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# Effects of High Temperature in the Nighttime and Shading in the Daytime on the Early Drop of Apple Fruit 'Starking Delicious' [1]

Satoru KONDO and Yuzi TAKAHASHI

*Kazuno Branch, Akita Fruit Tree Experiment Station, Kazuno, Akita* 018-52

**Summary**

The daily rate of fruit growth and elongation of the terminal shoots increased under the high night temperature (HNT). Fruit abscission was induced on the trees under NHT from 27 days and 34 days after full bloom (AFB). Under shading from 20 days, 27 days, and 34 days AFB, the daily rate of fruit growth decreased and fruit abscission was induced. The reducing sugar content per fruit was lower in the fruits under shading, in the fruits with interrupted growth and a yellow peduncle.

Ethylene evolution and carbon dioxide production per fruit weight were greater at the early stage of fruit development and increased with the increase of the environmental temperature. AVG application inhibited ethylene evolution and reduced the fruit abscission under a HNT, but hardly under shading.

From these results, it appears that fruit abscission under HNT was caused by the consumption of the nutrients associated with the increase of the vegetative growth and respiration rate and by the amount of ethylene evolved under a high temperature in the nighttime, while fruit abscission under shading was considerably affected by the reduction of the supply of metabolites.

## Introduction

A large number of studies on the abscission of immature fruits of apple(4, 30), peach (2, 5), grape(20), Japanese persimmon(32) and cherry (31) have been reported. The phytohormonal substances contained in the fruits(6, 8) and the translocation of photosynthates(22, 23) have been investigated in detail.

We indicated in a previous report(16) that the early drop of fruit of 'Starking Delicious' apple trees growing under natural environmental conditions was induced by a higher minimum temperature and shorter duration of sunshine. Tukey(27) observed that the early drop of fruit was brought about by heating in the nighttime after petal fall. Moreover, Schneider(24, 25) reported that the early drop of fruit was promoted by shading. However, it remains to be determined at which stage of development young fruits are affected by the environmental conditions mentioned above, and whether the early drop of fruits can be accelerated.

This report shows the effects of high temperature in the nighttime and shading in the daytime on apple fruit abscission, fruit growth and elongation of terminal shoots, and the effect of the application of AVG(aminoethoxyvinylglycine)—an inhibitor of ethylene synthesis(10, 21) on fruit abscission as well.

## Materials and Methods

1. *Effects of high temperature in the nighttime and shading in the daytime on fruit abscission, fruit growth and elongation of terminal shoots*

Eight-year-old 'Starking Delicious' apple trees grafted on 'M 26' rootstocks with uniform vigor and crop were selected. Four trees were used for each treatment. In the experiment on the effects of high tempera-

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**Table 1.** Mean night temperature during the night temperature treatment (1983).

| treatment | Mean night temperature (℃) (p. m. 7. 00～a. m. 6. 00) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | | | | B | | | | C | | | |
| | May | | Jun. | | Jun. | | | | Jun. | | | |
| | 30 | 31 | 1 | 2 | 6 | 7 | 8 | 9 | 13 | 14 | 15 | 16 |
| HNT[z] | 19. 5 | 21. 8 | 17. 3 | 16. 7 | 20. 2 | 18. 7 | 21. 0 | 20. 1 | 20. 5 | 18. 4 | 19. 1 | 21. 5 |
| | | | (828. 3)[x] | | | | (880. 0) | | | | (874. 5) | |
| NEC[y] | 16. 1 | 17. 6 | 11. 1 | 9. 8 | 16. 2 | 13. 1 | 15. 8 | 14. 7 | 14. 1 | 12. 9 | 14. 4 | 16. 4 |
| | | | (600. 6) | | | | (657. 8) | | | | (635. 8) | |

[z] HNT : High night temperature obtained by heating the pipe-house.
[y] NEC : Natural environmental conditions (mean night temperature outdoors).
[x] The total night temperature between p. m. 7. 00 and a. m. 6. 00 for 4 days.

ture in the nighttime, apple trees were enclosed in a pipe frame greenhouse covered with a 0. 1 mm clear polyvinyl chloride film, in which a warm-air heating apparatus with a thermostat was operated during the night. The temperature treatments shown in Table 1 were continued for 4 days as follows, respectively ; A : from May 30 (20 days after full bloom (AFB)), B : from June 6 (27 days AFB) and C : from June 13 (34 days AFB) in 1983. The polyvinyl film covering the pipe-house was opened during the day to avoid extremely high temperature and excessive shading of the trees. For the test of shading in the daytime, apple trees were enclosed in a similar pipe-house covered with a cheesecloth whose shading ratio was 51%. The shading treatments were applied continuously for 4 days as follows ; A, B and C as mentioned above and D : from June 20 (41 days AFB).

Central flowers of a cluster which were hand-pollinated with the pollen of 'Ohlin' on May 10 when they were in full bloom were used in the experiment and all the lateral fruits of a cluster were thinned on May 26. The fifty fruits and the twenty terminal shoots which had grown uniformly were marked just before the treatments. The terminal shoots were selected in the same manner as in the previous report(16). The number of fruits remaining on the trees was recorded regularly from the beginning of each treatment to the day when fruit abscission ceased. The diameter of the fruit equatorial part and the elongation of the terminal shoots were measured every day during the treatments for 4 days. In addition, the reducing sugar contents of the following fruits were analyzed every week from June 3 (24 days AFB) ; A : fruits growing uniformly under natural environmental conditions, B : fruits growing uniformly under high night temperature conditions for 4 days, C : fruits growing uniformly under shading for 4 days, D : fruits with interrupted growth, E : fruits with yellow peduncle. The fruits were ground into a fine powder after freeze-drying and kept at −20℃ till analysis. The Determination of the reducing sugar content was performed by applying the Somogyi-Nelson's method.

2. *Ethylene evolution and carbon dioxide production from young fruits and effect of AVG on fruit abscission*

The fruits for ethylene and carbon dioxide analysis at 13℃, 20℃ and 25℃ were collected every week from May 31 (21 days AFB) in 1983. The effect of AVG on fruit abscission was investigated under both the high night temperature and shading treatments in 1984. Nine-year-old 'Starking Delicious' apple trees grafted on 'M 26' rootstocks were used. The high night temperature treatment was applied continuously for 7 days from June 14 (19 days AFB) and shading was applied for 5 days from June 13 (18 days AFB), respectively. Fifty fruits for each treatment were sprayed with a 200 ppm AVG solution containing 0. 1% Atlox BI on June 13. The number of fruits remaining on the trees was recorded at regular intervals until July 7. On the other hand, the fruits grown under natural environmental conditions were spray-

ed with a 200 ppm AVG solution mixed with 0.1% Atlox BI on June 13 and ethylene and carbon dioxide production from the fruits was regularly analyzed.

Three fruits, whose transverse diameters were approximately the same, were enclosed in 100-300 ml glass vials after the determination of the fruit weight. The fruits in the sealed vials were kept in the dark in a controlled room at 20°C for 15 hours. Two ml gas sample for ethylene and carbon dioxide analysis was collected from the head-space in the vials by a pressure-lock gas syringe. Ethylene and carbon dioxide concentrations were estimated by gas-chromatography(Hitachi Model 163) under the following conditions ; column, porapak Q(80-100 mesh), steel column, 3 mm$\phi$×2 m ; column temperature, 60°C ; carrier gas, He 30 ml/min.; injection temperature, 70°C ; detector, TCD (carbon dioxide), FID (ethylene).

## Results

1. *Effects of high temperature in the nighttime and shading in the daytime on fruit abscission, fruit growth and elongation of terminal shoots*

Fig. 1 shows the effects of high night temperature (HNT) and shading on fruit abscission. In the treatments applied 20 days AFB, the mean night temperature under HNT was 3.4-6.9°C higher than that under natural environmental conditions (NEC). The final rate of fruit abscission amounted to 18.0% under HNT and 26.0% under NEC. The fruits on the trees under shading showed a high rate of abscission 3-5 days after the treatment and the final rate amounted to 90.0 %. In the treatments applied 27 days AFB, the mean night temperature under HNT was 4.0-5.6°C higher than that under NEC. The fruits under HNT underwent abscission 8 days after the treatment and the final rate of fruit abscission amounted to 34.0%. The fruits under NEC did not show any evidence of abscission. The fruits on the trees under shading experienced abscission 3 days after the beginning of the shading and the final rate of fruit abscission amounted to 36.0%. In the treatments applied 34 days AFB, the mean night temperature under HNT was 4.7-6.4°C higher than that under NEC. The fruits under both the HNT and shading underwent abscission 5 days after the treatment and the final rate of fruit abscission was 12.0 % and 22.0%, respectively. The fruits under NEC did not display abscission. In the treatments applied 41 days AFB, the fruits failed to experience abscission under both the shading and NEC. Thus, although the HNT applied 20 days AFB did not induce fruit abscission, the HNT applied 27 days AFB and the shading applied 20 days AFB affected most severely fruit abscission, and thereafter, these effects reduced when the treatment was delayed, respectively.

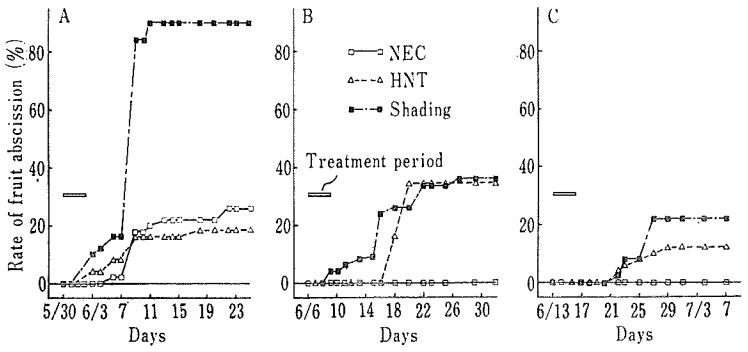


**Fig. 1.** Effects of high night temperature and shading treatments on fruit abscission (1983). The treatments were applied for 4 days from (A) : 20 days, (B) : 27 days and (C) : 34 days after full bloom, respectively. NEC : Natural environmental conditions. HNT : High night temperature.
Rate of fruit abscission is expressed as % of fruits treated.

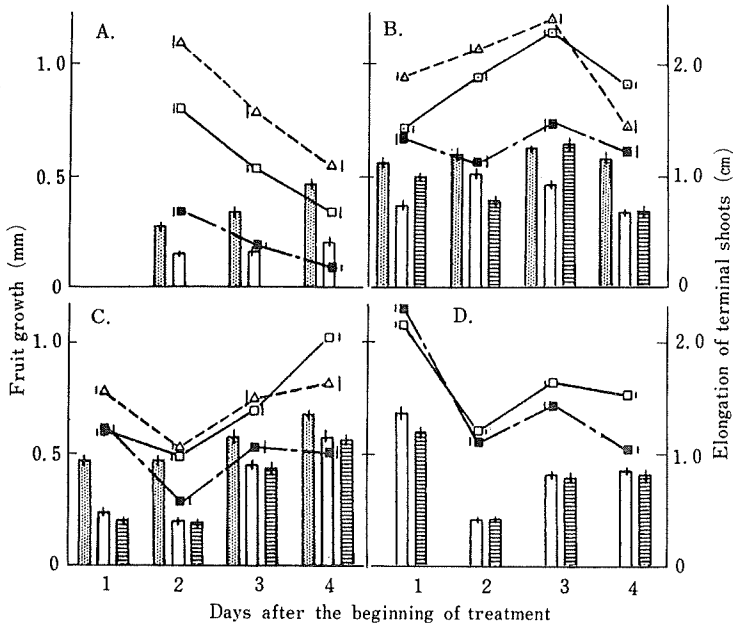


**Fig. 2.** Effects of high night temperature and shading treatments on the daily rate of fruit growth and elongation of terminal shoots (1983).
The treatments were applied for 4 days from (A) : 20 days, (B) : 27 days, (C) : 34 days and (D) : 41 days after full bloom, respectively. Vertical bars indicate S. E..

Fig. 2 shows the effects of these treatments on fruit growth and elongation of terminal shoots. The daily rate of fruit growth and elongation of terminal shoots increased under HNT. However, in the treatment applied 27 days and 34 days AFB, several fruits under HNT ceased growing, and the fruit growth rate on the 4 th day after the beginning of HNT decreased in comparison with that under NEC. These fruits under HNT exhibited abscission within 10 days. On the other hand, the daily rate of fruit growth under shading decreased regardless of the time of treatment. But the shading had little effect on the elongation of the terminal shoots. The reducing sugar content per gram dry weight of fruit hardly differed between the fruits, but the content per fruit was lower in the fruits under shading, in the fruits with arrested growth and a yellow peduncle (Table 2).

**Table 2.** Reducing sugar content of fruits collected at various stages (1983)

| Fruit | Jun. 3 (24 days)[z] | Jun. 10 (31 days) | Jun. 17 (38 days) | Jun. 24 (45 days) |
|---|---|---|---|---|
| A | 26.0[y] | 33.2 | 40.3 | 49.1 |
| | ( 9.4)[x] | (25.7) | (46.8) | (113.3) |
| B | 26.3 | 35.1 | 42.0 | |
| | (10.1) | (28.4) | (57.6) | |
| C | 28.1 | 35.1 | 42.1 | 48.4 |
| | ( 5.0) | (20.4) | (47.3) | (112.4) |
| D | 27.2 | 37.6 | 40.5 | 48.9 |
| | ( 3.7) | (10.7) | (20.1) | ( 46.3) |
| E | 26.0 | 34.0 | 41.5 | 48.2 |
| | ( 2.3) | ( 8.2) | (14.0) | ( 41.7) |

A : Fruit growing uniformly under natural environmental conditions.
B : Fruit growing uniformly under a high night temperature for 4 days.
C : Fruit growing uniformly under shading for 4 days.
D : Fruit with interrupted growth.
E : Fruit with yellow peduncle.
[z] Days after full bloom
[y] mg/gram d. w. [x] mg/fruit

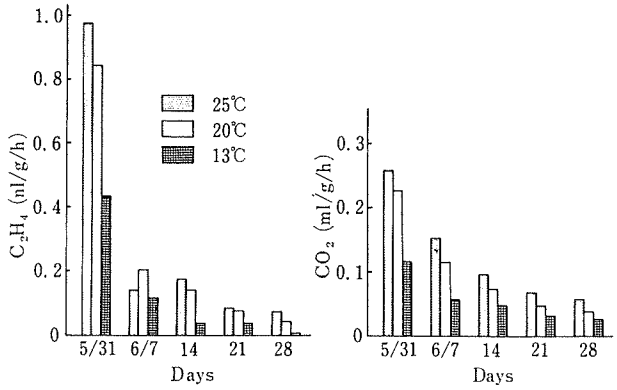


**Fig. 3.** $C_2H_4$ and $CO_2$ production from fruit under various temperature conditions (1983). Young fruits were collected every week from 21 days after full bloom (May 31) and kept at 25°C, 20°C and 13°C for 15 hours, respectively.

**Table 3.** Effect of AVG application on the $C_2H_4$ evolution and $CO_2$ production from fruit (1984).

| treatment | $C_2H_4$ nl(×10³)/g/h | | | | | | $CO_2$ ml(×10³)/g/h | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jun. | | | | | | Jun. | | | | | |
| | 15 | 17 | 20 | 23 | 26 | 29 | 15 | 17 | 20 | 23 | 26 | 29 |
| AVG | 144 | 5 | 5 | 2 | 19 | 18 | 119 | 89 | 71 | 78 | 86 | 51 |
| control | 167 | 29 | 43 | 24 | 22 | 15 | 110 | 86 | 75 | 71 | 79 | 44 |

AVG (200 ppm solution) was applied on Jun. 13 (18 days after full bloom).

2. *Ethylene evolution and carbon dioxide production from young apple fruits and effect of AVG on fruit abscission*

Fig. 3 shows the ethylene and carbon dioxide production from young fruit under various temperature conditions. Ethylene evolution and carbon dioxide production per fruit weight were greater at the young stage of fruit and increased with the increase of the environmental temperature. The ethylene evolution from fruits sprayed with AVG decreased markedly and was inhibited from 1/6 to 1/12 for 3-9 days after AVG application (Table 3). However, the effect of AVG application on the carbon dioxide production from fruit was uncertain.

Fig. 4 shows the effect of AVG on fruit abscission. Under HNT where the mean night temperature for 7 days was 24.1°C, the abscission rate of the fruits sprayed with AVG was 14.0% whereas that of the fruits which had not been sprayed with AVG was 46.0%. Thus, AVG application markedly reduced fruit abscission under HNT. On the other hand, the abscission rate of the fruits sprayed with AVG was 78.0% whereas that of the fruits without AVG spraying was 85.0 % under shading applied for 6 days, and the effect of AVG application was a little under shading.

## Discussion

In this report, it was confirmed that fruit abscission was induced by the short HNT and shading treatments for about 40 days AFB. It was previously reported that the fruit growth rate increased by HNT applied from the early stage of fruit development(26, 28). The results of this study are in agreement with the reports mentioned above and the elongation of the terminal shoots was also increased by HNT. Thus, the fruit size and vegetative growth were stimulated at a high minimum temperature but fruit abscission was also induced. Therefore, the effect of the temperature on ethylene and carbon dioxide production from young fruits was investigated, and it was shown that the production increased with the increase of the temperature. A large number of reports have indi-

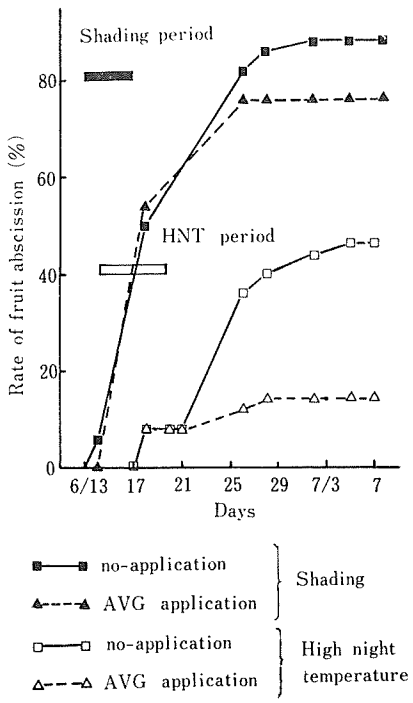


**Fig. 4.** Effects of AVG application under high night temperature and shading treatments on fruit abscission (1984).
AVG (200 ppm solution) was applied on June 13 (18 days after full bloom). The high night temperature treatment (HNT) was applied on Jun. 14-20. The shading treatment was applied on Jun. 13-17.

cated that fruit abscission is induced by ethylene(3, 4, 5, 18, 20, 29, 31). Chiba and Kubota(3) reported that physiological fruit abscission was related to ethylene evolution in apple fruits and was accelerated in cultivars with a high ethylene evolution. In this study, AVG application markedly reduced ethylene evolution from fruit, although the effect on carbon dioxide production was uncertain, and fruit abscission was reduced under HNT. These results suggest that ethylene evolution is closely related to fruit abscission.

Schneider(24) reported that the translocation of sucrose from foliage to fruit in peach was reduced by ethephon application. Weinbaum *et al.* (29) also showed that the transport of IAA and sucrose through the peach pedicel was reduced by ethephon application and these effects were more pronounced in smaller fruits. Moreover, Iwahori and Oohata (14) indicated that the cellulase activity in the leaf abscission zones of 'Satsuma' mandarin was enhanced by ethephon application. Several reports on the effects of AVG on fruit abscission indicate that the fruit set was promoted by the spraying of a 200 ppm solution on trees in full bloom(7, 11), by the application of a 1000 ppm AVG two weeks AFB(30), 250 ppm AVG on trees in full bloom(12) and 500 ppm AVG in the preharvest period of the preceding year(13). Although in these reports the time of application and the concentrations varied, the early drop of fruit was inhibited by all the applications of AVG. Williams(30) and Greene(11) showed that the promotion of fruit set by AVG application was associated with the reduction of endogenous ethylene production. According to these reports and the results of this study, it appears that fruit abscission of trees under HNT was caused by the following mechanism. Since the consumption of nutrients in the tree increased with the increase of the vegetative growth and respiration rate, competition among fruits took place. In addition, a large amount of ethylene was produced under a HNT and ethylene evolution affected the translocation of nutrients(24, 29), plant growth substances(29) and the formation of an abscission layer(14). As a result the fruits whose supply of nutrients was lower underwent abscission.

Nito(20) reported in grape fruit that ethylene evolution was induced with the increase of the auxin content, and that an abscission layer was formed leading to fruit abscission. However, Fukui *et al.* (9) indicated that in apple fruit ethylene evolution and the formation of an abscission layer were not observed immediately after the interruption of fruit growth, suggesting that these factors were not the primary factors causing fruit abscission. Moreover, Greene(12) indicated that AVG application in the preharvest period which promoted the fruit set in the following year did not affect the ethylene levels in the flowers, fruits and leaves produced in the following year. Thus, the mechanism controlling fruit abscission by ethylene has not yet been fully elucidated. In the current ex-

periment, AVG application under shading hardly inhibited fruit abscission. Therefore, studies should be carried out on the other factors responsible for the reduction of fruit abscission as well as on the inhibition of ethylene evolution.

The results of the current experiment indicate that the reducing sugar content per gram dry weight of fruit showed few differences among the fruits but that the content per fruit was lower in the fruits under shading compared with the fruits under NEC. Furthermore, the daily rate of fruit growth was decreased and fruit abscission was promoted in the trees under shading. Kuroda *et al.* (17) reported that the set of peach fruits supplied with sucrose was promoted. Schneider(23) also showed that the reduced translocation of sucrose was an important factor in fruit abscission. Besides, it has been shown that although the compensation point of apple leaves is less than 2% of full sunlight(107600 lux) (15), the leaves require the light intensity of about 15000 lux for sufficient assimilation(1) and net photosynthesis of leaves on 'Delicious' trees increases with the light intensity(19). These results tend to suggest that the supply of metabolites to fruit was reduced under shading, and that fruit abscission was induced.

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# 夜間高温および遮光がリンゴ‘スターキング・デリシャス’の早期落果に及ぼす影響

近藤 悟・高橋 佑治
秋田県果樹試験場鹿角分場 018-52 鹿角市花輪

## 摘 要

‘スターキング・デリシャス’を用い，前報にもとづき早期落果の程度を助長する気象条件について調査した．満開後20日，27日および34日から開始した夜間高温処理を，また，満開後20日，27日，34日および41日の各々から開始した遮光処理を，それぞれ4日間づつ同時間処理し，果実の落果率や肥大度，新梢伸長などに及ぼす影響を調査した．また，AVG 散布の果実落果に及ぼす影響についても検討した．

夜間高温処理は，果実肥大および新梢伸長を増加させた．しかしながら，満開27日後，34日後からの処理は果実落果を増加させ，特に満開27日後からの処理の影響が大きかった．一方，遮光処理は，満開20日後，27日後および34日後からの処理が落果を誘発し，処理開始とともに果実肥大を抑制した．果実あたりの糖含量は，遮光処理下の果実，肥大の停止した果実および果梗の黄変した果実で低かった．

果重あたりのエチレン発生量および呼吸量は，生育のステージが早いほど，また温度が高いほど多くなった．