# Growth and Development of 'Tainung No.1' Passion Fruit (*Passiflora edulis S*ims) in Taiwan

Suwimon Srikanya [1] Ching-Chang Sheish [2] Huey-Ling Lin [3]
Irvan Prawira Julius [4]

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## Summary

'Tainung No.1' is the major passion fruit cultivar in Taiwan. The fruit growth pattern was investigated after anthesis and hand pollination, the fruit was sampled at one-week intervals. The fruit size increased rapidly and reached a maximum size within 2 weeks. The fruit became juicy at 4 weeks after anthesis and the fruit skin color turned from green to purple at 8 weeks after anthesis. During fruit development, the total soluble solid increased in all developmental stages. On the other hand, the titratable acidity reached the highest peak at 6 weeks then began to decrease. As day after harvest increased, ethylene production gradually increased when harvested at week 6 to 8 after anthesis. However, the fruit harvested at week 9 and 10 after anthesis showed a decline in both ethylene production and respiration rate was probably due to the fruit has been ripened. In summary, the best harvest time for 'Tainung No.1 ' passion fruit was approximately at 8 weeks after anthesis.

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1) Graduate student in MS program, Department of Horticulture, National Chung Hsing University.
2) Associate professor, Department of Horticulture, National Chung Hsing University.
3) Professor, Department of Horticulture, National Chung Hsing University. Corresponding author.
4) Graduate Student in Ph. D. program, Department of Horticulture, National Chung Hsing University.

## Introduction

The purple passion fruit (*Passiflora edulis* Sims.) belongs to Passifloraceae family (Kishore *et al*., 2010) and is a native of Brazil. It is widely grown in tropical and subtropical countries (Chandler, 1958; Pruthi, 1963; Chan *et al*., 1980). The plant starts to produce fruit within-one year after planting, with a short productive life, varying from 3 to 5 years. The highest yield is obtained on the second and third year after planting and decreased thereafter. On average, 60–70 days are required from pollination to maturation of the fruit (Rodriguez-Amaya and Kimura, 2004). Juice of the purple passion fruit is deeper orange in color and is said to be somewhat more aromatic and less acidic than the yellow passion fruit (Chan *et al*., 1972; Pruthi, 1963). According to Chan *et al*. (1980), the purple passion fruit could be harvested at light to deep purple skin color and could be consumed right after harvesting. However, light purple fruit is the most desirable fruit for distant transport.

The purple passion fruit exhibits a climacteric respiratory pattern with considerable amount of ethylene production (Akamine *et al*., 1957). In addition, the highest climacteric peak in passion fruits occurs while the fruit is still attached to the plant (Biale, 1975). Ethylene is a gaseous plant hormone which plays an important regulatory role in various plants growth and development processes include fruit ripening (Yang and Hoffman, 1984). In Taiwan, passion fruit usually harvested after naturally drop to the ground (ground-harvest) which may lead to high possibility of soil-born infection. In addition, some rumors said that ground-harvest has less sour than tree-harvest. Therefore, the purpose of this study is to investigate the quality of passion fruit in different development stages and established the harvest maturity index of passion fruit.

## Material and Methods

1. Fruit sampling

'Tainung No.1' passion fruit growth pattern of was investigated in Puli county, Taiwan. During flowering season, 200 flowers were labeled, the fruit size (length, width, and weight) was measured and the pictures of the fruit appearance (inner and outer) were taken at one-week intervals with 10 fruits per replicates.

2. Quality analysis

The fruit was cut into halves and the juice was taken by squeezing the pulp using two-layered cotton gauze. Total soluble solid (TTS) of the juice was measured by using hand-held refractometer. Tritatable acidity (TA) was determined by using titration method to pH 8.2 with 0.1N NaOH. Organic acid composition was determined by using high performance liquid

chromatography (HPLC) with Mightysil RP-180 P 250-4.6, 5 µm column (Cica reagent Japan). Mobile phase pH was adjust into pH 2.4 using 2 % $KH_2PO_4$, flow rate 0.8 ml/min, measured at 220 nm and detected using Hitachi L-7400 UV detector and signal was recorded by Hitachi D-200 Chromato intregator. Standards include 0.1% malic acid, 0.1% tartaric acid, 0.1% oxalic acid, 0.01% ascorbic acid and 0.1% citric acid. Ten replicates were performed for each measurement.

3. Ethylene production and respiration rate

Ethylene production was measured everyday by using continuous flow rate system. two passion fruits were put into a 1 L chamber with an air flow rate of 1 L/hr. From each chamber, 1 ml of air was collected and analyzed by Gas Chromatograph, Shimadzu Model GC-8A with temperatures of injection port, column, and detector were set at 130, 90, and $130^0$C, respectively. Respiration rate was determined by using IR-analyzer, Maihak, Model UNOR610.

4. Statistical analysis

The data of the experiment underwent statistical analysis using SAS 9.2 (Institute Inc, 2002) and was subjected to one-way analysis of variance (ANOVA) for a completely randomized design (CRD) statistical model. Mean values among treatments, when significant, were compared by least significant difference tests at the 5% ($P \leq 0.05$) level of significance.

## Results

The fruits were picked up randomly every week after anthesis and measured. Figure 1 showed the skin color was green at weeks 1-7 after anthesis and began to change into purple at weeks 8 after anthesis. Furthermore, the pulps' color was white at second weeks and began to change into light yellow to dark yellow or orange at third weeks. The seed's color started to change from white to black color and the fruit became juicy at four weeks after anthesis. The peel thickness enlarged from weeks 2-7 after anthesis then became thinner during ripening at weeks 9-10 after anthesis (Fig. 1). The fruits' size (width, height and weight) increased rapidly and reached a maximum value within 2 weeks after anthesis and then remained constant till ripening (Fig. 2). During maturation, the total soluble solid constantly increased till the end of observation (weeks 10) (Fig. 3). The titratable acidity reached a peak value at 6 weeks after anthesis and then decreased rapidly till ripening (Fig. 3).

When harvested at six weeks after anthesis, the fruit began to produce ethylene at 5 days after harvest and reached the highest peak at 10 days. In 7 week-old fruit, ethylene production started at 6 days after harvest and increased gradually. The 8–week-old fruit produced ethylene at 4 days after harvest and slightly increased in the following days. The $9^-$ and $10^-$ week-old fruits

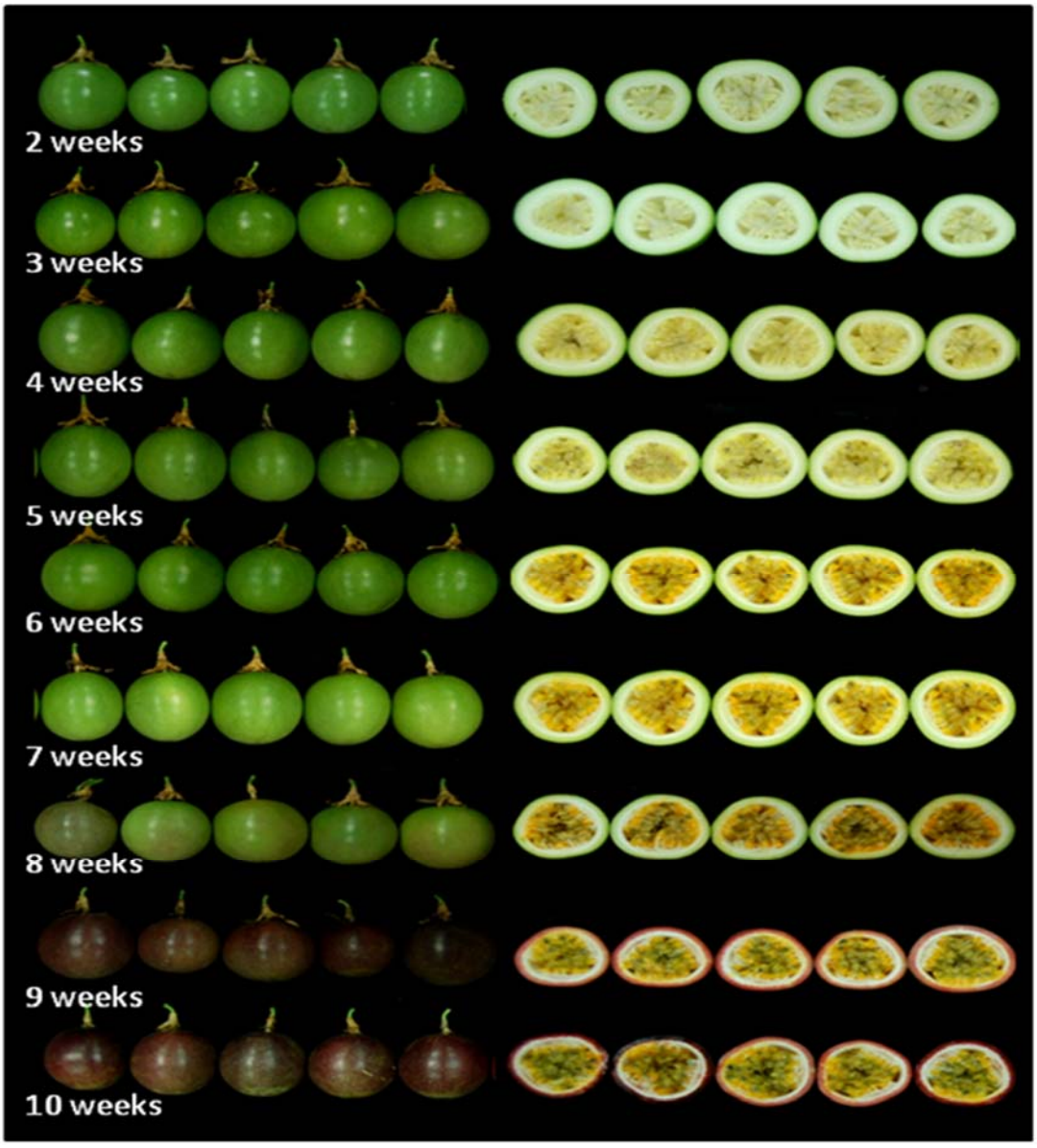


Fig. 1. Changes in the external and pulp appearance of 'Tainung No.1 ' passion fruit during growth and development.

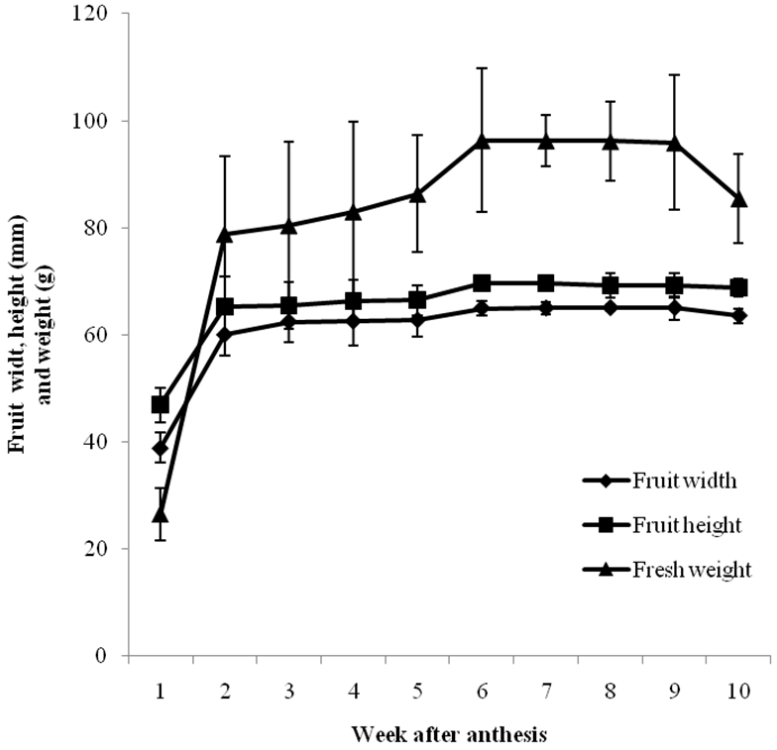


Fig. 2. Changes in fruit width (mm), height (mm) and fresh weight (g) of 'Tainung No.1' passion fruit during growth and development.

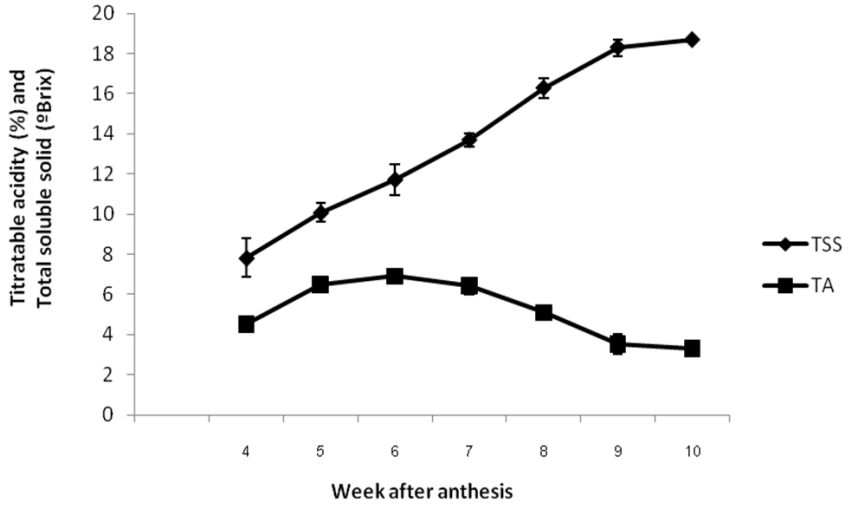


Fig. 3. Changes in titratable acidity (TA) and total soluble solid (TSS) of 'Tainung No.1 ' passion fruit during growth and development.

showed the highest ethylene production at the first day after harvest and began to decrease for the following days. Comparison of the ethylene production rate among fruits at different stage of maturity showed that fruit harvested at weeks 6, 9 and 10 after anthesis had higher ethylene production. The 6–week-old fruit has a respiration rate of about 42 ml$CO_2$/ kg hr at the first day after harvest and decreased to 22 ml$CO_2$/ kg hr at 11 days after harvest. The 7 week-old fruit reached a peak respiration rate at 7-9 days after harvest. The 8 week-old fruit showed a respiration peak at day 7 after harvest (38 ml$CO_2$/ kg hr) then decreased drastically in the next day and remained constant (14-15 ml$CO_2$/ kg hr) thereafter. The 9–week-old fruit had the highest respiration rate at day 2 and 3 after harvest then decreased gradually until day 11 (39 to 21 ml$CO_2$/ kg hr). The 10–week-old fruit had the highest respiration rate at day 1 and began to decrease until day 11 after harvest (Fig. 4).

In passion fruit, citric acid was the main organic acid followed by oxalic acid. The contents of citric acid gradually increased from week 4 and reached the highest peak at week 7 (5.688%) after anthesis then decreased during late developmental stages. The reverse result was found in malic acid content where its content gradually decreased at early developmental stages and increased at late developmental stages.

## Discussion

The cumulative growth curves of passion fruit have the characteristic of a single sigmoid growth (Fig. 3). A similar pattern of purple and yellow passion fruit was also reported by Ildo and Gazit (1993); Shiomi *et al.*, (1996a), and Enamorado *et al*., (1995). Moreover, passion fruit had grown faster (Akamine *et al*., 1957; Gacchanja and Gurnah, 1981) within 2 weeks after anthesis (Fig. 2) suggested that the cell division and expansion was completed within 2 weeks after anthesis as indicated by the complete seed formation and maturation (Fig. 1). A similar pattern also could be found in tomato by using cross section observation (Gillaspy *et al*., 1993). In addition, auxin and gibberellins (GAs) played an important role in cell expansion and could be found in surrounding cell and seeds (Gillaspy *et al*., 1993). These hormones regulated several enzymes related to cell/organ growth such as endo-1, 4-β-glucanase (EGases) or expansin for cell wall conformation during fruit development in tomato and grape berry (Brummell *et al*,. 1997; Ishimaru *et al*., 2007).

The total soluble solid gradually increased till week 9 after anthesis (Fig. 4). Similarly, Enamorado *et al*. (1995) reported that total soluble solid peaked at 63 days after flowering in yellow passion fruit. The fruit juice began to accumulate at 4 weeks after anthesis and the fruit

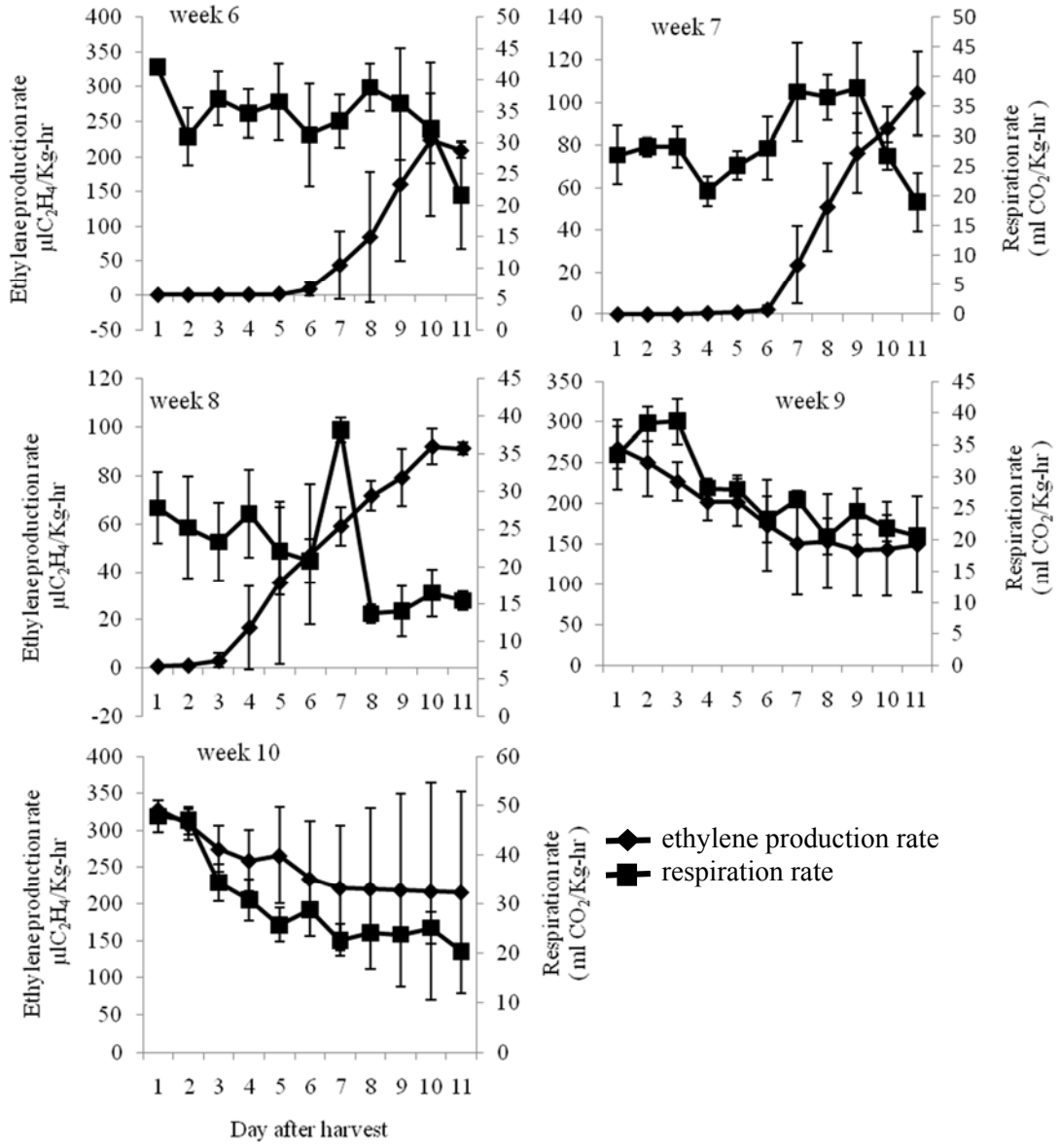


Fig. 4. Changes in ethylene production rate and respiration rate of 'TainungNo.1' passion fruit after harvested at various stages of maturity.

pulp color changed from yellow to orange at 8 weeks after anthesis (Fig. 1). Shiomi *et al*. (1996a) reported that the fruit juice began to accumulate 30 days after anthesis and fruit skin color changed from green to purple at about 60 days after flowering while specific aroma appeared as fruit matured. Titratable acidity reached a peak 6 weeks after anthesis followed by a rapid decrease (Fig. 4). This result showed a concomitant pattern that had been reported by Shiomi *et al*. (1996a) in purple passion fruit. Organic acid measurement using HPLC showed that major organic acids include oxalic acid, malic acid, ascorbic acid and citric acid (Table 1). Chan *et al*. (1972) studied organic acid in passion fruit also found that malic acid, ascorbic acid and citric acid were present in passion fruits. Moreover, among these organic acids, citric acid was the most abundant in passion fruit similar to what Shiomi *et al.* (1996b) has reported. Comparison of titratable acidity and total organic acid content (Fig. 2 and Table 1) showed that they were unequal suggesting the presence of other organic acids in it, though the contents were relatively less. During late developmental stages, malic acid decreased drastically within 1 weeks (from week 7 to 8 after anthesis) indicating that fruit began to enter the ripening stage.

In contrast, the ethylene production and respiration rate determined among various developmental stages showed that fruits harvested at 6-8 weeks after anthesis still required several days (about 2 to 5 days) to enter the climacteric peak, whereas those harvested at 9 and 10 weeks after anthesis had decreased trend of ethylene production after harvesting (Fig. 4). Interestingly, the ethylene production rate reached the highest when the fruit was ripened (9 and 10 weeks after anthesis) on the vine (Fig. 4) which might be related to different maturation in various parts of fruit tissue. According to Shiomi *et al*. (1996b), studies of observation in ethylene production at different stages of fruit maturity showed that all fruit tissues (seed, aril and peel) were able to produce ethylene. However, the ethylene production in different tissues did not happen at the same time (Shiomi *et al*., 1996b) which may explain why different amount of ethylene was produced at different harvest date. For harvest maturity selection, it is not recommended to harvest at week 6 and 7 due to high percentage of titratable acidity (Fig. 3) which might affect the consumers' acceptance (Harker *et al*., 2002; Marsh *et al*., 2004). Overall, the best harvest time for 'Tainung No.1' passion fruit was at 8 weeks after anthesis.

Table 1. Changes in organic acid content of 'Tainung No.1 ' passion fruit during growth and development. Means within a column followed by the same letter are not significantly different by LSD test at P ≤0.05.

| Weeks after anthesis | Organic acid (%) | | | |
|---|---|---|---|---|
| | Oxalic acid | Malic acid | Ascorbic acid | Citric acid |
| 4 | 0.097 a | 0.848 a | 0.025 b | 1.658 c |
| 5 | 0.079 c | 0.742 b | 0.045 a | 1.746 c |
| 6 | 0.075 c | 0.474 c | 0.022 b | 1.995 b |
| 7 | 0.084 b | 0.447 c | 0.018 c | 5.688 a |
| 8 | 0.045 e | 0.414 c | 0.017 c | 2.086 b |
| 9 | 0.054 d | 0.796 b | 0.026 b | 2.103 b |
| 10 | 0.044 e | 0.964 a | 0.028 b | 1.287 d |

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# '台農 1 號'百香果果實(*Passiflora edulis* Sims)之生長與發育

舒 瓊 冰[1] 謝 慶 昌[2] 林 慧 玲[3] 尤 澤 森[4]

關鍵字：果實大小，總可溶性固形物、可滴定酸、有機酸、呼吸率、乙烯釋放率

**摘要：**'台農 1 號'是台灣主要的百香果品種。本實驗在百香果人工授粉後，每週調查生長發育情形。果實在兩週內快速生長，並達到最大的果實大小；授粉後四週果實呈現多汁狀態，且在授粉八週後果皮開始轉色。在發育期間，總可溶性固形物逐漸上升。另外，授粉後第六週，可滴定酸達到最高峰，然後逐漸下降；授粉後六到八週採收，此時百香果的乙烯釋放率和呼吸率有上升的趨勢，並出現更年性高峰。然而，授粉後九到十週採收的百香果，呼吸率和乙烯釋放速率會下降，推測應是這個期間果實已經完熟進入更年後期。綜合上述結果，'台農 1 號'百香果在授粉後八週為最適採收成熟度，具有良好的採收後品質。

1) 國立中興大學園藝學系碩士班學生。
2) 國立中興大學園藝學系副教授。
3) 國立中興大學園藝學系教授，通訊作者。
4) 國立中興大學園藝學系博士班學生。