論 文 の 内 容 の 要 旨

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論文題目 Physiological studies on the regulation of solid accumulation in tomato fruits
（トマト果実における乾物蓄積の調節に関する生理学的研究）

Tomato (*Solanum lycopersicum* L.) is a highly nutritious vegetable and remains in high demand round the year throughout the world. In Japan, tomatoes are consumed in fresh as well as processed forms, but demand for high quality fresh produce is very high. Like other fleshy fruits water is the major component of tomato, while the solid portion is chiefly composed of sugar, organic acids, amino acids, vitamins and minerals. Consumers prefer fruit with high contents of sugars, organic acids, and amino acids owing to good taste and health-benefits concerns. For processing, fruits with low water content are preferable regarding processing efficiency and cost. Solid contents of fruit, therefore, not only define its nutritional value but indicate consumer preference and processing efficiency as well.

Solid content of fruit may be manipulated through modifying growing conditions, changing leaf to fruit ratios, or introgression of desirable traits from the wild relatives into the cultivated species. On tomato plants, except for the first truss, each fruit truss is preceded by usually 3 leaves which supply assimilates for the fruit growth on that truss. Fresh fruit growers usually keep 4-5 fruits on a single truss, but, to improve fruit solid content and quality, source-sink balance must be properly maintained. Plants assimilate carbohydrate in leaves, and then translocate them as

sucrose in the phloem vessels to sink organs along with water. Resultantly, any changes in sucrose concentration of phloem sap may affect the final solid content of fruits. Therefore, this relationship between phloem sucrose concentration and fruit solid content is of high importance.

Soil salinity and water deficit are serious problems in many tomato growing countries. Exposure of plants to saline- water-deficit-stress has long been shown to increase fruit solid contents. However, problem of saline-alkali soil or bicarbonate-rich irrigation water is more widespread than salinity, especially in Asia, Pacific and Australia. These soils and waters have high pH along with high EC. The exclusive influence of high EC on fruit solid contents have been studied extensively, but the combined effects of high pH and EC on fruit solid contents have never been studied before. If saline-alkali stress also improves solid accumulation in tomato fruit, whether soil pH besides EC also play a role in this improvement will be very interesting to know.

In this study, we firstly focused on the relationship between sucrose concentration of the phloem sap and fruit final solid contents under different leaf / fruit ratios. Secondly, we attempted to understand the impact of saline-alkali stress on the solid accumulation in fruits and the possible role of soil pH in the response.

1. Relationship between fruit solid contents and the sucrose concentration of the phloem sap at different source-sink ratios in tomato

Regarding the previous observations that more than 90% of the water is translocated via the phloem into a fruit in tomato, soluble solid content of fruits may be strongly influenced by the sucrose concentration of the phloem. In this experiment, we evaluated the relationship of fruit soluble solid contents and phloem sap sucrose concentration in tomato at various source-sink ratios (0.2, 0.4, 0.6, 0.75, 1, 2 and 3 leaf to fruit ratios [LFR). Fruit fresh weight was 40 g at the lowest LFR and increased to 80 g at LFR of 1 (80 g), but no obvious change was observed at higher LFR. Fruit dry weight increased linearly (r=0.930) from 3.5 to 7 g when LFR was increased from 0.2 to 1, indicating source dependent regulation of dry matter accumulation. However, it did not change when the LFR was beyond 1, indicating that dry matter accumulation was not affected by the source at high LFR.

By contrast, contents of fruit dry matter, total soluble sugars, and organic acids increased linearly within the whole range of LFR from 0.2 to 3 (r= 0.972, 0.890, and 0.943, respectively). Using these plants, phloem sap was collected from the cut end of

the pedicle in EDTA solution. The sucrose concentration of the collected phloem sap showed a positive correlation to fruit dry matter contents (r=0.930). Contents of fruit total sugars also correlated positively with phloem sucrose concentration (r=0.900). These data suggested that, while dry matter accumulation per fruit is not affected by the source above LFR of 1, the content of soluble sugars and dry matter on a fresh weight basis is determined source dependently via the sucrose concentration of the phloem sap.

2. Impact of saline-alkaline stress on the accumulation of solids in tomato fruit

Growing of tomato plants in saline conditions is often reported with high solid content in fruit, probably due to high EC in the rooting medium. Since saline-alkaline soil, unlike saline soil, also has high pH besides high electric conductivity (EC), whether it can influence fruit solid contents has not been investigated so far. Therefore, this experiment was performed to investigate the role of saline-alkaline stress (0-120 mM) in solid accumulation in tomato fruits. The pH and EC of soil leachate indicated that addition of 90 and 120 mM sodium bicarbonate (NaHCO3) to plants increased pH to above 8 two-week after the initiation of alkaline-salt application, while the pH of the control remaind at 7. Similarly, EC of soil leachate was increased to 5 and 6 dS•m-1 at 90 and 120 mM respectively, but, in control (0 mM) plants, EC gradually decreased from 4 to 1.5 dS•m-1.

Fruit size and fresh weight was similar in all treatments within the range of 0-90 mM, but only 120 mM treatment decreased fruit weight. Likewise, salt application had no effect on fruit dry weight but its dry matter content was increased significantly from 6.8% (0 mM treatment) to 8.5% (90 and120 mM treatment). Total soluble sugar (TSS) content increased in 90 mM treatment (3 %) in comparison to the control (2 %), but starch content remained unchanged. The increase in TSS in salt treatments was due to significant accumulation of hexose as well as sucrose in the ripe fruits. In addition to carbohydrates, saline-alkaline stress influenced organic acids accumulation as well. Citric acid, being the major acid, was significantly higher (21-32 mg g-1 FW) at NaHCO3 concentrations higher than 30 mM (18 mg g-1 FW). These results show that saline-alkaline stress (0-90 mM) can increase solid contents of fruits without reducing fruit weight, as is observed in saline stress. These results suggest that the high dry matter and sugar contents in saline-alkali treatments is because of metabolic alteration in fruit rather than condensation effects.

3. Comparative study on the accumulation of solid content in tomato fruit under saline-alkaline and saline stresses during different growing seasons

Increasing number of evidence support the hypothesis that high rhizospheric EC enhances solid contents of tomato fruits. The results in previous experiment showed that saline-alkaline stress, retaining high pH in addition to high EC in the medium, can also improve solid contents in tomato. To elucidate the role of soil pH in influencing solid content of fruit, we compared the effects of saline-alkaline (NaHCO3), saline (NaCl) and mix-salt (NaHCO3+NaCl) conditions in different growing seasons.

Results indicated that saline-alkaline treatment increased mean soil-leachate pH (pH 8), while, in saline treatment, pH was similar to the control (pH 6). On the contrary, mean soil-leachate EC was 2-time lower (5-6 dS•m-1) in saline-alkaline treatment as compared with saline treatment (11-13 dS•m-1), while EC was 3 dS•m-1 in the control. Fruit fresh weight and dry weight decreased in all salt treatments in similar fashion. Fruit dry matter content increased significantly from 7 to 14% and TSS from 3 to 5% in saline-alkaline and other stress treatments. Accumulation of sucrose, on fresh as well as dry weight basis, was increased in all stress treatments. Organic acids accumulated in stressed fruit higher than the control but their content was higher, particularly in saline-alkaline treatment. All the stress treatments increased citric acid content but the maximum content (8 mg g-1 FW) was recorded in saline-alkaline treatment in comparison to control plants (3 mg g-1 FW). The contents of fruit dry weight, TSS, and organic acids in all stress treatments were higher in winter crop than summer crop.

These results show that in spite of lower EC in saline-alkaline treatment, soluble sugar and organic acids contents were equal to that of high EC treatments, in both growing seasons. This data, therefore, suggest that, in saline-alkaline conditions, soil pH in association with soil EC also have a role in influencing solid content in tomato.

In conclusion, this study suggests that enhanced contents of fruit dry matter and soluble solids at high leaf to fruit ratio in tomato are attributable to increased sucrose concentration of the phloem sap. In addition, saline-alkali stress conditions can improve soluble solid content in tomato fruits either by decreasing fruit water content or by metabolic alteration.