Accumulation of Soluble Sugar in True Seeds by Priming of Sugar Beet Seeds and the Effects of Priming on Growth and Yield of Drilled Plants

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Abstract: For improving the yield of drilled sugar beet (Beta vulgaris L. ssp. vulgaris), it is important to promote germination and early growth. In this study, the priming of sugar beet seeds was examined in six cultivars to improve their germinability in cool conditions. The optimum water content of sugar beet seeds (which botanically are fruits) during priming was 24 to 25% when they were kept at 20°C for 5 d. In further experiments, after the water content of seeds was adjusted to 24% by adding distilled water, the primed seeds were air-dried to below their original water content. The primed true seeds contained 0.5 to 4% more soluble sugar, by dry weight, than the control true seeds. The levels of amylase activity of the primed true seeds were 1.9 to 11.5 times higher than those of the control true seeds, though there was little change in α-glucosidase activity. Priming shortened the average germination period at SoC by 1.6 to 4.0 d and seedlings from the primed seeds emerged significantly faster than did seedlings from the control seeds in the field. The advanced emergence in the primed seeds brought about a significant increase in early growth compared with control seeds, and the root yield from the primed seeds tended to exceed that from the control seeds by 3% on average at harvest time. Priming did not affect the sugar, potassium, sodium or amino nitrogen content in the root.

Key words: Amylase activity, Early growth, Germination, Priming, Root yield, Soluble sugar, Sugar beet, True seed.

Recently, most farmers in Japan have adopted transplanting systems for their sugar beet cultivation, but the advancing age of Japanese farmers will necessitate drilling systems that are less laborious and less costly. In transplanting systems, sugar beets are sown in paper pots and grown in a greenhouse in spring before the snow outside melts. This allows a longer growing period for sugar beet cultivation in Hokkaido. On the other hand, when a drilling system is used, the spring growing period can begin only after the snow has melted. As a result, the yield of sugar beets grown under a drilling system is usually much lower than that of transplanted beets (Fletcher, 1984; West, 1984). Thus, for sugar beet farmers in Japan to use a drilling system, it is essential to improve the yield.

Yoshimura (1996) reported that the lower yields produced by a drilling system was mainly due to slower dry matter increase than in transplanted sugar beets in early growth period. The expansion of leaf area was found to be especially important for the increase in dry matter during early growth. Therefore, many researchers have taken various approaches to promote early growth: the application of starter fertilizer (Shichijii, 1968; Saunders, 1998), the improvement of seed bed suppression (Yoshimura and Shirahata, 1997), the improvement of methods for sowing germinated seed (Sekiguchi and Wada, 1969) and so on. Priming, one of the techniques to promote germination, advances the physiological status of seeds just before root extrusion by controlling the water supply. The important characteristic of priming is that air-dried primed seeds can keep the promoted germination for a long time. Accordingly, primed seeds are suitable for commercial use, and primed seeds of some vegetables are already available in Japan. A number of priming methods have been reported for vegetable seeds, such as halopriming with salt solution, osmopriming with polyethylene glycol solution (Khan et al., 1983) and solid matrix priming with damped solid minerals that have a high water-holding capacity (Taylor et al., 1988; Rush, 1991). Priming experiments have also been undertaken for sugar beet seeds (Swensen and Murray, 1991), and primed sugar beet seeds have been practically used in parts of England (Heyes et al., 1997; Jarvis and Patchett, 1998; Heyes, 1999).

In the present study, using the drum priming method (Rowse, 1996) in which seeds are moistened and kept in a rotating drum, we evaluated a simple priming method in which only the water content of sugar beet seeds was controlled. Sugar content and starch hydrolyzing enzyme activity were investigated to assess the change in the main storage reserves in primed seeds. Then the emergence, early growth and yield of primed seeds were compared with control seeds in the field in Japan.

Received 15 April 2002. Accepted 15 July 2002. Corresponding author: Y. Mukasa (mukasa@affrc.go.jp, fax +81-155-61-2127).

Abbreviations: PBS, phosphate buffered saline (10 mM phosphate buffer, pH 7.4, 145 mM NaCl).
Materials and Methods

1. Optimum water content for priming sugar beet seeds

Four seed (botanically fruit and monogerm) lots of three cultivars ('Stoke' (produced in 1999; average 1 fruit weight was 11.7 mg; pericarp/true seed ratio (dry weight) was 1.96), 'Megumi' (in 1999; 15.8 mg; 1.88), 'Nozomi' (12.1 mg; 1.76), 'Kabutomaru' (12.1 mg; 1.89), 'Kitasayaka' (11.4 mg; 2.49) and 'Hokkai-84' (9.7 mg; 1.76)) were preincubated at room temperature for 20 min. The seeds were dried to below the original water content. The dried seeds were powdered in a mortar with a pestle, and the powder was lyophilized to remove residual water so that the sugar content could be determined.

Soluble sugars were extracted as described in Lawrence et al. (1990). Thirty milligrams of the lyophilized powder from each lot was homogenized in 1.5 mL PBS on ice and sonicated for 30 s using a microprobe. The homogenates were centrifuged for 10 min at 2000 g, and the supernatants were used in the following analyses.

Soluble sugar contents were determined as described in Lawrence et al. (1990) by the conversion of sucrose, maltose or fructose to glucose. The glucose content was measured by the formation of NADPH upon the conversion of glucose to gluconate-6-phosphate. For the glucose assay, the mixture consisted of 870 \mu L of 0.75 M triethanolamine hydrochloride/NaOH buffer (pH 7.6, containing 10 mM MgSO\textsubscript{4}), 30 \mu L 50 mg mL\textsuperscript{-1} ATP (adenosine triphosphate disodium salt), 30 \mu L 10 mg mL\textsuperscript{-1} NADP (nicotinamide adenine dinucleotide phosphate), 10 \mu L 1 mg mL\textsuperscript{-1} glucose-6-phosphate dehydrogenase (EC 1.1.1.49), 10 \mu L 2 mg mL\textsuperscript{-1} hexokinase (EC 2.7.1.1) and 50 \mu L seed extract was incubated at room temperature for 20 min, and the absorbance at 340 nm was measured. The quantity of glucose-6-phosphate was determined by omitting hexokinase from the assay mixture.

To determine the sucrose content, we preincubated 50 \mu L of seed extract with 60 \mu L of 0.32 M citrate/NaOH buffer (pH 4.6) and 10 \mu L 5 mg mL\textsuperscript{-1} invertase (EC 3.2.1.20) at 37°C for 5 min. For the determination of maltose, we preincubated 50 \mu L of seed extract with 60 \mu L 0.1 M CH\textsubscript{3}COOH/CH\textsubscript{3}COONa buffer (pH 6.6) and 10 \mu L 5 mg mL\textsuperscript{-1} \alpha-glucosidase (EC 3.2.1.20) at 20°C for 20 min. The sucrose and maltose contents were determined by measuring glucose content as described above and then subtracting the original glucose and glucose-6-phosphate contents from the values.

The assay for fructose was similar to that for glucose. The mixture consisting of 800 \mu L 0.75 M triethanolamine hydrochloride/NaOH buffer (pH 7.6, containing 10 mM MgSO\textsubscript{4}), 30 \mu L 50 mg mL\textsuperscript{-1} ATP, 30 \mu L 10 mg mL\textsuperscript{-1} NADP, 10 \mu L 1 mg mL\textsuperscript{-1} glucose-6-phosphate dehydrogenase (EC 1.1.1.49), 10 \mu L 2 mg mL\textsuperscript{-1} hexokinase (EC 2.7.1.1) and 50 \mu L seed extract were preincubated at room temperature for 20 min. Then 30 \mu L 2 mg mL\textsuperscript{-1} phosphoglucose isomerase (EC 5.3.1.9) was added and the mixture was incubated at 20°C for 20 min. For the determination of fructose, the absorbance at 340 nm was measured and the original glucose and glucose-6-phosphate contents were subtracted.

2. Soluble sugar content of primed seed

Monogerm sugar beet seeds (cv. 'Monoace-S' (average 1 grain weight was 10.4 mg; pericarp/true seed ratio (dry weight) was 1.96), 'Megumi' (in 1999; average 1 grain weight was 11.7 mg; pericarp/true seed ratio (dry weight) was 1.96), 'Nozomi' (12.1 mg; 1.76), 'Kabutomaru' (12.1 mg; 1.89), 'Kitasayaka' (11.4 mg; 2.49) and 'Hokkai-84' (9.7 mg; 1.61)) that had been rubbed and graded were used. Priming was performed by adjusting seed water content to 24% and maintaining the content at 20°C for 5 d with gradual rotation. Then the primed seeds were dried to below their original water contents at room temperature.

Primed seeds were dried to below the original water content. The dried seeds were powdered in a mortar with a pestle, and the powder was lyophilized to remove residual water so that the sugar content could be determined.
3. Starch hydrolyzing enzyme activity of primed seed

The materials were from the same lots of primed and control seeds used in the determination of soluble sugar content. From the fruits of each cultivar and treatment, 150 true seeds were picked up by tweezers and powdered in a mortar with a pestle with liquid nitrogen. The powders were lyophilized to remove moisture.

Crude enzymes were extracted as described by Lawrence et al. (1990). Thirty milligrams of the lyophilized powders was homogenized in 1.5 mL PBS on ice and sonicated for 30 s using a microprobe. The homogenates were centrifuged for 10 min at 2000 g, and the supernatants were used in the following analyses.

Amylase activity was determined by the starch–iodine method using soluble starch from potato as a substrate. The amylase assay consisted of 300 µL 1% (w/v) soluble starch from potato, 450 µL CH₃COOH/CH₃COONa (pH 4.5) buffer, 50 µL 0.1 M CaCl₂ and 200 µL seed extract. This mixture was incubated at 37°C, and 200 µL aliquots were collected 0 and 5 min after the start of incubation. The reaction was stopped by the addition of 200 µL 1% (w/v) KI+0.1% (w/v) I₂ and the mixture was diluted 8 times with distilled water to measure the absorbance at 620 nm. One unit of amylase activity was defined as a 10% decrease in absorbance at 620 nm min⁻¹.

The activity of α-glucosidase was measured from the amount of glucose released from maltose. For the α-glucosidase assay, a mixture consisting of 100 µL 1% (w/v) maltose, 250 µL 0.1 M CH₃COOH/CH₃COONa (pH 5.3) buffer and 100 µL seed extract was incubated at 37°C, and 100 µL aliquots were collected 0, 5 and 15 min after the start of incubation. The reaction was stopped by heating at 95°C for 5 min, and glucose was measured as we described previously. One unit of α-glucosidase activity was defined as 1 µg glucose liberated min⁻¹.

All the assays described above were carried out with three replications, and the averages are shown in tables and figures as representative.

4. Germination and emergence of primed seeds, and the early growth, yields and root quality of the plants from the primed seeds

The materials were from the same lots of primed and control seeds used in the determination of soluble sugar contents. Germination tests were performed as described above, and the average germination periods at 8°C were calculated.

The experimental field was located at the National Agricultural Research Center for Hokkaido Region in Memuro, and consisted of volcanic ash loam soil. As a basal dressing, compound fertilizer consisting of N : 15.6 g m⁻², P₂O₅ : 26.0 g m⁻² and K₂O : 15.6 g m⁻² was mixed by a rotary harrow to a depth of 10 cm across the whole layer. Seeds were sown on April 23, 2001, by a pneumatic seeding machine (row width: 60 cm, theoretical intrarow space: 4.3 cm). At the same time, starter fertilizer (N : 1.6 g m⁻² and P₂O₅ : 3.8 g m⁻²) was applied into the rows. The plot was 6.75 m long and 2.4 m wide, and four replicated plots were used in randomized block design. At the 38th day after sowing, the seedlings were thinned to 20 cm average intrarow space.

The emerged seedlings were counted every day until no more seedlings emerged, and then the average emergence period was calculated. Top dry weight was investigated at the 23rd, 37th and 51st days after sowing and taproot dry weight was also measured at the 51st day. For the determination of dry weight, 20 plants were sampled from each plot, washed completely with tap water, divided into top and root and dried at 80°C for 48 hrs.

In reference to the weather condition in spring of 2001, the average values of daily maximum temperature in the latter 10 days of April, in the first 10 days of May and in the middle of May were 14.1°C (+ 0.1°C; the difference from the average value of the last 10 years), 11.1°C (−3.8°C) and 22.1°C (+ 5.1°C), respectively. The average values of daily minimum temperature were −1.1°C (−2.5°C), 2.5°C (−0.4°C) and 6.3°C (+1.2°C), respectively. The average values of daily mean temperature were 6.7°C (−0.6°C), 6.5°C (−2.4°C) and 13.8°C (+2.8°C), respectively. The accumulated values of precipitation in 10 days were 0 mm (0%; the relative percentage to the average value of the last 10 years), 30 mm (92%) and 1 mm (3%). The accumulated values of day light hours in 10 days were 77.4 hr (127%), 22.4 hr (44%) and 72.0 hr (144%), respectively. All of these data were provided from the weather station of the meteorological agency in Memuro.

In order to investigate the root and top yields, 40 plants were harvested and normally topped on October 24, and top weight was measured in the field. Root weight, sugar content, sodium content, potassium content and amino–nitrogen content were measured at the sugar beet analysis facilities of the National Agricultural Research Center for Hokkaido Region in Memuro. Sugar content was measured by a refractometer, sodium and potassium contents were measured by a flame photometer, and amino–nitrogen content was measured by a fluorescence photometer after reacted with o-phthalaldehyde according to the global standard methods for sugar beet analyses.

Results

1. Optimum water content for priming sugar beet seeds

As shown in Fig. 1, the higher the water contents of seeds during the priming, the shorter was the average germination period. Among the four seed lots, ‘Stoke’ had the shortest germination period in both the original seeds and the primed seeds that had been treated at the
Fig. 1. Relationship between water content of seeds during priming and average germination period of primed seeds at 8°C. The average germination periods of original seeds were 'Stoke', 7.3 d; 'Monoace-S' (produced in 1997), 8.0 d; 'Monoace-S' (produced in 1999), 8.3 d; and 'Megumi', 8.1 d.

Fig. 2. Comparison of sugar contents in true seeds between control and priming. Priming was performed by adjusting the water content of seeds to 24%, keeping them at 20°C for 5 d and drying them to below their original water contents at room temperature. The asterisks in this figure show statistically significant differences between control and priming by t-test. ** at 1% level, * at 5% level.

same water content during priming. The average germination period of 'Stoke' was shortest when the water content during priming was about 24%. In the other seed lots, the average germination periods were shortest when the water content of seeds were from 24.7 to 25%. In most seed lots, cracking of the seed cap or root extrusion was often observed when the water content of seeds during priming was kept above 25.5%. In conclu-
2. Soluble sugar content and starch-hydrolyzing enzyme activity of primed seeds

The contents of total soluble sugars (glucose + fructose + maltose + sucrose) of primed seeds exceeded those of control seeds in all cultivars (Fig. 2). On average, primed seeds contained more total soluble sugar than control seeds by 2 to 3% of dry weight. For monosaccharides, primed seeds had a statistically significantly higher content than those of control seeds, except for the fructose content of 'Monoace-S'. The maltose contents of primed seeds were also significantly higher than those of control seeds, except for 'Hokkai-84'. On the other hand, the sucrose contents of primed seeds
Table 1. Effects of seed priming on the germination, emergence and early growth of sugar beet.

| Cultivar | Germination at 8 Degree Celsius | Emergence in the Field (Sown on April 23) | Early Growth at the 51st Day after Sowing |
|----------|--------------------------------|----------------------------------------|----------------------------------------|
|          | Average germination period (days) | Final germination percentage (%) | Average emergence period (days) | Final emergence percentage (%) | Top dry weight (mg) | Taproot dry weight (mg) |
|          | ** | ** | ** | ** | ** | ** |
| 'Monoace-S' | 8.9 | 5.0 | ** | 16.1 | 4.2 | 1974 | 126 |
| 'Megumi' | 4.9 | 7.8 | ** | 13.4 | 5.1 | (143) | (187) |
| 'Nousoi' | 7.1 | 8.5 | ** | 15.6 | 6.7 | 2073 | 212 |
| 'Kabutomaru' | 4.2 | 9.5 | ** | 17.1 | 7.5 | (111) | (148) |
| 'Kitasayaka' | 6.7 | 9.7 | ** | 14.6 | 7.9 | 2568 | 261 |
| 'Hokkai-84' | 4.5 | 99.3 | ** | 13.3 | 7.4 | 2236 | 240 |
|          | 8.5 | ** | n.s. | 15.3 | 57.4 | 2140 | 209 |
|          | 6.9 | ** | n.s. | 14.8 | 54.7 | 2256 | 260 |
|          | n.s. | n.s. | n.s. | 13.2 | 56.6 | n.s. | n.s. |
|          | n.s. | n.s. | n.s. | 15.0 | 51.2 | n.s. | n.s. |
|          | ** | ** | ** | 14.7 | ** | ** | ** |
|          | n.s. | n.s. | n.s. | 62.8 | n.s. | n.s. | n.s. |
|          | ** | ** | ** | ** | ** | ** | ** |
|          | n.s. | n.s. | n.s. | ** | ** | n.s. | n.s. |
|          | ** | ** | ** | n.s. | n.s. | n.s. | n.s. |
|          | n.s. | n.s. | n.s. | ** | ** | n.s. | n.s. |
|          | ** | ** | ** | n.s. | n.s. | n.s. | n.s. |

C, Control; P, Priming. Priming was carried out as described in Fig. 2. Figures in parentheses indicate relative percentages to control. Symbols in the table show statistical significances in t-test. **, significant difference at 1% level; *, significant difference at 5% level; n.s., no significant differences.

In all cultivars, the primed seeds had significantly shorter germination periods than the control seeds (Table 1). The germination period of 'Monoace-S' primed seeds was approximately 4 d shorter than that of the control seeds. In the case of 'Hokkai-84', the difference in the average germination period between the primed and the control seeds was only 1.6 d. This may be due to the smallest increase of sugar content in true seeds and the lowest rise of amylase activity in all cultivars as a result of priming (Fig. 2, Fig. 3). The primed seeds had significantly shorter emergence periods than the control seeds, except for 'Hokkai-84' (Table 1). However, no significant differences were observed in the final germination percentage or in the emergence percentage (Table 1).

With regard to early growth, the plants grown from the primed seeds were superior to those grown from the control seeds in all cultivars. The relative growth percentages of primed to control seeds were from 108 to 143 in top dry weight and from 115 to 187 in taproot dry weight at the 51st day after sowing (Table 1). The differences in early growth between the primed and control seeds were statistically significant except for 'Kitasayaka' and 'Hokkai-84'. The change with time of the top dry weight of 'Monoace-S' is shown in Fig. 5 with the logarithmic scale of the Y-axis. An almost linear relation was observed in both priming and control because the early growth of sugar beet is generally exponential. The line of priming was parallel to and higher than that of the control. In other words, the priming did not accelerate the growth rate but only advanced the germination, emergence and early growth. The same tendency was observed in other cultivars (data...
Table 2. Effects of priming on yield and sugar content at harvest time.

|                | Monoace-S | Megumi | Nozomi | Kabutomaru | Kitasayaka | Hokkai-84 |
|----------------|-----------|--------|--------|------------|------------|-----------|
|                | C (P)     | C (P)  | C (P)  | C (P)      | C (P)      | C (P)     |
| Top weight (kg/m²) | 6.16 (102) | 5.53 (106) | 5.99 (101) | 5.87 (109) | 6.18 (105) | 6.00 (101) |
| Root yield (kg/m²) | 4.38 (110) | 5.33 (101) | 5.38 (104) | 5.80 (102) | 5.52 (104) | 5.26 (99) * |
| Total weight (kg/m²) | 10.54 (105) | 10.86 (103) | 11.37 (102) | 11.67 (106) | 11.69 (105) | 11.26 (100) |
| Sugar content (%) | 18.9 (101) | 18.5 (100) | 18.4 (100) | 18.4 (99) | 17.9 (100) | 18.5 (100) |
| Sugar yield (g/m²) | 828 (111) | 986 (101) | 988 (104) | 1069 (102) | 988 (104) | 973 (99) |

C, Control; P, Priming. Figures in parentheses indicate relative percentages to control. Symbols in the table show statistical significances in t-test. *, significant difference at 5% level; n.s., no significant differences.

At harvest time, the differences between priming and control became obscure, and statistically significant differences were observed only in the root weight of ‘Monoace-S’ (Table 2). The percentage relative to control, however, mostly exceeded 100 in top, root and total weight. Priming tended to make the sugar beet yield higher. On the other hand, the relative percentage of sugar content was from 99 to 101, and no differences were observed between primed and control seeds. Finally, the priming tended to bring approximately 3% more sugar yield, on average, than the control (Table 2). Concerning the quality of sugar beet root, the contents of noxious ions, such as sodium, potassium and amino nitrogen, which obstruct the crystallization of sugar during the refining process, fluctuated by priming, and no consistent tendency was observed (Table 3).

Discussion

1. Optimum water content of seeds during priming

It is very important to control the water supply to seeds in order to advance their physiological status just before the root extrusion. The priming effects may be insufficient if not enough water is supplied to the seeds. On the other hand, if water is over supplied, the seeds will germinate irreversibly and drying will be impossible. In this study, the water supplies were adjusted on the basis of seed water content, and we concluded that 24 to 25% was the best water content for priming sugar beet seeds (Fig. 1). Durrant and Mash (1990), in their priming experiments, adjusted the water content of sugar beet seeds to 124% of the weight of air-dried seeds. However, the water contents of air-dried seeds would vary with the drying conditions. If the water content fluctuated by 5 to 10%, the water content of seeds during priming would change from 23.4 to 27.4% by adjusting the weight of air-dried seeds to 124% of the original weight. Since the physiological status of seeds is considered to be determined by their water content, priming treatment should be done on the basis of water content of seeds itself.

This study revealed that the optimum water content was 24 to 25% for priming sugar beet seeds at 20°C. However, accurate water content should be preliminarily determined for each seed lot. Generally, a commercial sugar beet seed is botanically a fruit and the true seed is covered with a thick, corky pericarp. The ratios of true seed versus pericarp and the characteristics of pericarp
differ among cultivars and among seed lots, and these differences may affect the optimum water content for priming. Besides, corky pericarps are usually rubbed in commercial sugar beet seeds, and the degrees of rubbing are not always consistent. In the case of solid matrix priming (SMP), Taylor et al. (1988) pointed out that the osmotic potential of penetrated solution from seeds greatly affected the effect of SMP because the amount of applied water for SMP was very small. It is widely known that the pericarp of sugar beet contains water-soluble substances preventing germination. It was likely that these water-soluble substances remaining in the pericarp also affected the optimum water content of seeds for priming.

2. Soluble sugar content and starch hydrolyzing enzyme activity of primed seeds

The physiological changes in primed sugar beet seeds have been mainly investigated in the embryo. Redfearn and Osborne (1997) reported an increase of high molecular DNA and RNA in the embryo of primed seeds and referred it to DNA replication at the root apical meristem. Concerning the storage proteins in the embryo, Job et al. (1997) primarily reported the solubilization of the B-subunit of 11-s globulin. The relationship between the content of soluble B-subunit and the promotion of germination was then analyzed (Capron et al., 2000) and the B-subunit content of individual seed was investigated (Bourgne et al., 2000). On the other hand, it was reported that the main storage substance of the sugar beet seed was starch existing in endosperm and perisperm (Lawrence et al., 1990; Elamrani et al., 1992), but few reports focused on the metabolism of carbohydrates during priming.

In this study, increases in soluble sugar content and in amylose activity were observed in the primed seeds as compared with the control (Fig. 2, Fig. 3). These findings indicated that the metabolism was activated not only in the embryo but also in the endosperm or perisperm. Elamrani et al. (1992) pointed out that the lipids in the embryo served as the main respiratory substance of sugar beet during germination, and that starch was mainly hydrolyzed after the root extrusion in order to promote root and hypocotyl elongation. Lawrence et al. (1990) investigated the starch hydrolyzing enzyme activity during germination of sugar beet and reported the rise of α-glucosidase activity just before root extrusion. The results obtained in this study suggested the hydrolysis of starch during priming without root extrusion. Moreover, α-glucosidase activity did not increase by priming (Fig. 4) while amylase activity rose considerably. Accordingly, the limited water content of seeds during priming might result in a different metabolism in the endosperm and perisperm from that during usual germination.

In this study, the increase in soluble sugar contents and the rise of amylase activity in the seeds by priming were relatively small in 'Hokkai-84' (Fig. 2, Fig. 3). The optimum water content for priming seeds of 'Hokkai-84' may be higher than 24%, because the rubbing of the corky pericarp did not seem to be completely relative to the other cultivars and water soluble substances remained in the pericarp.

3. Germination and emergence of primed seed, and early growth, yields and root quality of the plant from primed seed

In this study, priming obviously shortened the average period of germination or of emergence, but the final germination or emergence percentage of the primed seeds was almost the same as that of the control seeds (Table 1). On the other hand, Durrant and Loads (1987) obtained 5 to 8% more stands in their seed advancement of sugar beet. However, the improvement of germination or emergence percentage by priming would not be expected for the seed lots with good germinability, like in the cultivars used in this study except for 'Monaco S'. The germination percentages of sugar beet seeds have been steadily improved by the progress of selection techniques (Prince and Durrant, 1990). The final emergence percentages in the field, however, were low on the whole in both the primed and the control seeds. This may be due to the usage of the pneumatic seeding machine which sowed the seeds deeper than the optimal depth for sugar beet. Shichijii (1968) reported that the final emergence percentage of sugar beet sown at a 6 cm depth was 25% lower than that sown at a 2 cm depth.

Durrant and Loads (1987) also mentioned the promotion in Great Britain of the early growth of sugar beet by priming. They reported that the plant dry weight at the 50th day after sowing increased from 113 to 146 mg in 1984, and from 93 to 115 mg in 1985, as a result of priming. In the present study, we measured the plant dry weight at the 51st day after sowing and also observed significant increases in top and root dry weight (Table 1). The absolute values of dry weight in this study were much larger than those in a British study, probably because the temperature in Japan increases faster after spring sowing of the sugar beet. In any case, it is obvious that priming promotes the early growth of sugar beet.

As for the improvement in the yield of sugar beet by priming, Durrant et al. (1995) calculated a 0.048 t ha⁻¹ d⁻¹ increase in yield by the promotion of emergence in Great Britain. Heyes et al. (1997) reported a 1.8% increase in yield in 1995 and a 1.7% increase in 1996 in Western European countries by using primed seeds. In the present study, the average increase in yield was about 3%, exceeding the values found in the Western European studies. We suspected that the advantage of the primed seeds was more highly evaluated in Japan than in Western Europe, since the growing period of drilled sugar beets in Japan is generally shorter and the yield level of drilled sugar beet in Japan is lower than
that in Western Europe. In other words, the promotion of germination and early growth by priming had a remarkable effect for the increase of sugar beet yield in a short growing period such as in Japan. In conclusion, the priming of seeds is expected to improve the yield of drilled sugar beet in Japan, and further detailed field experiments should be undertaken to evaluate how priming affects the yield.

References

Bourgne, S., Job, C. and Job, D. 2000. Sugarbeet seed priming: solubilization of the basic subunit of II-S globulin in individual seeds. Seed Sci. Res. 10: 153-161.

Bradford, K. J. 1986. Manipulation of seed water relations via osmotic priming to improve germination under stress conditions. Hortscience 21 (5): 1105-1112.

Capron, L., Corbineau, F., Dacher, F., Job, C., Come, D. and Job, D. 2000. Sugar beet seed priming: effects of priming conditions on germination, solubilization of II-S globulin and accumulation of LEA proteins. Seed Sci. Res. 10: 243-254.

Durrant, M.J. and Loads, A.H. 1987. Experiments to determine the optimum advancement treatment for sugar beet seed. Seed Sci. Technol. 15: 185-196.

Durrant, M.J. and Jaggard, K.W. 1988. Sugar beet seed advancement to increase establishment and decrease bolting. J. Agric. Sci. 110: 367-374.

Durrant, M.J. and Mash, S.J. 1990. Sugar-beet seed treatments and early sowing, Seed Sci. & Technol. 18: 839-850.

Durrant, M.J., Mash, S.J. and Jaggard, K.W. 1993. Effects of seed advancement and sowing date on establishment, bolting and yield of sugarbeet. J. Agric. Sci. 121: 333-341.

Elamrani, A., Raymond, P. and Saglio, P. 1992. Nature and utilization of seed reserves during germination and heterotrophic growth of young sugar beet seedlings. Seed Sci. Res. 2: 1-8.

Fletcher, B. 1984. Sugar beet growing in Japan. British Sugar Beet Review. 52(4): 8-10.

Heyes, V., Osborne, B., Halmer, P. and Bowles, D.J. 1990. Mobilisation of storage reserves during germination and early seedling growth of sugar beet. Physiologia Plantarum. 78: 421-429.

Prince, J. and Durrant, M. 1990. Progress in seed quality and seed treatments. British Sugar Beet Review. 58(4): 4-6.

Redfearn, M. and Osborne, D.J. 1997. Effects of advancement on nucleic acids in sugar beet (Beta vulgaris) seeds. Seed Sci. Res. 7: 261-267.

Rowse, H.R. 1996. Drum priming – a non-osmotic method of priming seeds. Seed Sci. & Technol. 24: 281-294.

Rush, C.M. 1991. Comparison of seed priming techniques with regard to seedling emergence and pythium damping off in sugar beet. Phytopathology. 81(8): 878-882.

Saunders, P. 1998. Enhancement of seedling growth. British Sugar Beet Review. 66(2): 38-40.

Shichiji, M. 1968. A preliminary report on sowing methods for a genetic monogerm seed in sugar beets. Bulletin Sugar Beet Res. suppl. 11: 110-112*.

Swensen, J.B. and Murray, G.A. 1991. Optimal priming conditions and persistence of enhanced emergence in osmotically primed sugar beet seed. J. Sugar Beet Res. 28: 31-40.

Taylor, A.G., Klein, D.E. and Whitlow, T.H. 1988. SMP: solid matrix priming of seeds. Scientia Horticulturae. 37: 1-11.

West, K. 1984. Sugar beet from transplants in England. British Sugar Beet Review. 52(4): 12-14.

Yoshimura, Y. 1996. Growth analysis of sugar beet cultivated by either of drilling and transplanting. Proc. Japan. Soc. Sugar Beet Technol. 28: 105-116**.

Yoshimura, Y. and Shirahata, M. 1997. Improvement of suppression and fertilization method in drilled sugar beet culture. Proc. Japan. Soc. Sugar Beet Technol. 39: 155-165**.

*In Japanese.

**In Japanese with English summary.