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EFFECT OF ACCUMULATED MINIMUM TEMPERATURE ON SUGAR AND ORGANIC ACID CONTENT IN PASSION FRUIT

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ABSTRACT

To determine the suitable harvest timing of passion fruit, the effect of accumulated minimum temperature (AT*min*) on the content of sugar and organic acid of passion fruit was studied. We used AT*min* instead of fruit development period (FDP) as a scale to determine the relationship with fruit quality, because FDP was found to be influenced strongly by the average of daily minimum temperature (r = -0.788**), and also because the quality parameters were found to be associated more significantly with AT*min* than with FDP. Fructose and glucose started to increase, and citric acid began to decrease when AT*min* reached 1000 ^{o}C day. The fruit reached acceptable quality as 15.0 and 2.9 g/100mL for the total sugar and organic acid content, respectively, when AT*min* reached 1350 ^{o}C day, and it was found that the fruit with more AT*min* had a higher quality. On the other hand, the fruit drop occurred frequently when AT*min* was less than 1350 ^{o}C day, indicating premature drop. We suggest that AT*min* can be a suitable parameter to discuss passion fruit quality which might well contribute to check the best harvest timing of passion fruit cultivating countries in Southeast Asia.

Key words: acidity, fruit quality, maturation, premature drop, thermal time

INTRODUCTION

Passion fruit is now cultivated not only in tropics and subtropics but also in warm regions of the temperate zones. Although the South American countries, especially Brazil, dominate the world production, it is also cultivated in the Southeast and East Asian countries, such as Taiwan, Indonesia and Japan. A report noted that more than 82,000 tons of passion fruit were produced in 21 Indonesian provinces in 2005 (Morey, 2007). This tropical fruit is consumed either by fresh fruit or processed one. The price of fruit for fresh consumption is far higher than that for processing one, since high quality is required for fresh consumption (Kondo, 2013).

In general, passion fruit is harvested after natural dropping. To achieve acceptable quality for fresh consumption, the sugar and acid content is required to be over 15.0% and below 2.9%, respectively. Total soluble solid of the passion fruit varies between 15.0 and 18.0% in fresh markets (Kondo, 2013). The suitable acid content for fresh consumption is about 2.0%: the acidity could be declined down to 1.0% from 3.1 to 2.1% by storing at 25^{o}C for 7 days, but prolonging the storage period and/or increasing the temperature reduce the commercial value due to the shrinkage on the pericarp (Yonemoto *et al*., 2004). Thus, fruit with the acid content below 2.9% at fruit drop stage can be consumed as full ripen fresh fruit.

The patterns of the change in quality parameters during passion fruit development period (FDP) have been studied based on the number of days after pollination (DAP). However, it is known that FDP is influenced largely by temperature condition (Utsunomiya, 1992; Macha *et al*., 2006), so it varied markedly among the reports. For instance, Shimoi *et al*. (1996) cultivated passion fruit at 20^{o}C constant condition in Kenya, and reported that the fruit drop occurred frequently from 90 DAP, but

Ishimoto *et al*. (2007) grew the tropical fruit in an unheated greenhouse in Kagoshima, and noted that 70 DAP was needed for the fruit drop. In an open field in Chiba, in addition, FDP was observed to differ from 46.3 to 73.0 days, depending on the time of flowering (Shiiki *et al*., 2008). Therefore, by the data of simple day intervals, it is difficult to determine when the fruit achieves the acceptable quality for fresh consumption.

Accumulated temperature (AT) is the most frequently used methods to ponder the relation between plant development and temperature (Stenzel *et al*., 2006). AT has been related to the changes in sugar and acid content in grape (Almanza-Merchan *et al*., 2010), and to the change in total soluble solid in pitaya fruit (Nomura *et al*., 2005). However, the change in the sugar or acid content during FDP has not yet been related to AT in passion fruit.

Since passion fruit is produced in regions with quite different temperature conditions, a scale which can take such differences in temperature conditions into account is required to determine when the fruit attains the acceptable quality for fresh consumption. Moreover, it was expected that accumulated minimum temperature (AT*min*) can reflect the consumption of sugar due to respiration and/or the formation of anthocyanin in the pericarp than AT. Therefore, the purpose of the present study was to suggest AT*min* as a more suitable parameter to determine fruit quality such as the content of sugars or organic acids.

MATERIALS AND METHODS

Vines of 'Summer Queen' passion fruit (*Passiflora edulis* x *P. edulis* f. *flavicarpa*) were grown by cutting in a greenhouse from 9 October 2010. Each rooted cutting was transplanted into a 30 L plastic pot containing loam soil, and was supported by a stake in each pot. On 6 May 2011, two vigorous plants were selected and transferred to an experimental field (about 20 m^2) in the Setagaya Campus in Tokyo University of Agriculture. Trellis training was practiced at 180cm high, and therefore all the fruit were located just beneath the trellis. During the experiment, the plants were irrigated several times a day when necessary, and 1 L of liquid fertilizer (N 60ppm; P_2O_5 100ppm; K_2O 50ppm; MgO 0.5ppm; Mn 0.01ppm; B 0.05ppm) was applied once a week for each plant.

Flowers were tagged and dated at hand-pollination, thereafter the fruit was covered with net bags. To determine changes in quality parameters before the onset of fruit drop, randomly selected 3 to 4 fruits were sampled from the vines artificially from 15 to 55 DAP at the interval of about 10 days. In this experiment, 24 fruits were categorized as "sampled" fruit. Fruit started to abscise from the vines naturally but not by physical stimuli from 50 DAP. There were 27 of such fruits in this experiment, namely "harvested" fruit. FDP of each harvested fruit was calculated as the number of days from the hand pollination to the fruit drop. The pericarp color was determined as a* value by a handy colorimeter for the sampled and harvested fruit (NR-3000, Nippon Denshoku).

The juice of the sampled and harvested fruit was extracted from arils with strainers just after the sampling or harvesting, and stored at -80^{o}C. For analyses of the content of sugars and organic acids by HPLC, the defrosted juice was diluted 10 times with distilled water and, percolated through 0.45 μm membrane filters. The total sugar content (TSC) of the juice was indicated in the sum of the concentrations of sucrose, glucose and fructose. The total organic acid content (TOAC) of the juice was indicated in the sum of the concentration of citric acid and malic acid.

Daily minimum, mean and maximum temperature was recorded by a datalogger placed around the fruiting zone throughout the experiment. For each fruit, the average of daily minimum, mean or maximum temperature, the average of daily diurnal range, and AT*min* from the hand pollination to the sampling or harvesting were calculated. AT*min* was the simple sum of the daily minimum temperature (^{o}C day) during the period.

RESULTS AND DISCUSSION

The changes of daily minimum and maximum temperature in the experimental filed are shown in Fig.1. As for the 27 harvested fruits, the fruit drop occurred from 49 to 69 DAP, and the average FDP was 55.4 days (Fig. 2). The FDP of the harvested fruit was influenced more strongly by average daily minimum temperature during FDP (r = -0.788**) than by average daily maximum or mean temperature, and than average daily diurnal range (Table 1).

Table 1. Relationship between the duration of fruit development period (FDP) and the average of daily maximum, mean, minimum temperature or the average diurnal range in the harvested fruits.

	Average of daily temperature of			Average of
	Max	**Mean**	**Min**	**daily diurnal range**
FDP	-0.644**	-0.689**	-0.788**	-0.387
Pericarp color	-0.220	-0.281	-0.441*	-0.027

[1]Data are correlation coefficients (d.f.=25). ** = significant at 1% level.

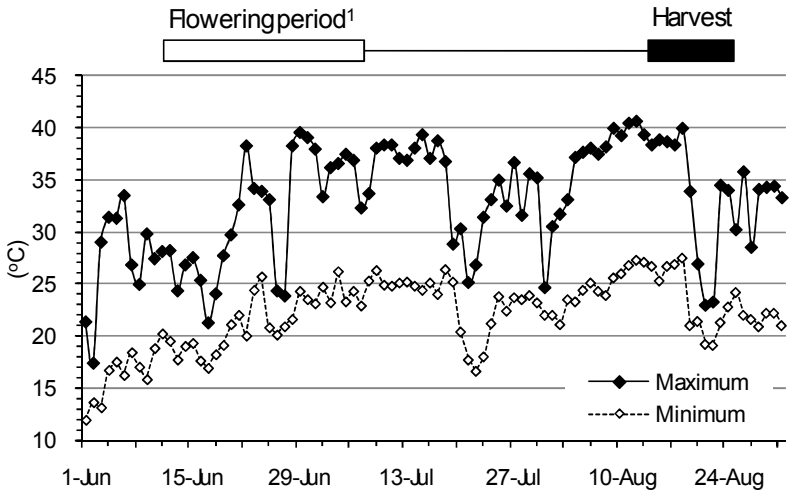

Fig. 1. The change of daily maximum and minimum temperatures around the fruiting zone during the experiment. [1] Both sampled and harvested fruit flowered during the indicated period.

In passion fruit, high temperature has already been reported to accelerate fruit drop (Utsunomiya, 1992; Macha *et al*., 2006). In *Citrus*, physiological fruit drop were also promoted by a 2^{o}C increase in air temperature after full bloom (Sato *et al*., 2010). Nevertheless, the results of the present study in passion fruit suggested that particularly the average of daily minimum temperature during FDP had a strong association to the duration of FDP, indicating the possibility that the difference in minimum temperature condition among the fruits might be a factor inducing the variation in FDP. It should also be noted that low temperature as well as light encouraged the formation of anthocyanin in passion fruit (Utsunomiya *et al*., 2005). In this study, only the average of daily minimum temperature during FDP was significantly associated with the pericarp color (Table 1). Since the color of the pericarp is an element of the external appearance, daily minimum temperature should be an important factor affecting passion fruit quality.

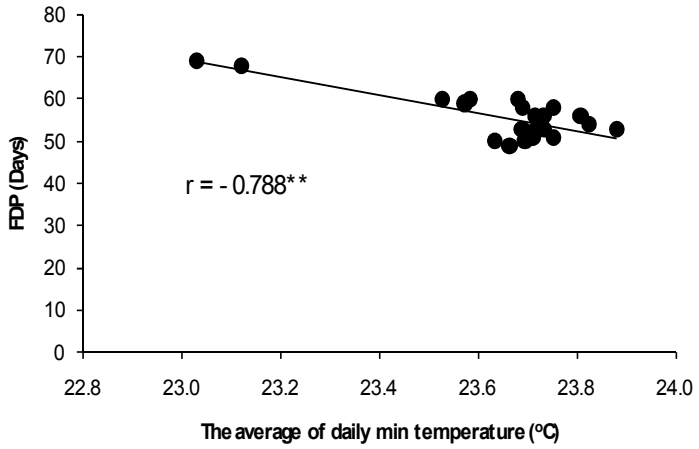

Fig. 2. The relationship between the duration of fruit development period (FDP) and the average of daily minimum temperature in the harvested fruit

As for the passion fruit quality parameters, they were found to be correlated more strongly with AT*min* than with FDP (Table 2). Previously, titratable acidity of passion fruit juice at harvest was found to correlate negatively with FDP (Kondo and Higuchi, 2011). Changes in sugars and organic acids during FDP have been discussed based on DAP (Shimoi *et al*., 1996; Ishimoto *et al*., 2007). However, AT*min* can be a more flexible scale to determine the change in quality parameters than FDP.

Table 2. Relationship between quality parameters and the duration of fruit development period (FDP) or accumulated minimum temperature (AT*min*) during FDP in the harvested fruit.

Quality parameter	**FDP**	**AT*min***
TSC	0.110	0.141
Sucrose	-0.745**	-0.756**
Glucose	0.524**	0.555**
Fructose	0.510**	0.539**
TOAC	-0.538**	-0.545**
Citric acid	-0.525**	-0.532**

[1]Data are correlation coefficients (d.f.=25).
*, ** = significant at 5% and 1% level respectively.

Acceptable TSC for fresh consumption (15.0 g/100mL) was attained when AT*min* was 1240 °C day, and three quarters of the harvested fruits exceeded this TSC at fruit drop (Fig. 3). TSC changed much slowly from 15.5 to 16.0 g/100mL as AT*min* increased from 1350 °C day to 1600 °C day. The glucose and fructose content began to increase from 1000 °C day. Then, the content of the two reduced sugars kept increasing and the sucrose content kept decreasing until AT*min* exceeded 1600 °C day. In passion fruit, invertase (INV) is known to be involved in the resolution of sucrose into fructose and glucose (Ishimoto *et al*., 2007). The individual sugars directly influence fruit quality components like sweetness which ranks as follows: fructose>sucrose>glucose (Yamaguchi *et al*., 1970). These indicate that although TSC did not vary markedly among the harvested fruit, the sweetness differed depending on AT*min* at fruit drop.

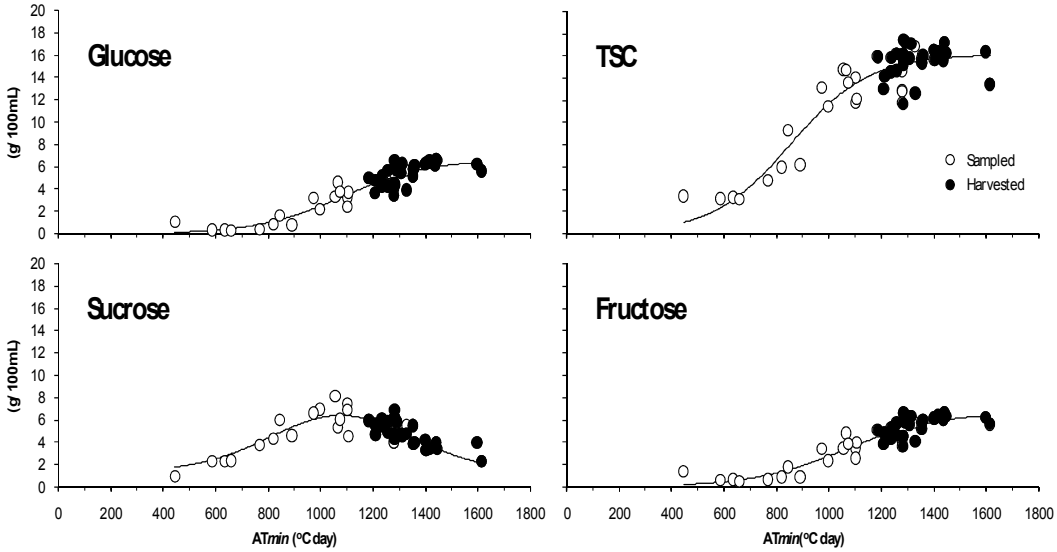

Fig. 3. Change in sugars at different accumulated minimum temperature (AT*min*) during fruit development in passion fruit

Acceptable TOAC in passion fruit for fresh consumption (2.9 g/100mL) was achieved when AT*min* reached at 1350°C day (Fig. 4). The reduction in TOAC to the acceptable level required more AT*min* than the increase in TSC. Thus, acceptable fruit quality for fresh consumption was achieved by the time when AT*min* reached at 1350 °C day, and fruit dropped with more AT*min* showed higher quality. However, more than half of the fruits dropped before 1350 °C day. Premature drop occurs because the development of the abscising layer in the peduncle, which is influenced by minimum temperature condition, progresses before maturating events in the fruit complete.

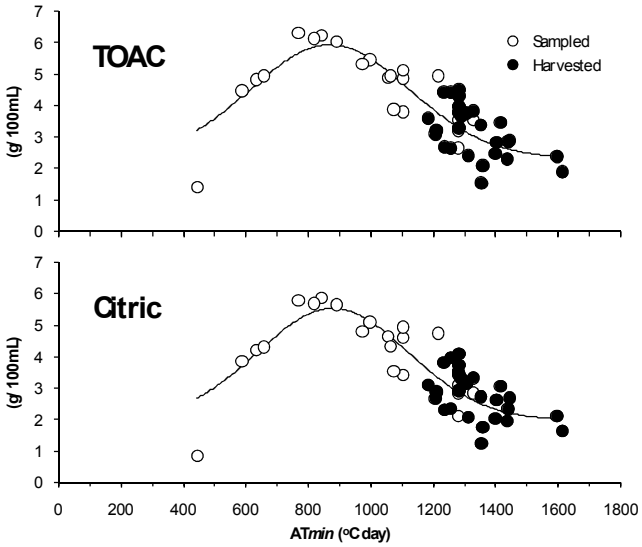

Fig. 4. Change in organic acids at different accumulated minimum temperature (AT*min*) during fruit development in passion fruit

CONCLUSION

Based on AT*min* data, further researches are needed to prevent premature drop under high night temperature conditions which is a feature of the Southeast Asian counties.

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(*: in Japanese, **: in Japanese with English abstract)