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Effect of Calcium Application on the Growth of Sweet Potato (*Ipomoea batatas* Lam.) plant

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Abstract: The effect of calcium application on the growth of sweet potatoes plant (*Ipomoea batatas* Lam. var. Beniotome and Benisatsuma) grown on river-sand with three Ca levels; (low, medium and high treatments) were studied. The tops (leaves and stems), roots and tuberous root weights of both varieties decreased with the increase of the Ca level. The long and narrow tuberous roots were developed in Beniotome as a result of the calcium addition, while the tuberous roots were narrow in Benisatsuma. The content of calcium, total sugar and crude starch in all of the plant parts increased with the increase of the Ca level, but the potassium content of those decreased. In every treatment, the calcium content and amount of the tuberous roots were higher in Beniotome than in Benisatsuma. These results indicate that calcium affects the quality of a sweet potato and that there is a difference in a response for calcium in a tuberous root between both varieties.

Key words: Calcium, starch, sugar, sweet potato, tuberous root

Introduction

Sweet potato ranks eighth by weight in agricultural products in Japan. The southern Kyushu area (including Kagoshima and Miyazaki prefectures) accounts for 36% of all planted area and 39% of production in Japan, which Kagoshima is Japan's leading producer, with 339,000 tons in 1999 (Anonymous, 2000a). A sweet potato cultured in southern Kyushu under severely environmental conditions, such as typhoon and drought, has mainly been utilized as a material of starch and shochu. However, recently the culture area of a sweet potato as a perishable food of which quality is important has continued to increase. In addition to variety, nutrients may affect to produce a better quality of tuberous root of sweet potato. A lot of experimental results indicate that major nutrients have an effect on the growth of a sweet potato. For example, potassium has a strong influence on tuberous root growth. Under low potassium conditions, a long slender tuberous root was formed (Schermerhon, 1923) and a high application of potassium (124.4 and 186.7 kg ha^{-1}) significantly increased the starch content of the tuberous root (Sharfuddin and Voican, 1984). High levels of soil nitrogen stimulated vine growth at the expense of the tuberous roots (Stino and Lashin, 1953; Schermerhorn, 1924). Nitrogen can also affect the quality of sweet potatoes, for example, the sucrose, protein, amino acid, carotenoid and starch contents of a tuberous root (Yeh *et al.*, 1981), while the application of high levels of phosphorus increases the length of the tuberous root and starch content (Zhao *et al.,* 1995).

Although there are many reports on the effect of the aforementioned minerals on the growth and performance of a sweet potato, there are a few reports on the effect of calcium for its growth. Recently, the inner necrosis often observed only in Beniotome, being cultured in Kagoshima prefecture where Kuroboku soil is widely distributed, may be physiologically injured due to calcium deficiency, but this has not been observed in Benisatsuma, being of the same phyletic variety. This suggests that there may be a difference in the response to the Ca level between both varieties. This study, was designed to clarify the effect of calcium on the growth of sweet potato plant and the difference between both varieties for calcium requirement.

Materials and Methods

Plant culture: The effect of calcium application on the growth of sweet potato plant was studied during the cropping season (June to October 2000), in the experimental field of the Faculty of Agriculture, Kagoshima University, Kagoshima City, Japan. Two sweet potato (*Ipomoea batatas* Lam.) varieties (Beniotome and Benisatsuma) were used in this study. A vine 25 cm in length with 7 stem nodes were transplanted to a tray (60 x 50 x 10 cm) filled with about 10 kg of river-sand containing about 17 mg kg^{-1} of exchangeable Ca and 2 mg kg^{-1} of soluble calcium in water. The trays were place on a downward sloping condition with a 15° tendency and covered with sliver sheets as mulching. The plants were supplied with 500 ml of a nutrient solution containing the following elements weekly; 57.5 g L^{-1} NH_4NO_3, 60.6 g L^{-1} KNO_3, 120.0 g L^{-1} $MgSO_4$, 38.3 g L^{-1} KH_2PO_4, 24.0 g L^{-1} Fe-EDTA, 2.86 g L^{-1} H_3BO_3, 0.22 g L^{-1} $ZnSO_4 \cdot 7H_2O$, 0.079 g L^{-1} $CuSO_4 \cdot 5H_2O$, 0.40 g L^{-1} $MnCl_2 \cdot 4H_2O$ and 0.037 g L^{-1} $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ with 3 Ca levels as follows, 0 mg L^{-1} (L treatment), 4 mg L^{-1} (M treatment) and 28 mg L^{-1} Ca (H treatment) as $CaCl_2$. Ten trays were prepared for each treatment.

Experimental procedure and chemical analysis: Five plants which were harvested at 90 and 120 days after transplanting, respectively and then were separated into top (stems and leaves), non-tuberous roots below 1 cm diameter (roots) and tuberous roots over 1 cm diameter. The fresh weight, length (1 cm in diameter at the base and 1 cm in diameter at the tip) and width (maximum width) of tuberous roots were measured. Dry weight of each organ were determined after oven drying executed for 48 h at 80°C. After the powder of each organ and wet decomposition ($HClO_4$ - NO_3), the calcium and potassium were determined by the atomic absorption method, while, being extracted from each organ (Inanaga and Nagatomo, 1993), the total sugar and crude starch was determined as glucose by the Anthrone Method (Trevelyan and Harrison, 1952).

Statistical analysis: Experiment was arranged using completely randomized design and collected data were analyzed using ANOVA. Duncan's Multiple Range test was employed to determine the differences among treatments.

Results

The dry or fresh weight of all the plant organs at 90 and 120 days after transplanting are shown in Fig. 1. In every treatment, the dry weight of the top and roots in both varieties decreased from 90 to 120 days, while the fresh weight of the tuberous roots increased. The weight of all the plant organs in both varieties tends to decrease with the increase of the Ca level, remarkably in the top and tuberous root.

Comparing the performance of the varieties, the weights of all the plant organs in Benisatsuma was higher than those in Beniotome.

Table 1 shows the effect of different Ca levels on the length and width of the tuberous roots. In each treatment, the length of the tuberous root was longer in Beniotome than in Benisatsuma. The length of the tuberous root in Beniotome increased significantly with the increase of the Ca level at 90 and 120 days but decreased in Benisatsuma. The width of the tuberous roots in both varieties decreased significantly with the increase of the Ca level.

The calcium content of all the plant parts increased significantly in both varieties with the increase of the Ca level at 90 and 120 days (Fig. 2). In each treatment, both varieties show the same value in the calcium content of the top and root. However, the calcium content of the tuberous root in Beniotome increased more than those in Benisatsuma. The calcium content of the root and tuberous root in both varieties decreased from 90 to 120 days, but that of the top increased.

The calcium amount of all the plant parts with different Ca levels is shown in Fig. 3. The effects of the Ca level on the calcium amount of the top and roots were not significant in Beniotome at 90 and 120 days. However, the calcium amounts of the top and the roots in Benisatsuma increased significantly with the increase of the calcium application. The effects of the treatments were more pronounced on Benisatsuma than on Beniotome. On the other hand, the calcium amount of the tuberous root in Beniotome increased significantly with the increase of the

Table 1: Effect of different Ca levels on the length and width of tuberous root of two sweet potato varieties at 90 and 120 days

Variety	Treatment	Day	Length/tuberous root (cm)	Width/ tuberous root (cm)
Beniotome	L	90	8.1±0.2	2.04±0.05
		120	9.1±0.4	2.11±0.06
	M	90	8.5±0.2	1.77±0.04
		120	9.6±0.5	1.90±0.03
	H	90	9.5±0.4	1.67±0.04
		120	10.8±0.2	1.85±0.06
Benisatsuma	L	90	7.5±0.5	2.66±0.05
		120	8.4±0.2	2.87±0.05
	M	90	6.1±0.2	2.35±0.04
		120	6.9±0.3	2.56±0.08
	H	90	6.2±0.3	2.17±0.10
		120	7.2±0.3	2.26±0.11

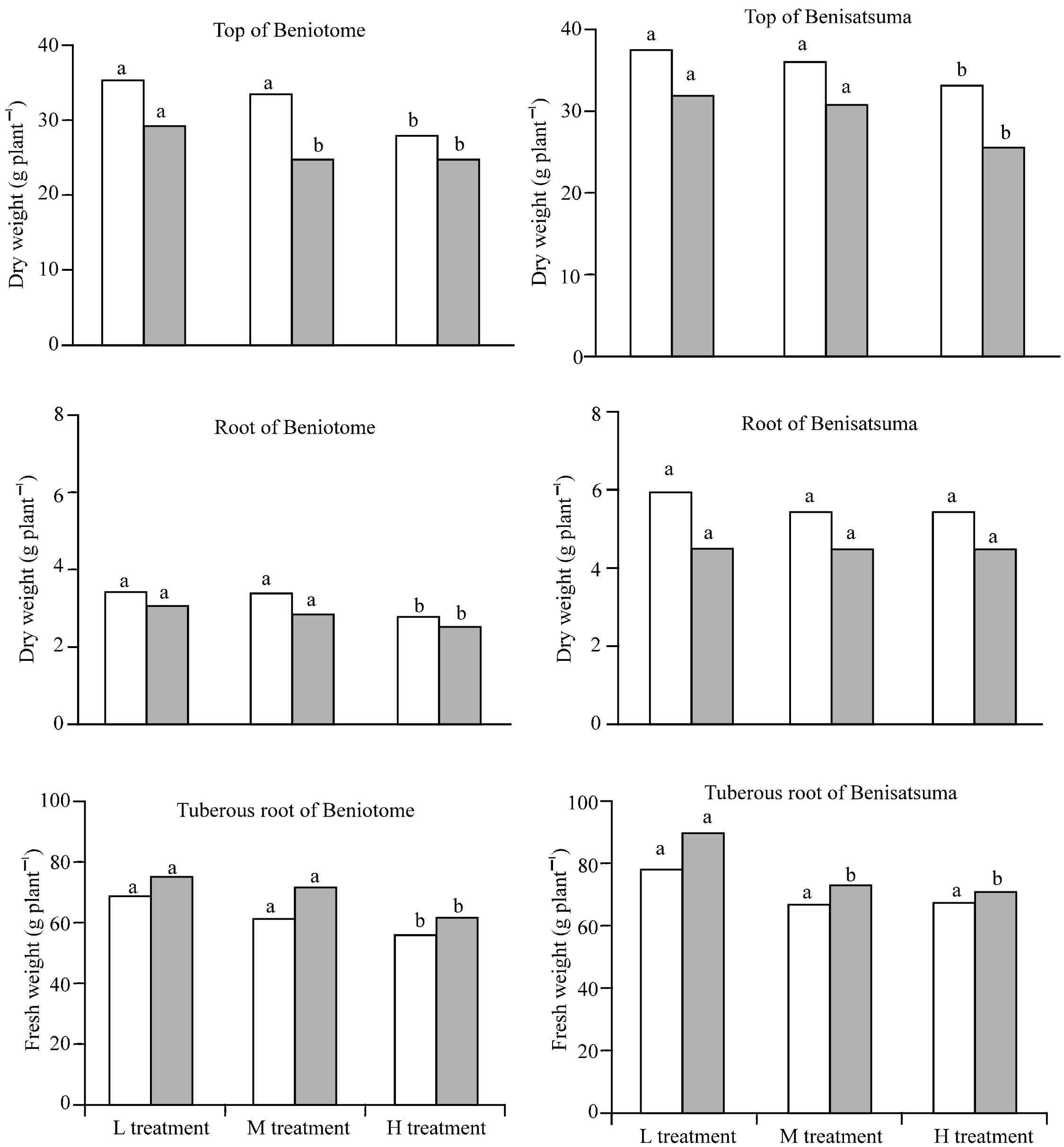

Fig. 1: Effect of different Ca levels on the weights of all the plant organs of sweet potato plants.□: 90 days; ■:120 days. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. Means with the same superscript were not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time

Ca level at 90 and 120 days, while, in Benisatsuma the lower calcium amount increased with the increase of the Ca level.

The potassium content of all the plant organs at 90 and 120 days tended to decrease with the increase of the Ca level, but there were not any significant differences among the treatments (Fig. 4). The potassium amounts of all the plant parts in both varieties decreased with the increase of the Ca level at 120 days and those were lower in Beniotome than in Benisatsuma at 90 and 120 days (Fig. 5).

In both varieties, the total sugar contents of all the plant parts increased significantly from 90 to 120 days with the increase of the Ca level (Fig. 6). The total sugar content of the top in every treatment was lower in Benisatsuma at 90 and 120 days than in Beniotome. However, the roots in both varieties showed the same value in each treatment. Under H treatment, the total sugar content of the tuberous

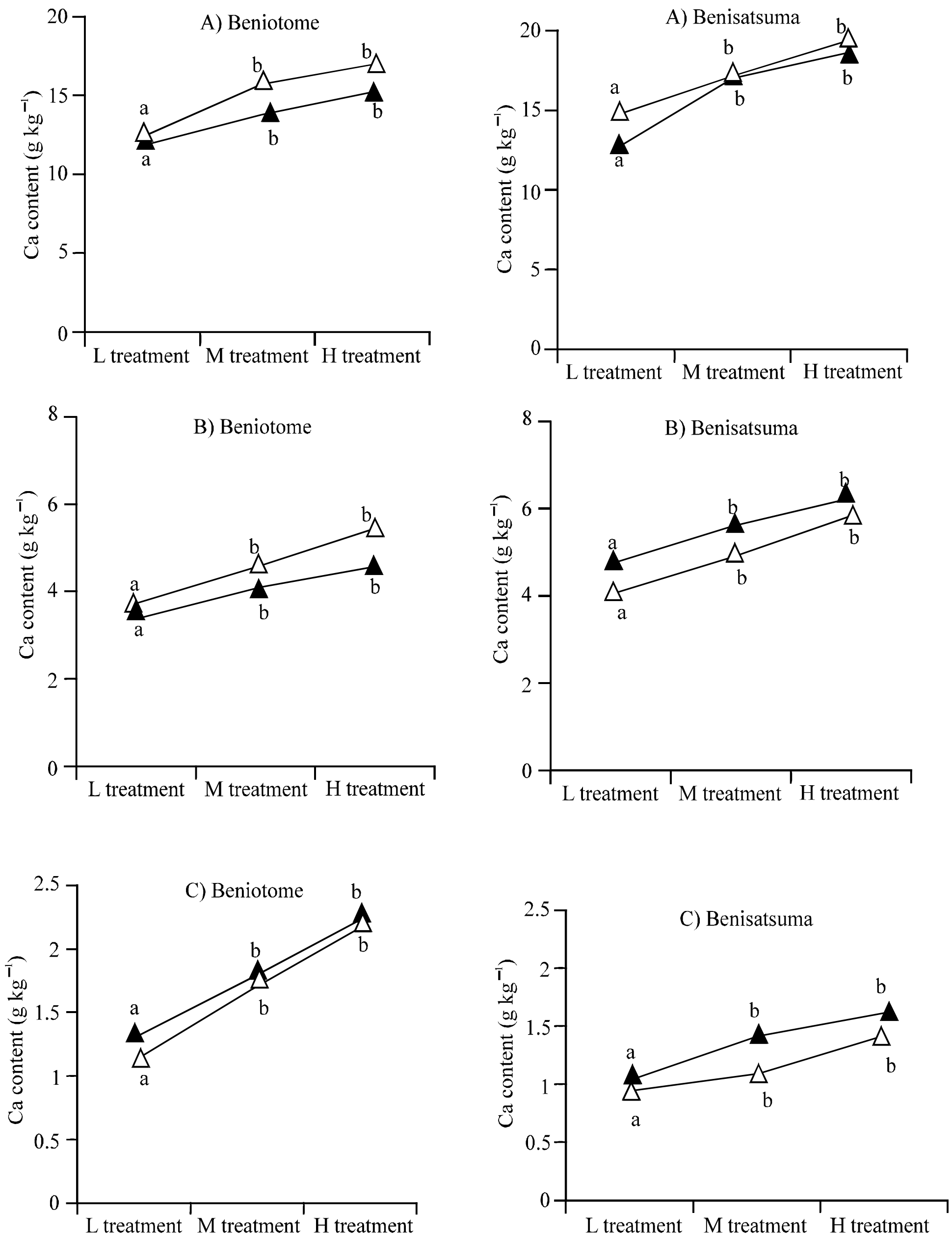

Fig. 2: Changes in the calcium contents in all of the plant organs of two sweet potato varieties grown under different Ca levels. (A) Top. (B) Root. (C) Tuberous root. ▲: 90 days; Δ: 120 days. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. The values with the same letter(s) are not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time.

root was higher in Benisatsuma than in Beniotome.

Fig. 7 shows the total sugar amounts of all the plant parts with different Ca levels. The total sugar amounts of the top in both varieties increased significantly with the increase of the Ca level at 120 days after transplanting. In each treatment, these were higher in Beniotome than in Benisatsuma. However, the total sugar amounts of the roots and tuberous root in every treatment were lower in Beniotome than in Benisatsuma.

As shown in Fig. 8, the crude starch contents in all the

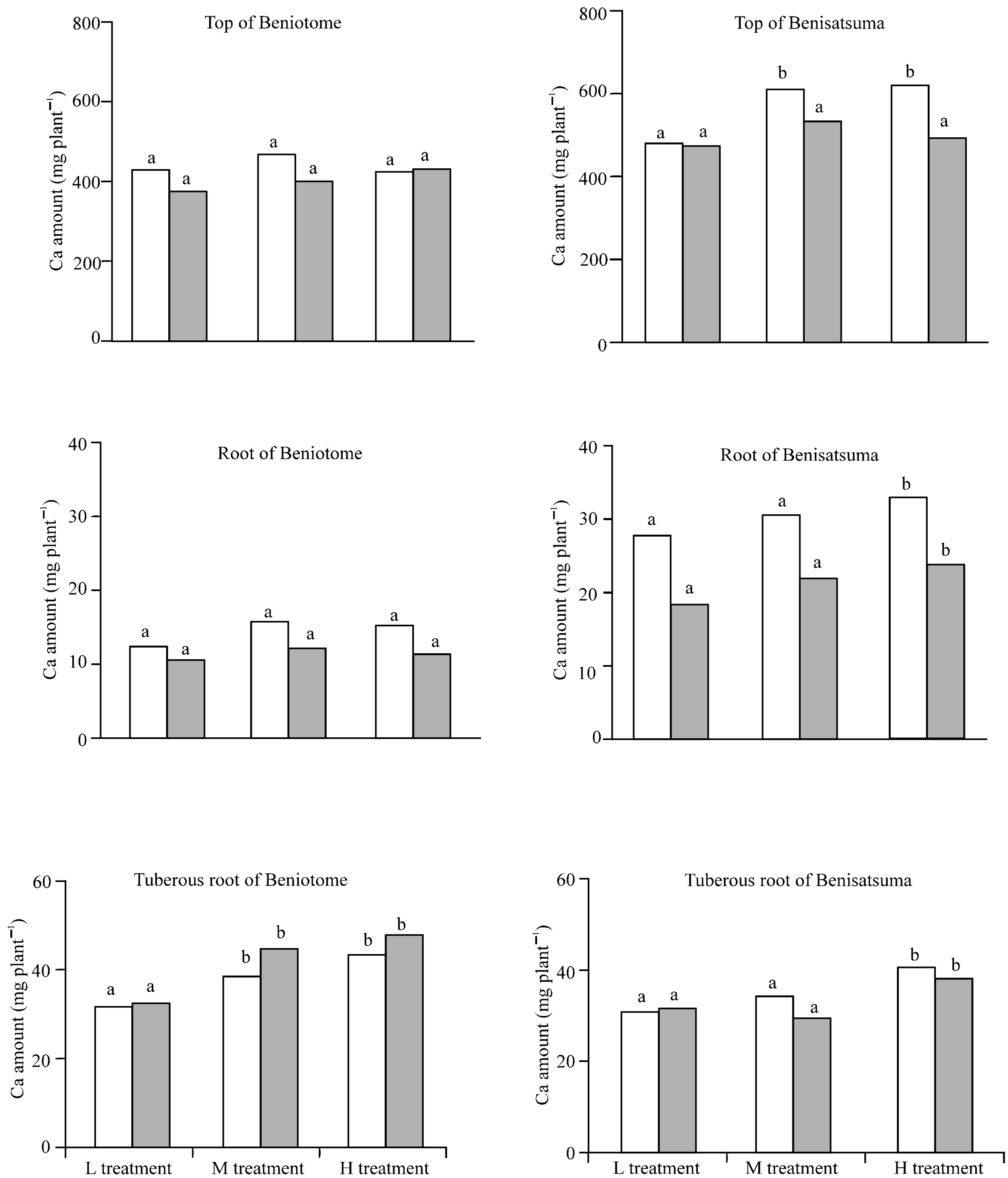

Fig. 3: Effect of different Ca levels on the calcium amounts in all of the plant organs of sweet potato plants. □: 90 days, ■ :120 days. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. Means with the same superscript were not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time.

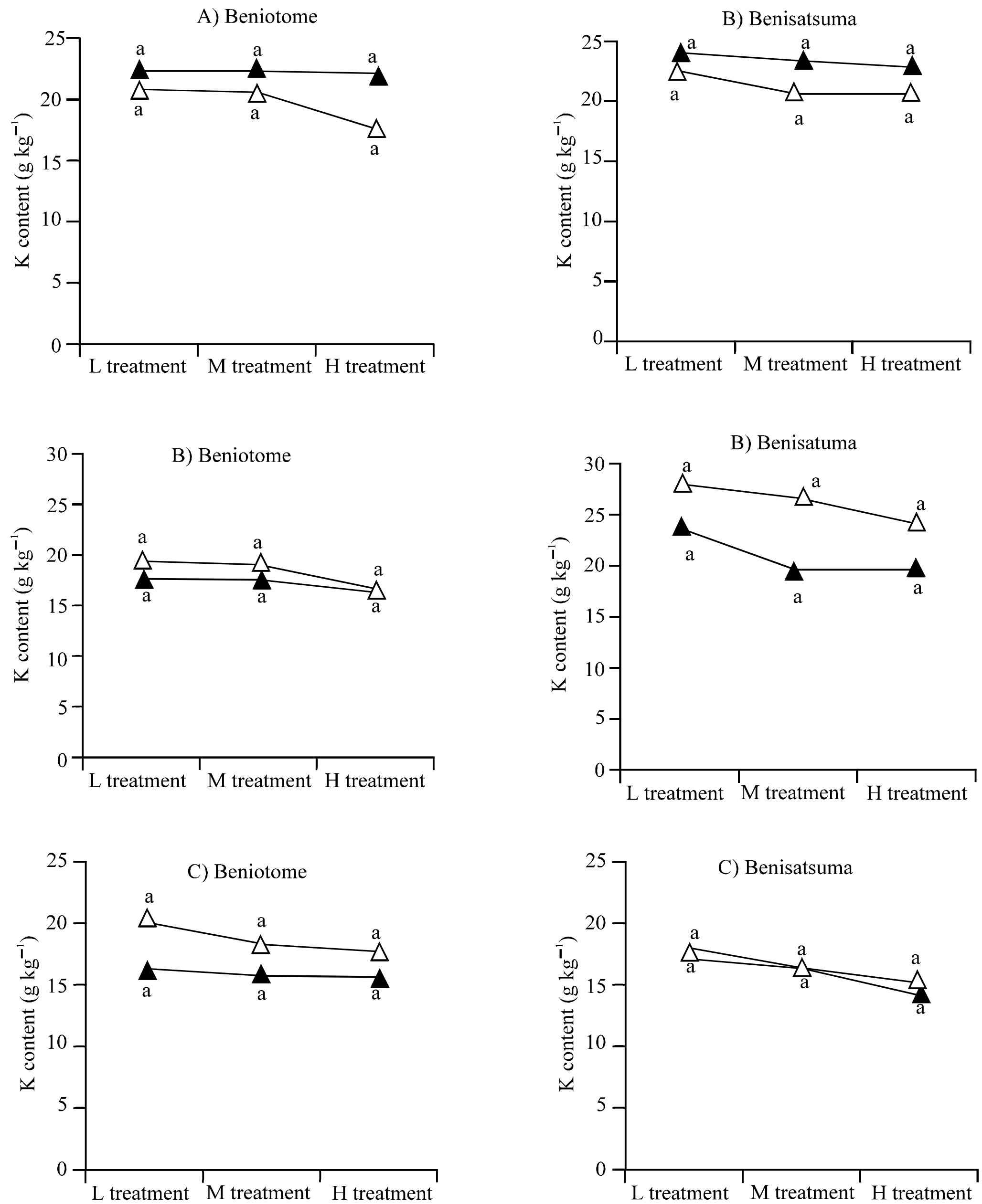

Fig. 4: Changes in the potassium contents in all of the plant organs of two sweet potato varieties grown under different Ca levels. (A) Top. (B) Root. (C) Tuberous root. ▲: 90 days; Δ: 120 days. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. The values with the same letter(s) are not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time

plant parts at 90 and 120 days increased significantly with the increase of the Ca level. The crude starch contents of the top and root in Benisatsuma showed the same value with those in Beniotome corresponding to the same treatment. However, the tuberous root in each treatment was higher in Benisatsuma than in Beniotome.

The crude starch amount of the tuberous root in both varieties increased from 90 to 120 days, while that of the root decreased (Fig. 9). In both 90 and 120 days, the crude starch amounts of all the plant parts in every treatment were higher in Benisatsuma than in Beniotome. In both varieties, those of the top and tuberous root at 120 days

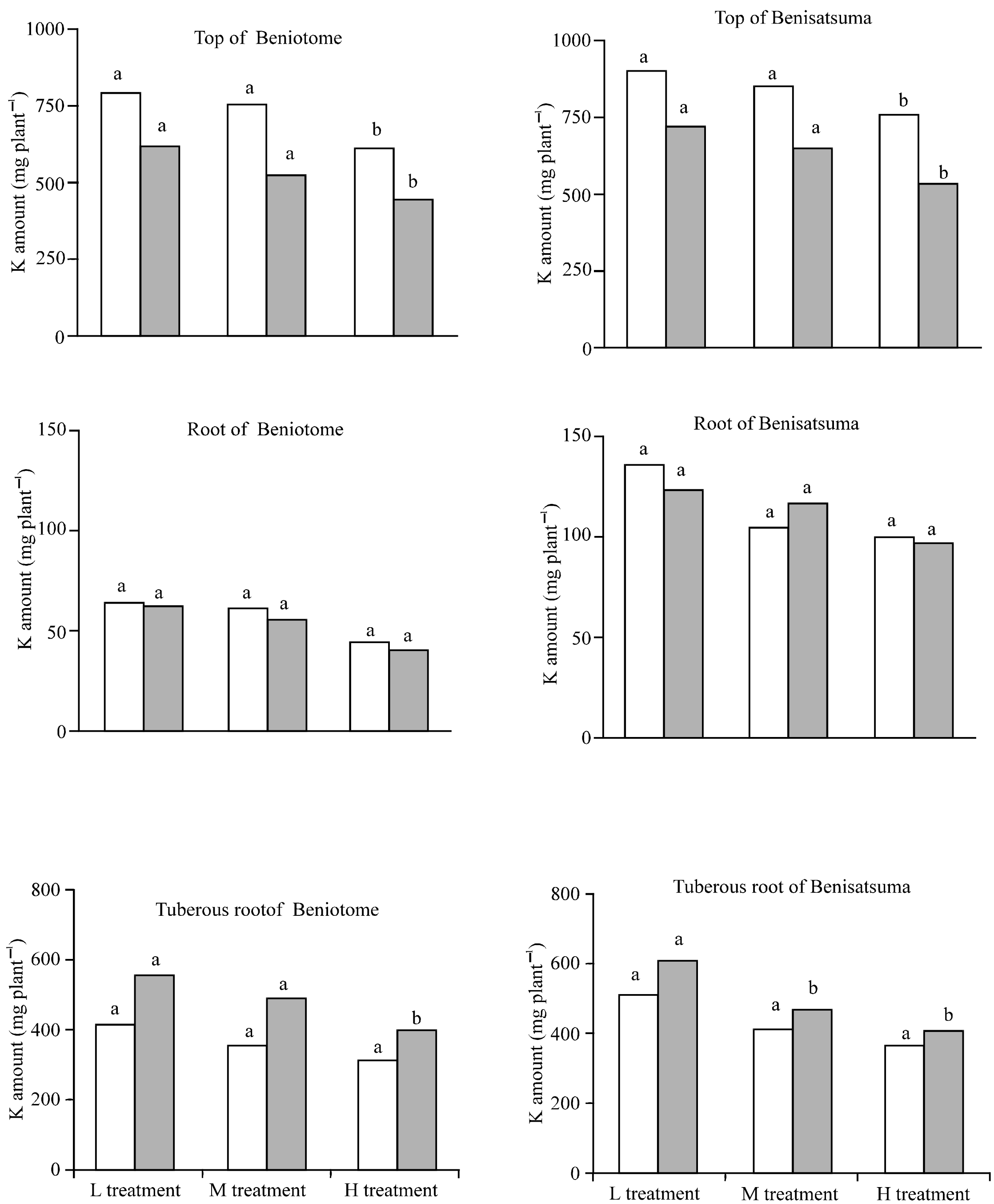

Fig. 5: Effect of different Ca levels on the potassium amounts in all of the plant organs of sweet potato plants.□: 90 days; ■ :120 days. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. Means with the same superscript were not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time.

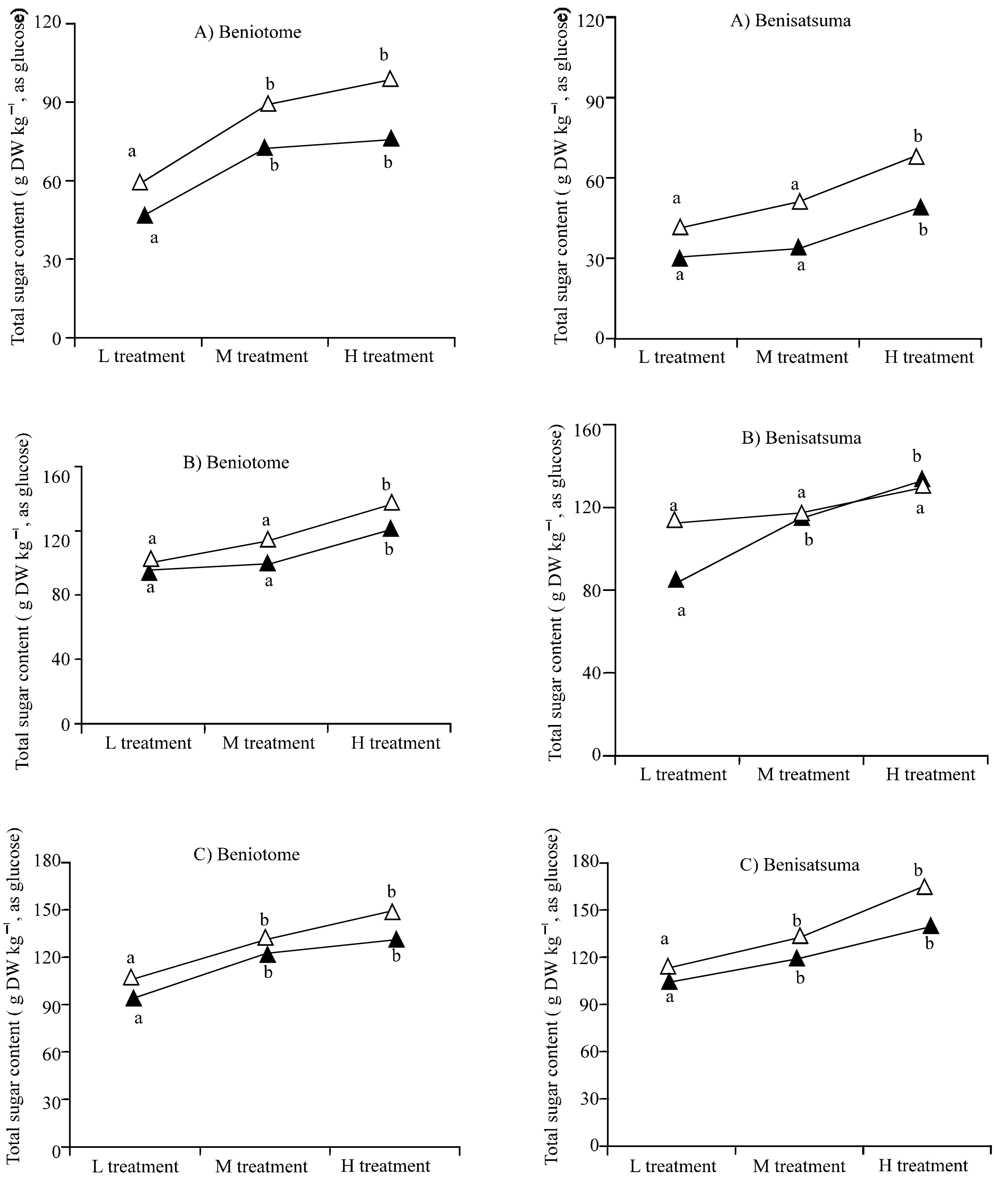

Fig. 6: Changes in the total sugar contents in all of the plant organs of two sweet potato varieties grown under different Ca levels. (A) Top. (B) Root. (C) Tuberous root. ▲:90 days; Δ: 120 days. DW shows the dry weight. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. The values with the same letter(s) are not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time

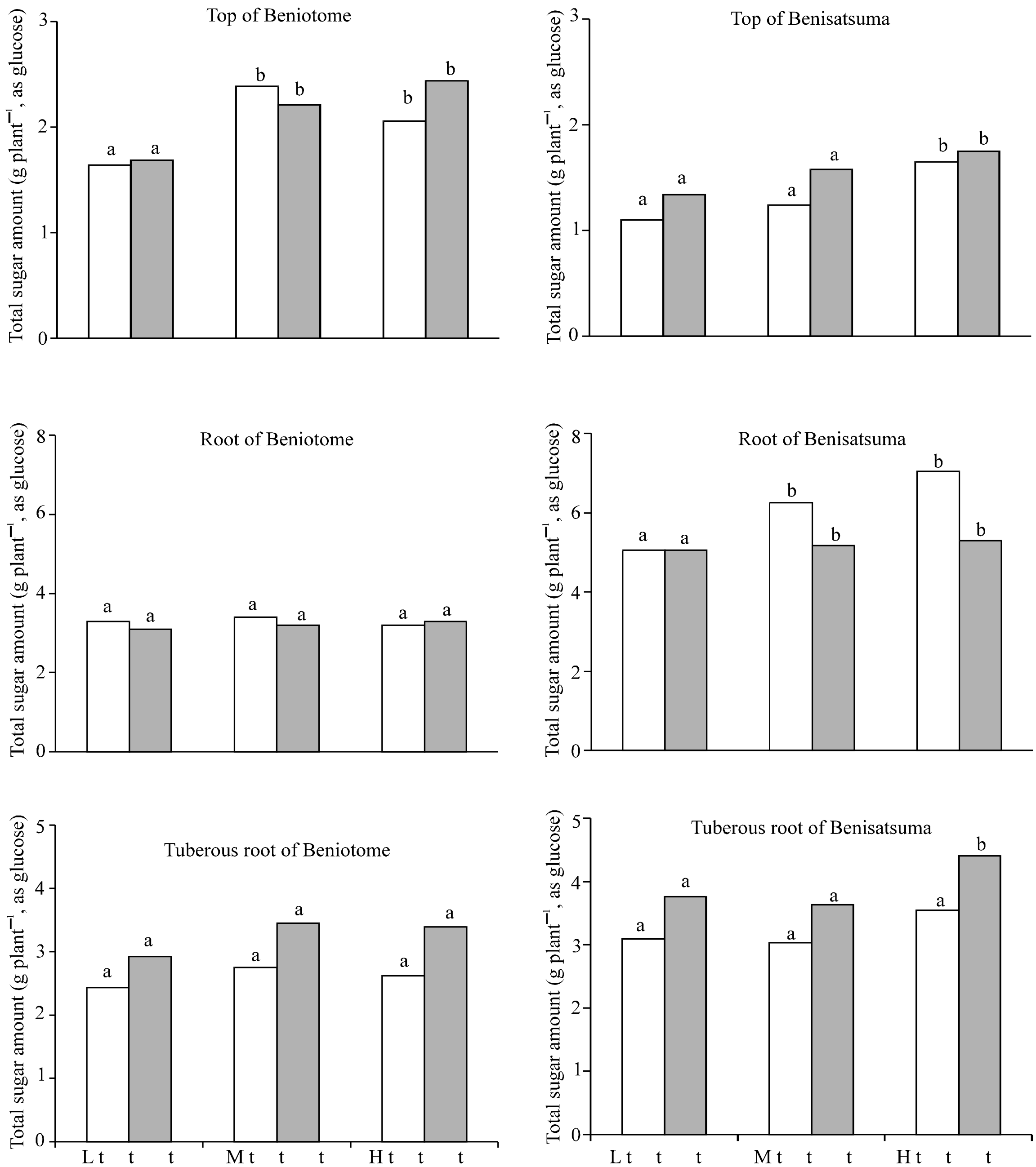

Fig. 7: Effect of different Ca levels on the total sugar amounts in all of the plant organs of sweet potato plants.□: 90 days; ■ :120 days. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. Means with the same superscript were not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time.

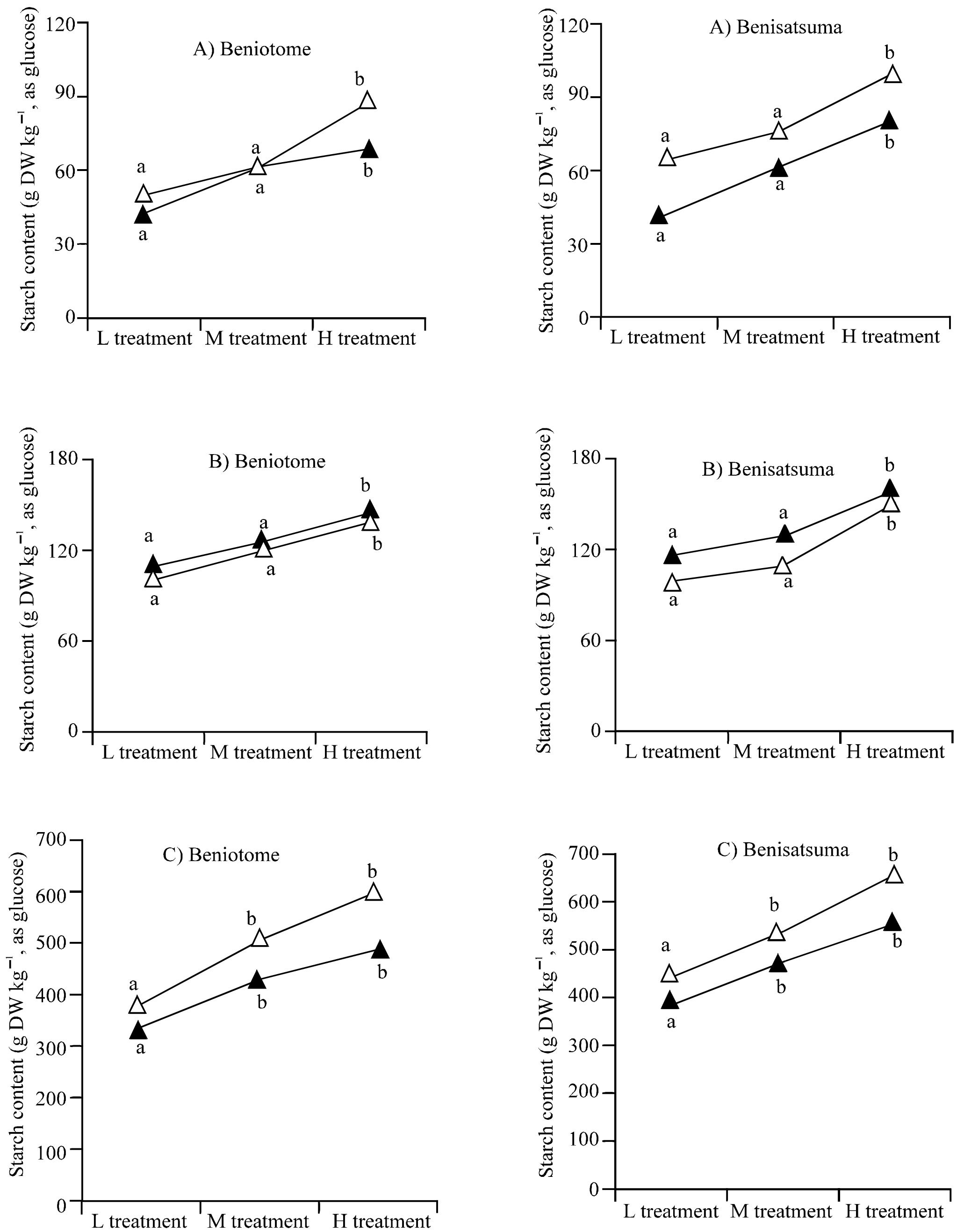

Fig. 8: Changes in the starch contents in all of the plant organs of two sweet potato varieties grown under different Ca levels. (A) Top. (B) Root. (C) Tuberous root. ▲: 90 days; Δ: 120 days. DW shows the dry weight. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. The values with the same letter(s) are not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time.

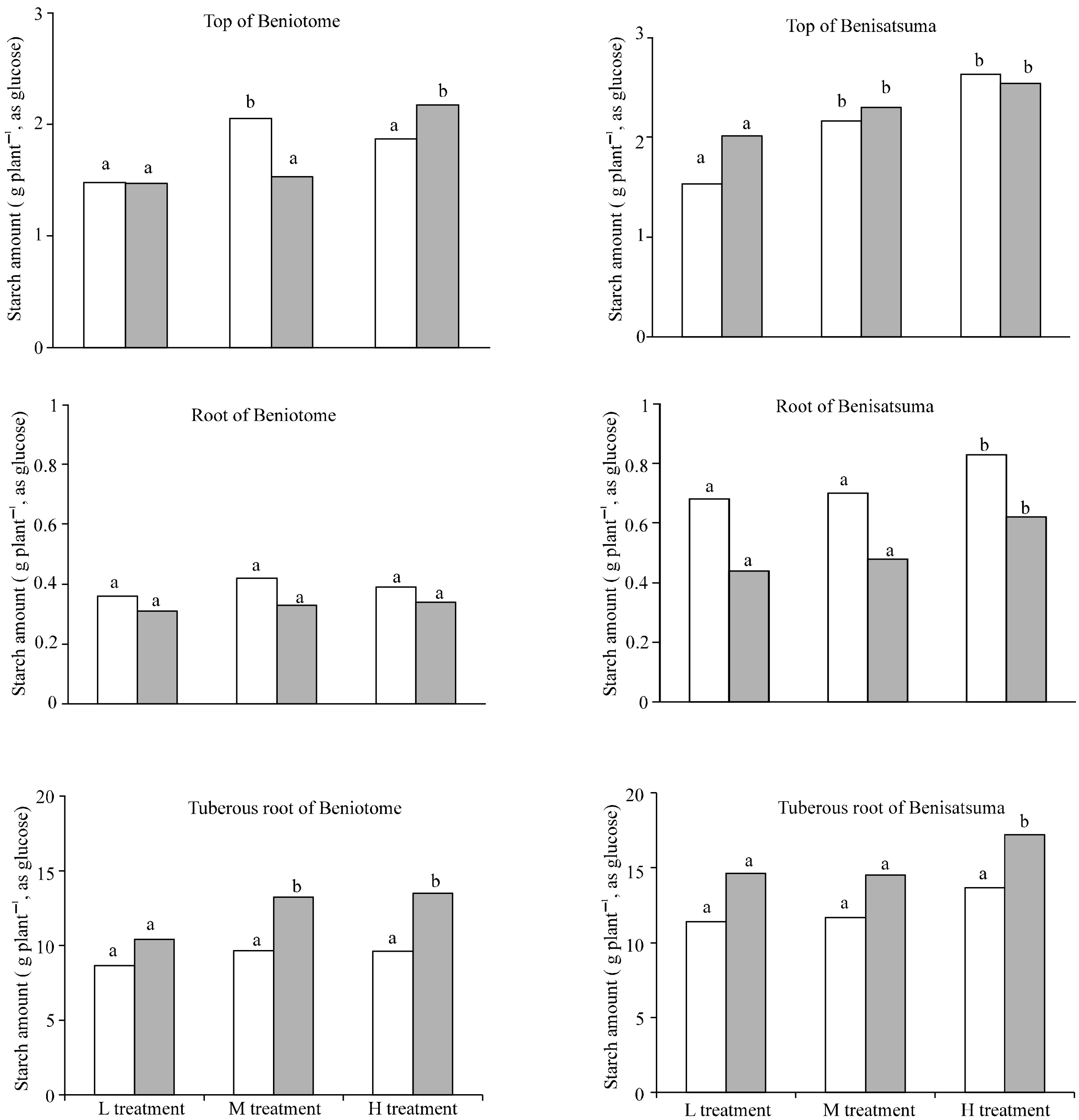

Fig. 9: Effect of different Ca levels on the starch amounts in all of the plant organs of sweet potato plants. □: 90 days; ■ :120 days. L shows the treatment without supplying Ca, M shows the treatment with supplying 4 mg L^{-1} Ca and H shows the treatment with supplying 28 mg L^{-1} Ca. Means with the same superscript were not significantly different ($p < 0.05$), according to Duncan's multiple range test at each harvesting time.

after transplanting were higher in H treatment than in L and M treatments.

Discussion

In this study, the inner necrosis, this may be physiologically injured due to calcium deficiency was not observed in Beniotome under the low calcium condition treatment. As shown in Fig. 1, the weights of all the plant organs decreased with the increase of the calcium application. There are many reports that physiological injury by calcium deficiency occur in many fruits (Hardenburg and Anderson, 1981; Bramlage *et al.*, 1985;

Marmo *et al.*, 1985), seeds (Inanaga *et al.*, 1988) and roots (Burstrom, 1968; Schiefelbein and Somerville, 1990) but there are a few reports on the inhibition of growth in the crops from an excessive calcium application. As described previously, in a sweet potato, potassium is necessary for the growth of the tuberous roots and promotes the translocation of photoassimilate to the tuberous root in sweet potatoes, which is beneficial for expanding the tuberous root (Tsuno and Fujise, 1965; Wang *et al.*, 1995). As shown in Fig. 5, potassium absorption was depressed by a greater calcium application. However, the total sugar and crude starch amounts increased with the increase of the Ca level (Fig. 7 and 9) and a weaker difference was observed in the potassium content between both varieties and among the treatments (Fig. 4). These results indicate a weak effect of potassium on the growth of all the plant organs. In peanut plant, level of lipid in the seed was lower by a few calcium in fruiting zone (Inanaga *et al.*, 1979). As shown in Table 1, the length of the tuberous root was longer in Beniotome with the increase of the calcium application at both 90 and 120 days, while the width was narrower. Furthermore, the increasing ratio of the length from 90 to 120 days was more than that of its width. While, in Benisatsuma, the width of the tuberous root became narrower with the increase of the calcium application and its increasing ratio from 90 to 120 days was smaller in H treatment than in L treatment. Thus, the smaller fresh weight in a tuberous root by a higher calcium application may be due to the formation of a narrow width. Although calcium maintains the cell wall by binding with a pectin material, the cell wall increases the plasticity through the association of calcium, with tectonic acid (Burstrom, 1968). The width of a tuberous root at 90 and 120 days decreased with the increase of the calcium application in both varieties and became narrower in Beniotome than in Benisatsuma. On the other hand, the calcium content of the tuberous roots in both varieties rises with the calcium application, but was lower in Benisatsuma than in Beniotome (Fig. 2). These facts suggest that the narrow width of a tuberous root by an increase of the calcium application may be due to the increase of the plasticity in the cell wall according to the increase of calcium.

As previously stated, the calcium content and the amount of the tuberous root in every treatment was higher in Beniotome than in Benisatsuma (Fig. 2 and 3). Furthermore, the calcium amount of the tuberous root in Beniotome increased from 90 to 120 days, but it was not observed in Benisatsuma. Whereas, those of the top and the roots in Beniotome were lower at both 90 and 120 days compared with those in Benisatsuma (Fig. 3), while the potassium amount in all of the plant parts in both varieties decreased with the increase of the calcium application and in every treatment it was lower in Beniotome than in Benisatsuma (Fig. 5). These show that the calcium amount translocated to the top was lower in Beniotome than in Benisatsuma and that Beniotome has a mechanism requiring more calcium for the growth of the tuberous root or remaining more calcium only in one. As a result, a difference may occur in the response to the Ca level between both varieties.

In sweet potatoes, sucrose is translocated from the leaves to the sink (tuberous root) (Kays, 1985). The total sugar content and amount of the top in every treatment was lower in Benisatsuma than in Beniotome (Fig. 6 and 7), whereas the starch content and amount of the tuberous root were higher at both 90 and 120 days in Benisatsuma than in Beniotome (Fig. 8 and 9), suggesting that the formation of a larger fresh weight of the tuberous root in Benisatsuma than in Beniotome may be due to the higher translocation of sugar to the tuberous root or to the larger capacity of the tuberous root for accumulating starch. Inanaga *et al.* (1988) reported that the seeds of a peanut tree from a calcium deficient medium had an increased sugar and crude starch contents. In sweet potatoes, although the weight of all the plant organs in both varieties decreased with the increase of the calcium application, the total sugar and crude starch contents increased. In both varieties about 40 and 50% of the crude starch content of the amount in the L and M treatments respectively was lower 60-70% than results obtained in many varieties of sweet potato (Woolfe, 1992; Anonymous, 2000b), indicating that photoassimilates might be used for the growth of all the plant organs under low calcium conditions, or that photosynthesis may be promoted through a greater calcium application.

Generally, in Japan consumers prefer a tuberous root in the sweet potato, which are slender as a perishable food. A short and wide tuberous root was obtained in Kuroboku soil widely distributing in Kagoshima with a high CEC and larger amount of humic acid (Anonymous, 1996a, b), but this phenomena was improved by the addition of a larger amount of river sand with a low CEC. In broad bean (*Vicia faba* L.) it was difficult for a root to absorb calcium associating with an organic material (Chishaki, N., personal communication).The results obtained in this study indicate that this phenomena observed in Kuroboku soil may be due to the slight calcium absorption from the high CEC and that a slender tuberous root of a sweet potato may also be produced in Kuroboku soil with a greater calcium application.

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