Change in Carbohydrate Concentration in Kiwifruit (*Actinidia deliciosa*) while Fruit Growth Was Restricted

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Abstract

Sugar concentration, starch concentration, water content, and dry weight in fruit tissue of kiwifruit (*Actinidia deliciosa*) were investigated when the fruit growth was being restricted with ϕ 43 mm and ϕ 52 mm acrylic sleeves. Fruit fresh weight, dry weight, and water content of both the sleeve treatment fruits did not increase as much as those of control fruit did. The water content stopped increasing for treatment fruit of acrylic sleeves at fruit growth stage III. The total sugar concentration suddenly increased and then decreased to the level of control fruit in both acrylic sleeve treated fruit. At that time, starch concentration was not shown to be lower tendency than that of the control fruit, and dry matter percentage was not different between treatment fruit and control fruit. Therefore, the total sugar concentration increment at the growing fruit restricted with acrylic sleeves may be effective for water content decrement in fruit tissue.

Key words: acrylic sleeve treatment, dry weight, dry matter percentage, starch, water content

Introduction

High quality fruits has fine appearance, texture, color, and a particular taste. The fruit taste is made up of sugar and organic acid. The sugar concentration in fruit tissue is very important in determining the quality, which affects its marketability.

Many horticultural crops need to accumulate more than 80% water for these growth. If the water accumulation rate is high, sugar concentration is low because of late sugar accumulation and dilution. Peaches have been known to lose sweetness when they are harvested after rainfalls. In the case of tomatoes, it was experimentally confirmed that the sugar concentration is low if the rainfall has been high (Rudich et al., 1977). Ketsa (1988) also confirmed negative correction between sugar concentration and fruit size for tangerines.

Enlargement of cultivation area for mulching cultivation, high bed cultivation, and box cultivation (container cultivation) are used to increase sugar concentration with soil dryness in satsuma mandarin (Takatsugi, 1991).

However, these methods have deleterious effects on trees for the next year's growth, and the fruit quality becomes very poor due to reduced photosynthesis. Therefore, farmers need to use a direct decreasing method for controlling the amount of water in the fruit tissue.

The passageway for water between the tree and its fruit is the xylem. The water flows into the fruit tissue through these organs. Part of the water is discharged by transpiration and the other part accumulates in the fruit tissue. Lang and Thorpe (1989) suggested that water was able to flow backward from fruit to tree through the xylem, as in the case of apple. If water movement in the xylem responds to a gradient of water potential, the photosynthate must be easier to be controlled. If we can reduce the sugar concentration dilution function in the fruit tissue, we will be able to promote sugar concentration in all fruit species regardless of the environmental factors.

Kiwifruits harvested before they are physiologically mature do not fully ripen and do not store well. Internal soluble solids concentration (SSC) is the current maturity index for kiwifruit; the fruit can be harvested for export

once a minimum of 6.2% SSC is exceeded (Salinger et al., 1993). My last experiment indicated that the reason for different fruit tissue sugar concentration for each year was due to water accumulation at fruit maturity (Han et al., 1996). These facts suggest that fruit volume and different water accumulation rates can affect the sugar concentration levels. Ushijima et al. (1998) reported effects of soil moisture on fruit quality and tree growth in kiwifruit. Therefore, sugar concentration, flowing of water, and dry materials related to photosynthate inflow were investigated in fruit tissue as the fruit growth was restricted In this paper, I aimed to clarify water flux affected factors on sugar concentration during the fruit growth.

Materials and Methods

Fifteen-year-old kiwifruit vines (*Actinidia deliciosa* cv. Hayward) at the orchard of the Faculty of Agriculture, University of Tokyo in Ninomiya prefecture were selected at random. Four weeks after anthesis, fruit from exposed positions in the upper part of the vines were randomly selected about every two weeks and continued until commercial harvest. On each occasion, one fruit was harvested from each tree of the five combined replicates and the fruit growth was examined.

The acrylic sleeve's dimensions are 100 mm in length with a diameter of 43 mm or 52 mm and a thickness of 3 mm. The sleeves were also cut vertically in half and wound with a piece of steel wire. The sleeves covered the fruit and then were fixed to a branch with a piece of plas-

Fig. 1. Fruit growth of a kiwifruit being restricted in an acrylic sleeeve with an inner diameter of 43 mm.

tic coated wire (Fig. 1). Some fruits were first treated on July 19th with ϕ 43 mm sleeves during fruit growth stage I (ϕ 43 mm fruit). Then on September 13th during fruit growth stage III, other fruits were treated with ϕ 52 mm sleeves (ϕ 52 mm fruit). Every 2 weeks, the sleeve treated fruits were sampled and examined for their growth.

The pulps were cut into slices and freeze-dried to determine their dry weight. The slices through the equatorial region of the fruit were collected for analysis of total sugar and starch concentration. The outer pericarp tissue at each of the proximal and distal ends of the fruit and core tissue were used.

The freeze-dried materials were ground into powder using a mortar and pestle, and diluted with 80% ethanol at 80°C for 1.5 h. The extract was centrifuged at 1,000 × g for 30 min. The supernatant was dried in a rotary evaporator and re-dissolved in water. The solution was centrifuged at 19,500 × g for 10 min., loaded on a column Cosmosil 5 NH2 (Nakarai Co, Japan) and diluted with 80% acetonitril-water (80:20) at the rate of 1 ml · min^{-1} at 33°C, using a Shimadzu 6A HPLC system fitted with a refractive index detector (RI-2, Japan Analytical Industry).

Starch was extracted from the residue of soluble carbohydrate with boiling water for 1 h. The fraction was hydrolyzed with amino-glucosidase overnight. The glucose concentration was determined enzymatically. The amount of starch was calculated as the glucose value is multiplied by 0.9 (Agricultural and environmental biology Graduate School of Agricultural & Life Sciences, University of Tokyo, 1999).

The water content in fruit was estimated by subtracting the dry weight from fresh weight. The daily rates of water accumulation were computed.

Results

Change in fruit growth amount : The fresh weight of the ϕ 43 mm-fruit was lower than the control fruit after 2 weeks of the treatment, but it remained close to the control fruit's fresh weight until September 27th when it stabilized at about 100 g, which was 25 g lower than the control fruit's fresh weight. On the other hand, the ϕ 52 mm-fruit had a lower fresh weight than the control-fruit after 30 days, but it overtook the control-fruit on the last
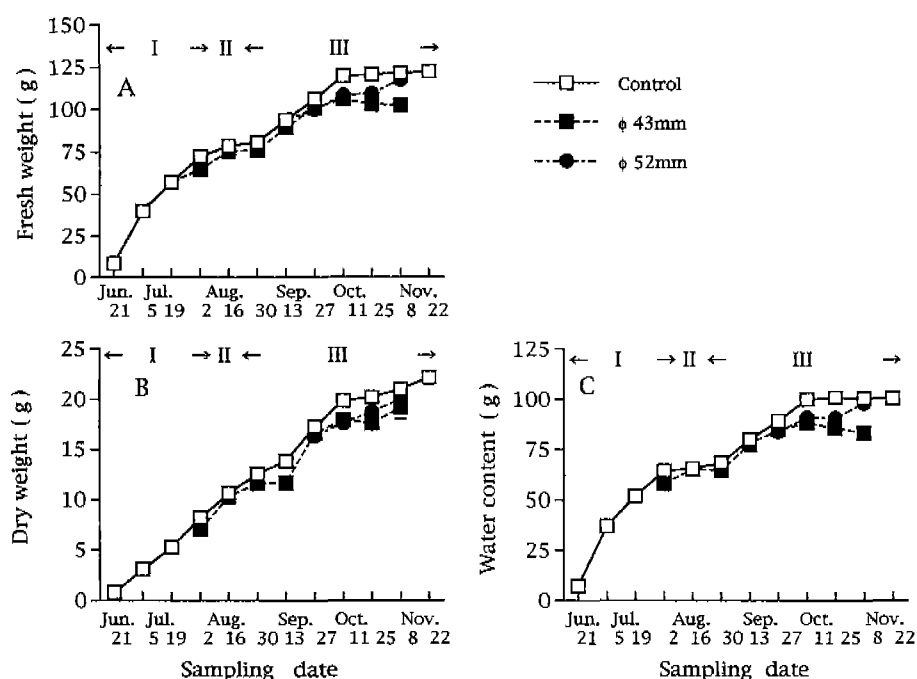
Fig. 2. Seasonal change in freash weight (A), dry weight (B), and water content (C) of kiwifruit in 1996 as the enlargement was restricted in an acrylic sleeve with an inner diameter of 43 mm and 52 mm. Three growth stages were shown as I, II, and III. Values are means ± SE for n=5.

day (Fig. 2A). Changes in dry weight are indicated in Fig. 1B. The ϕ43 mm-fruit had a lower dry weight than the control-fruit and a great difference in fruit growth. In the case of the ϕ52 mm-fruit, it was also lower than that of the control-fruit. The change in water content was very similar to the change in dry weight, however the ϕ52 mm-fruit's water content surpassed the control-fruits on the last day (Fig. 2C).

The rates for dry weight and water content for one day are indicated in Fig. 2. In the case of dry weight (Fig. 3A), the ϕ43 mm-fruit was almost zero from August 30th to September 13th, but it climbed to its highest point during treatment from September 13th to September 27th. It also had negative values between October 11th and 25th but overtook the control fruit on the last day. On the other hand, the ϕ52 mm-fruit was at its' lowest point during its' treatment on September 2th and was at its highest value on the last day which was still higher than the control fruit. With water content (Fig. 3 B), the ϕ43 mm-fruit was zero between August 16th and 30th and had negative values on the last day. The ϕ52 mm-fruit had negative values from September 13th to September 27th, but it

climbed into positive values thereafter and climbed to the highest values during the whole treatment on the last day. The dry matter percentage was very similar in all the treatments, but it was highest for the ϕ43 mm-fruit on the last day (Fig. 3C).

The fruit diameter stabilized in the acrylic sleeves with an inner diameter of 43 mm and 52 mm after 2 weeks of the acrylic sleeve treatment (Fig. 4 A). The ratio of fruit length to fruit diameter showed that the fruit grew vertically as the fruit enlargement was restrained (Fig. 4 B). The ratio of the ϕ43 mm-fruit was higher than that of the ϕ52 mm-fruit. These results indicate the success of fruit enlargement restraint.

Change in carbohydrate concentration : Total sugar and starch concentrations are shown in Fig. 5. The ϕ43 mm-fruit values are much higher than that of the control fruit on September 13th, but after 2 weeks were lower than that of the control fruit, then they become similar thereafter. This pattern was similar to ϕ52 mm-fruit. The starch concentration started decreasing for all the fruit during fruit growth stage III (Fig. 5B). The concentration was not different between acrylic sleeve treatment fruit
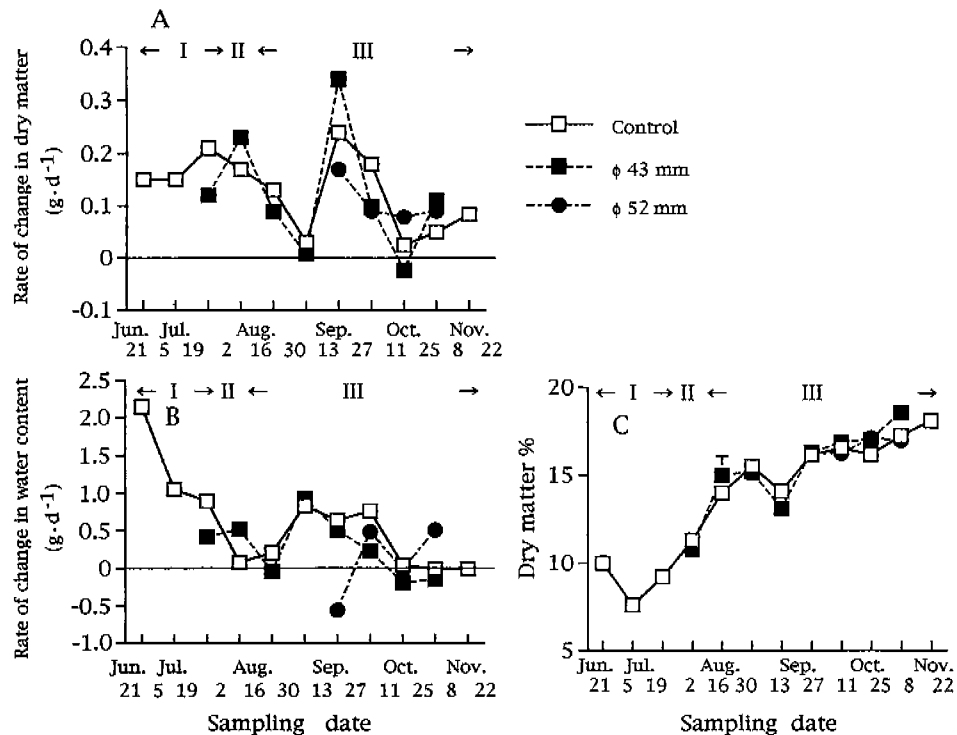
Fig. 3. Seasonal change in daily rate of the dry weight (A), water content (B), and dry matter percent (C) of kiwifruit in 1996 as the enlargement was restricted in an acrylic sleeve with an inner diameter of 43 mm and 52 mm. Three growth stages were shown as I, II, and III. Values are means ± SE for n=5.
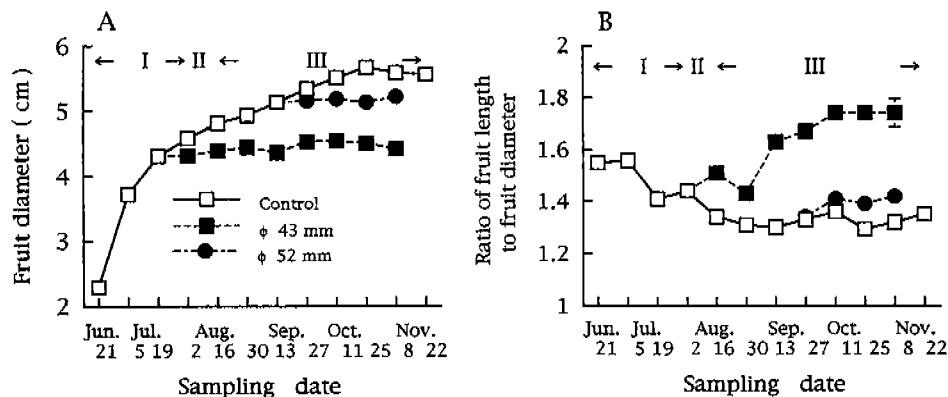

Fig. 4. Seasonal change in fruit diameter (A) and the ratio of the fruit length to fruit diameter (B) of kiwifruit in 1996 as the enlargement was restricted in an acrylic sleeve with an inner diameter of 43 mm and 52 mm. Three growth stages were shown as I, II, and III. Values are means ± SE for n=5.

and control fruit.

Discussion

The dry material and water content increased rapidly at

fruit growth stage I, but slows down at stage II and then increase again at stage III for kiwifruit (Fig. 4 A, B). The results for the ϕ 43 mm acrylic sleeve treatment during fruit growth stage I show that the diameter of the fruit is stable during the stage. The fruit length for the fruit
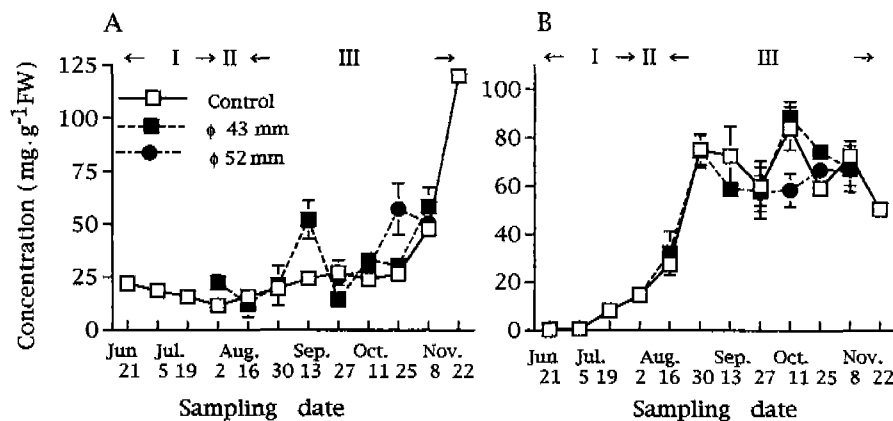
Fig. 5. Seasonal change in suger (A) and starch (B) concentration of fruit in kiwifruit 1996 as the enlargement was restricted in an acrylic sleeve with an inner diameter of 43 mm and 52 mm. Three growth stages were shown as I, II, and III. Values are means ± SE for n=5.

treated with the acrylic sleeve was much longer than control fruit because the vertical enlargement was not being restricted (Fig. 4 A, B). Judging from the fresh weight data, the restraint effect of fruit enlargement started in the middle of fruit growth stage III. Therefore, this result suggests that there was no fruit enlargement control during fruit growth stage I and II.

Water flowing into the fruit tissue, and the fruit tissue cells absorbing water was thought to the reason for the difference in the gradient of water potential with passivity (Lay, 1967). Irreversible cell wall expansion decreases the tugor pressure which in turn makes the cell wall yield to apoplastic water potential, the turgor pressure, and turgor pressure decreases. The water flowing cell is the result of the water potential decrease (Cosgrove, 1986). In the case of the treated fruit, water potential decrease can not rise from relaxation of stress because the acrylic sleeve prevents expansion of the cell walls. Therefore, the fruit tissue can not take up water for those reasons.

The water content of one fruit and the water accumulation ratios indicated that there was not a complete disturbance of water flowing into the fruit tissue. The result may be due to the ability of the fruit to grow vertically. The dry matter percentage of the ϕ 43 mm-fruit was high in the latter half at the end of the testing period.

The total sugar concentration was very high in ϕ 43 mm-fruit and ϕ 52 mm-fruit after 1-1.5 months of acrylic sleeve treatment. A phenomenon of momentary high sugar concentration was observed in cucumbers (no pub-

lication). Therefore, the sugar concentration increment was suggested that the concentration dilution not occur during fruit growth at strong cell wall of fruit tissue.

Acknowledgements

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참다래 과실의 생장 억제에 따른 과실 생장기의 탄수화물의 농도변화

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동경대학 농학 생명과학 연구과 일본 토교도 분쿄구 야요이 1-1 113-8657
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적 요

본 연구에서는 참다래 과실의 생장을 직경 43 mm와 52 mm의 아크릴파이프 처리로 억제시켜, 과실 생장에 따른 과실조직의 수분 함량과 건물중 변화에 대한 과실의 전당 및 전분 농도를 조사하였다. 과실의 생체중, 건물중과 수분 함량은 파이프 처리에 의해 감소하였으나, 과실이 비대함에 따라 일정한 비율로 증가하였다. 직경 43 mm 아크릴파이프처리 과실은 과실 생장 제3기 동안 수분 함량 증가가 정지되었고 과실의 수확기 적기에는 건물률이 다른 처리보다 높았다. 당농도는 아크릴파이프 처리의 과실에 있어, 일시적으로 증가한 후에 무처리 과실의 농도까지 감소하였다. 그때에 전분 농도와 건물률은 처리간에 차이가 없었다. 그러므로, 아크릴파이프로 처리로 과실의 비대가 억제된 과실의 당 농도는 과실의 수분함량 감소에 따른 것으로 생각되었다.

주제어 : 아크릴파이프 처리, 건물중, 건물률, 수분함량, 전분