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Diurnal Change in Water Status of Fruit Tissues During the Growth of Kiwifruit (*Actinidia deliciosa*)

Han, Sang Heon

Laboratory of Horticultural Science, Graduate School of Agricultural & Life Science, University of Tokyo, 1-1 Yayoi, Bunnkyo-ku Tokyo 113-8657, Japan
**Present address: Laboratory of Genetic Plant Resources, Faculty of Agriculture, Saga University, Saga 840-8745, Japan*

Abstract

Fruit growth in kiwifruit shows double sigmoid curve, but it does not certainly indicate as years. Therefore, I thought the reason to be easy to the effect of water state change in kiwifruit, investigated diurnal change in water status of fruit tissues with an isoipiestic psychrometers against the fruit growth stage of kiwifruit in 1995 and 1996. Diurnal change in the fruit tissue water potential were little, but violent for fruit growth stage III in 1996. The potential of two years dropped gradually approach to harvest time. On the other hand, osmotic potential of the tissues indicated to very similar to water potential, dropped rapidly -1.5 MPa before dawn, recovered -1 MPa after 3 h on October 14, were -1~-1.7 MPa at the fruit commercial harvest in 1995. It had a tendency to lower in 1996 than in 1995. It was recorded to the minimum air temperature at the first for an autumn in 1995; 13°C from the middle night of October 13 to dawn of October 14. Leaves water potential, which is related to water status of xylem, nearly fell below -1 MPa at before dawn from stage II in 1996. However, it fell so low only at commercial in 1995. At the stage II, osmotic potential and ascent of the turgor pressure was high than 1995-fruit. These parameter suggested that threes of kiwifruit in 1996 were status of water stress for stage III. The results from this study indicated that difference of fruit growth between 1995-fruit and 1996-fruit was affected by water status of the fruit tissues, which was influenced by weather condition.

Key words: growth, osmotic potential, turgor pressure, volume, weather condition, water potential

Introduction

Fruit quality is generally determined by fruit sweetness and fruit size, but the important constitution factor is concentration of sugar. Accumulation of sugar into fruit is dependent on the materials produced in leaves. Those materials are loaded to phloem of source organs, translocated to phloem of sink organ as mass flow, unloaded on a fruit and inflowed actively in parenchyma of fruit tissue (Damon et al, 1988; Lang and Thorpe, 1989). The fruit growth in size occurs mostly by increasing in cell water. The enlargement generates because solute concentrations are high enough inside the cell to extract water osmotically from the surrounding. As a result, the pressure in the cell (turgor) rises and extends the walls irreversibly enlarging the cell comportment (Grange, 1955; Pomper et al, 1995).

There has been discussion on fruit growth of kiwifruit by Bollard (1970), Pratt and Reid (1974) and Hopping (1976). The growth of the fruit is not linear but is instead thought of as being cyclic, as in stone fruit but, the fruit growth curve is not clear environmental factors, particularly the availability of water, can have marked effects on rates of fruit growth. The growth curve of fruit in kiwifruit was reported to be very different for two years as water content of fruit tissues (Han et al., 1996).

Studies on the daily change in fruit size of the Japanese pear indicated to diurnal fluctuation in fruit diameter, which was closely related to environmental condition (Endo, 1975). On satsuma mandarin trees, fruit drowth was closely related to leaf water potential and leaf diffusion resistance (Maotani, 1977). Although water potential and osmotic potential decreased, turgor pressure of both roots and pericarps of the stressed trees did not

decrease under water stress conditions. Because turgor pressure was maintained, osmoregulation occurred in satsuma mandarin trees in response to water stress (Yakushiji et al, 1996). In case of kiwifruit, Judd et al. (1989) examined the effect of water stress on fruit development, but not on change in turgor pressure of fruit tissue for fruit growth with environmental conditions.

In the present study, diurnal change in water status of fruit tissue during the growth of kiwifruit was investigated in order to find a clear relationship fruit growth curve with environment conditions.

Materials and Methods

Plant material and fruit sampling

Fruit : Kiwifruit (*Actinidia deliciosa* cv Hayward) vines, 15 years old, at an orchard of Faculty Agriculture, University of Tokyo at Ninomiya prefecture were selected at random. Fruits from exposed positions in the upper part of the vines were randomly selected every about 2 weeks from 4 weeks after anthesis until commercial harvest.

Measurement of water status : Three fruits were picked with interval of 3 h from before dawn, measured water potential and osmotic potential of the nearest outer pericarp tissue with an isopiestic psychrometer (HR-33T, Company of Wescor), used an annual report of physics and chemistry in deciding before dawn (National Astronomical Observatory, 1995). The turgor pressure of fruit tissue was a difference between water potential and osmotic potential of the tissue.

Leaf tissues were sampled with a leaf sampler. Leaf water potential was measured with the same psychrometer described above.

Measurement of weather condition : Temperature, relative humidity (HMP 133), and photosynthetic photon flux (Li-COR) were measured. The data were stored in a computer (HP E1300A, Hewlett Packard Co.).

Results

Change in water status of fruit and leaf tissues for fruit growth stage I

Fig. 1 shows the diurnal change in water status of fruit tissues during fruit growth stage I. Fruit water potential (Ψ_w) on July 7 to 8 in 1995 (Fig. 1A) were near 0 MPa in the morning and the evening because of rainfall, but they were stable at -0.2 MPa without remarkable fluctuation. Fruit Ψ_w on July 15 to 16 (Fig. 1B) was -0.3 MPa at the measurement before dawn, which was highest for the day. After sunrise, it was about -0.5 MPa. On July 15 to 16 (Fig. 1C) fruit Ψ_w was about -0.5 MPa for 1 day. The pattern of change in osmotic potential was similar to that in water potential. Turgor pressure was highest before dawn when measurements were made for a day from July 7 to 8 and from 15 to 16.

On July 12 to 13 in 1996 (Fig. 1D), fruit Ψ_w was stable at -0.2 MPa 3 h before dawn, began to rise to -1 MPa at sunrise and became again about -0.2 MPa at 10 AM. On

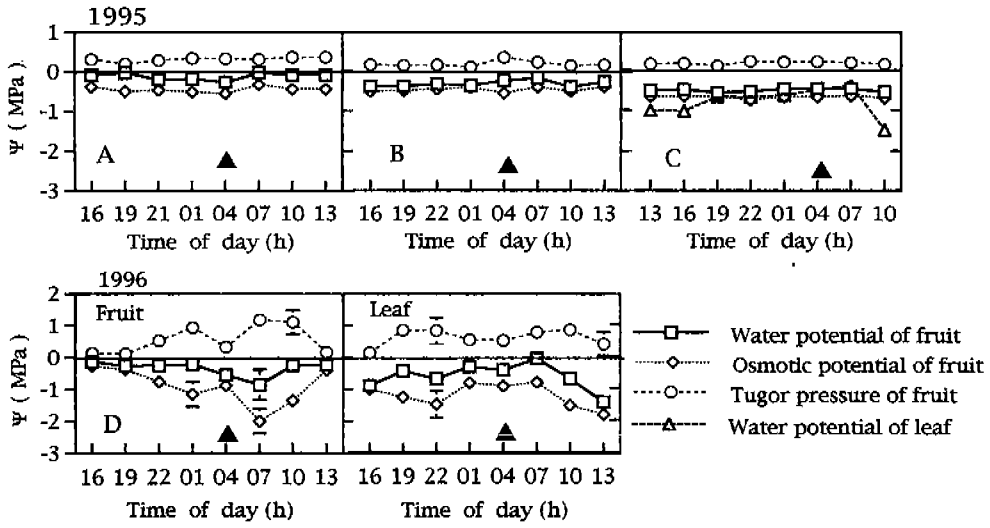

Fig. 1. Diurnal change in water status of fruit and leaf at the fruit growth stage 1 in 1995, 1996. Values are means ± SE for n=3. A; Jul. 7-8, B; Jul. 15-16, C; Jul. 29-30, D; Jul. 12-13 ▲ ; The last measurement before dawn.

the other hand, osmotic potential began to decrease from 10 PM, indicating the lowest value of -0.2 MPa. Turgor pressure rose gradually from evening. However, it temporarily decreased before dawn and recorded at 1 MPa after sunrise.

The fluctuation in leaf Ψ_w for a day was as large ranging from -0.5 to -1.8 MPa. It became the same value with fruit Ψ_w before and at dawn and just after sun rise in 1995 (Fig. 1C). On the other hand, leaf Ψ_w in 1996 (Fig. 1) ranged between -0.5 and -1 MPa until sunrise, but became near 0 MPa thereafter. Then it decreased to -1.8 MPa after sunrise. The change in leaf osmotic potential was similar to that in leaf Ψ_w. Turgor pressure was near 0 MPa at 4 PM, but it was stable at -0.8 MPa for the rest of a day.

Change in water status of fruit and leaf tissues for fruit growth stage II

The water status of fruit and leaf tissues for growth stage II was shown in Fig. 2. Fruit Ψ_w deteriorated suddenly to -1.8 MPa after sunrise for a day from September 18 to 19 in 1995. Turgor pressure became instantaneously negative because osmotic potential did not decrease as Ψ_w. Leaf Ψ_w was slightly less than -1 MPa, which was lower than that at stage I. At 1 PM of September 18 and 10 PM of September 19, leaf Ψ_w of about -3 MP was recorded as a result of strong wind after a typhoon passed.

Fruit Ψ_w began to decrease gradually from 4 PM to -1 MPa at 3 h before dawn in 1996. After increasing after sunrise, it became near 0 MPa at 10 AM. Fruit osmotic potential was stable at -1.5 MPa. Fruit turgor pressure changed as it at fruit growth stage I. On the other hand, leaf Ψ_w maintained -1.2 MPa until 3 h before dawn, increased to near 0 MPa between dawn and sun rise, and then decreased to -1.8 MPa. Osmotic potential changed similarly to Ψ_w until 3 h before dawn, but it dropped suddenly to -3.8 MPa after sunrise and recovered to a value between -2 and -3 MPa. Fruit turgor pressure also fluctuated as the osmotic potential began to increase from a lower value 3 h before dawn to 4 MPa after sunrise and decreased thereafter.

Change in water status of fruit and leaf tissues for fruit growth stage III

The water status of fruits and leaves were shown in Fig. 3. Fruit Ψ_w did not fluctuate remarkably for a day from September 29 to 30 in 1995 (Fig. 3A). Osmotic potential and turgor pressure were not constant either. Leaf Ψ_w was higher than fruit Ψ_w before dawn and just after sunrise. The change in diurnal fruit Ψ_w was like of the potential at before dawn for a day from October 13 to 14. However, in case of osmotic potential, it changed very differently from that in fruit Ψ_w. It deteriorated rapidly at predawn. With fluctuations, it deteriorated suddenly once to -1 MPa at sunrise and recovered to about -0.5 MPa thereafter. The reason for such a change in osmotic potential was that fruit turgor pressure became

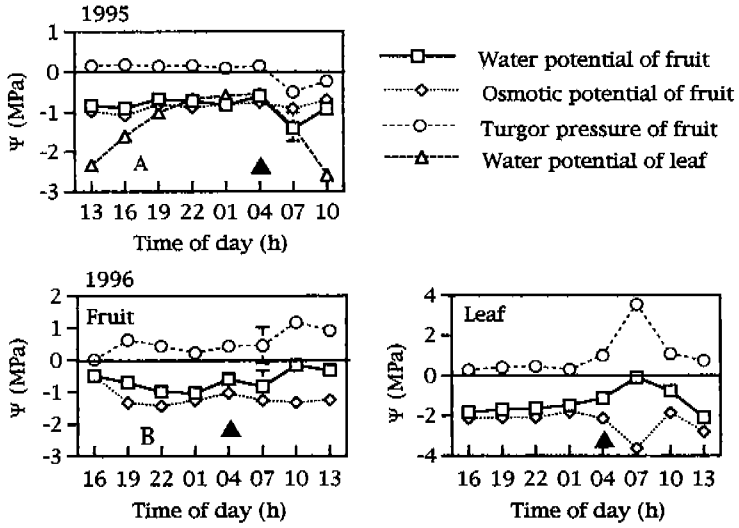

Fig. 2. Diurnal change in water status of fruit and leaf at the fruit growth stage 2 on Sep. 18-19, 1995, Sep. 16-17, 1996. Values are means ± SE for n=3. ▲ ; The last measurement before dawn.

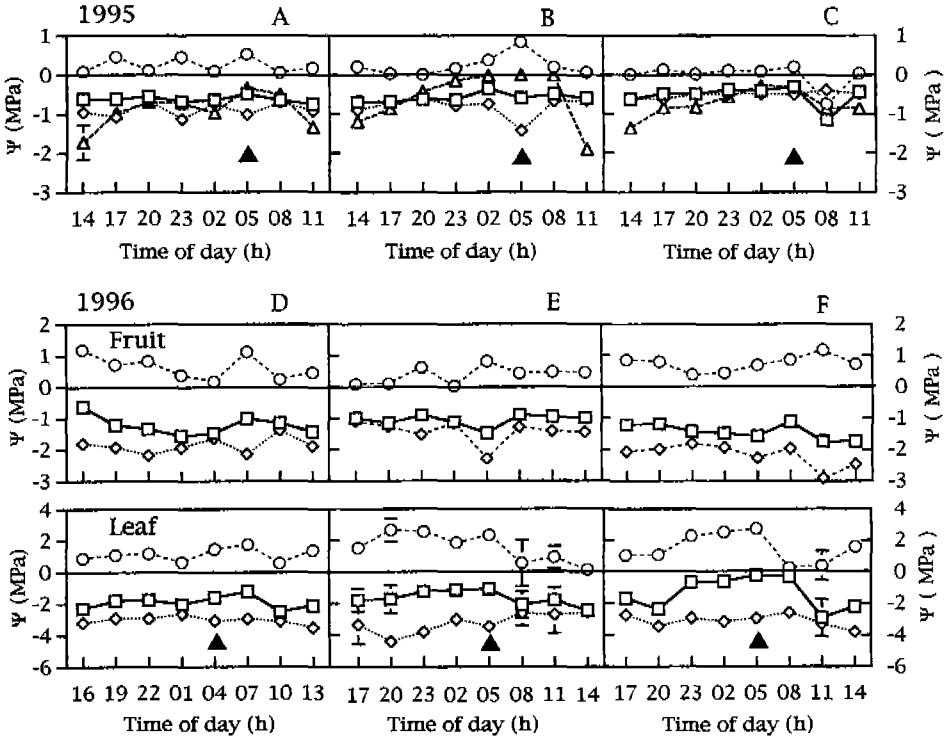

Fig. 3. Diurnal change in water status of fruit and leaf at the fruit growth stage III; A, Sep. -30, B, Oct. 13-14, C, Oct. 29-30 in 1995, D, Aug. 23-24, E, Oct. 11-12, F, Oct. 25-26 in 1996.
□ , water potential, ◇ , osmotic potential, ○ , tugor pressure, △ , water potential of leaf, ▲ , the last measurement before dawn. Values are means ± SE for n=3.

negative and water potential also was lower during that time (Fig. 3C).

Fluctuation of diurnal water status was very large during the first half of fruit growth III for a day from August 23 to 24 in 1996. Fruit Ψ_w showed the highest value of -0.5 MPa at 4 PM and decreased gradually until predawn, became to -1.5 MPa, decreased to -2 MPa after sunrise, and increased again thereafter. Turgor pressure decreased gradually from 1.2 MPa at 4 PM to near 0 MPa at predawn, rose suddenly to 1.2 MPa after sunrise and then decreased (Fig. 3D).

The change in fruit Ψ_w was very little in the middle of stage III, stable at about -1 MPa. However, it became -1.5 MPa at 2 AM on October 12. Fruit turgor pressure increased while osmotic potential decreased. It was the highest when osmotic potential was the lowest (Fig. 3E).

Fruit Ψ_w fluctuated between -1 and -1.8 MPa for a day from October 25 to the latter half of stage III. Osmotic potential changed between -1.8 and -2.2 MPa during the night. However, it became -3 MPa at 11 AM of following morning. On the other hand, fruit turgor pressure indicated to the most values, 1 MPa in the evening and 11 AM of following morning (Fig. 3F).

Fluctuation of leaf Ψ_w was comparatively small with -2 MPa for the first and middle parts of stage III (Figs. 3D and 3E). Leaf osmotic potential was almost stable to -3.4 MPa in the first half of stage III. However, it was -3 MPa and drop to -4 MPa at 8 PM at the middle of stage III. Leaf turgor pressure changed between 1 and 1.8 MPa for the first part of stage III and between 0 and 2.8 MPa for the mid-part. Leaf Ψ_w was stable at 0 MPa from 11 PM to sunrise. It dropped to about -3 MPa in the daytime for the latter half of stage III (Fig. 3F). The change in leaf osmotic potential was very little at about -3.5 MPa. Leaf turgor pressure ranged between 0.3 and 1 MPa.

Change in water status of fruit and leaf tissues for commercial harvest of fruit

Change in fruit osmotic potential and turgor pressure

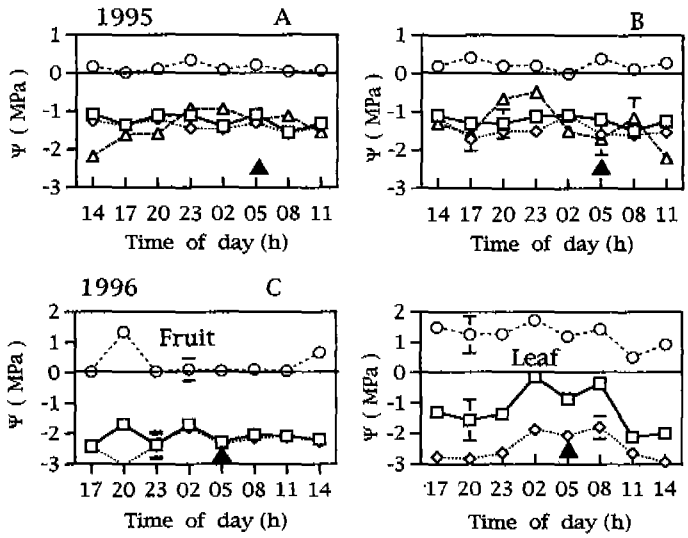

Fig. 4. Diurnal change in water status of fruit and leaf at the commercial harvest; A, Nov. 10-11, B, Nov. 18-19, in 1995, C, Nov. 22-23 in 1996.
□ , water potential, ◇ , osmotic potential, ○ , tugor pressure, △ , water potential of leaf, ▲ , the last measurement before dawn. Values are means ± SE for n=3.

was not observed at predawn. The diurnal change was very little for a day from November 10 to 11 in 1995 (Fig. 4A). The water status of fruit tissues between November 18 and 19 was similar to that in Fig. 4A (Fig. 4B). However, the fluctuation was very big (Fig. 4B). Fruit Ψ_w changed between about -2.5 and -1.8 MPa in 1996. Fruit osmotic potential was -3 MPa at 8 PM and similar to fruit Ψ_w for the rest of a day. Fruit turgor pressure was about 0 MPa except 1.3 MPa at 8 PM. On the other hand, leaf Ψ_w was less than -1 MPa between 5 PM and 11 PM, 0 to -1 MPa between 2 AM and sunrise. It decreased after sunrise. Leaf osmotic potential changed similarly to leaf Ψ_w between -3 and -2 MPa. Leaf turgor pressure changed relatively little than other stages of fruit growth (Fig. 4C).

Change in water status of fruit before dawn during the fruit growth

There was an notable observation on fruit water statues at predawn in 1995; fruit Ψ_w was very low at fruit growth stage I, increased at stages II and III and dropped suddenly on November 10 and 11. Change in fruit osmotic potential was very similar to that in fruit Ψ_w at stage I and II. However, it deteriorated abruptly at stage III. Fruit turgor pressure was low but, relatively stable at 0.2 to 0.3 MPa at stage II. However, it was 0 MPa at the first period of stage III and stable at 0.6 MPa. It decreased to 0 MPa at the commercial harvest.

The weather conditions between October 13 and 18 at the middle period of stage III in 1995 were shown in Fig. 6. It was cloudy on October 12 and later it was clear. The relative humidity was very stable at about 100% from the midnight of October 13 to sunrise of October 14. Though data were not shown, the minimum air temperature was at 12°C from the midnight of September 20 to before dawn of September 21. The minimum temperature of a day was at about 20°C until on October 6 after on September 21 but, become to 15°C from October 6 to 12. For a day from the midnight of October 13 to predawn of October 14, it decreased to 13°C but it abruptly increased to 18°C at 8 AM.

Discussion

Enlargement of cell volume can be analyzed by pattern of water content increasing into fruit tissues (Grange, 1995). It was reported by Jao et al. (1990) to a interrupting period of cell division on kiwifruit 'Haywad' outer pericarp, inter pericarp and center core be 24~30 days after anthesis. In this study there was no increase of the cell number, but only cell elongation because of beginning of the fruit growth from 5 weeks after anthesis at the last report.

Taking in water into cells is very important factor to the cell elongation. Water from soils is transported on

leaves and fruits though xylem as transpiration occurs. However, water states of leaves are possible to inhibit water transport into fruit during daytime (Berüter, 1989; Araki, 1993; McFadyen et al., 1996). Before dawn, the lowest temperature and the highest relation humidity for one day, noting a confusion of thermal equilibrium for emission of solar heat. It is near equilibrium between the state of water on each part of plants. Difference of water potential against each part in plants is smallest for one day (Slatyer, 1969).

Plant tissues enlarge when it take in water into the tissues. The model of volume enlargement as taking in water was proposed by Lockhart (1965) and expanded to model of tissues by Cosgrove and Boyer (1986). Cosgrove (1985, 1987a, 1987b, 1989, 1993) thought yield of cell wall plays an important part in cell elongation. If turor pressure, i.e., stress in cell wall, exist, it is difficult for passive flowing of water to happen because the pressure inside cells rises. On the other hand, when the pressure decrease and water potential becomes lower than outside of cell, the results make absorb water into cell in case of the cell wall being yielded. Berüter (1989) discussed on the importance of starch, which played in control of osmotic potential, in the research of carbohydrate partitioning and changes in water relation of growing apple fruit.

When comparison is made on the last result (Han et al., 1996) of the 1995-fruit growth with turgor pressure (Figs. 1A, B and C), the increase in turgor pressure was not at stage I but, very high rate of the growth. I thought the rate of the growth rose from high cell wall yield and ability of lower limit turgor pressure. On the other hand, as turgor pressure increased before dawn of stage III, fruit growth began again (Figs. 3A, B and C). This phenomenon suggested to the possibility that cell elongation is due to high turgor pressure because of a little cell wall yield at that time.

The increase in turgor pressure accompanied decrease in osmotic potential (Fig. 5). The phenomenon has not been reported. It is might bc due to starch hydrolysis. The

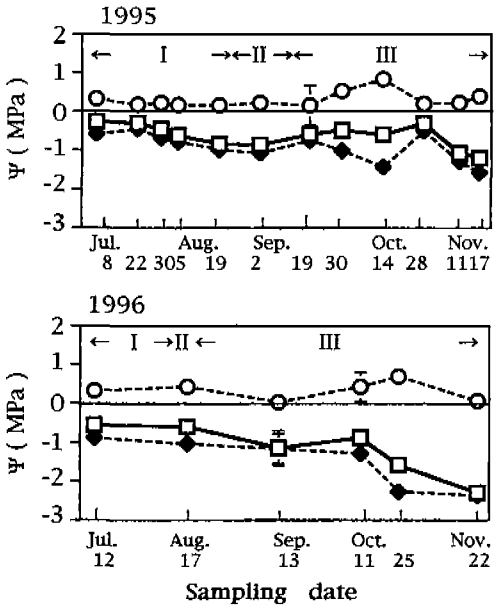

Fig. 5. Seasonal change in water status of fruit measured just before dawn in 1995, 1996. Three growth stage were shown as I,II and III.
□, water potential, ◆, osmotic potential, ○, tugor pressure. Values are means ± SE for n=3.

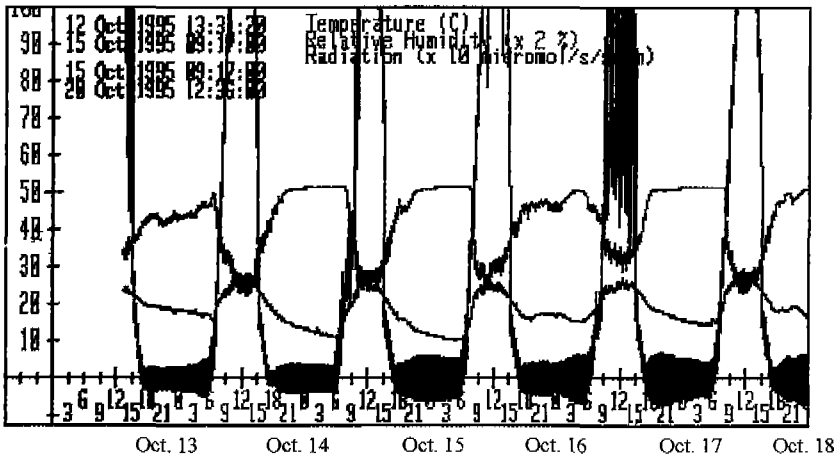

Fig. 6. Change of weather condition during fruit growth on October 12-18, 1995.

minimum air temperature was lowered at the first time in the autumn in 1995 to 12°C during the night from mid-night of September 20 to predawn of September 21 and to 13°C from the mid-night of October 13 to predawn of October 14 (Fig. 6). The second chilling may be involved in the beginning of starch hydrolysis. Even though air temperature before dawn was near to 20°C, there were also ascent in the turgor pressure accompanied by decreasing of osmotic potential on September 30. A decrease in osmotic potential may have been affected by low temperature before dawn on September 20.

There was generally no case showing negative turgor pressure. However, negative tugor pressure was observed immediately after sunrise at middle part of stage II and the latter half of stage III in 1995 (Figs. 2A and 3C). At these times, relative humidity decreased and air temperature increased rapidly after sunrise. Therefore, negative turgor pressure was thought to have occurred, as equilibrium state in water potential on fruit tissue was broken at dawn.

Generally, environment conditions greatly effect on fruit growth. Nakagawa (1978) reported that growth of a berry in grapevine was different as humidity of soil changed and that there were cases of double sigmoid curve or regular curve in the growth depending on soil humidity. It was reported to double sigmoid curve of fruit growth in apple 'Fuji' could not be observed when it was affected by drought weather (Yogoda, 1982). Endo (1975) studied on the daily change in fruit diameter of the Japanese pear as affected by climatic factors. In short and long term growth of navel orange fruit, diurnal diameter means of fruit young trees showed a signification relationship to daily ambient temperature maxima and diurnal growth profiles paralleled the diurnal temperature profiles of the rind. In contrast, the diurnal growth rhythms of fruit from mature trees was insensitive to ambient temperature maxima and the rhythms appeared to reflect the water statues of the tree (Storey et al., 1999).

Though water status of soil was not measured, the status of leaf water judged from leaf at predawn measurement. Irrigated vines typically exhibited values of between -0.03 and -0.08 MPa, which correspond to mid-day values of -0.4 and -0.8 MPa. On withholding irrigation, the potential at pre-dawn fell below -0.1 MPa within 4 days in mid-summer as a consequence of the small water reservoir available to the vines (Judd et al., 1989). In my last experiment on fruit growth of kiwifruit, the results of growth and sugar concentration was different between 1995 and 1996 (no publication). Leaf Ψ_w related to water status of xylem nearly fell below -1 MPa at before dawn from stage II in 1996, and only at the commercial in 1995 (Figs 3 and 4). At that time osmotic potential of fruit tissues began to increase and turgor pressure was higher than 1995. Ascent of turgor pressure in 1996-fruit against 1995-fruit was made by high concentration of sugar. The change in these parameter suggested that kiwifruit in 1996 were status of water stress for stage III. In satsuma mandarin Ψ_w and osmotic potential decreased, but turgor pressure of both roots and pericarps of the stressed trees did not decreased. Because turgor pressure was maintained, osmoregulation occurred in the trees in response to water stress (Yakushiji et al., 1996). Therefore, it may have been due to osmoregulation that fruit grow very well in 1996 at stage III even if under water stress conditions.

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참다래 과실의 생장에 따른 과실조직의 일중 수분상태 변화

한 상 헌*

동경대학 생명과학연구과 원예학연구실, 일본 토쿄도 분쿄구 야요이 1-1 113-8657

*현주소 : 사가대학 농학부, 일본 사가시 혼죠마찌 1번지 840-8502

적 요

참다래 과실의 생장은 2중 S자 곡선적으로 생장을 하지만, 그 곡선은 해에 따라서 불확실할 때가 있다. 이러한 원인을 과실조직의 수분상태에 의한 것으로 생각되어, 1995년과 1996년에 참다래 과실의 생장기간 중에 psychrometer를 사용하여 일중 과실조직의 수분생태 변화를 조사했다. 과실조직의 수분 포텐셜의 변화는 1996년의 과실생장의 제 3기를 제외하고는 크지 않았다. 1995년과 1996년 모두 과실의 수확기에 가까울수록 수분 포텐셜이 점진적으로 떨어졌다. 한편, 과실조직의 삼투 포텐셜은 수분 포텐셜과 비슷하게 변화를 했지만, 1995년 10월 14일의 동이 트기 전에 -1.5 MPa로 급격히 떨어진 후, 3시간이 경과한 후 -1 MPa로 회복되었고, 과실수확 적기에는 -1.7 MPa까지 떨어졌다. 1996년의 과실은 1995년 과실보다 낮은 삼투 포텐셜을 나타냈다. 도관의 수분상태에 관계되는 잎의 수분 포텐셜은 1996년의 경우, 과실생장 제 2기에 동이 트기 전에 불구하고 -1 MPa 이하로 떨어졌다. 1995년은 과실수확 적기에만 1996년과 같이 -1 MPa 이하로 떨어졌다. 1996년 과실은 과실생장 제2기에 과실의 삼투 포텐셜과 팽압의 상승이 1995년 과실 보다 높았다. 이러한 요인들이 1996년 과실의 당 농도를 높게 하였다. 이들 parameter의 변화는 1996년 과실이 과실생장의 제3기에 수체가 수분 스트레스를 받았다는 사실을 암시하는 것이다. 따라서, 1995년 과실과 1996년 과실의 생장 차이는 기상변화에 따른 과실 조직의 수분상태에 의한 것으로 판단된다.

주제어 : 참다래, 수분포텐셜, 삼투포텐셜, 팽압, 과실체적, 기상조건