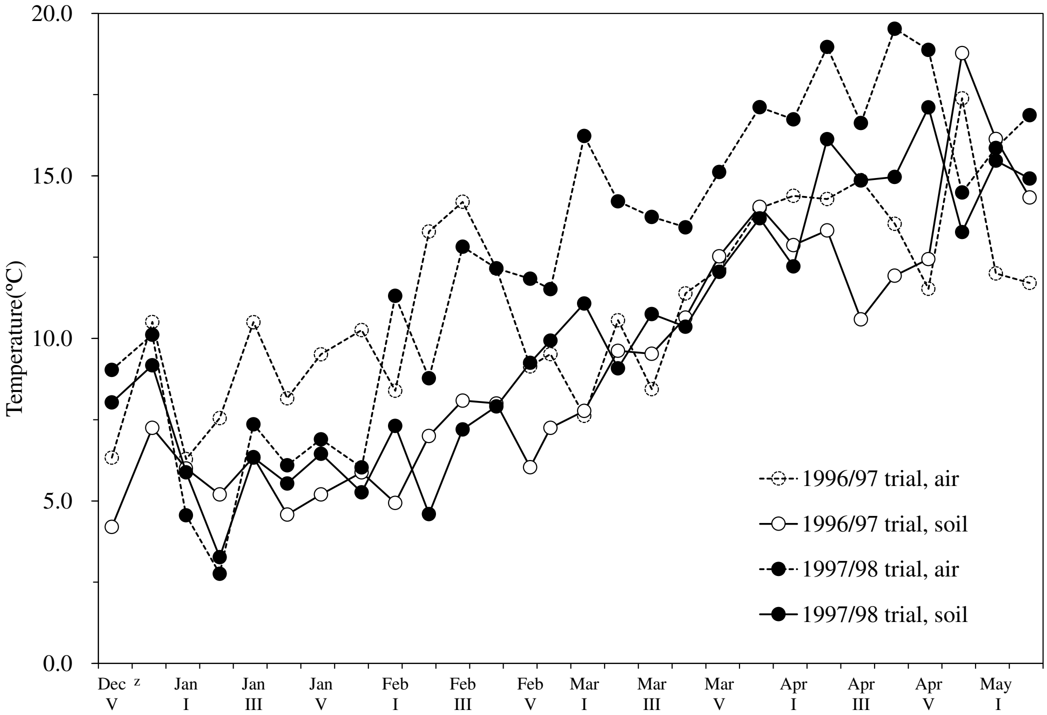


Fig. 2-2. The mean temperature of air and soil in plastic greenhouses during nursery production in the 1996/97 and 1997/98 trials.
z Roman numerals indicate 5 days within a month.

2.3.4 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. The leaf lengths of the SON seedlings sown in December and January were longer than those of the seedlings sown in February and March on April 25 and May 2 (Table 2-3).

In KW3, leaf length, fresh leaf number and leaf sheath diameter clearly differed due to the combination 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 date.

The same trend was observed in the 1997/98 trial for the above three characteristics 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.

2.3.5 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. 2-3). In the 1997/98 trial, the mean temperature in late April was 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. Bulbing and leaf lodging had already occurred in all cultivars at

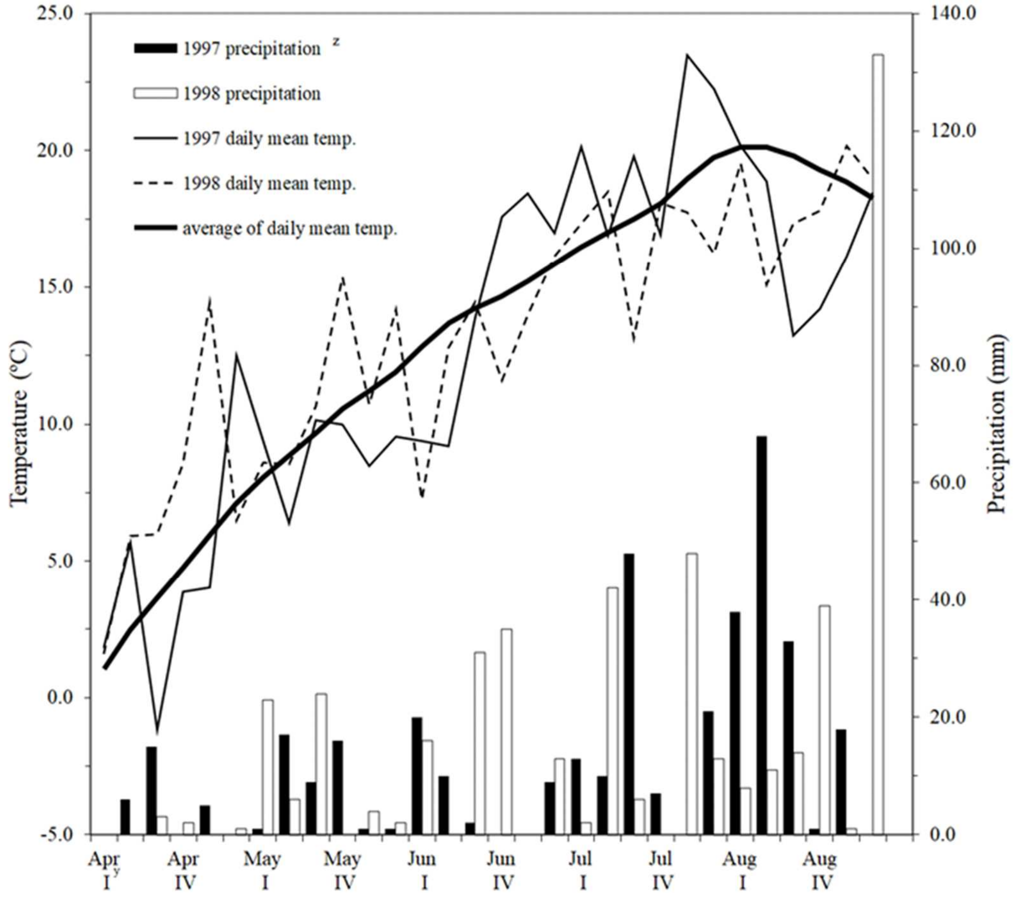


Fig. 2-3. Temperature and precipitation during the growth period in the 1996/97 and 1997/98 trials.

[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.

Table 2-3. 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.

that time (Table 2-4 and Fig. 2-4). In the 1997/98 trial, the standard cropping (March sowing and mid-May transplanting) method produced a leaf length of 61–65 cm with eight fresh leaves, and a 14–15 mm leaf sheath diameter for KW3, OK1, and KM86 on June 30th (Table 2-5). The early sowing method (December to February with 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, KW3 sown from December to February and transplanted in April, had leaf lengths and leaf sheath diameters were over 70 cm and 17 mm, respectively, which were greater than those of standard cropping from March sowing and mid-May transplanting.

2.3.6 Bulbing, leaf lodging, and bulb ripening time

Transplanting in April and early May accelerated the bulbing date. Bulbing began in late June for KW3 and OK1, and in early July for KM86 in the 1996/97 trial (Table 2-4). Bulbing began in mid-June for KHT and KW3, and for late June in OK1 in the 1997/98 trial (Table 2-5).

The acceleration of the bulbing date influenced lodging time. The December and January sowings of KW3, OK1, and KM86 with April and early May transplanting caused the lodging date to be 5–10 days earlier than for the March sowing and mid-May transplanting for each cultivar. Particularly, the lodging date in the 1996/97 trial for KW3 was 18–23 days earlier compared to the standard cropping for OK1 and KM86, which

Fig. 2-4. Differences in onion growth between two cropping types in 1996/97 trial field.
Left: standard cropping. Right front: cropping of early sowing and early transplanting after unwoven row cover removal.

Table 2-4. Effect of sowing date and transplanting date on plant growth in the 1996/97 trial.

Cultivar	Sowing date	Trans-planting date	Growth on Jul. 30: Leaf length (cm)	Fresh leaf no.	Leaf sheath diameter (mm)	Bulbing date[z]	Lodging date[y]	Ripening date[x]
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

Table 2-4. Continued.

Cultivar	Sowing date	Trans-planting date	Growth on Jul. 30			Bulbing date[z]	Lodging date[y]	Ripening date[x]
			Leaf length (cm)	Fresh leaf no.	Leaf sheath diameter (mm)			
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 of 40–50% of plants was twice that of the leaf sheath diameter. 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 symbol for SON on December 19 and January 16 seedings indicates that onion leaves were already dried with no data available and those on February 19 and March 11 indicate lack of data.

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

occurred on July 31 and August 5, respectively (Table 2-4). A similar tendency was observed in the acceleration of the lodging date for the 1997/98 trial, although the lodging times were delayed due to the 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 to the standard cropping (March sowing and mid-May transplanting) for all cultivars used in the 1996/97 trial (Table 2-4). The SON seedlings ripened in mid-July. The ripening date for KW3 extended from July 28 to August 6 for the April and early May transplanting. The ripening dates for 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. 2-3). Nevertheless, KHT ripened from July 30 to August 2 in the December 19 and January 16 sowings and April 21 and May 1 transplanting. Moreover, KW3 also ripened on August 7 in the December sowing (Table 2-5).

2.3.7 Bolting

The frequency of unseasonable bolting was 0.6%–3.3% for KM86 under the combination of sowing in either December or January and

Table 2-5. Effect of sowing date and transplanting date on plant growth in the 1997/98 trial.

Cultivar	Sowing date	Trans-planting 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		NS[v]	**	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	+

Table 2-5. Continued.

Cultivar	Sowing date	Trans-planting 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]
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.

transplanting in April or the beginning of May in the 1996/97 trial (Table 2-6). This did not occur for any other cultivars. KM86 also showed bolting in the 1997/98 trial (Table 2-7).

2.3.8 Bulb weight and yield

Difference in bulb weight occurred among the cultivars; bulb weight tended to increase in the order of KW3, OK1, and KM86 for both trial years (Tables 2-6 and 2-7). In the 1996/97 trial, the mean bulb weight of SON in all plots was nearly always less than 100 g, which indicated that early sowing and late transplanting led to a lower bulb weight (Table 2-6). 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. Bulb weight reached approximately 130 g in almost treatments where seedlings were transplanted by May 2 (Fig. 2-5; Table 2-6). Bulb weight was more than 150 g for OK1, reaching a maximum of 172 g, in all plots, particularly when seedlings were transplanted by 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. Bulb weight from the December and January sowings exceeded 200 g. while bulb weight from the February or March sowings were less than 200 g.

In the 1996/97 trial, SON had the lowest yield (102–297 $kg \cdot a^{-1}$) due to its low bulb weight (Table 2-6). The yield of KW3 onions sown in December and January was more than 500 $kg \cdot a^{-1}$ for the April transplanting, which was

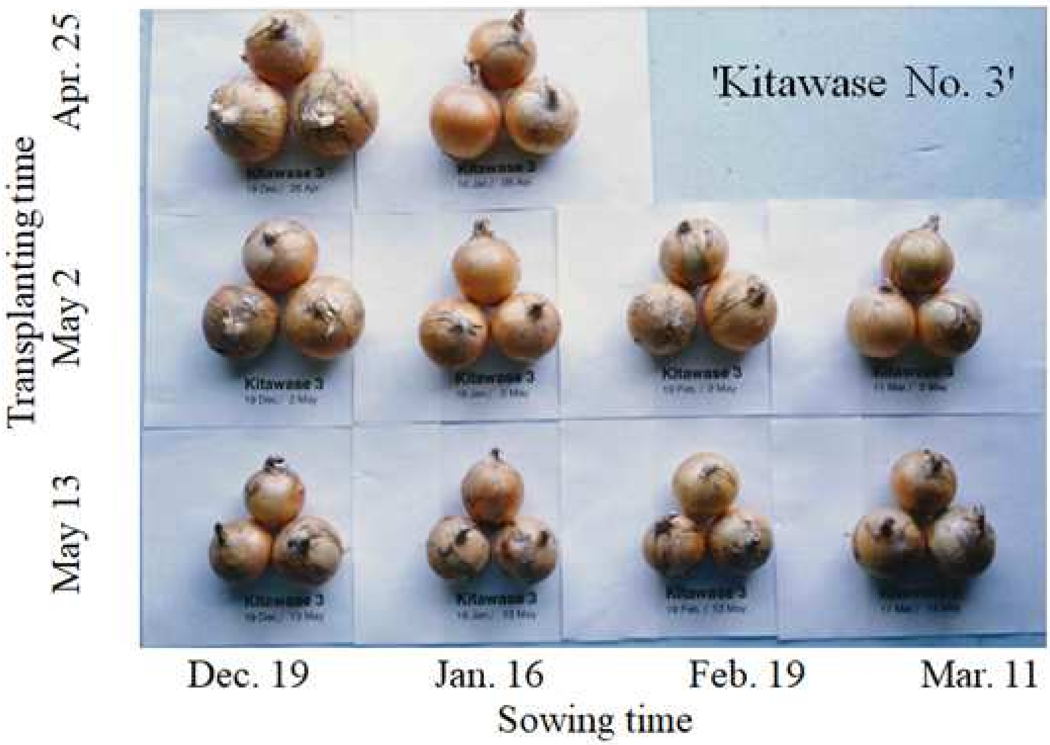


Fig. 2-5. Appearance of bulbs of 'Kitawase No. 3' by combination of sowing and transplanting time on the 1996/97 trial.

Table 2-6. Effect of sowing date and transplanting date on yield and bulb quality in the 1996/97 trial.

Cultivar	Sowing date	Trans-planting date	Bolting (%)	Unmarket-able 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

Table 2-6. Continued.

Cultivar	Sowing date	Trans-planting date	Bolting (%)	Unmarket-able small bulb (%)[z]	Bulb weight (g)	Yield ($kg \cdot a^{-1}$)	Skin color (1–9)[y]	Skin retention (1–9)[x]
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 2-7. Effect of sowing date and transplanting date on yield and bulb quality in the 1997/98 trial.

Cultivar	Sowing date	Trans-planting date	Bolting (%)	Unmarket-able 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		–	NS[w]	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

Table 2-7. Continued.

Cultivar	Sowing date	Trans-planting date	Bolting (%)	Unmarket-able small bulb (%)[z]	Bulb weight (g)	Yield ($kg{\cdot}a^{-1}$)	Skin color (1–9)[y]	Skin retention (1–9)[x]
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.

reduced in the mid-May transplanting. The OK1 yield was more than 500 kg·a^{-1}, except for the combination of sowing in December and transplanting in mid-May. All KM86 plots exhibited sizable 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 sowing date and transplanting date for all cultivars used (Table 2-7). In the early harvest, through a combination of the December and January sowings and April 21 and May 1 transplanting of KHT, the bulbs grew to be more than 230 g and yielded more than 700 kg·a^{-1}. The KW3 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.

2.3.9 External appearance of bulbs

The effect of sowing date and transplanting date on the skin color score and skin retention score was unclear in the 1996/97 trial (Table 2-6). The skin color scores for OK1 and KM86 were greater than 5, which is the standard color (Tables 2-6 and 2-7). 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, since a little skin was missing from the outer leaves (Table 2-6). The skin color and skin retention of KW3 were near standard. The skin color scores of KW3 improved (>5.5) for the 1997/98 trial, especially when transplanted before early May (Table 2-7).

2.4 Discussion

2.4.1 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 for 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. Taken together with the findings from this study, these result indicate that onion seeds can successfully germinate and grow in a non-heated plastic greenhouse during the winter.

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

The number and size of emerged leaves in the seedlings sown in December and January were larger than those sown in March for all spring transplanting dates, except for the leaf numbers of SON and OK1. In particular, the leaf number of KW3 was 1.7 times higher at the time of transplanting in April. Early sowing contributed to the production of large seedlings, even for seedlings grown in mid-winter.

2.4.2 Cultivar differences in bulb formation

Harvest time acceleration was the most important aim of this study. Leaf lodging is determined by bulbing, bulb formation, and the subsequent development of internal leaf scales, as well as the ceased production of long leaf blades. Since root undercutting is generally carried out after leaf lodging for the smoother drying of enlarged bulbs in Hokkaido, bulb harvesting was performed almost three weeks after lodging time in the standard cropping types. 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 were reached in an experiment with two cultivars and 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 when transplanted early. The bulb size for late transplants was smaller than those of early transplants, since a lower number of leaves emerged. In addition, a cultivar difference in leaf emergence in the trial was recognized, and cultivar selection was considered important when the transplanting date was altered.

In the present experiment, the lodging and ripening dates were earlier for all cultivars sown and transplanted earlier compared to standard cropping (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 during 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). KW3 bulbing was observed late in June for the December and January sowing combined with the April and early May transplanting. Subsequently, leaf lodging occurred in the middle of July, and onion bulbs were harvested in early August. OK1 and KM86 bulbing began in early July, even with the combined treatment of early seeding and transplanting, and harvesting was moved to mid or late August.

From the results described above, KW3 and KHT were proven to be suitable cultivars for early shipping. These are ID cultivars that begin bulb formation 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. 2-3). The small KW3 and KHT seedlings were fully exposed to LD lengths in the field, but did not start bulbing in May and early June because of the low temperatures, instead they 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, resulting in KHT harvest in early August and KW3 harvest in mid-August. The average duration from bulbing to lodging in KW3 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. 2-3).

The harvest times for OK1 and KM86 were earlier with the December, January, and February sowing; however, the obtained harvest times from mid to late August and were not suited to early shipping. Since Hokkaido LD cultivars require long day lengths (>14 h) and high temperatures (>20°C) (Miyaura, 2001), the start of bulbing was delayed, and the lodging time was not accelerated.

2.4.3 Yield and quality of harvested bulbs

Yield and bulb quality are also significant traits for early shipping harvesting. Thus, SON was excluded from the cultivars due to its low yield. KW3 exhibited a sufficient yield from 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 up 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 (e. g., attractive dark brown color), and should not have lost any skin due 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 KW3 bulb color was slightly brown in the 1996/97 trial (Table 2-6), the outer dry skin remained intact, and the bulb quality was marketable. In the 1997/98 trial, both KW3 scores were 4 for the standard cropping (sown on Mar. 11 and transplanted on May 12), but early transplanting improved the score to 4.5 or higher (Table 2-7). Onions that were lifted to 10% top-down and topped after curing had a higher proportion of bulbs with three or more intact skins compared to onions lifted at 90% top-down and topped after curing (Wright and Grant, 1997). In this study, the onion root was cut 10 days after the lodging date. Since it was a complete lodging period, skin retention could potentially be improved if the roots were cut a little earlier. In conclusion, KW3 and KHT were suitable ID cultivars for early sowing and early transplanting in regards to harvest time, bulb yield, and bulb quality.

Chapter 3

Field evaluation of onion (*Allium cepa* L.) cultivars with intermediate-day trait for early shipment in northeastern Hokkaido

3.1 Introduction

Early shipping of Hokkaido onions is high demand. New cropping methods, such as early sowing and early transplanting with intermediate day (ID) cultivars was established (Chapter 2). Specifically, larger seedlings were obtained by sowing in December or January, two or three months earlier than the conventional sowing time. These were then transplanted into an outdoor field in late April, two weeks earlier than the conventional cropping. This cropping system could contribute to the early shipping of Hokkaido onions since the onion bulbs were harvested in late July or early August.

This cropping system is based on bulb formation stimulated by daylength. Conventionally-used cultivars in Hokkaido start bulb formation under long day (LD) conditions of more than 14 hours daylength. Bulb formation in ID cultivars usually occurs around 13–14 hours (Brewster, 2008). In Hokkaido, the day length reaches 13 to 14 hours in May, but ID cultivars cannot start bulbing due to the low temperature of spring time. By transplanting larger seedlings, onion plants can begin to grow to maximum size in mid-June, and eventually grow the bulb size required by the market.

Hokkaido island is located at a higher latitude than the rest of Japan and is cold in the winter. LD cultivars are most suitable to the natural growing condition in Hokkaido, and usually planted in spring. Conventionally, the breeding of LD cultivars has been promoted (Hanaoka, 1963; Miyaura et al., 1985; Tanaka et al., 1987; Tanaka et al., 1996a).

From the first-mentioned request of early shipment of onion, cultivars adaptable to early harvest were also requested in Hokkaido. Among the ID cultivars, the late maturity cultivars were found to be most suitable due to their large bulbs and high yield (Chapter 2). ID cultivars have already been used for over winter production in Honshu, Shikoku and Kyushu islands. Recently, onion cultivation research is progressing in the Tohoku and Hokuriku regions as well, and there is a large variation in sowing time, from autumn to late spring, in ID cultivars (Yamasaki, 2019). In the Tsugaru region of Aomori Prefecture, late-mature cultivars for autumn sowing in Honshu, and the early and middle-mature cultivars for spring sowing in Hokkaido were considered most suitable and sufficient yields were obtained in the off-season from July to August (Oku et al., 2018).

Differences in soil conditions, transplanting times, and seedling size greatly affected the growth and yield of onion crops (Moriyama, 2014). In Toyama Prefecture, bulb weight may increase when bulb enlargement starts after leaf differentiation and development: after the leaf node position has risen (Asai and Nishihata, 2015a). In Yamagata Prefecture, when sown in February and transplanted in April, 'Shippoama 70' could be harvested on early July with a marketable yield of $5t \cdot 10a^{-1}$ (Ito and Ueda, 2012). In Iwate prefecture, it has been shown that LD and ID cultivars can be compared at the same time by the spring sowing cultivation method (Ikeda et al., 2020).

When selecting ID cultivars for onion production in northeastern

Hokkaido, three characteristics are especially important: (1) its adaptability to the regional climate, (2) its marketable yield for growers, and bulb quality for consumers. Onion plants produce maximum-sized leaves in late June prior to leaf lodging, in order to obtain the standard yield at harvest time (Chapter 2).

The bulb quality of Hokkaido onions has been characterized as a hard texture, rich flavor, good processing ability, and a good storage ability (Tamaki et al., 2002a and 2002b), which is the result of onion breeding programs that have focused on bulb quality in Hokkaido (Sato et al., 1996; Hokkaido Prefecture and Hokuren Federation of Agricultural Cooperatives, 1996; Hokuren Federation of Agricultural Cooperatives and Hokkaido Research Organization, 2000).

In this experiment, the selection of suitable ID cultivars in northeastern Hokkaido around Kitami city for early harvest, late July or early August, was examined for two years. In Chapter 2, it was found that KW3 was suitable cultivar for early shipment, although the yield and external appearance of KW3 (e. g., skin color and retention) were not sufficient compared to the LD cultivars such as OK1 and KM86. Detailed evaluation of cultivars including new ID cultivars used in the autumn sowing area, in Honshu, Shikoku, and Kyushu, has not been conducted in Hokkaido.

The purposes of this chapter were (1) to select suitable ID cultivars for a new cropping type with early sowing and early transplanting in northeastern Hokkaido, and (2) to discuss characteristics needed for ID cultivars used in the spring sowing system in a cool region, such as Hokkaido.

3.2 Materials and Methods

3.2.1 Location and meteorological data

All experiments were conducted at the Kitami Agricultural Experiment Station, Hokkaido Research Organization, Kunpeppu, Hokkaido Japan (43°73′ N, 143°74′E and 142 m a.s.l.) in the 2017 and 2018 harvest years. The soil in the experimental field was classified as brown lowland soil. The meteorological data were obtained from the Automated Meteorological Data Acquisition System (AMeDAS, Sakaino station) located 7 km west southwest of the trial site.

3.2.2 Cultivars trial used

In 2017 and 2018, a total of 32 ID cultivars were investigated. Nine of these were tested for 2 years and compared with OK222 (LD), one of the current leading cultivars grown in Hokkaido (Table 3-1).

3.2.3 Seedling establishment

Table 3-2 showed outline of the trial method and cultivation. The onion seedlings were grown in plastic tray (619 mm × 315 mm × 25 mm) with 448 cells, named “Minoru pot” (Minoru Industrial Co., Ltd., Akaiwa, Japan). The trays was contained the artificial soil, “Onion ace P-up” (Katakura & Co-op Agri Corporation, Tokyo, Japan) and were placed on the ground surface in the greenhouse without artificial heating.

Table 3-1. Cultivars used in 2017 and 2018 trials.

Cultivar	Abbreviation	Seed provider
Amagashi 2	AMA2	Nanto Seed Co., Ltd.
YOK573	YOK	Sumika Agrotech Co., Ltd.
Aurora	AUR	Watanabe Seed Co., Ltd.
KAR-004	KAR	Kaneko Seeds CO., Ltd.
Tsuritama 2 go	TSU2	Asahi Noen Seed Co., Ltd.
Kitawase No. 3	KW3	Shippo Co., Ltd.
Sojiro	SJR	Hokuren Federation of Agricultural Cooperatives
Kitahayate No. 2	KHT2	Takii & Co., Ltd.
Bullet Bear	BB	Takii & Co., Ltd.
Okhotsk 222[z]	OK222	Shippo Co., Ltd.

[z] 'Okhotsk 222' was known to have the photoperiodic trait of long day (LD).

Table 3-2. Operation calender and management in the examination.

	2017	2018
Location and soil	Kitami Agricultural Experiment Station, Kunneppu, Hokkaido. Brown rowland soil	
Cultivar	see Table 1	
Cropping type	Early sowing and early transplanting	
Sowing date	Feb. 17	Feb. 17
Transplanting date	Apr. 21	Apr. 25
Nursery system	Minoru pot 448 system with artificial pot soil, "Onion Ace P-up"	
Row cover period	38 days after transplanting	35 days after transplanting
Planting pattern	spacing 10.5 cm, row width 30 cm (3,175 plants・a^{-1})	
Fertilizer amount	$N:P_2O_5:K_2O$ = 1.5 : 2.0 : 0.9 (kg・a^{-1})	$N:P_2O_5:K_2O$ = 1.5 : 1.5 : 1.0 (kg・a^{-1})
Root cut[z]	7 days after completely lodging date[y]	5 days after completely lodging date, do cut on Jul. 23 at the latest even if not completely lodged
FBR test [x]	sowing and transplanting date as same as above	-

[z] Each onion bulb in the plot was picked up by hand.

[y] Compeletely lodging: date of almost 80% plants had lodged in each plot.

[x] Inoculation field test of resistant to Fusarium basal rot (FBR) caused by *Fusarium oxysporum* f. sp. *cepae* (Sugiyama et al., 2016).

The seeds were sown on February 17 in both trial years, and the seedlings were manually transplanted to the open field on April 21, 2017 and April 25, 2018. Growth characteristics of seedling, such as the fresh leaf number and the leaf sheath diameter, were measured using ten plants in each cultivar on the transplanting date. The leaves of the onion plants were cut to approximately 17 cm heigh to adjust to transplanter system.

3.2.4 Onion growth in the field

A compound chemical fertilizer containing 1.5 $kg \cdot a^{-1}$ nitrogen, 2.0 $kg \cdot a^{-1}$ phosphate, and 0.9 $kg \cdot a^{-1}$ potassium was applied as a basal dressing prior to the 2017 transplanting. In 2018, the contents of applied chemical fertilizer was 1.5 $kg \cdot a^{-1}$ nitrogen, 1.5 $kg \cdot a^{-1}$ phosphate, and 1.0 $kg \cdot a^{-1}$ potassium was applied in. No side dressing was applied in either trial year. Two tons of compost per 10 a had also been applied to the trial field each previous autumn.

In 2017, 88 seedlings were transplanted in a plot (1.2 × 2.5 m; 3.0 m^2) in four lines at a distance of 30 cm and 10.5 cm between the lines and the plants, respectively. In the 2018 trial, 110 seedlings were transplanted in a plot (1.5 × 1.5 m; 3.75 m^2) in five lines using the same spacing. The plant density was 3,174 $plants \cdot a^{-1}$ in both trial years. The plots were set by randomized block design with two replications each year.

The planted seedlings were covered with unwoven fabric sheets (“Paopao 90”; Mitsubishi Chemical Agri Dream Co. Ltd., Tokyo) until May 29, 2017 and May 30, 2018. Onion plants grew leaves and began to enlarge their bulbs, then emerged leaves fell down to the ground. Root cutting treatments, which is important mechanical work to ensure the effective skin drying of the enlarged bulb, was carried out by lifting the lodged plant and returning it to the ground, 7 days and 5 days after the complete lodging in 2017 and 2018, respectively.

The growth characteristics of the plants, such as bulbing dates, leaf lodging, and bulb ripening, were recorded through visual observations. The bulbing date was recognized as the date on which the ratio of bulb diameter to leaf sheath diameter reached twice in 40–50% of the observed plants. The lodging date and ripening date were decided when the leaves had fallen to the ground and dried out in 40–50% of the observed plants, respectively. The harvest time is almost the same as the ripening time, since dried leaves cannot get entangled in the harvest machine.

3.2.5 Lateral bud development process

The growth and tillering process of KHT2, SJR, BB, and OK222 in the field were investigated in 2018. The transplanting date of KHT2, SJR and BB was April 25, and that of OK222 was on May 1. Planting density, fertilizer application, and other field managements were the same as the above trials. Sampling dates were transplanting day, June 1, 11, and 25, July 7 and 20, and August 1. Those meant 0, 37, 61, 73, 86, 98 days after the transplanting, respectively, except for OK222. On the sampling day, nine plants with average growth were collected in each cultivar, and the plant height, number of leaves, leaf sheath diameter, bulb diameter, number of fresh roots, and fresh weight (excluding roots) were measured. Afterwards, the plants were dissected under a stereoscopic microscope (SZ-40, Olympus Corp., Tokyo) until the main bud (shoot apex with growing point) appeared. At that time, the node numbers where the lateral buds differentiated were recorded.

3.2.6 Yield and external appearance of harvested bulb

After harvest, the onion yield and external appearance of the bulb (e. g., bulb shape, skin color and retention) were recorded. The skin retention score indicated the strength of skin attachment and the thickness of the outer dried leaves by touch and visual observation. The skin color was judged by visual observation and compared to KW3. The survey was conducted by professional workers who have supported onion trials for more than 10 years at this experiment station for distinct evaluation.

3.2.7 Internal quality of bulb

Harvested bulbs were air-dried naturally for one month. Eight bulbs with marketable size and shape were collected from each plot for internal quality measurements. After peeling off the outer skin leaf, the top and bottom of the bulb were removed, and the scale leaves was divided vertically into eight wedges. Four diagonally-located wedges were done for dry matter measurements, and two wedges were used for soluble solids content (SS) measurements. The dry matter content (DM) measurements were determined by cutting a 1 cm-thick sample from each of the four wedges. These samples were dried in a drying oven at 60°C for 120 hours, then the DM was calculated. In the measurement of SS, the wedges were crushed with a food processor for

1 min. and onion juice was obtained by filtration through gauze. SS (°Brix) was then measured from the bulb juice using a digital sugar meter (Pocket PAL-1, ATAGO Co., Ltd., Tokyo, Japan). The amount of enzymatically formed pyruvic acid (PA) was measured according to the modified method from Sato and Nagai (1997) using the final two wedges.

3.2.8 Field test for determining the resistance to Fusarium Basal Rot (FBR)

A field test of resistance to FBR was carried out using Sugiyama's method (Sugiyama et al., 2016) in 2017. The seedlings were grown in the Minoru pot system, were picked up from their cell trays, then roots and basal part of leaves were dipped momentarily into spore suspension of the *Fusarium oxysporum* f. sp. *cepae,* 'NO101' strain with a spore concentration of 1.0×10^6 ml^{-1} and 0.05% Tween20. After air drying for 1 hour, the inoculated seedlings were manually transplanted in the FBR test field. Diseased plants were periodically picked off by visual observation in each plot. FBR infection rates were calculated from the sum of infected plants and bulbs. Indicator cultivars were 'Super Kitamomiji' (SKM) (Shippo Co., Ltd. Mitoyo, Japan) for resistance and 'Sarari' (Hokuren Federation of Agricultural Cooperatives, Sapporo, Japan) for susceptible.

3.2.9 Statistical analysis

All data were analyzed by a two-way ANOVA using "Statcel ver.4" (Yanai, 2016). Multiple comparisons between the cultivars and trial years were made using the Tukey-Kramer test. PCA was conducted using data on plant growth, unmarketable bulb ratio and bulb quality, using ”Mulcel” (Yanai, 2011).

3.3 Results

3.3.1 Climate in the examined year

From transplanting time to harvest time, the daily mean temperature in the first and fourth pentad of May 2017 and the second and third pentad of July 2017 were 4.1, 4.7, 6.6 and 7.4°C higher than those of the average year, respectively (Fig. 3-1). In June it was 5.4°C lower in the first pentad. In 2018, it was 4.5 and 5.4°C higher in the first pentad of June and the sixth pentad of July, respectively. In the third pentad of June 2018, it was 6.1°C lower. The cumulative temperature from April 21 to July 31, 2017 was 994.7°C degree day. From April 25 to July 31, 2018 was 914.6°C degree day. The total precipitation from April 21 to July 31, 2017 and April 25 to July 31, 2018 were 350.5 mm and 369.5 mm, respectively. Precipitations were 80 mm in the fourth pentad of July 2017 and 121 mm in the first pentad of July 2018 during the bulb growing period.

In general, in 2017, the temperature after transplanting was high, and the onion growth in the open field was better. Higher temperatures and subsequent rains created large bulbs. In 2018, the temperature was low or normal after transplanting, and there were heavy rains before bulbing. Since the temperature did not rise, the onion growth was stunted.

3.3.2 Seedling growth in the greenhouse

The number of leaves was slightly smaller in AUR when seedlings were transplanted into the open field (Table 3-3). On the other hand, no significant differences in leaf sheath diameter. And no significant differences in seedling growth in both trial years. The means of fresh leaf number and Leaf sheath diameter of 9 ID cultivars were 2.5 leaves and 3.9 mm, respectively. The seedling size of ID cultivars and OK222 (LD) were almost the same.

3.3.3 Plant growth in the field

Leaf length in early June was small in AUR and high in SJR among ID cultivars (Table 3-4). In early July, leaf length was high in SJR and KHT2, and small in YOK. YOK had low leaf numbers and a small leaf sheath diameter. YOK had the earliest bulbing and lodging date of June 13 and July 12, respectively, among all cultivars. The latest bulbing time was June 25 for SJR, and June 26 in BB. The latest lodging date was July 21 for KHT2 and BB. The ripening dates were from the end of July to the beginning of August for all ID cultivars. OK222 (LD) had a bulbing date of July 5, and its ripening date was August 9.

The onion growth and bulbing process were investigated in more detail for KHT2, SJR, BB, and OK222 (Fig. 3-2, 3-3). In KHT2, SJR, and BB, lateral buds started to occur 47 days (June 11) after transplanting. OK222 (LD) initiated lateral buds from 61 days (June 25) after transplanting. The number of roots and leaves of all cultivars increased sharply toward the bulbing date.

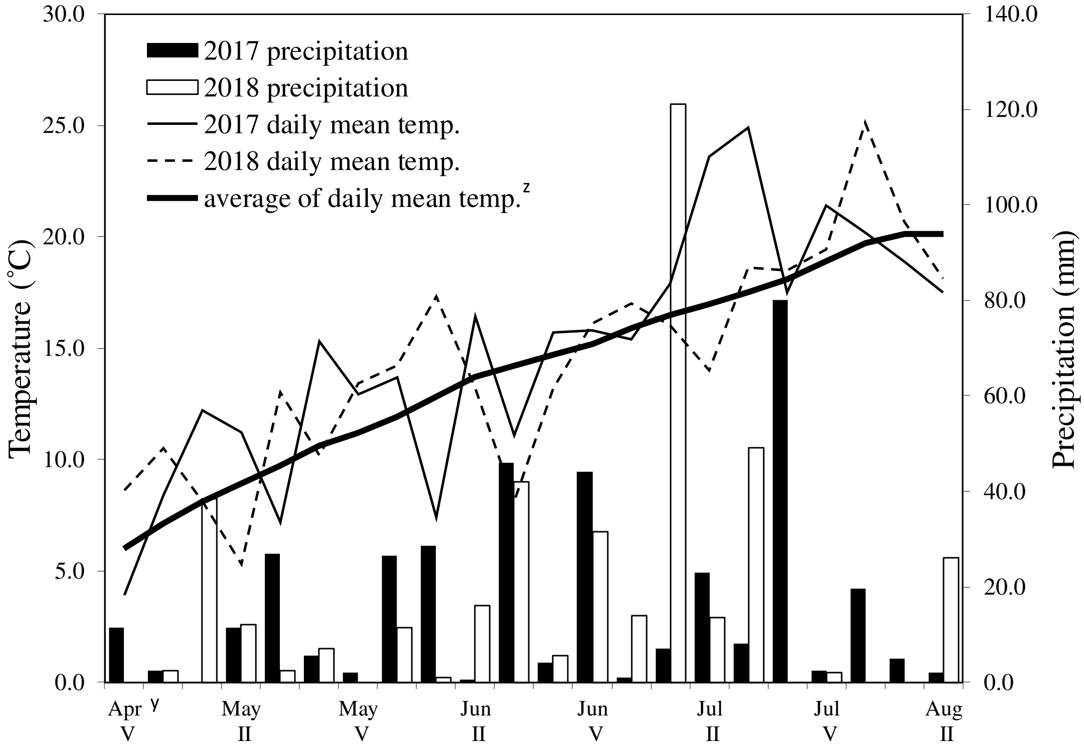


Fig. 3-1. Temperature and precipitation during the growth period in 2017 and 2018 trials.

[z] Daily mean temperature is the average of each 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 1981-2010.

[y] Roman numerals mean each 5 days within a month.

Table 3-3. Onion growth at transplanting time.[z]

Cultivar	Fresh leaf number	Leaf sheath diameter (mm)
AMA2	2.6 a[y]	3.7
YOK	2.5 a	3.9
AUR	2.3 b	3.8
KAR	2.6 a	4.0
TSU2	2.6 a	3.9
KW3	2.5 a	3.9
SJR	2.8 a	4.1
KHT2	2.5 a	3.9
BB	2.5 a	4.0
OK222	2.5 a	3.8
Cultivar	+[x]	NS
Year	NS	NS

[z] Data from average of 2017 and 2018 trials.

[y] Different letters within the same column indicate significant difference by Tukey-Kramer test at $P<0.05$.

[x] + and NS indicate significant difference at $P<0.1$ and non-significant difference, respectively, by two-way ANOVA.

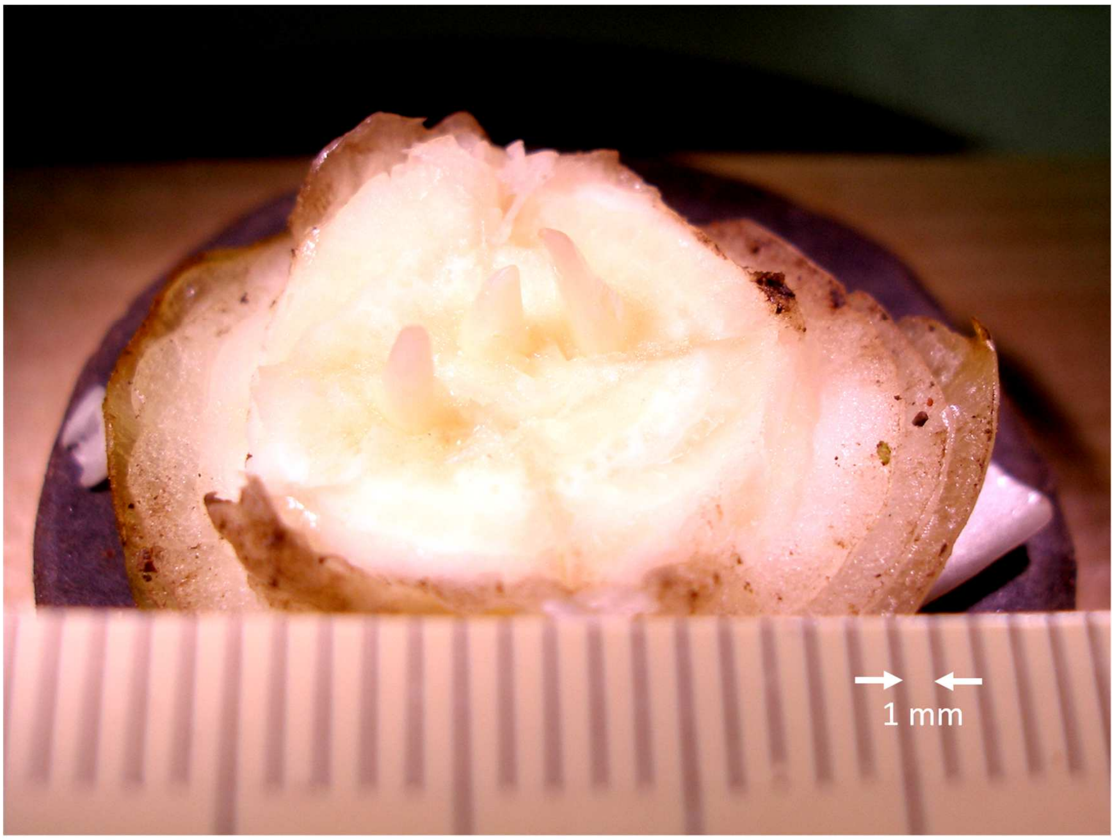


Fig. 3-2. Main bud (center) and lateral buds (both sides)
Date: Jul. 21, 2018, Cultivar: 'Bullet Bear'.

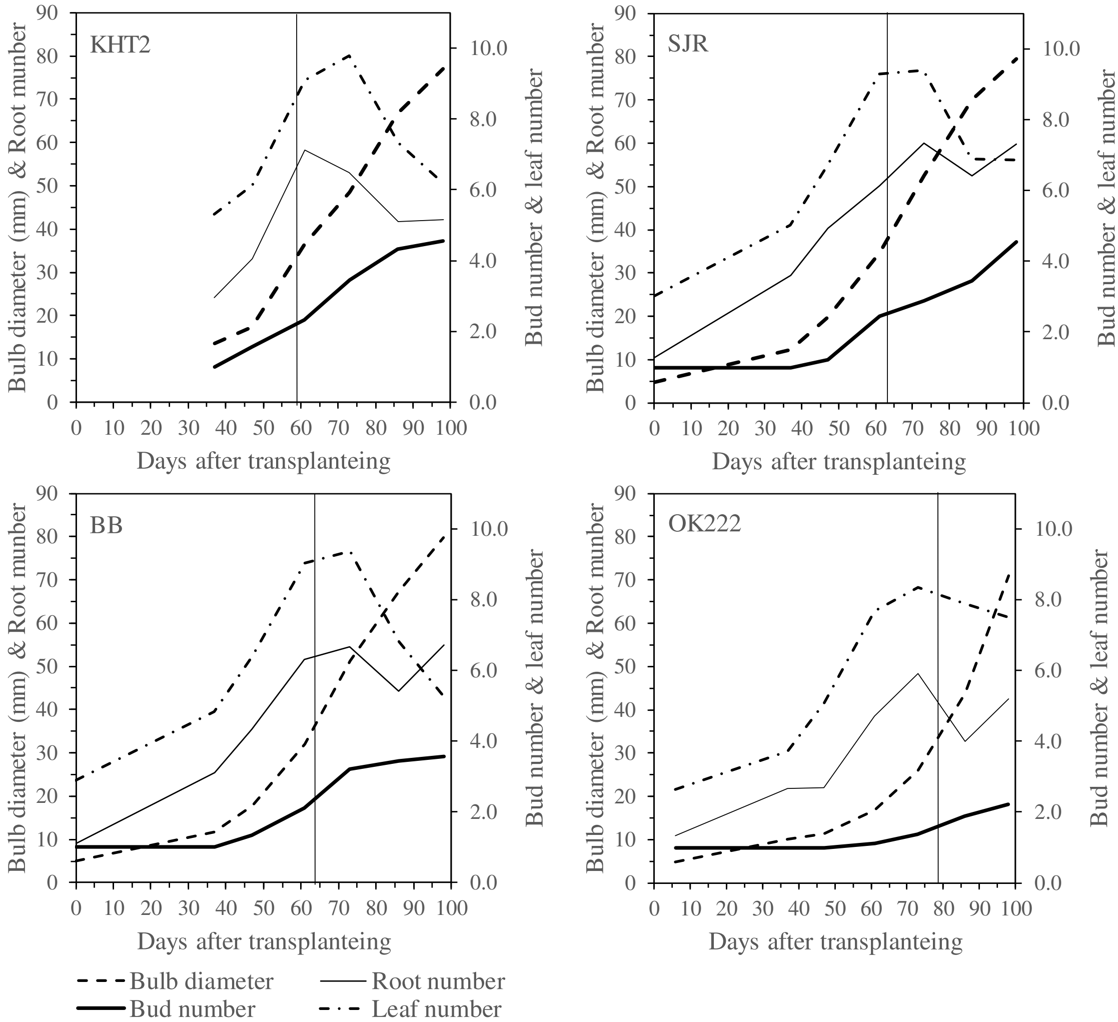


Fig. 3-3. Trends of Bulb diameter, root number, bud number, and leaf number in 2018 trial[z].

[z] KHT2, SJR and BB were transplanted on Apr. 25, 2018, however OK222 was transplanted on May 1. Date 98 means the 98th days after transplanting, however 92 days for OK222. Nine bulbs per cultivar were investigated each observation date. KHT2 had no data on 0 day. The vertical lines of each figure indicates bulbing date of cultivar omparison test plot adjacent sampling area.

Table 3-4. Plant growth and growth stage in 2017 and 2018 trials.

Cultivar	Growth in early June		Growth in early July			Bulbing date[z]	AD [y]	Lodging date[x]	AD	Complete Lodging date[w]	AD	Ripening date[v]	AD
	Leaf length (cm)	Fresh leaf no.	Leaf length (cm)	Fresh leaf no.	Leaf sheath diameter (mm)								
AMA2	44.2 ab[u]	5.8 a	70.8 cd	8.8 a	19.4 cd	Jun. 22 cd	-2	Jul. 14 d	2	Jul. 16 de	4	Jul. 29 e	-1
YOK	48.0 ab	6.0 a	63.4 d	7.5 c	14.8 e	Jun. 13 e	0	Jul. 12 e	-1	Jul. 15 e	-1	Jul. 29 e	-5
AUR	41.2 b	5.8 a	74.0 bc	8.6 ab	18.7 cd	Jun. 18 d	2	Jul. 15 d	1	Jul. 17 de	1	Jul. 30 de	-3
KAR	43.4 ab	5.7 a	73.7 bc	8.6 ab	19.2 cd	Jun. 23 bc	1	Jul. 18 c	1	Jul. 20 bc	2	Aug. 1 bcd	-6
TSU2	45.2 ab	5.9 a	68.0 cd	8.0 bc	18.1 d	Jun. 19 d	0	Jul. 15 d	0	Jul. 18 cd	-1	Jul. 31 cde	-6
KW3	44.7 ab	5.7 a	72.9 c	8.4 ab	19.4 cd	Jun. 21 cd	2	Jul. 20 bc	3	Jul. 22 b	3	Aug. 2 bcd	-7
SJR	50.2 a	5.8 a	88.3 a	8.4 ab	19.8 cd	Jun. 25 b	5	Jul. 18 c	3	Jul. 21 b	3	Aug. 2 bc	-6
KHT2	47.1 ab	5.9 a	86.5 a	8.4 ab	20.6 bc	Jun. 23 bc	1	Jul. 21 b	3	Jul. 23 b	3	Aug. 3 bc	-8
BB	45.6 ab	6.0 a	79.7 ab	8.8 ab	22.4 ab	Jun. 26 b	5	Jul. 21 b	3	Jul. 23 b	4	Aug. 4 b	-6
OK222	41.6 b	5.8 a	81.8 a	8.8 ab	22.8 a	Jul. 5 a	10	Jul. 26 a	4	Jul. 27 a	3	Aug. 9 a	-10
2017 (mean)	43.8	5.6	74.7	8.3	19.5	Jun. 22		Jul. 17		Jul. 19		Aug. 5	
2018 (mean)	46.5	6.0	77.1	8.5	19.6	Jun. 24		Jul. 19		Jul. 21		Jul. 30	
Cultivar	*[t]	NS	***	***	***	***		***		***		***	
Year	*	***	*	*	NS	***		***		***		***	
Interaction	NS	*	NS	***	*	***		*		*		**	

[z] Date on which the bulb diameter was twice that of the leaf sheath diameter in 40–50% of plants observed.

[y] AD: Annual difference, date subtraction 2017 from 2018.

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

[w] Date on which 80%< of plants had lodged.

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

[u] Different letters within the same columnindicate significant difference by Tukey-Kramer test at P <0.05.

[t] ***, **, *, and NS indicate significant difference at P <0.001, 0.05, and 0.1 and non-significant, respectively, by two-way ANOVA.

In addition, there was a difference in the root numbers of the investigated cultivars. SJR tended to produce a larger number of roots than KHT2, BB, and OK222, except 0 and 61 days after transplanting. Especially, a larger number of roots in SJR were maintained until just prior to harvest. Lateral bud development was observed inside the enlarging bulbs (Table 3-5). Except for OK222, lateral buds occurred after 47days transplanted (in June 11) with average node positions at about the tenth leaf. At 61 days after transplanting, the average node position of SJR was at leaf 13.3, with a range of 11−16 leaves, which were both slightly higher than those of KHT2 and BB.

3.3.4 Yield and marketable ratio

The average bulb weight and yield in 2018 in cultivars was about 80% of those obtained in 2017 (Table 3-6). The total yield of BB and AUR were over 800 $kg{\cdot}a^{-1}$, but, their marketable yields were only 581 and 333 $kg{\cdot}a^{-1}$, respectively. SJR showed the highest marketable yield at 659 $kg{\cdot}a^{-1}$, and the ratio of unmarketable bulbs was smallest, 16.6%. There were differences among the cultivars in terms of unmarketable bulb classifications, (e. g., flat, multiple, irregular, or skinning). AUR's unmarketable bulb was mostly flat shape.

3.3.5 External and internal quality of Bulb

There were significant differences in bulb uniformity and skin color among the cultivars (Table 3-7). SJR had good uniformity in bulb shape, while BB had a brown skin color. Differences in bulb firmness among the cultivars

Table 3-5. The node location of lateral bud development during bulb enlargement in 2018 trial.

Cultivar[z]	Node number									
	Jun. 11 (47)		Jun. 25(61)		Jul. 7 (73)		Jul.20 (86)		Aug. 1 (98)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
KHT2	10.0	9-11	11.1	9-13	13.4	9-16	13.3	9-18	13.6	9-18
SJR	10.0	9-11	13.3	11-16	13.2	11-15	13.5	10-17	13.9	9-17
BB	10.8	10-13	10.5	9-14	12.4	9-17	13.4	10-19	13.8	10-17
OK222	-[y]	-	-	-	14.3	12-16	15.4	16-17	14.9	13-16

[z] KHT2, SJR and BB were transplanted on Apr. 25, 2018, however OK222 was transplanted on May 1," 98 days" means actually 92 days of OK222. Nine bulbs per cultivar were dissected for observation.

[y] Lateral buds had not occurred yet.

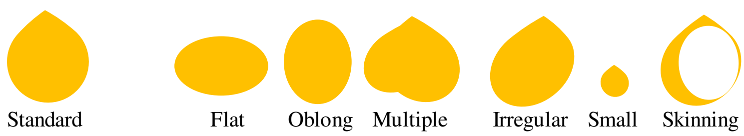
Table 3-6. Onion yield and classification of unmarketable bulbs in 2017 and 2018 trials.

Cultivar	Bulb weight (g)	Total yield ($kg \cdot a^{-1}$)	Marketable yield ($kg \cdot a^{-1}$)	Unmarketable bulb number (%)[z]						
				Total	Flat	Oblong	Multiple	Irregular	Small	Skinning
AMA2	221 ef[y]	679 bcd	372 c	43.1 ab	12.0 bc	0.0 a	20.9 a	7.3 bc	0.4 a	2.6 a
YOK	204 f	607 d	427 bc	31.5 bc	0.7 c	0.7 a	3.1 bcd	22.6 a	0.0 a	4.4 a
AUR	269 ab	847 a	333 c	59.5 a	46.5 a	0.0 a	1.3 d	6.2 bc	0.3 a	5.2 a
KAR	234 cde	730 bc	468 bc	33.5 bc	9.7 bc	0.0 a	12.8 abc	8.8 bc	0.0 a	2.4 a
TSU2	228 def	665 cd	352 c	45.8 ab	22.5 b	1.1 a	4.1 bcd	14.3 abc	0.0 a	3.9 a
KW3	250 bcde	782 ab	492 abc	37.0 b	1.0 c	0.0 a	16.3 ab	17.8 ab	0.0 a	2.1 a
SJR	254 bcd	791 ab	659 a	16.6 c	4.4 c	0.0 a	5.2 bcd	5.7 bc	0.0 a	1.4 a
KHT2	254 bcd	775 abc	505 abc	34.5 b	5.4 c	0.0 a	18.1 a	4.8 c	0.0 a	6.3 a
BB	289 a	859 a	581 ab	31.9 bc	7.8 c	0.0 a	12.4 abc	8.8 bc	0.0 a	3.1 a
OK222	258 bc	767 abc	572 ab	28.9 bc	4.0 c	0.0 a	7.0 bcd	11.5 abc	0.4 a	6.0 a
2017 (mean)	273	844	547	34.2	13.4	0.0	13.6	4.9	0.1	2.2
2018 (mean)	219	656	379	38.2	9.3	0.4	6.6	16.6	0.1	5.2
Cultivar	***[x]	***	***	***	***	NS	***	***	NS	*
Year	***	***	***	+	*	NS	***	***	NS	***
Interaction	***	***	***	***	***	NS	***	*	NS	*

[z] Percentage of bulb nunber classified by a skilled researcher based on observation. The typical shape is shown in the figure below.Flat: shape index (bulb height / diameter)×100) was 80 or less, Oblong: shape index was 110 or more, Multiple: Shape change derived clearly from inner doubling or more dividing that can be seen from the appearance, Irreguler: distortional shape that can be seen from the weaker appearance than 'Multiple', Small: bulbs less than 5 cm in diameter, Skinning: outer skin crack over 1 cm width in the circumference and/or outer skin peeled off more than 1/3 of the circumference.

[y] Different letters within the same columnindicate significant difference by Tukey-Kramer test at P <0.05.

[x] ***, **, *, +, and NS indicate significant difference at P <0.001, 0.01, 0.05, 0.1, and non-significant, respectively, by two-way ANOVA.



were not revealed, but there was an overall annual difference. The difference in skin retention was not clear among them from visual or touch observations.

The value of DM and SS in 2017 were lower than in 2018, while PA was higher (Table 3-8). Those of KAR was as high as those of OK222, while those of AUR was the lowest. The PA of ID cultivars, except for KW3 and SJR, were smaller than those of OK222.

3.3.6 Fusarium basal rot resistance

The incidence of FBR in the test cultivars was not found in AMA, KAR, KW3, SJR, KHT2 and BB (Fig. 3-4). The average of infected plants rate of ‘Sarari’, which was a susceptible cultivar, was 28.9% in 2012–2015 (data not shown). The reason for the low incidence of FBR in 2017 trial was that the soil temperature was low due to early transplanting and that the observation period was limited till the time of root cutting.

3.3.7 PCA based on the characteristics of ID cultivars

The component characteristics for plant growth are shown in Table 3-9. Each eigenvalue in Components 1 and 2 was over 1.0, and the cumulative contribution ratio reached 78.9%. Strong negative correlations were observed in the early July leaf growth, and the date of the growth phase and bulb weight for Component 1. A positive correlation with leaf length in early June were found for Component 2. Only KHT2, SJR, and BB were plotted in the positive direction in the third quadrant in the scatter plot by component 1 and 2 (Fig. 3-5).

Table 3-7. Onion bulb quarity of external appearance in 2017 and 2018 trials.

Cultivar	Bulb firmness[z]		AD[y]	Bulb uniformity		AD	Skin color		AD	Skin retention		AD
AMA2	4.8	a[x]	0.5	3.8	c	0.0	4.3	b	-1.0	4.8	a	0.5
YOK	4.8	a	-0.5	4.3	abc	-1.5	5.5	ab	0.0	4.3	a	0.5
AUR	5.0	a	0.0	4.0	bc	-1.0	4.3	b	0.5	4.5	a	0.0
KAR	5.0	a	0.0	4.5	abc	0.0	4.5	ab	0.0	5.0	a	0.0
TSU2	4.5	a	1.0	4.0	bc	-2.0	5.3	ab	-0.5	4.8	a	0.5
KW3	5.3	a	0.0	4.5	abc	0.0	5.0	ab	0.0	5.0	a	0.0
SJR	5.0	a	1.0	5.5	a	0.0	5.3	ab	-0.5	5.0	a	0.0
KHT2	5.0	a	0.0	5.3	ab	-0.5	5.3	ab	-0.5	4.5	a	-1.0
BB	5.0	a	0.0	5.0	abc	-1.0	5.8	a	-0.5	4.8	a	-0.5
OK222	5.0	a	0.0	4.5	abc	-2.0	5.0	ab	-1.0	4.8	a	-0.5
2017 (mean)	4.8			5.1			5.1			4.8		
2018 (mean)	5.1			4.0			4.9			4.7		
Cultivar	NS[w]			**			**			NS		
Year	*			***			NS			NS		
Interaction	NS			NS			NS			NS		

[z] Score ratings were made by the observation and touch of trained researcher. Scores as follows: Bulb firmness: 1: very soft, 3: soft, 5: moderate (standard), 7: tight, 9: very tight, Bulb uniformity: 1: bad, 3: a little bad, 5: good (standard),7: better, 9: excellent, Skin color: 1: poor light yellow, 3: light brown, 5: brown (standard), 7: dark brown, 9: excellent dark brown, Skin retention: 1: skin missing, 3: skin missing slightly, 5: standard, 7: thick skin, 9: thick skin, intact.

[y] AD: Annual difference, date subtraction 2017 from 2018.

[x] Different letters within the same column indicate significant difference by Tukey-Kramer test at P <0.05.

[w] ***, **, *, and NS indicate significant difference at P <0.001, 0.01, 0.05, and non-significant, respectively, by two-way ANOVA.

Table 3-8. Internal quarity of onion bulb in 2017 and 2018 trials.

Cultivar	Dry matter content (%)		AD[z]	Soluble solids (°Brix)		AD	Pyruvic acid (μmol·g^{-1})		AD
AMA2	9.1	ab[y]	-0.7	9.2	bc	0.0	8.7	b	-2.9
YOK	8.1	bc	-0.1	8.4	d	-0.2	9.2	b	-0.6
AUR	7.3	c	0.1	7.6	e	-0.4	9.4	b	-2.5
KAR	9.9	a	0.0	9.7	ab	0.0	8.7	b	-2.3
TSU2	9.3	ab	1.3	8.9	cd	1.1	9.6	b	-0.6
KW3	9.3	ab	1.0	9.7	ab	0.8	10.0	ab	-3.8
SJR	9.0	ab	0.6	9.6	bc	0.8	9.9	ab	-4.9
KHT2	8.9	ab	0.3	9.0	bcd	0.8	9.6	b	-4.7
BB	8.2	bc	0.6	8.4	d	0.5	9.5	b	-4.4
OK222	10.0	a	1.0	10.4	a	1.3	12.7	a	2.0
2017 (mean)	8.7			8.8			11.0		
2018 (mean)	9.1			9.3			8.5		
Cultivar	***[x]			***			**		
Year	*			***			***		
Interaction	NS			**			+		

[z] AD: Annual difference, date subtraction 2017 from 2018.

[y] Different letters within the same columnindicate asignificant difference by Tukey-Kramer test at *P* <0.05.

[x] ***, **, *, +, and NS indicate significant difference at *P* <0.001, 0.01, 0.05, 0.1, and non-significant, respectively, by two-way ANOVA.

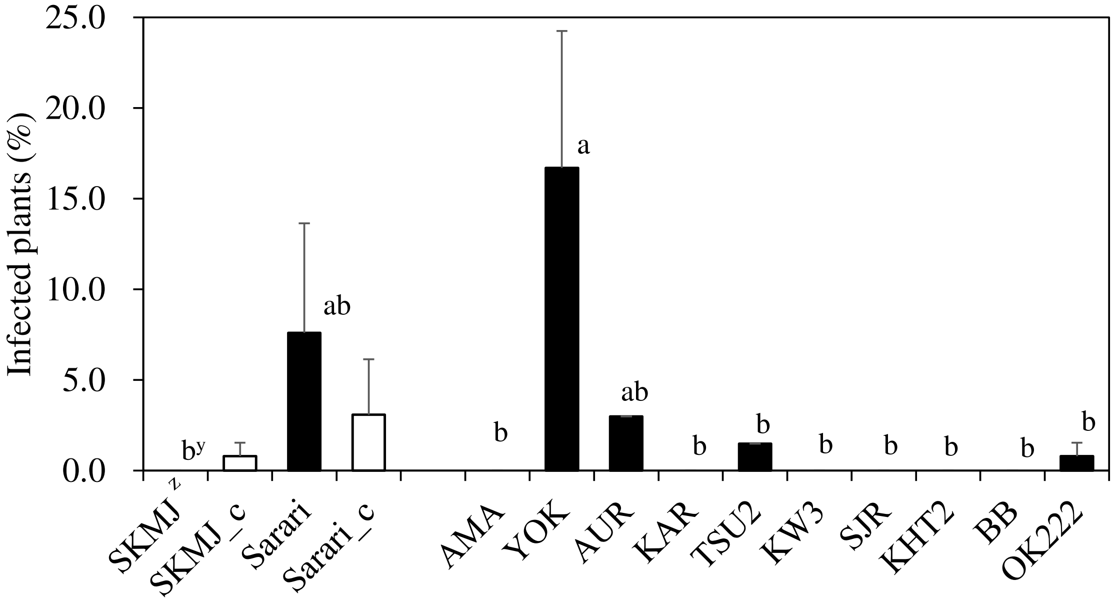


Fig. 3-4. Field test of *Fusarium oxysporum* inocuration till root cutting time in 2017 trial.

[z] cv. 'Super Kitamomiji' (SKMJ) indicated tolerant and 'Sarari' indicated suscepetible to Fusarium basal rot (FBR). 'Sarari' and SKMJ marked with "_c" were indicators of the degree of natural infection in the FBR trial field without inocuration when transplanting.

[y] Difference of infected plants (%) in cultivars except for SKMJ_c and 'Sarari_c' is significant at P<0.001 by two-way ANOVA. Different letters indicate significant difference by Tukey-Kramer test at P<0.05. However, analysis of data were performed after arcsine transformation. Bars indicate SE(n=2).

In Table 3-10, the component characteristics of unmarketable bulbs were given. A positive correlation was observed in the oblong and irregular characteristics for Component 1. A positive correlation with flat and skinning and a negative correlation with multiple were found for Component 2. The plots of BB, KAR, and SJR were very close to the center of the scatter plot by component 1 and 2 (Fig. 3-6). The component characteristics of bulb quality are given in Table 3-11. A positive correlation was observed for skin retention, DM, bulb uniformity and bulb firmness in Component 1. A positive correlation with skin color and bulb quality was found for Component 2. A scatterplot was created from Components 1 and 2 (Fig. 3-7). The plots of BB and KHT2, and KW3 and OK222 were very close to each other. All other cultivars were isolated.

3.4 Discussion

3.4.1 Onion plant growth and bulb formation

3.4.1.1 Leaf and root development in early stage

Large onion bulb production requires a cultivation method that increases the leaf number and leaf area of plants as much as possible until the daylength and temperature reach the required level for bulb formation (Aoba, 1964). Among the ID cultivars used, there was a slight difference in the number of seedling leaves at the time of transplanting (Table 3-3), but there were no differences in the number of leaves in the field in early June, when the temperature was still lower, although there was a difference in leaf length (Table 3-4). SJR showed the highest leaf length even at low temperatures and

Table 3-9. Factor loading, eigenvalue and contribution ratio of each principal component of plant growth in PCA.

Characteristics[z]	Component No.		
	1	2	3
Leaf length, early Jun.	0.305	0.838	-0.361
Fresh leaf no., early Jun.	0.285	0.682	0.625
Leaf length, early Jul.	-0.784	0.427	-0.237
Fresh leaf no., early Jul.	-0.810	-0.387	0.120
Leaf sheath diameter, early Jul.	-0.973	0.026	0.125
Bulbing date	-0.922	0.001	-0.109
Lodging date	-0.927	0.117	-0.075
Complete lodging date	-0.908	0.208	-0.110
Bulb weight	-0.777	0.134	0.394
Eigenvalue	5.53	1.58	0.79
Contribution	61.4	17.5	8.8
Cumurative contribution	61.4	78.9	87.7

[z] Characteristics: see Table 3-4 and 3-6.

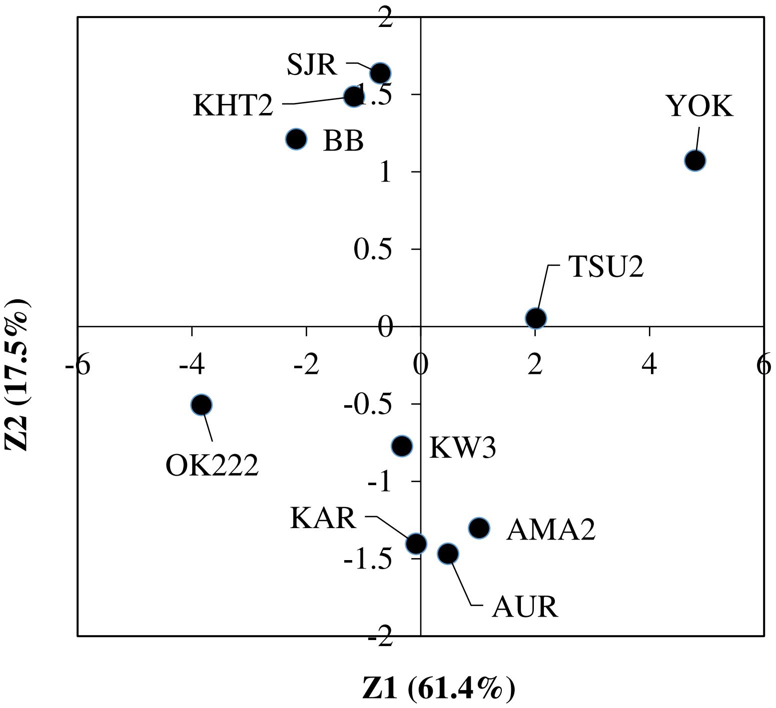


Fig. 3-5. Scatterplot of the principal component scores for plant growth of the cultivars. The Z1 and Z2 axes are defined by Components 1 and 2 in Table 3-9.

Table 3-10. Factor loading, eigenvalue and contribution ratio of each principal component of unmarketable bulb (%) in PCA.

Characteristics[z]	Component No.		
	1	2	3
Flat	-0.175	0.814	-0.435
Oblong	0.857	0.264	0.009
Multiple	-0.532	-0.653	0.268
Irregular	0.821	-0.135	0.353
Small	-0.562	0.503	0.346
skinning	-0.059	0.632	0.632
Eigenvalue	2.04	1.83	0.90
Contribution	34.0	30.0	15.1
Cumurative contribution	34.0	64.0	79.1

[z] Characteristics: see Table 3-6.

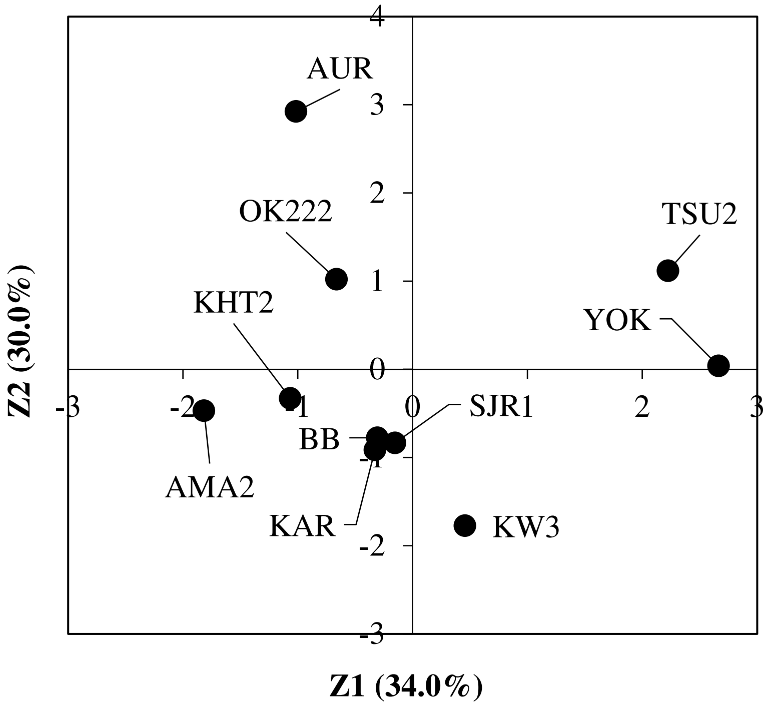


Fig. 3-6. Scatterplot of the principal component scores for unmarketable bulb (%) of the cultivars. The Z1 and Z2 axes are defined by Components 1 and 2 in Table 3-10.

Table 3-11. Factor loading, eigenvalue and contribution ratio of each principal component of bulb quarity in PCA.

Characteristics[z]	Component No.			
	1	2	3	4
Bulb firmness	0.605	0.096	-0.706	0.297
Bulb uniformity	0.639	0.640	-0.176	-0.232
Skin color	0.247	0.811	0.396	-0.231
Skin retention	0.704	-0.497	-0.096	-0.380
Dry matter content	0.667	-0.524	0.402	-0.154
Pylvic acid	0.577	0.055	0.417	0.686
Eigenvalue	2.11	1.60	1.03	0.83
Contribution	35.2	26.7	17.2	13.9
Cumurative contribution	35.2	61.9	79.1	93.0

[z] Characteristics: see Table 3-7 and 3-8.

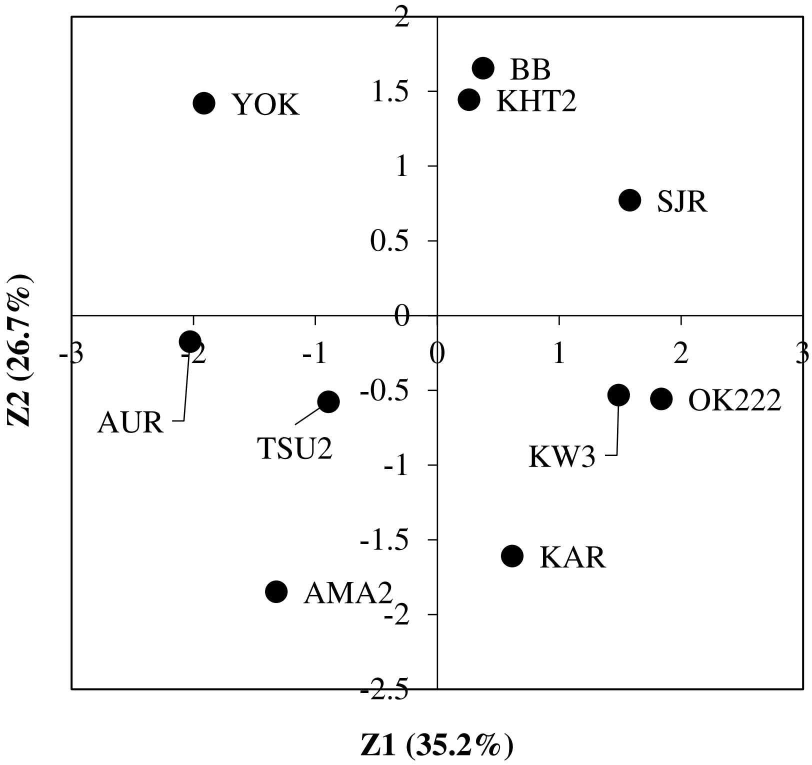


Fig. 3-7. Scatterplot of the principal component scores for external and internal bulb quarity of the cultivars. The Z1 and Z2 axes are defined by Components 1 and 2 in Table 3-11.

increasing of root number caused such vigorous leaf growth (Fig. 3-3). From early June to early July, the leaf length of each ID cultivar increased 1.3 to 1.8 times (Table 3-4), and the number of leaves increased 1.3 to 1.5 times.

De Melo (2003) indicated the root length density (L_v), which was calculated from the root length per unit volume of soil. And L_v of old Dutch cultivars showed denser root systems than modern cultivars, which indicates that onion breeding in the Netherlands, with genotype selection under high fertilization levels, led to a reduction in root development. The difference in root number of SJR from the other F_1 cultivars may be attributed to the genotype background.

Tanaka et al. (1997) found that the rapidly increase of the number of roots promoted leaf growth in OK1. Although the increase in the number of roots declined as bulb enlargement (Kato, 1963), SJR maintained its higher number of roots until harvest (Fig. 3-3). Increase of root number per plant has been reported to be an important trait for yield increase in onion (Islam et al, 2007) and Aoba (1955) planted out that many roots produced larger bulbs.

3.4.1.2 Bulb formation

The difference in bulbing time between 2017 and 2018 were 5 days for SJR and BB, and 10 days for OK222, but the rest of the ID cultivars had few differences. The temperature factor was likely not very involved in the bulbing of the tested cultivars, except for SJR, BB, and OK222.

Even in LD treatment, the both formation was influenced by air temperature. Terabun (1980) reported ‘Kaizuka-wase’ (SD) formed bulb at

10°C, however SPK (LD) did not at such temperature. SJR and BB may also tend to require certain temperatures, which may be caused by the genetic background of their parent lines. The ripening dates of the ID cultivars was from July 29 to August 4. From a maturity perspective, all tested ID cultivars could be shipped early in August when they are sown in mid-February and transplanted in late April.

The growth process of onion bulb has been studied (Abe et al., 1955; Aoba, 1955; Kato, 1963 and 1964; Terabun, 1981). Increases in the number of internal lateral buds are important for the enlargement of onion bulbs (Aoba, 1955; Kato, 1963; Nagai and Hanaoka,1963; Yakuwa, 1975). In onions, branching and splitting frequently occur at high temperature and light levels (Brewster, 2008), and it is thought that the summer environment also causes lateral bud development. Onions were sensitive to the formation of multiple centers with water stress at the four-leaf to late six-leaf stages (Shock et al., 2007). The lateral buds of OK1, an early maturing LD cultivar, have been found to increase earlier than other LD cultivars (Tanaka et al., 1996b); however, there have only been a few studies on the relationship between lateral bud development and the irregular shape of bulb.

Unmarketable shapes, including multiple and flat shapes, were measured to be more than almost 30% in eight of the studied ID cultivars, excluding SJR (Table 3-6). The development of individual lateral buds would disturb the bulb’s appearance and is considered to be a factor of unmarketable shape, especially if there are the category of unmarketable shape, “multiple” or “irregular” bulbs.

Yakuwa (1963) broadly studied the lateral bud formation and bulb division of genus *Allium* plants. He found that the node formed lateral in onion was from the 10th to 13th leaf, which was a higher node than that in other cultivated *Allium* plants. When ‘Tarzan’ was sown in spring, primary lateral bud occurred between 9th to 13th nodes, and such occurrence was almost same in autumn-sown production in Toyama Prefecture (Asai and Nishihata, 2015b). Under SD conditions, only the first lateral buds developed in ‘Senshuki’, while under LD conditions, up to 3 lateral buds did (Kato, 1963). Aoba (1964) compared the growth of 'Imaiwase' (ID) between Sapporo (43 degrees north latitude) and Tsuruoka (38 degrees north latitude), and the number of leaf within the lateral bud formed was slightly more in Sapporo than in Tsuruoka. This indicates that the lateral bud differentiation time was relatively earlier in Sapporo than in Tsuruoka. In higher latitude regions, the development of the lateral bud starts earlier, and the bulb shape tends to be disturbed due to increases in the lateral buds number and individual bud enlargement. This may indicate that even the cultivars which produce good shapes grown in Honshu may lose their shape when grown in Hokkaido.

Regarding the bulb shape of SJR, the range of the portion of node differentiated lateral bud was higher than those of KHT2 and BB on the 61st day of transplanting (Table 3-5). This indicates that many leaves surrounded the scales of the SJR bulb, thus preventing the lateral buds from being able to freely enlarge. This is the reason why the shape of the SJR was not disturbed unless many lateral buds (Table 3-7).

3.4.1.4 External appearance

The external appearance of each bulb is very important in the Japanese fresh market. The marketable yield is more important than the total yield for onion growers in terms of agricultural management. In addition to size, the distortion of the bulb shape and the bulb's skinning are strictly judged in onion factories.

In the 2018 trial, root cutting work was performed 5 days after the complete lodging in YOK and AUR. The roots of other cultivars were forcibly cut on July 23 even if they had not yet been lodged, because that date was the deadline for early shipment plan by the Agricultural Cooperative in Kitami. This advanced root cutting might reduce the number of multiple and irregular bulbs, because of stop growing of lateral buds. The flat bulb ratio in AUR had a large reduction from 63.1% in 2017 to 29.9% in 2018. The timing of root cutting is very important for maintaining a marketable yield.

3.4.2 Bulb quality

Bulb firmness, pungency, storage ability and high dry matter levels were the original characteristics of the Hokkaido onion (Sato and Nagai, 1997; Tamaki et al., 2002a and 2002b). The hardness of onions has been established from the demand of long-term storage. For example, Ito (1998) measured the hardness of onions with a simple measuring machine and indicated that the main cultivars in Hokkaido were hard. Kanetani et al. (1978) measured the limit for stacking 'Sapporoki' (2 m in height) and its drop limit (0.2 m in height) on concrete floor. The limit value of deformation with no bruising was measured within 2 mm using a press (Shimada, 1980).

The bulb firmness of the tested ID cultivars was generally moderate, and there was no difference found between the ID cultivars and OK222 (Table 3-7). There was a significant positive correlation between the penetration resistance of one leaf and the hardness evaluation by hand-touching, with differences among the cultivars and trial years, respectively (Meguro et al., 1997).

Shimada (1980) confirmed that bruising, severe damage, and scuffing can occur from the tapping roller of an onion harvester, and that bruising also occurs when bulbs fall into a large steel harvest container. Currently, a certain degree of bulb firmness is desired, since all onions are mechanically harvested into steel containers using a high-speed onion harvester after drying on the ground surface in the field in Hokkaido.

In addition, the brown skin color of onion is a symbol of Hokkaido onion, called as ‘fox color’, and is commercially important factor. In tested cultivars, YOK, TSU2, SJR, KHT2, BB, and also KW3 had a brown skin color same as or better than OK222, leading cultivar in Hokkaido. The retention of dried protective skin is also an important property for the mechanical handling of bulbs at harvest (Brewster, 2008), to protect the bulb from bruises during long-distance transportation from Hokkaido, and as a quality-measure for consumers.

Dry matter (DM) and Pyruvic acid (PA) are the main factors in the taste and flavor of onions. PA content is an indicator of hot flavor, and is a desired characteristic of Hokkaido hot onions. The highest PA (12.7 $\mu mol \cdot a^{-1}$) was recognized in OK222, and KW3 and SJR followed. The rest of ID cultivars might have milder flavor. In this Chapter, the correlation coefficient between PA and SS was not significant (R = 0.528, NS), due to the small number of cultivars and the early harvest time. Pyruvate values were highly and significantly correlated to onion pungent flavor (Marisa and Corgan, 1992). Although phenotypic correlations between PA and SS were positive (Lin et al., 1995), it was not significant relationship of ID cultivars between SS and PA (R = 0.049, NS), because the reason may be that the number of cultivars analyzed is small and the genetic background of each cultivar is different. It was highly significant relationship of ID cultivars between DM and SS (R = 0.922, P<0.001) in this trial. The amount of pyruvic acid and SS are genetic traits (Havey and Randle, 1996), and these characteristics can be improved by breeding.

3.4.3 Resistance to FBR

FBR is caused by *Fusarium oxysporum* f.sp. *cepae,* and is one of the most serious soil borne diseases in Hokkaido (Brewster, 2008; Higashida and Ohsaki, 1982; Kodama, 1983; Takakuwa et al., 1981). Unfortunately, FBR infection still sometimes occur at the market or at the consumer level in hot summers. even if no FBR symptoms are observed until harvest time. Regardless, resistance in cultivars is indispensable for Hokkaido onion industry (Kojima, 2013). At present, the occurrence of FBR is decreasing due to the optimization of the amount of fertilizer applied (i. e., reduced fertilizer) and crop rotation (Higashida et al., 1982) in onion fields. The FBR infection rate tended to be low in the tested ID cultivars, except YOK, but a multi-year test is required in the future since environmental factors can be affect the infection rate. Since FBR was often an economic problem after the bulbs arrived on the market, it is necessary to test bulb infection rates to judge disease resistance (Mandel and Cramer, 2020). FBR resistance has been effectively selected in breeding programs (Cramer, 2000), and has already widespread in the major LD cultivars in Hokkaido. FBR resistance will also be successful in ID cultivars (Cramer, 2000; Gutierrez et al., 2006; Taylor et al., 2019).

3.4.4 Integrated evaluation of ID cultivar characteristics by PCA

Wako et al. (2009) investigated several traits of bunching onions (*Allium fistulosum* L.) which were related to morphological and growth characteristics via PCA. In order to make a comprehensive judgment of the characteristics of ID cultivars suitable for Hokkaido, PCA method was effective. Following characteristics were revealed. In early spring cultivation in northeastern Hokkaido, it is important that the plants grow vigorously even at low temperatures, which ensures bulb enlargement and promotes early shipment (e. g., SJR, KHT2, and BB; Fig. 3-5). In terms of external quality, the cultivars maintained a stable globe shape without biasing toward oblong or flat shapes and skinning (e.g., SJR, BB, and KAR; Fig. 3-6). In internal quality, a higher dry matter content and a certain degree of flavor are needed for maintaining the uniqueness of Hokkaido onions (e. g., SJR; Fig. 3-7).

3.4.5 Conclusion

In 2017 and 2018 trials, the author examined the characteristics of 9 ID cultivars suitable for early shipment in the northeastern Hokkaido region. SJR was higher in leaf length in early June. Bulbing time of the ID cultivars was in the middle of June, lodging time was in the middle of July, and ripening was reached from the end of July to the beginning of August. According to the dissection of the onion plant, the occurrence of the lateral buds in KHT2, SJR, and BB started in the second pentad of June. The number of lateral buds increased sharply and promoted bulb enlargement. Many ID cultivars showed a high total yield that matched OK222 (LD), but some cultivars had reduced marketable yields due to unfavorable bulb shapes. The internal quality was clearly different among the various cultivars and trial years. The dry matter content of KAR was as high as that of OK222. The PA of KW3 and SJR was as high as that of OK222. FBR disease up to the time of harvest did not occur in AMA2, KAR, KW3, SJR, KHT2, or BB; however, since meteorological factors can affect disease occurrence, additional, multi-year studies are necessary.

The onion growth phase varies due to annual fluctuations in weather conditions. In order to select a cultivar that is adaptable for the local production environment and domestic market demand, it is necessary to comprehensively consider multiple characteristics over multiple years.

Growth needs to be vigorous in early June, bulbing time needs to occur in late June at the latest, lodging time needs to occur in mid-July, and ripening time needs to occur from the end of July to early August for the selective breeding of onion cultivars for early shipment from northeastern Hokkaido. Furthermore, cultivars need to produce only a few multiple and irregular-shaped bulbs, have a high marketable yield similar to OK222, and resistant to FBR. Suitable cultivars should be also selected with the characteristics of good bulb quality, including bulb firmness, attractive brown skin color, good skin retention, and the taste and flavor of typical Hokkaido onions.

In this study, suitable cultivars, such as SJR were found to be desired. Selecting cultivars with characteristics of maturity time, marketable yield, and bulb quality will ensure that the early shipment of onions is possible.

Chapter 4

General Discussion

The purpose of this research was to enable the early shipping of onions produced in northeastern Hokkaido to fulfill the current market demand. From the results obtained, the cropping type, which combines the application of ID cultivars with early sowing and early transplanting, is the best way to achieve this goal. (Fig. 4-1).

4.1 Effectiveness of cultivar selection for early harvest

4.1.1 Improvement of LD cultivars in Hokkaido

Originally, LD cultivars, such as ‘Yellow Globe Danvers’ were introduced to Hokkaido from the USA because this spring-sown cultivar originated in North America at almost the same latitude and climate as Hokkaido. Open pollinated famous cultivar, ‘Sapporoki’ was derived from ‘Yellow Globe Danvers’. Then, ‘Kitamiki’ and ‘Sorachiki’ were improved from growers’ seeds around 1970s. Recently, the share of F_1 cultivars (e. g., ‘Kitamomiji2000’, ‘Okhotsk222’) released by private seed companies has become quite large. Selective breeding has mainly focused on disease (FBR) resistance, higher yield, longer term, overwinter storage abilities.

4.1.2 Limitation of early harvest in LD cultivars

There are some early mature cultivars (e. g., ‘Okhotsk222’) and some late mature cultivars (e. g., ‘Super Kitamomiji’). These cultivars are

Fig. 4-1. Onion cropping types in Japan with the achivement of this studies.

Cropping type	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Cultivar
Hokkaido													
Autumn sowing	---- (under snow) ----	----	----	----	----	----	----	Sowing Harvest, shipment		Transplanting		------------	Turbo Momiji No.3 Lucky
Early sowing & early transplanting			Sowing --------		Transplanting	-------------	-------------	Harvest, shipment					**Sojiro** **Kitahayate No.2** **Bullet bear**
Spring sowing with row cover				Sowing ----------		Transplanting	---------------		Harvest, shipment				Okhotsk No. 1
Spring sowing, standard				Sowing ---------		Transplanting	--------------------		Harvest, shipment				Super Kitamomiji Kitamomiji 2000
Honshu and Kyushu													
Autumn sowing	----------	----------	----------	Harvest & shipment						Sowing -----	Trans-planting	-------	Lucky
Autumn sowing, "Tsuridama"	----------	----------	----------	----------	Harvest, store, & shipment						Sowing	Trans-planting	Momiji No. 3

classified as LD cultivars due to their bulb formation needs. LD cultivars start bulb formation around mid-July and can be harvested in late August or mid-September via in-field, bulb-drying process. There is a small difference in harvest time of almost 2 weeks between the early and late maturing LD cultivars. Although these seedlings are transplanted in late April, approximately 2 weeks earlier than conventional transplanting times, LD cultivars are harvested in the middle of August, which makes them unsuitable for use in early shipment.

4.1.3 Insufficient growth and low yield of SD cultivars

SD cultivars, (e. g., 'Sonic') require only 12.5 hours for bulbing to begin (Miyaura, 2001), and temperatures of only about 10°C. Under Hokkaido weather conditions, the bulbing starts in early to mid-June when plant growth is still small. As a result, the harvested bulb is small and unmarketable, with poor skin properties. Thus, SD cultivars are not suitable for early shipment in northeastern Hokkaido.

4.1.4 Effectiveness of early bulb formation in ID cultivars

ID cultivars begin to enlarge their bulbs in early July when temperatures are sufficient, though daylength is already acceptable in mid-May. As a result, they could be harvested in late July or early August if early transplanting was used. Such harvest time in ID cultivars contributes to the early shipment of Hokkaido onions.

4.2 Growth characteristics and yield in ID cultivars in Hokkaido

4.2.1 Early leaf growth relates to onion yield

Even if the ID cultivars are used for early shipment, it is necessary to obtain the same yield as the major LD cultivars from the viewpoint of agricultural income. Some data has indicated that there is a strong relationship between plant growth before leaf lodging and onion yield (Aoba, 1964; Kato, 1964; Tanaka et al., 1997). Thus, it is important to obtain vigorous leaf growth in the period before leaf lodging (in late June or early July). In the case of early transplanting, maximum leaf growth, including leaf number, leaf height, and sheath diameter occurred in late June, and early July in ID cultivars, such as KW3, and KHT in the examination from the 1990's and SJR in the examination from the 2010's. The size of leaf growth in ID cultivars were similar to the standard growth in LD cultivars, and a similar yield is expected for ID cultivars, compared to the LD cultivars.

4.2.2 Growth of ID seedlings in mid-winter

Plant growth and, consequently, higher yields, can be obtained via the transplantation of large seedlings. In this study, early sowing from December to February was most effective for getting a large. Usually, onion seedlings are grown in the plastic greenhouse without artificial heat from the middle of February until April. Even when the air temperature in the plastic tunnel inside the greenhouse fell to −14.4°C, the seed bed's temperature was kept at almost 0°C. The emergence of the seeds took approximately 20 to 35 days in December sowing, but the seedlings produced were larger at transplanting.

4.2.3 Avoiding from unseasonal bolting in the field in ID cultivars

Early transplanting sometimes causes unseasonal bolting in the field in LD cultivars, due to green plant vernalization-responses to cool temperatures in May and June (Tanaka et al., 1997; Yoshikawa et al., 1984). No bolting was found in the ID cultivars, and only 0.6–9.2% of LD cultivars bolted (Table 2-6 and 2-7). Japanese ID cultivars were originally produced overwinter in Honshu, Shikoku, and Kyushu, and have a resistance to bolting in cool temperature compared to LD cultivars. Small risk of bolting in ID cultivars will be an advantage in the early transplanting system.

4.3 Breeding objectives in earliness, external appearance, internal quality, and disease resistance

Cultivars grown as a commercial product in northeastern Hokkaido require appropriate photoperiod trait, marketable yield, disease resistance, and bulb quality. The origin of the cultivars tested in Chapters 2 and 3, were investigated. Seed parents of some of the F_1 cultivars were the progeny of OP, autumn-sown cultivars (ID) in Honshu. Pollen parents were 'Sapporoki' (LD), which is also an OP cultivar, but is spring-sown in Hokkaido (Tokumou, 2013; Watanabe, 2006). In addition, some F_1 cultivars were thought to use autumn-sown cultivars (ID) for both parents (Iwata, 1988; Ochi, 2000; Yamatsuta, 2016; Yanagida et al., 2012). Originally, these ID cultivars were bred for autumn sowing for the aims of high yield and long-term storability. When these ID cultivars were used in spring sowing in Hokkaido, their photoperiodic sensitivity exhibited as earliness in the higher latitude region than in their original grown regions. Such cultivars are suitable for early shipment.

There are many studies on the shape of bulbs, such as the size of bulbs, cultivation time, weather condition, amount of fertilizer, and planting density. For the bulb shape index and heritability, the effect of bulb selection (of fixed varieties) can be expected (Nakamura, 1959). The breeder can achieve high heritabilities when selecting for a specific mean shape index (Dowker and Fennell, 1974). The shape can vary with different markets having different requirements by sowing time and plant density (Grant and Carter, 1991). But, there have only been a few studies on bulb shape distortions, which are an important trait related to marketability in Japan. In this study, it was inferred that bulb shape distortions may be related to the node on which the lateral bud occurs. In other words, if the lateral buds occur in higher nodes, it may be easier to maintain an orderly globe shape, as more leaves have already covered around the bulbs and each bud cannot grow on its own.

Negative correlations exist between skin thickness, tensile strength, and skinning rate. In order to breed F_1 cultivars that are physically resistant to skinning, both parents must have a thick skin (Tanaka et al., 1985). For the development of a parent line with a thick epidermis, selection in early generations is ideal, based on the number and the weight of the skins (Hole et al., 2002).

Genetic variation and heritability of SS and PA in cultivars or parent lines were investigated (Lin et al., 1995). Breeders must use that information to continue selecting and improving new cultivars.

The occurrence of FBR not only causes a decrease in farmers revenue, but also economic losses, and the loss of trust among the farmers, markets, and consumers, leading to deterioration production area's image in Hokkaido. FBR resistance is an essential property for Hokkaido onions (Kojima, 2013).

In regards to the above discussed characteristics, onion genome research continues to progress (Atif et al., 2020; Gökçe, 2018; Ikeda et al., 2020; Khosa et al., 2016; Lee et al., 2013; Rashid, 2016; Taylor, 2009). In the future, it will be possible to use this knowledge for more efficient selective breeding.

4.4 Technical improvement for practical application

Some limits to early transplanting do exist. First, farmers have to care for the onion seedlings for almost 3 months after they are germinated in January or February.

Second, field preparation for transplanting, is an issue, since the average date of snowmelt in spring in the Kitami district is April 7, and farmers usually till the field around April 25 to prepare for seedling transplanting. In order to enable the early planting system in this region, farmers would have to spread a snow melting agent on the field.

Third is seedling senescence. The yield of KW3 onions seeded in December and January were more than 500 $kg \cdot a^{-1}$ for the April transplanting, but the same seedlings transplanted in May reduced yield. Since, most farmers use the Minoru nursery system with plastic trays, there is no need to sow in December or January. Nevertheless, seedling senescence is a problem when planting is not possible due to inappropriate conditions. An aging problem in the seedling is likely the reason for this phenomenon, due to its long period growth after germination. Onodera et al. (2018) showed that the split application of fertilizer was more effective than the whole spring fertilizer for spring seeded onions. This can be also applied to the early cropping type.

4.5 Significance of the present research in onion cropping studies around the world

Countries like the USA can grow onions under the full range of daylength (SD, ID, and LD), which results in an ability to offer a diverse range of onion types (Steenge, 2001), and the ability to supply domestic onions year around. Countries with small cultivated areas, such as Japan, will have limited harvest time, production amounts, and year-round supplies if the cultivation method is not selected carefully. Thus, cropping types are needed. Cropping type is a typological, technical system for economically cultivating crops in a natural environment that differs depending on the region and season. The main components of the technical system are cultivar selection, control of the growth environmental, and cultivation management technology (Natl. Res. Inst. Vegetables and Tea., 2010).

There are also cultivation season strategies in other countries. When deciding the sowing time, the purpose is to select the time when water can be supplied to avoid the occurrence of bolting and doubling, and to aim for the price premium of jumbo bulbs (Bosch Serra and Currah, 2002). In New Zealand, cultivars, sowing times, and planting densities were studied in order to produce onions in shapes that met the needs of the export target countries (Grant and Carter, 1991). The present study, which also mentions the disorder of the bulb shape, would be beneficial when considering exports to countries with strict quality standards for bulb appearance.

'Surarippu' was bred by Kitami Agricultural Experiment Station and Nippon Norin Seed Co. The bulb of this cultivar has large and oblong shape traits for easy to peel. In the future, a cultivation method that promotes those traits is required for providing domestic processing user.

The present research discussed the possibility to introduce ID cultivars, which show earliness in harvest time, to an area where LD cultivars are typically grown by cropping method with early sowing and early transplanting. The marketable yield and bulb quality of the introduced ID cultivars was similar to those of the standard-cultivated LD cultivars and could enable a continuous supply of Hokkaido onion without any discomfort. This research is set up to solve the demands of the Japanese market, and the established agricultural system is an advanced cultivation technique.

As the future issues, the research will be required to find the optimal solution for a precise combination of management technologies, such as melting the frozen soil for early field preparation, and maximizing onion growth in nursery and open field controlled by temperature, irrigation, and fertilization for each cultivar, based on accurate weather forecasts.

4.6 Conclusion

The early harvest system for Hokkaido onions was studied to provide onions from northeastern Hokkaido for domestic demand during the summer season, which is defined as the period between the harvest time of autumn planted and spring planted onions. The early harvest, from late July to early August, was achieved by early transplanting well-developed seedlings from the ID cultivar, such as ‘Sojiro’. which was bred in regional condition of northeastern Hokkaido. This cultivar would be a typical model that will spread for early shipment in the onion market. Additional ID cultivars with similarly suitable characteristics are expected to be developed in the future. The cropping system obtained in this study could apply to northern Japan and other regions with similar condition.

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Summary

Allium vegetables are an important part of the human diet have been cultivated for 4,700 years. Onions are cultivated all over the world including countries with tropical climates. Fresh and processed onions are consumed year-round and contains both nutritional and functional ingredients.

Onion is a relatively new vegetable in Japan that was introduced from the United States in 1871. Domestic cropping types are roughly divided into autumn-sown cultivars used on Honshu, Shikoku, and Kyushu, and spring-sown cultivars used Hokkaido. Hokkaido onions are harvested from summer to autumn, and then, continuously shipped while being stored during winter. After that, onions are supplied from Honshu, Shikoku, and Kyushu, but from June to early August, domestic products are in the off-season, and imports increase. The onion growing area except Hokkaido has been declining since 1964. This downward production trend has continued in recent years due to further urbanization and aging. Increasing weather disasters has also caused production volume stability to decrease. For these reasons, market demands require that the shipment of Hokkaido onions be accelerated. In particular, expectations for early shipment are increasing in the Kitami area in northeastern Hokkaido, which occupies about 30% of the total 26,200 ha onion production area.

Bulb enlargement is strongly influenced by daylength. SD cultivars require about 12 hours, while LD cultivars require 14 hours or more. ID cultivars fall between SD and LD. In Hokkaido, which has higher latitudes

than other part of Japan, LD cultivars are mainly sown in the spring, and root cutting work is performed after the leaf lodging period, which results in dead leaves after a week and bulbs can be harvested. Thus, in order to harvest in early August, cultivation techniques that induce leaf lodging in mid-July are needed, such as cultivar selection, and the optimum combination of sowing and transplanting times.

Chapter 1, outlined techniques to accelerate harvesting, such as standard cropping with unwoven row covers, autumn-sowing in cold regions, and cultivar development. In addition, the results of a grower questionnaire verified the effect that individual technologies have on shipment in early August.

In Chapter 2, the following hypotheses were made with the aim of harvesting in early August: (1) Early transplanting of large seedlings promotes leaf growth in early summer and enlarges bulbs until lodging time. (2) The harvest time of ID cultivars is earlier than that of LD cultivars because the bulbing time is earlier. The effects of the combination of sowing and planting time on harvest time, yield and quality were studied in the 1996/97 and 1997/98 seasons using a total of 5 SD, ID, and LD cultivars. The results showed that seedlings could be raised in a normal, unheated greenhouse. Even if the temperature inside the film tunnel reached −14.4°C during extreme cold weather, the sowing bed temperature was maintained at nearly 0°C. When seed was sown from December to January, it took about 20 days in the 1996/97 trial and about 35 days in the 1997/98 trial to germinate. The earlier the sowing time, the longer the leaf length and the leaf sheath diameter of the seedlings at the time of planting. The seedlings sown from December to January were also significantly larger than those sown from February to March. 'Kitawase No. 3' and 'Kitahayate' (both ID) were sown from December to January, and could be harvested from late July to early August if they had been transplanted from late April to early May. Although the harvest time for 'Sonic' (SD) was as early as mid-July, the cultivar shifted to bulb formation too quickly after transplanting, it had limited plant growth, and its yield was low due to its smaller bulb. In addition, although the yields of 'Okhotsk No. 1' and 'Kitamomiji 86' (both LD) increased from early sowing and early transplanting, they did not mature by the target of early August. From these results, it can be concluded that ‘Kitawase No. 3’ and ‘Kitahayate’ are appropriate for early cropping type in northeastern Hokkaido.

Chapter 3 discussed the characteristics required for ID cultivars to be used for early cropping type in Hokkaido. A total of 32 ID cultivars were surveyed in 2017 and 2018 trials. Nine of these were tested and compered with 'Okhotsk222' (LD) for 2 years. The results showed that 'Sojiro' grew vigorously starting its early stage of growth in early June, when temperature were still low. Bulbing time for all tested ID cultivars was from the middle to the end of June, and the maturity time was from the end of July to the beginning of August. A more detailed investigation of the bulb growing process by dissecting 'Kitahayate No.2', 'Sojiro' and 'Bullet bear' revealed that a lateral but occurred in the second pentad of June and that the number of lateral buds increased sharply. It may be that the occurrence of lateral buds and their increase in number promoted bulb enlargement. In addition, ‘Sojiro’ tended to have many roots from the beginning of June until the time of harvest. ‘Aurora’, ‘Kitawase No.3’, ‘Sojiro’, ‘Kitahayate No.2’ and ‘Bullet bear’ showed high yields. Some cultivars decreased their marketable yield due to changes in bulb shape, which are thought to be associated with the occurrence and amount of lateral buds. The bulb shape of ‘Sojiro’ was stable. In bulb external quality, ‘Sojiro’ had good bulb shape uniformity, and ‘Bullet bear’ had good brown skin color. In internal quality, the dry matter content of ‘KAR-004’ was as high as in ‘Okhotsk222’. The amount of PA in ‘Kitawase No.3’ and ‘Sojiro’ were as same as that of ‘Okhotsk222’. The incidence of FBR was low in ‘Sojiro’, ‘Kitahayate No.2’, etc.

All of these characteristics were analyzed via principal component analysis and all (except ripening time) are required if the onions are to grow vigorously, even at low temperatures in early June. Specifically, the following characteristics are required for early cropping in Hokkaido. Bulb shape needs to not bias toward oblong or flat, and needs to be well-aligned. Bulb firmness, brown colored skin, and skin retention are also required. Thus, it was concluded that it is possible to comply with the strict shipping standards, while securing a marketable yield using the early cropping technique in Hokkaido. Moreover, a suitable supply system for Hokkaido onions can be established without any decrease in quality or the ordinary cultivars (LD) shipped after early shipment, since the internal bulb quality is good (firm, not too soft), the dry matter content is high, and there is some spiciness to the onion.

In the past, Hokkaido onion production has been expanded via various technological developments, such as breeding, the introduction of highly storable cultivars, long-term winter storage technologies, and labor-saving mechanizations. This study contributes to the production of early onion shipments from the northeastern region of Hokkaido. This cropping type is also useful for the early shipment of onions in subarctic regions where autumn sowing is difficult.

Future developments in onion genomics research may utilize molecular biological methods to create early cropping cultivars suitable for Hokkaido.

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北海道北東部におけるタマネギの早期出荷作型の確立に関する研究

田中静幸

要約

Allium 属野菜は世界的に重要な品目である．とくにタマネギ（*Allium cepa* L.）は約 4700 年前から栽培され，現在では赤道直下の国々を含め，南アフリカから北欧まで広く生産されている．世界中で約 9,680 万 t 算出され，野菜の中ではトマト，スイカに次いで第 3 位の位置を占めている．幅広い調理法に適し，日々の食材としてだけではなく，我々の健康維持に欠かせない多様な機能性成分を含む野菜である．国内では比較的新しい野菜として，北海道開拓使時代（1871 年）にアメリカから導入された．

我が国の栽培方法は，府県の秋播栽培と北海道の春播栽培に大別される．道産タマネギは夏から秋に収穫後，冬季間貯蔵しながら継続出荷される．その後，府県産が供給されるが，6 月から 8 月初旬にかけて国産品は端境期となり，その期間は輸入品が増加している．府県産地では，1964 年以降，栽培面積は減少傾向にあり，近年とくに都市化や高齢化による生産縮小が続いている．また，気象災害等により生産量が不安定となることがある．このため，市場からは道産品の出荷開始を早めることが求められている．とくに，全国作付面積 26,200ha の約 30％を占める北海道北東部の北見地域に早期出荷の期待が高まっている．

食用部位である球（りん茎）の肥大開始には日長の影響が強く，短日

性品種（SD）では約12時間程度，長日性品種（LD）では約14時間以上必要とされている．SDとLDの中間の品種は中間性品種（ID）と呼ばれている．緯度の高い北海道では，主にLD品種が春播栽培されている．北海道では葉の倒伏期後に根切り作業を行い，その後1週間程度で枯葉したものが収穫可能となる．そのため，8月上旬に収穫するためには，7月上中旬には倒伏する栽培技術（品種選択，播種・定植時期の組合せ等）を組み立てなくてはならない．

第1章では収穫を早めるための栽培技術の改善（べたがけ栽培，寒地秋まき栽培）や品種開発を概括した．また，栽培者へのアンケート結果から，8月上旬の早期出荷に向けた個別技術の効果を検証した．

第2章では8月上旬の収穫を目指して次の仮説を立てた．①大苗の早期定植は初夏の葉部生育を進め，倒伏期まで植物体を大きくする．②ID品種はLD品種より肥大期が早まることで収穫期も早まる．そこで，SD，ID並びにLDののべ5品種を用い，播種と定植時期の組合わせが収穫時期，収量，品質に及ぼす効果を1996/97年，1997/98年に試験を行った．その結果，通常の無加温育苗ハウス下で，厳寒時にフィルムトンネル内の気温が-14.4℃になっても，播種床地温はほぼ0℃に保たれ，育苗は可能であった．厳寒期の12月から1月に播種した場合，出芽までに1996/97年試験では約20日，1997/98年試験では約35日を要した．播種時期が早いほど，定植時の苗の葉長，葉鞘径は増加し，2月から3月播種に比べ，12月から1月播種苗は顕著に大きかった．‘北早生3号’と‘北はやて’（いずれもID）は，12月から1月播種で，4月下旬から5月初旬に定植すると，7月下旬から8月上旬に収穫可能であった．しかし，‘ソニック’（SD）は収穫期が7月中下旬と早かったも

のの，定植後，地上部の生長量が小さいうちに，短期間で球形成に移行するため，小球で低収となった．また，‘オホーツク 1 号’と‘北もみじ 86’（いずれも LD）は早期播種，早期定植により増収したが，目標とする 8 月上旬までに成熟しなかった．以上より，北海道北東部のタマネギ栽培地帯における早期作型には‘北早生 3 号’と‘北はやて’が適応可能であった．

第 3 章では,第 2 章の新作型に適応する実用品種が少ないことから，冷涼な北海道北東部の春播栽培で早期出荷向け ID 品種に求められる特性を検討した．2017，2018 年に ID 品種のべ 32 品種を調査し，このうち，2 ヵ年供試した 9 品種を用いて，‘オホーツク 222’（LD）と比較しながら解析を進めた．その結果，‘早次郎’は気温の低い生育初期（6 月初旬）から生育旺盛で草丈が高かった．球肥大期はいずれの ID 品種も 6 月中から下旬，成熟期は 7 月末から 8 月初旬となった．総収量では，‘オーロラ’，‘北早生 3 号’，‘早次郎’，‘北はやて 2 号’，‘バレットベア’が高かったが，球形状不良により規格内収量を低下させる品種が多かった．‘北はやて 2 号’，‘早次郎’，‘バレットベア’及び‘オホーツク 222’を用い，経時的に植物体を解剖し，より詳細に生育経過を調査した．‘早次郎’は定植後約 2 ヵ月の時点で，他品種より腋芽発生葉位が高く，外葉数が多いことから個々の腋芽の生育肥大に伴う球外周の変形が起こりにくいことが推察された．また，‘早次郎’は 6 月初旬以降収穫時まで根量が多かった．そのため，‘早次郎’は規格外となる形状不良が起きにくく，収量も安定していることが推察された．球外観では，‘早次郎’は地球型の揃いが良く，‘バレットベア’は皮色が良かった．内部品質では，‘KAR-004’の乾物率は‘オ

ホーツク 222’並に高かった．ピルビン酸生成量は，‘北早生 3 号’，‘早次郎’が‘オホーツク 222’並であり，他の ID 品種は低かった．乾腐病の発病率は，‘早次郎’，‘北はやて 2 号’等で低かった．これらの特性を主成分分析により解析すると，北海道北東部の春播栽培で早期出荷向け ID 品種には，定植直後の低温時期に初期生育が旺盛なこと,球形は地球型で揃い,皮張り,皮色の良いことが求められる.また，LD 品種並の硬さがあり，機械収穫に耐えられること，内部品質では乾物率が高く，ある程度の辛さも必要である．これらの特性により，現行の厳しい出荷規格に対応し，また，後続して出荷される普通栽培の LD 品種との違和感がなく，流通する ID 品種となり，北海道産タマネギの安定供給体制が確立される．

本研究は国産タマネギの端境期に向けて，タマネギ主産地の北海道北東部における早期出荷体系の構築に寄与する．さらに，早期播種作型は，土壌凍結等により秋播栽培が困難な亜寒帯地帯でタマネギの早期出荷を行う場合に参考となる．また，*Allium* 属野菜の球肥大に関するゲノミクス研究は最近急速に進んでいる.今後，分子生物学的手法が生かされ，早期出荷作型に適する品種開発が効率的に進むことが期待される．

一方，今後の作型・栽培法研究では，外観品質，とくに形状の均質化を図ることが求められるであろう．タマネギ輸出国であるニュージーランドでは，相手国の嗜好に即した形状（大球や扁平等）に揃える栽培法の研究が行われている．我が国でも,縦長で剥皮歩留りが高い加工向け品種‘すらりっぷ’（北見農業試験場，日本農林社）が育成され，今後の普及に向けて，その形状を生かした栽培法が求められている．