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Effect of Sucrose Solution Injection at Different Growth Stages on Production and ADP–glucose Pyrophosphorylase Activity of Roots in Sweet Potato, *Ipomoea batatas* Lam. Cultivars.

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Sucrose solution, as an artificial photosynthetic–source, was injected into two sweet potato cultivars, Koganesengan (KOG, an early production type) and Minamiyutaka (MYK, a late production type), to investigate the cultivaral difference in the sucrose injection effect on root growth and the activity of ADP–glucose pyrophosphorylase (AGPase) in tuberous roots. The sucrose injection applied on the 35th day after rooting was highestly effective in increasing the productivity and AGPase activity of tuberous roots in KOG. This time corresponded to the growth stage at which the ratio of dry matter distribution to stems began to drop. By this treatment, the tuberous root of KOG doubled in weight and the activity of AGPase was 25% higher compared to those of the control plant. This may suggest that the formation and production of tuberous roots in KOG are possible to be promoted by temporarily enhancing the source potential at the adequate growth stage. However, in MYK a clear changing point was not detected in the dry matter distribution ratio during the experiment period and the effect of sucrose solution injection was almost negligible.

INTRODUCTION

In root crops such as sweet potato, the synthetic activity and accumulation rate of starch in roots are important as a yield–determining factor. Obata–Sasamoto and Suzuki (1979) detected the positive relationship between tuberization and the activity of enzymes related to starch synthesis in potato plants. Nakatani and Komeichi (1992), and Sowokinos (1976) pointed out that ADP–glucose pyrophosphorylase (AGPase), catalyzing the synthetic reaction from glucose–1–phosphate to ADP–glucose, is the key enzyme in the starch synthetic process. The positive relationship between AGPase activity and dry matter weight of tuberous roots in sweet potato was also reported by Tsubone *et al.* (1997).

It has been known on various crops that the activation of enzymes related to starch synthesis in organs is regulated by sugars (Koch, 1995). Müller–Röber *et al.* (1990), Sokolov *et al.* (1998) and Harn *et al.* (2000) also reported that the expression of AGPase was induced by sugars. Tsubone *et al.* (2000) confirmed that AGPase activity and tuber-

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ous root growth were enhanced by sucrose solution injections into sweet potato plants. Also, Kadowaki *et al.* (2001a, 2001b) described that an adequate concentration of sucrose solution to increase tuberous root production was 6%, and the most effective treatment time was predicted directly before the commencement time of tuberization.

The results mentioned above may suggest that the sugar solution injection plays a role of a trigger to activate enzymes and promote starch accumulation in roots. If the yield can be effectively increased by a temporary increase of photosynthetic source activity at a particular growth stage, it may give an important viewpoint for improvement of sweet potato cultivation.

In this report, we further tried sucrose solution injections at different growth stages using two cultivars having different traits in the root growth, and observed the cultivaral difference in the effects of sugar solution injection on the production and AGPase activity in roots.

MATERIALS AND METHODS

Of the two sweet potato cultivars used here, Koganesengan (KOG) is characterized by an early productivity of tuberous roots, and Minamiyutaka (MYK) has a late productivity. Both cultivars were grown during the summer in 2001 in a green house set up in the experimental farm of Kyushu University (33° 35' N, 130° 23' E).

The cultivation and treatment methods used here were similar to those mentioned in a previous paper (Kadowaki *et al.*, 2001b). Sucrose solution of 6% was injected into pot–grown plants having two leaves for three days from the 14th day (the 14th treatment), 21st day (the 21st treatment) and 35th day (the 35th treatment) after rooting of transplanted shoots (Fig. 1). Control plants were not injected. Plants were sampled on the treatment day and on the 49th day after rooting. The root having more than five *mm* in diameter was classified as tuberous root, and that of 2–5 *mm* diameter as thick root. The leaf photosynthetic rate was measured at 7–day intervals with a portable photosynthesis system (SPB–H3, Analytical Development Co. Ltd., Herts, UK). AGPase activity

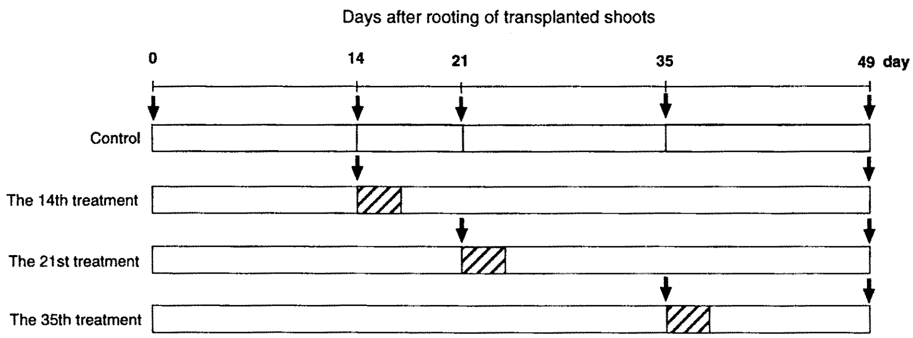

Fig. 1. The design of injection time of 6% sucrose solution.
▨, 6%sucrose solution injection for 3 days; ↓, Sampling day.

and the weight of carbon fed from sucrose solution were determined according to the method described in the previous paper (Kadowaki *et al.*, 2001a).

RESULTS AND DISCUSSION

Fig. 2 shows the dry matter weight of tuberous roots and thick+tuberous roots sampled on the 49th day after rooting. A large cultivaral difference was found in the effects of sucrose solution injection on the dry matter production of tuberous roots; the tuberous root weight significantly increased in KOG but not or little in MYK during 49 days. The 35th treatment was the most effective in KOG, showing that the tuberous root weight of the treated plants increased more than two times than that of the control plants. It is an interesting fact that such a large increase occurred during a limited period of 14 days

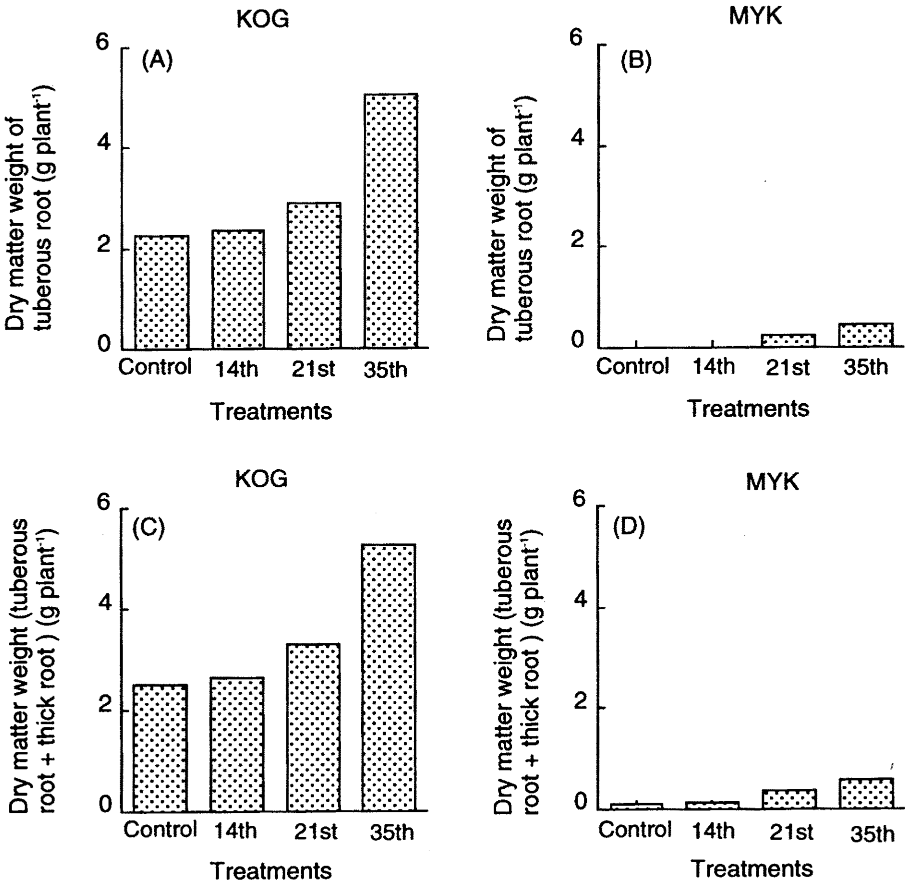

Fig. 2. The effects of sucrose solution injection on dry matter weight of tuberous root or tuberous root+thick root in KOG and MYK. The dry matter weights were mesured on the 49th day after rooting. See Fig. 1. for 14th, 21st and 35th.

from the 35th to 49th day. Although the tuberous roots was not found in the 14th treatment in MYK as shown in Fig. 2–B, the weight of thick+tuberous roots was increased in the 21st and 35th treatments (Fig. 2–D). It may be thought that the formation of thick roots and the transformation from thick roots to tuberous roots were promoted in MYK by sucrose solution injections. There was a large difference in the effect of sugar solution injections between the early (KOG) and late (MYK) cultivar.

In the previous paper (Kadowaki *et al.*, 2001b), the sucrose solution injection on the 14th day after rooting was the most effective in increasing tuberous root production in KOG. There was a three–week difference between the previous and the present results concerning the best injection time. This fact may predict that the effect of injections on tuberous root production is not governed simply by the days after rooting. The growth stage of tuberous root formation beginning is regarded as a most effective timing of sucrose solution injection to plants. The dry matter distribution ratio in a plant is considered to be one of the indicators showing an adequate injection time.

Fig. 3 shows changes in the ratio of dry matter distribution to stems and tuberous roots in KOG grown in 2000 and 2001. When the injection treatment was made at such a growth stage that the ratio of dry matter distribution to stems began to drop, the effect on tuberous root production more increased in both years. As mentioned in the reports of Hojo *et al.* (1971) and Nakatani *et al.* (1988a), the stem of sweet potato is the major storage organ of photosynthetic substances until tuberous roots begin to develop. The decrease in the ratio of dry matter distribution to stems means that the major sink organ for photosynthate has begun to change from stem to tuberous root at this time. It may be understood that the sink function of tuberous roots is enhanced by the injection of

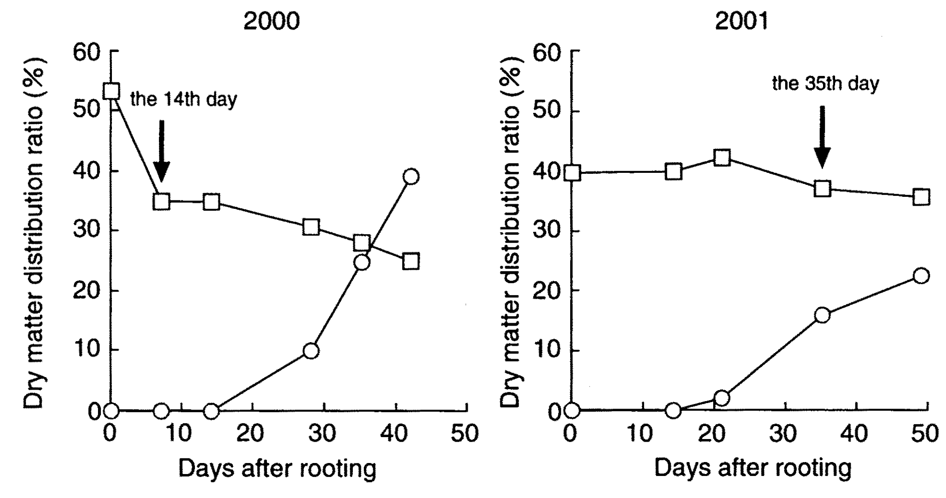

Fig. 3. Changes in dry matter distribution ratio to stems and tuberous roots in the control plant of KOG. -□-, Stems; -○-, Tuberous roots. Dry matter diatribution ratio (%)=(dry matter weight of each organ / dry matter weight of a plant)×100

sucrose solution, and this promotes the translocation of photosynthate to tuberous roots as described in the previous paper (Kadowaki *et al.*, 2001b).

The effects of sucrose solution injection on the activity of AGPase in tuberous roots were surveyed using plants sampled on the 49th day after rooting (Table 1). The highest AGPase activity is detected in the 35th day treatment, in which the tuberous root production also shows the largest as mentioned in Fig. 2–A. The evidence that the production increase is connected with a high activity of AGPase is similarly shown in the experiments conducted in 2001 as well as in 2000 (Kadowaki *et al.*, 2001b). From Table 1, it is confirmed that AGPase activity is possible to be enhanced by only a little amount of sucrose, or carbon, injection to a plant, which results in a great increase of tuberous root production.

The distributions of dry matter accumulated for 49 days in stems and tuberous roots of KOG were measured (Fig. 4). The fixed carbon was evenly distributed to both organs in the control plant. On the other hand, by injecting sucrose solution the distribution of carbon was increased in tuberous roots. Particularly it was greatly increased by the 35th treatment; the distribution ratio to roots became about 3–fold that to stems. It may be understood that the injection of sucrose solution at this time effectively increases the activity of sink organ, by which the inter–organ distribution ratio in dry matter is changed and the root production is significantly increased. However, the ratio of dry matter distribution to stems in MYK does not drop, remaining at a high level for 49 days (Fig. 5–A), and the sucrose solution injections are not significantly effective in increasing the root production, although a slight positive effect is recognized in the formation of tuberous or thick roots by applying the 21st or 35th treatment (Fig. 5–B).

The cultivaral difference in the effect of sucrose solution injections is considered to depend on the genetic characteristics in root formation and production system in both cultivars. But it is impossible to experimentally understand here what is the physio–genetic cause of making difference in the injection effect between the two cultivars. However, it may be predicted that one of the mechanisms switching from fibrous to tuberous root formation is based on sugar concentration levels in roots. This prediction has been possible from some reports published. For example, Davies (1984) described that the

Table 1. The effects of sucrose solution injection treatments on AGPase activity in the tuberous roots.

Treatments	AGPase activity (unit gFW^{-1})
Control	0.467(100)
The 14th treatment	0.482(103)
The 21st treatment	0.560(120)
The 35th treatment	0.588(126)

Tuberous roots sampled on the 49th day after rooting. See Fig. 1. for the treatments. The figures in parentheses are values relative to the control.

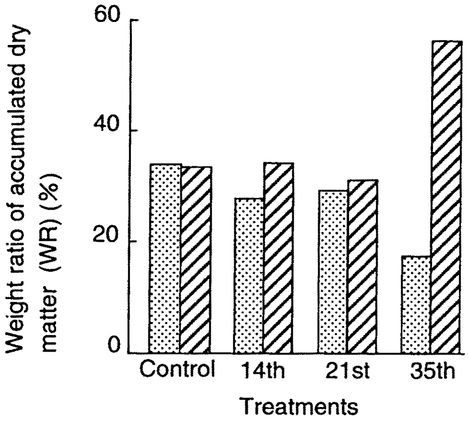

Fig. 4. The effects of sucrose solution injection treatments on the weight ratio of accumulated dry matter (WR) in stems and tuberous roots of KOG. ▧, Stems; ▨, Tuberous roots. WR (%)=dry matter weight of stems or tuberous roots increased for 49 days/dry matter weight of total plant increased for 49 days. See Fig. 1. for 14th, 21st and 35th.

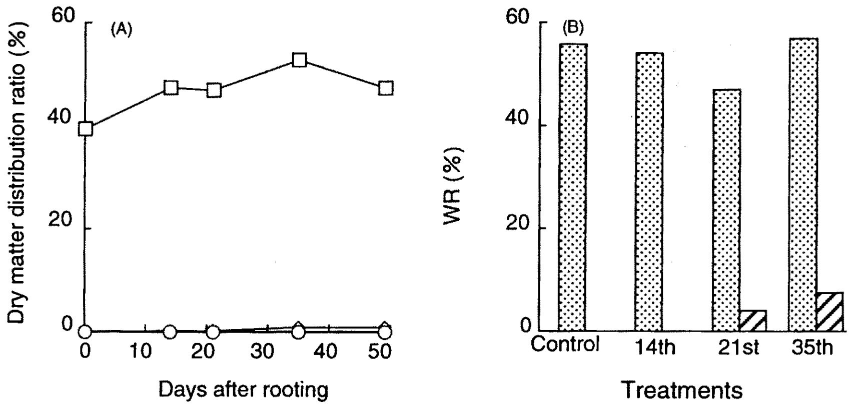

Fig. 5. Changes in dry matter distribution ratio of stems, thick roots and tuberous roots in the control plant (A), and the effects of sucrose solution injection treatments on WR in stems and tuberous roots of MYK on the 49th day after rooting (B). -□-, Stems; -◇-, Thick roots; -○-, Tuberous roots; ▧, Stems; ▨, Tuberous roots. See Fig. 3. for dry matter distribution ratio. See Fig. 4. for WR. See Fig. 1. for 14th, 21st and 35th.

tuber root growth was related to the ratio of glucose: fructose or glucose + fructose: sucrose, and Viora *et al.* (2001) mentioned that the phloem unloading in stolons switched from apoplastic to symplastic routes at the early stage of root tuberization and the sucrolytic pathway also changed.

As described, the injection of a small amount of sucrose solution makes it possible to enhance the sink activity and vary the inter-organic matter distribution ratio in a plant, by which the production of tuberous roots is significantly increased in the early cultivar, KOG. This finding may indicate one of the key points for improving the productivity of sweet potato cultivars and other starch producing crops.

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