한국농림기상학회지, 제5권 제4호(2003)
*Korean Journal of Agricultural and Forest Meteorology*, Vol. 5, No. 4, (2003), pp. 218~225

# Fruit Quality of 'Tsugaru' Apples Influenced by Meteorological Elements

**Hyeong-Ho Seo[1] and Hee-Seung Park[2]**
[1]*Fruit Tree Cultivation Division, National Horticulture Research Institute, RDA, Suwon 440-706, Korea*
[2]*Division of Biological Science and Resources, Chung-ang University, Anseong 456-756, Korea*

# 사과 '쓰가루' 품종의 과실 품질에 영향을 미치는 기후요인

**서형호[1] · 박희승[2]**
[1]농촌진흥청 원예연구소 과수재배과
[2]중앙대학교 원예과학과

**ABSTRACT**

**An analytical study was conducted in 2002 to observe the relationship between meteorological elements and the fruit quality of 'Tsugaru' apples at 8 orchards. The higher average air temperature in August made a higher content of soluble solids, but showed a lower anthocyanin content. As the average air temperature from April through August increased, flesh firmness decreased; and as the maximum air temperature from April through August increased, Hunter a value also decreased. Additionally, it was observed that the cytohistological characteristics of 'Tsugaru' apples were correlated with the average air temperature during the growing season. As average air temperature during the growing season increased, the epidermal layer of the fruit skin became thinner, starch density in the flesh decreased, intercellular space was larger, and tissue structure became looser.**

***Key words** : apple trees, meteorological element, fruit qualities, cytohistological characteristics*

## I. INTRODUCTION

Although orchards in the United States, Europe, and Japan produced higher quality fruits as 80 percent of their total production, orchards in Korea made those fruits as mere 20 to 40 percent (Choe, 1996; Park *et al.*, 1998), which might be a result of inappropriate cultural methods including excessive fertilization, improper training techniques, and unsuitable fruit management. However, it was more likely that unsuitable orchard sites were more responsible for the poorer fruit quality.

In A Statistical Survey of Fruit Trees, Ministry of Agriculture, Forestry, and Fisheries (MAF) reported that apple orchards were distributed widely throughout the Korean peninsula up to the 1980s, but later orchards were grouped in certain areas such as the north province of Gyeongsangbuk-do (MAF, 1983, 1987, 1992, 1997). These facts could explain the straggling of the improper orchard sites and the remaining of the suitable ones (Kim *et al.*, 1991). Jang *et al.* (2002) and Yun *et al.* (2001a, 2001b) insisted that weather conditions could affect the growth of fruit trees and also might influence fruit quality. Therefore, weather conditions would be one of the major factors in determining fruit quality. In spite of its importance, the study of meteorological elements for fruit trees has not been sufficiently carried out except for some climatic damage like freezing injury (Kang *et al.*, 1987; Shin *et al.*, 1987). There have been few studies of the relationship of meteorological elements to tree physiology and fruit quality.

Consequently, this study was carried out to analyze

Corresponding Author: Hee-Seung Park(koussa@post.cau.ac.kr)

the relationship between meteorological elements and fruit quality for 'Tsugaru' apples at 8 orchards in 2002, and to prove the effect of weather conditions on fruit skin development. Then this study will contribute to the theoretical establishment for orchard management with a consideration of weather conditions.

## II. MATERIALS AND METHODS

### 2.1. Selection of surveying sites and collection of meteorological data

Eight orchards were selected for this study. Seven were located in the north part of Gyeongsangbuk-do: Bonghwa (two orchards), Yeongju (two orchards), Uiseong (two orchards), and Gunwi (one orchard). The eighth was in Suwon, Gyeonggi-do (Fig. 1, Table 1). All selected orchards had similar tree age and vigor.

To observe meteorological elements, automated weather stations (AWS's) with the same equipment were established in the orchards in Gyeongsangbuk-do, and the local meteorological data of Suwon were collected from the Meteorological Administration in Suwon. Meteorological data were collected from January through September 2001, and the data collected from April through August were analyzed for this study. All data were measured every 60 seconds and stored with the mean and accumulated value in one-hour intervals. The 24-hour average, maximum, and minimum air temperature data were stored at 0 o'clock.

At 120 days from full-bloom, those fruits having regularity in size, shape and skin coloring were harvested from every orchard. Fruiting position in the canopy was also considered so as to represent the characteristics of each orchard.

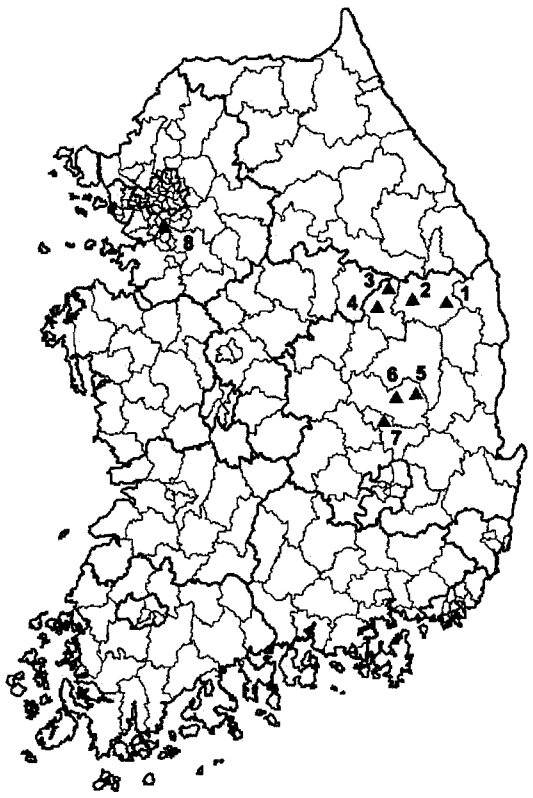



**Fig. 1.** Map of study area with locations of observed 'Tsugaru' apple orchards (local names are those listed in Table 1).

To measure the content of soluble solids and titratable acidity, juice was extracted from each fruit. The content of soluble solids was measured by the use of a digital refractometer, PR-100 (Atago, Japan). Titratable acidity was determined; NaOH was inserted into the extracted juice to titrate pH 7.0 to 8.1, and later, the inserted amount of NaOH was calibrated to yield the amount of

**Table 1.** Locations of observed 'Tsugaru' apple orchards.

| Station ID | Observation site | Elevation (m) | Tree age (year) | Slope (°) | Aspect (°) | Latitude (DD)[z] | Longitude (DD)[z] |
|---|---|---|---|---|---|---|---|
| 1 | Bongwha Myungho | 540 | 20 | 10 | SW | 36.4820 | 128.5134 |
| 2 | Bongwha Mulya | 460 | 15 | 7 | E | 36.5831 | 128.4659 |
| 3 | Youngju Busuk | 400 | 15 | 5 | SE | 37.0010 | 128.3911 |
| 4 | Youngju Bonghyun | 330 | 15 | 10 | S | 36.4811 | 128.3100 |
| 5 | Uiseoung Oksan | 290 | 18 | 2 | SW | 36.2334 | 128.4557 |
| 6 | Uiseoung Danchon | 150 | 20 | 2 | S | 36.2505 | 128.4557 |
| 7 | Gunwi Sobo | 100 | 12 | 4 | SE | 36.1629 | 128.2759 |
| 8 | Suwon Imok | 70 | 15 | 2 | S | 37.1822 | 126.5847 |

[z] DD : decimal degree

malic acid. Flesh firmness was measured by the use of a 5 mm hardness meter (FHM, Japan) at the two points on equator level after peeling the fruit skin.

Ten fruits with regular skin coloring were harvested, and ten disks of fruit skin were collected by the use of a cork borer (1.1 mm). Those disks were immersed in a mixing solution of 0.1 N HCl and 100% ethanol (15:85 V/V) for 24 hours. Later, light absorption was measured with a 535 nm spectrophotometer (UV-2501 PC, Shimadzu) to determine anthocyanin content by the Fuleki and Francis method (1968a, 1968b). To establish chlorophyll content, disks prepared by the same method described above were immersed in a solution of 100% MeOH for 24 hours in the dark and then anthocyanin was removed by the use of PVPP (Poly Vinyl Poly Pyrrolidone). After the treatment, light absorption was observed at 651 nm and 664 nm by spectrophotometer (UV-2501 PC, Shimadzu).

Skin coloring was determined from 20 fruits of each orchard using a spectrophotometer (CM-508im Minolta, Japan) in Hunter L, a, b mode. The results were the mean value of the two samples at the equator of each fruit.

### 2.3. Analyzing the relationship between meteorological elements and fruit quality

The growth stage of 'Tsugaru' apple fruits was divided with the entire development stage as from April through August, and ripening stage as from July through August. The latter period was divided into 15-day intervals. Meteorological elements (average, maximum and minimum air temperature, and accumulated air temperature) collected from AWSs were analyzed for correlation with fruit characteristics (L/D rate, content of soluble solids, titratable acidity, flesh firmness, the content of anthocyanin and chlorophyll, and Hunter a value). Linear regression was used to express significant correlations.

### 2.4. Cytohistological observation for fruit skin of 'Tsugaru' apples

To find out the difference of the cytohistological characteristics of 'Tsugaru' apples according to different local weather conditions, three fruits of each orchard were collected to evaluate distinguishable characteristics (Fig. 1, Table 1; Station ID 1, 3, 5, 7).

Skin disks from every fruit were treated with the first fixation of 2.5% glutaraldehyde and with a second fixation of 1% osmic acid. Then, disks were laid in a silicon mold of 60°C with epon+D.M.P. 30 for 4 days after dehydration by ethanol. 10~15 epon blocks of 3 fruits of each orchard were prepared, and these disks were cut at a thickness of 1,500 nm by the use of ultramicrotome (Ultracut R, Leica Co). The prepared disks were dyed with Schiff's reagent after they were dried on a slide glass. The disks were observed and photographed 24 hours following the application of polymount and cover glass. Skin tissue was analyzed using the photographed results described above.

## III. RESULTS AND DISCUSSION

### 3.1. Local weather conditions for experimental sites

**Table 2.** Local meteorological elements measured by AWS in the 8 site of the 'Tsugaru' apple orchards during growing season from April to August in 2002.

| Station ID | Elevation (m) | Air temperature (°C) | | | | Cumulative rainfall (mm) | Cumulative sunshine duration (hr) | Cumulative solar radiation ($MJ/m^2$) |
|---|---|---|---|---|---|---|---|---|
| | | Avg. | Max. | Min. | Diurnal range | | | |
| 1 | 540 | 17.7 | 23.0 | 13.4 | 9.6 | 1,105 | 813 | 2,415 |
| 2 | 460 | 17.9 | 23.8 | 12.8 | 11.1 | 1,108 | 745 | 2,242 |
| 3 | 400 | 18.7 | 24.7 | 13.9 | 10.8 | 1,228 | 725 | 2,173 |
| 4 | 330 | 18.9 | 24.9 | 13.9 | 10.9 | 767 | 624 | 1,851 |
| 5 | 290 | 18.9 | 25.9 | 12.3 | 13.6 | 693 | 835 | 2,456 |
| 6 | 150 | 19.0 | 26.3 | 12.3 | 14.0 | 2,829 | 780 | 2,328 |
| 7 | 100 | 19.5 | 25.7 | 13.9 | 11.8 | 1,020 | – | 1,424 |
| 8[z] | 70 | 19.8 | 24.5 | 15.6 | 8.9 | 1,032 | 853 | 2,559 |

[z] Reference station of Korea Meteorological Administration in Suwon

The local weather conditions were compared among the seven orchards in Gyeongsangbuk-do and one orchard in Gyeonggi-go (Table 2).

The average air temperature from April through August was lower at the higher altitude, and the difference between the average air temperature at 540 m and 100 m was 1.8°C . A regular tendency was not found between increasing altitude and decreasing maximum or minimum air temperature. It could be thought that the irregular tendency might result from different weather conditions between the experimental sites and the meteorological observation stations. The diurnal range decreased as the altitude increased from 150 m to 540 m.

There was a four times difference between the maximum and minimum amount of rainfall, and there were 230 hours' difference between the maximum and minimum sunshine duration during the growing season.

Additionally, 1,135 MJ/m$^2$ accumulation difference was found in solar radiation between the experimental sites. These facts showed the various differences in comparing the local meteorological elements.

### 3.2. Relationship between meteorological elements and fruit quality of 'Tsugaru' apples

Those fruits surveyed in this study were harvested 120 days after full bloom, and the relationship between the local weather conditions and fruit quality was analyzed. The significant correlation was expressed as the linear regression shown in Fig. 2.

The content of soluble solids for 'Tsugaru' apples had a positive correlation with the average air temperature of August. An average air temperature of August above 22°C was thought necessary to obtain 'Tsugaru' apples of superior quality (Shin *et al.*, 1993). Higher average air temperature in August may not always correspond with higher content of soluble solids in 'Tsugaru' apples because the content of soluble solids might be affected by not only cultural techniques such as fertilization but also weather conditions. Nevertheless, the reason for significant correlation

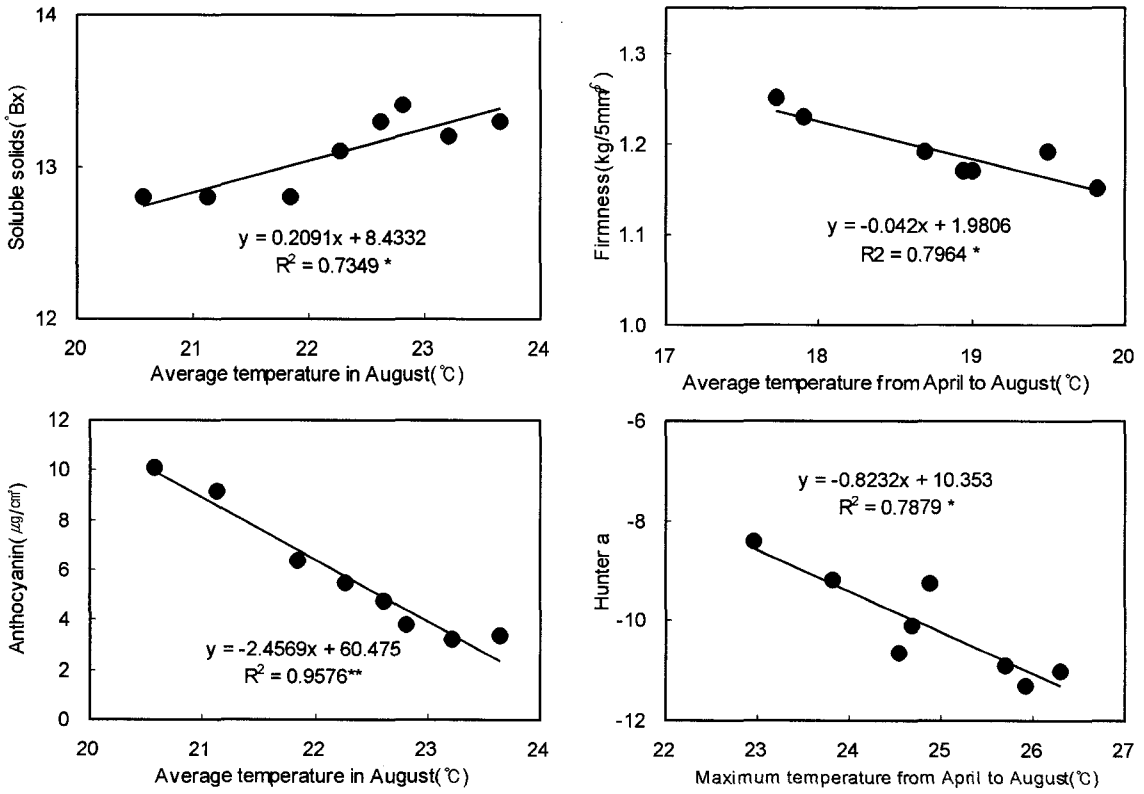



**Fig. 2.** Regression of the soluble solids, flesh firmness, anthocyanin contents and Hunter a value in 'Tsugaru' apple against selected climatic variables in 2002. *Significant at 5% level, **Significant at 1% level.

could be explained by the shorter ripening period, which could express the importance of weather conditions as well as cultural techniques. From our results, meteorological elements appear to affect the content of soluble solids. Similar results reported that the different conditions of cultural sites and the variation of cultural season could influence fruit quality including the content of soluble solids (Marguery and Sangwan, 1993; Yamada *et al.*, 1998). Therefore, more detailed research is needed with various harvesting times, weather conditions, and cultural techniques.

Flesh firmness of 'Tsugaru' apple fruits showed a negative correlation with the average air temperature from April through August. Flesh firmness might be the major factor in longer storability and marketing time. Japanese farmers classified the fruits for storing or marketing according to producing area (Kim *et al.*, 1990). The local weather conditions had a close relationship with flesh firmness affecting fruit storability. As fruits ripened, flesh firmness was significantly decreased with the rapid increasing of respiration which took an important role in the process of ripening and ethylene activity.

Anthocyanin content in the fruit skin had a negative correlation of high significance with the average air temperature of August. Lower air temperature likely contributes to form and the revealing of anthocyanin (Lee, 1999; Tomana and Yamada, 1988) that is closely related to forming red skin color (Arai, 1998). Therefore, it could be thought that the proper sites for 'Tsugaru' apple orchards might be in the north part of Gyeongsangbuk-do. A similar relationship was found between Hunter a value and the maximum air temperature from April through August. Thus, it was possible to decide that lower air temperature might be more suitable for the expression of red fruit skin.

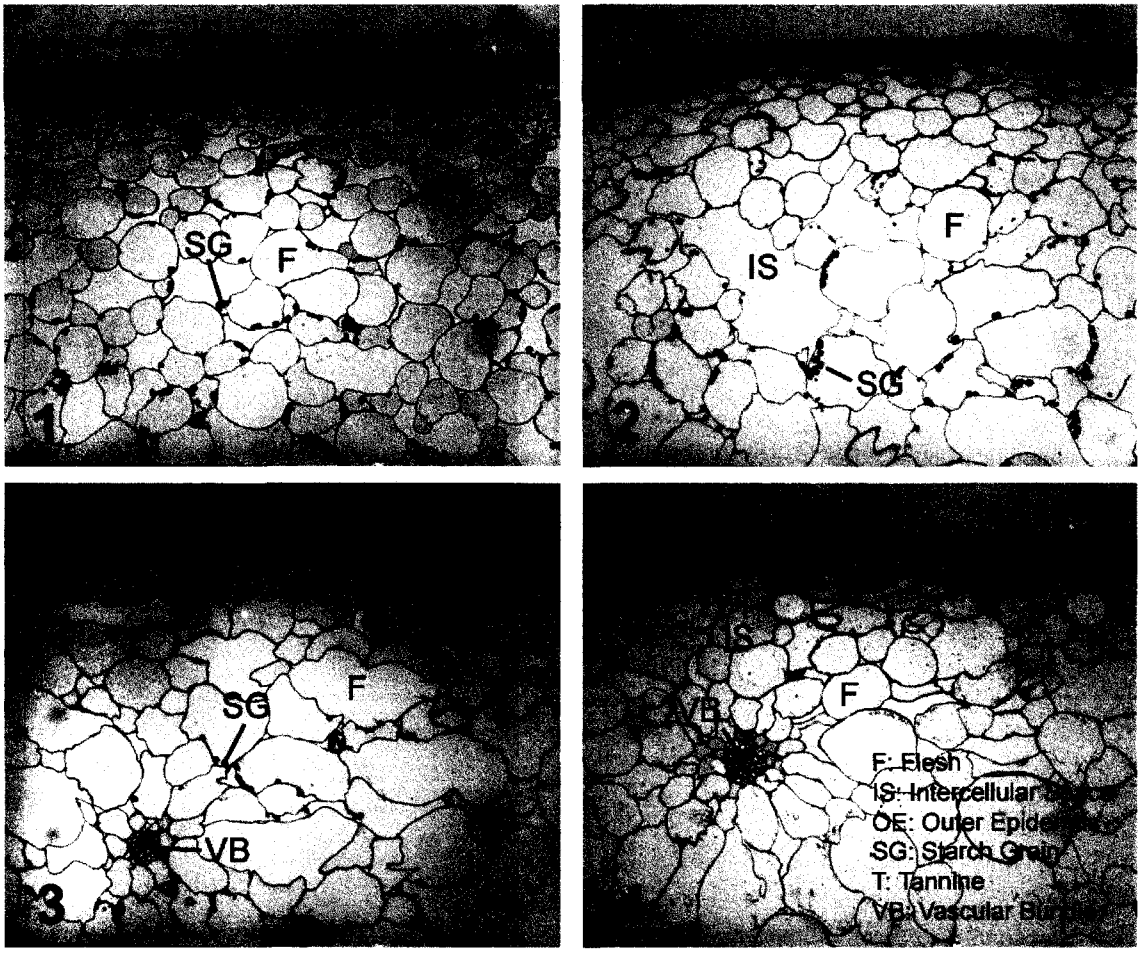
Consequently, some relationship between fruit quality such as the content of soluble solids, flesh firmness, anthocyanin content and Hunter a value, and meteorological elements was found. A regressive model of meteorological elements and fruit quality of 'Tsugaru' apples was derived:

Content of total soluble solids (°Bx)
..... $Y = 8.433+0.209x$
(x = average air temperature in August)
Flesh firmness (kg/5mm)
..... $Y = 1.981+0.042x$
(x = average air temperature from April through August)
Anthocyanin content ($\mu g/cm^2$)
..... $Y = 60.475-2.457x$
(x = average air temperature in August)
Hunter a value
..... $Y = 10.353-0.823x$
(x = maximum air temperature from April through August)

### 3.3. Cytohistological characteristics for 'Tsugaru' apples according to weather conditions

Fig. 3 shows the cytohistological difference in fruit skin of 'Tsugaru' apples according to average air temperatures during the growing season. Increasing average air temperature 1°C made a significant difference in fruit skin. The fruit with the highest average air temperature had one layer of outer epidermis and two or three layers of inner epidermis. As average air temperature decreased, the inner epidermis increased. It was observed that lower air temperature could induce a thicker epidermal layer. It was also found that the average air temperature could result in a different cell number and in structural differences of fruit skin tissue. Fruit skin cells at higher average air temperature had larger intercellular space and showed less tight tissue than those at lower average air temperature. Consequently, it was thought that the accumulation of anthocyanin might be affected by the structural factors such as the thickness and the number of fruit skin colls, and the accuracy of fruit skin tissue. Similar results were obtained by comparing the color degree of fruit skin according to the accuracy of fruit skin layer of 'Fuji', 'Hongro', and 'Jonathan' (Lee, 1999).

Starch distribution in flesh tissue showed a clear difference according to average air temperature, and an increased starch amount could be found in the tissue at lower air temperatures during the growing season. This implies that a different maturity of fruit might influence the starch content of fruit skin tissue. Cherrad and Park (1998) predicted that the starch content of a fruit would increase as fruit ripening proceeded, but content rapidly decreased with the process of skin coloring and there was little content at maturity. Additionally, Park and Park (2000) indicated that starch content steadily increased from full bloom to 158 days after full bloom, and decreased rapidly at maturity in 'Fuji' apples. Accordingly, the starch content at different average air temperatures might be related to fruit maturity.




| Picture ID | Elevation (m) | Air temperature April to August (°C) Avg. | Max. | Min. | Diurnal range | Cumulative rainfall (mm) | Cumulative solar radiation ($MJ/m^2$) | Soluble solids ($°Bx)^z$ | Hunter $a^z$ | Firmness $(kg/5\ mm)^z$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 540 | 17.7 | 23.0 | 13.4 | 9.6 | 1,105 | 2,415 | 12.8 | −8.4 | 1.25 |
| 2 | 400 | 18.7 | 24.7 | 13.9 | 10.8 | 1,228 | 2,173 | 12.8 | −10.1 | 1.19 |
| 3 | 290 | 18.9 | 25.9 | 12.3 | 13.6 | 693 | 2,456 | 13.3 | −11.3 | 1.17 |
| 4 | 100 | 19.5 | 25.7 | 13.9 | 11.8 | 1,020 | 1,424 | 13.2 | −10.9 | 1.19 |

[z] harvesting time : August 30

**Fig. 3.** Cross sectional features of 'Tsugaru' apples influenced by different climatic conditions described in 4 orchards seen by optical microscope in August 2002.

At higher temperatures the soluble solids content was higher and fruit ripened earlier. However, comparing skin coloring, those fruits with higher average air temperature showed later fruit development. These results did not agree with the report that the accumulation of anthocyanin was closely related with the increasing of starch content (Williams, 1946), but Tomana and Kataoka (1979) had reported that anthocyanin content decreased with increasing air temperature regardless of starch content. Moreover, Kataoka *et al.* (1982) also reported that if other conditions were favorable, accumulation of anthocyanin

proceeded regardless of the starch amount. This supports the conclusion that fruits at lower average air temperature show higher Hunter a values and produce more fruits with better color.

It was concluded that the air temperature, within a certain range, affects not only anthocyanin formation, but also the development of fruit skin tissue. In addition, air temperature affects the space forming for the accumulation of anthocyanin. This study demonstrates that further research to quantify the environmental impacts on fruit quality is needed and is likely to be of direct value to apple production in Korea.

## IV. CONCLUSION

These studies showed that local weather conditions varied significantly according to orchard sites. These weather conditions affect fruit quality directly or indirectly. That is, it was observed that soluble solid content and anthocyanin content were differed according to the average air temperature in August with certain relationships. Moreover, certain relationships were also perceived in flesh firmness to average air temperature from April to August and Hunter a value to maximum air temperature from April to August. The model gives a quantitative estimate of the extent of weather influence on cytohistological characteristics. The temperature influence on epidermal layers and cell size, together with the model results, appears to explain much of the variability of fruit quality observed within the production zones observed.


### 적 요

본 실험은사과원의 위치에 따라 국지기후조건이 다양함을 보여주었으며, 이와 같이 다양한 기후환경은 과실의 품질에 직간접적으로 많은 영향을 미치고 있는 것으로 조사되었다. 즉, 당함량과 anthocyanin 함량은 8월의 평균기온에 따라 다른 것으로 나타났으며 일정한 상관관계를 가지고 있었다. 또한 4월에서 8월까지의 평균기온과 과육의 경도 사이에 일정한 상관이 인정 되었으며, 4월에서 8월까지의 최고기온과 Hunter a 값 사이에도 상관관계가 인정되었다. 이러한 기후조건의 범위는 세포조직학적 특성에도 영향을 미쳤으며, 온도는 과피층 세포의 수와 크기에 영향을 주었다. 따라서, 사과 주산지의 과실 품질은 기후의 영향을 크게 받아 매우 다양하게 나타나는 것으로 조사되었다.


## REFERENCES


Arai N., 1998: *Fruit growth and development*. Asakura Co. Tokyo. Japan. p.1–8.

Cherrad. M. and H.S. Park, 1996: Starch in the ovaries, flowers, and berries of 'Cabernet-Sauvignon' and 'Merlot' grapevines during the development of fruits. N° Hors Série du *J. Int. Sci. Vigne Vin*, La Viticulture à l'aube du III$^{e}$ millénaire, 59–63.

Choe, U., 1996: *The tendency of apple cultivation for main competition countries: The tendency of American apple industry and the corresponding vision of Kyungbuk apple industry*. Taegu apple research Institute, Rural Development Administration(RDA), 82pp.

Fuleki, T. and F.J. Francis, 1968a: *Quantitative methods for anthocyanins. 1. Extraction and determination of total anthocyanin in cranberries. J. Food Sci.*, **33**, 72–77.

Fuleki, T. and F.J. Francis, 1968b: Quantitative methods for anthocyanins. 2. Determination of total anthocyanin and degradation index for cranberry juice in cranberries. *J. Food Sci.*, **33**, 78–83.

Kang, H.I., H.H. Seo and S.J. Park, 2002: Strategy for fruit cultivation reseach under the changing climate. *Kor. J. Hort. Sci. Technol.*, **20**(3), 270–275.

Kang, A.S., Y.S. Jung, and J.Y. Moon, 1987: Agroclimatological characteristics at flowering period of pear trees and a trial application of topoclimatological index for frost damage. *Res. Rept. RDA(P. M. & U.)*, **29**(2), 43–47.

Kataoka I., A. Sugiura, N. Utsunomiya, and T. Tomana, 1982: Effect of abscissic acid and defoliation on anthocyanin accumulation in Kyoho grapes (*Vitis vinifera* L. x *V. labruscana* BAILEY). *Vitis*, **21**, 325–332.

Kim, J.H. and 28 other authors, 1991: *Specifics in Pomology*. 3rd ed. Hyangmunsa. Seoul. Korea, 47–81.

Kim, J.H. and 33 other authors, 1990: *Principles in Pomology*. 3rd ed. Hyangmunsa. Seoul. Korea, 36–39.

Lee, H.C., 1999: *Physiological and ecological factors affecting fruit coloration and color enhancement in Malus domestica Borkh. cv. Fuji*. Ph. D. thesis. Seoul Natl. Univ.

Marguery, P. and B.S. Sangwan, 1993: Sources of variation between apple fruits within a season and between seasons. *J. Amer. Soc. Hort. Sci.*, **68**, 309–315.

Ministry of Agriculture, Forestry, and Fisheries, 1983: *Statistical survey of fruit trees in 1982*. Dongyangmunhwainswae Co. Seoul, Korea.

Ministry of Agriculture, Forestry, and Fisheries, 1987: *Statistical survey of fruit trees in 1987*. Dongyangmunhwainswae Co. Seoul, Korea.

Ministry of Agriculture, Forestry, and Fisheries, 1992: *Statistical survey of fruit trees in 1992*. Imungiup Co. Seoul, Korea.

Ministry of Agriculture, and Forestry, 1997: *Statistical*

*survey of fruit trees in 1997.* Dongyangmunhwainswae Co. Seoul, Korea.

Park, J.G., J.S. Hong, I.M. Choi, J.B. Kim, S.H. Kim, and H.S. Park, 1998: Applications of artificial pollination spraying gibberellin $A_{4+7}$ plus Benzxyladenine for Production of uniform fruits in 'Fuji' apples. *Kor. J. Hort. Sci. Tech.*, **16**(1), 27–29.

Park, H.S. and J.Y. Park, 2000: Development of fruit structure in 'Fuji' apples. *Kor. J. Hort. Sci. Tech.*, **18**(3), 368–372.

Shin, K.C., J.S. Choi, S.B. Kim, J.Y. Moon, and J.H. Kim, 1987: Influence of low temperature and its duration in cold injury of deciduous fruit tree. *Res. Rept. RDA(Hort.)*, **28**(1), 48–52.

Shin, Y.U., W.C. Kim, H.Y. Kim, H.S. Sea, D.S. Son, H.Y. Kim, J.J. Choi, and M.S. Yun, 1993: *Expounder on Fruit tree variety: Fruit tree variety.* Rural Development Administration. p.57–58.

Tomana T., N. Utsunomiya, and I. Kataoka, 1979: The effect of environmental temperatures on fruit ripening on the tree. II. The effect of temperature around whole vines and clusters on coloration of Kyoho grapes. *J. Jap. Soc. Hort. Sci.*, **48**, 261–266.

Tomana, T. and H. Yamada, 1988: Change in sugar composition during maturation stage of apple fruits grown at different locations. *J. Japan. Soc. Hort. Sci.*, **57**, 178–183.

Williams W.O., 1946: California vineyard fertilizer experimentation. *Proc. Am. Soc. Hort. Sci.*, **48**, 269–278.

Yamada, K., Y. Oura, H. Mori, and S. Yamaki, 1998: Cloning of NAD-dependent sorbitol dehydrogenase from apple fruit and gene expression. *Plant & Cell Physiol.*, **39**, 1375–1379.

Yun, S.H. and J.T. Lee, 2001a: Climate change impacts on optimum periods of rice plant and its countermeasure in rice cultivation. *Korean Journal of Agricultural and Forest Meteorology*, **3**(1), 55–70.

Yun, S.H. Yun, J.N. Im. J.T. Lee, K.M. Shin, and K.H. Hwang, 2001b: Climate change and coping with vulnerability of agricultural Productivity. *Korean Journal of Agricultural and Forest Meteorology*, **3**(4), 220–237.