VARIETAL DIFFERENCES IN CELL DIVISION AND ENLARGEMENT PERIODS DURING PEACH (Prunus persica Batsch) FRUIT DEVELOPMENT

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Summary

Fruit growth and increases in the flesh cell number and size from blossom to maturity were investigated on early-ripening 'Saotome', mid-season 'Akatsuki', late-season 'Yuzora' and wild 'Ohatsuomomo' peach cultivars. The duration of each growth stage differed with the cultivar, especially Stage II; three stages were short in 'Saotome'. It was confirmed that the fruit growth after the cessation of cell division was dependent on cell enlargement. Mesocarp cells did not grow uniformly during Stage III; rather, the radial cell length near the stone was greater than those of outer portions. Flesh cells continued to divide for four to five weeks after full bloom, and increased in size thereafter. The time when cell division ceased showed varietal differences; 'Saotome', in which cell division ceased early, had a small number of flesh cells and produced small fruit. The wild peach 'Ohatsuomomo', whose cells divided more slowly than the commercial cultivars had the fewest and the smallest cells, resulting in very small fruit.

Key Words: cell division, cell enlargement, fruit development, Prunus persica.

Introduction

Wide variations of fruit size exist among peach cultivars; some are peach cultivars that produce small fruit less than 40 g, such as the flowering peaches and edible cultivars developed during or before the Edo Period in Japan; other cultivars produce large fruit of ranging from 200 to 300 g; some a new cultivar can exceed more than 500 g. As fruit size has a big influence on the price of peaches in the market, most peach growers aim to produce fruit as large as possible.

The growth of peach fruit has been widely studied, and many researchers emphasize the characteristic double sigmoid curve consisting of Stage I when the fruit actively develop after flowering, Stage II during which fruit growth stalls, and Stage III when the fruit again grow rapidly and mature (Dorsey and McMunn, 1926; Gage and Stutte, 1991; Lilien-Kipnis and Lavec, 1971; Lileland, 1935; Pavel and DeJong, 1993; Rangland, 1934; Tukey, 1934). The growth process has been investigated in relation to the mechanisms of embryo abortion and development suspension in early-ripening peaches (Harrold, 1935; Lott, 1933; Tukey, 1934) and of pit splitting (Blake, 1925; Davis, 1933). Studies were made on the formation of fruit organs and the division and enlargement of flesh cells during each growth stage (Masia et al., 1992; Ragland, 1934; Reeve, 1959). These studies showed that cells began to divide and cease during Stage I, the hardening of stones and embryo development take place during Stage II, and cells enlarge rapidly during Stage III.

However, the differences in fruit size among cultivars are not well clarified nor fully understood. The fruit size is apparently determined by the numbers and the sizes of flesh cells (Coombe, 1976). Understanding the fruit size differences among cultivars should lead to a more effective times of fruit thinning and adequate crop loading, and to an efficient breeding of big peach cultivars.

In this study, fruit growth and the division and growth of flesh cells of several cultivars with different ripening characteristics and sizes were investigated.

Materials and Methods

In 1995, the relationship between fruit growth and increase in the number and length of mesocarp cells during fruit development was studied. An early-ripening cultivar, 'Saotome', is harvested 72 days after full bloom (DAF), a mid-season cultivar 'Akatsuki' matures 100 DAF, and a late-season cultivar 'Yuzora' is harvested 130 DAF. The trees are growing at the Chiyoda Farm of the National Institute of Fruit Tree Science, Chiyoda, Ibaraki Prefecture. The three cultivars were at full bloom on April 12. The fruit were sampled from each cultivar every 10 days starting on 26 DAF. The weight and the equatorial diameter of each fruit and stone were measured; the fruit cross section at the

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maximum diameter was obtained and photographed under a microscope. A schematic diagram made from the photograph is shown in Fig. 1. A line was drawn from the stone to the fruit skin at the equator on the photograph. The length of cells that touched the line were measured (Radial Cell Length: RCL). The ratio of flesh thickness (FT) to mean RCL (FT/mRCL) was obtained by subtracting the stone thickness from diameter and dividing these differences, FT, by the mean RCL. The FT/mRCL ratio represents the number of cells lining up from the stone to the skin at the equator of the fruit, and should reflect the total number of flesh cells. Five medium-sized fruit from one tree of each cultivar were measured, and the RCL determined twice for each fruit.

Because our 1995 study showed differences in the date when cell division ceased, the changes in FT/mRCL and mRCL during the growth of young fruit were investigated in 1996. In addition to the three cultivars examined in 1995, a late-season ‘Ohtsukumo’; a wild cultivar which produces very small fruit and is widely used as rootstocks, was studied. The trees are also planted in the Chiyoda Farm. Five fruit were sampled from each cultivar at full bloom, and at weekly intervals thereafter for seven weeks. Immature and mature fruit were measured as in 1995 to estimate their final cell number and mean RCL. At the anthesis, flowers that were not fully open were sampled, and their ovaries weighed after removing each calyx cup (torus).

Results and Discussion

1. Relationship between fruit growth and either cell number or cell length after the cessation of cell division

Growth stages of each cultivar were estimated from the growth curves of their fruit weight and stone thickness. In ‘Saotome’, Stage I ended 46 DAF, Stage II continued for 10 days, and the fruit grew rapidly from 56 DAF until they ripened 76 DAF. The fruit weight was 1 g at the beginning measurement and increased up to 111 g. In ‘Akatsuki’, Stage I ended 56 DAF, Stage II continued for 20 days, the fruit weight increased rapidly from 76 DAF for 30 days, and the fruit ripened on 106 DAF with over 220 g in weight. Stage I of late-season ‘Yuzora’ ended on 56 DAF, Stage II continued for 40 days, and Stage III that started on 96 DAF, continued for 40 days, and ripened on 137 DAF. The fruit weighed about 210 g.

All cultivars showed double sigmoid growth curves, but the duration of each stage was different. The duration of Stage I of ‘Saotome’, ‘Akatsuki’ and ‘Yuzora’ was 46, 56, and 56 days; Stage II was 10, 20, and 40 days; and Stage III was 20, 30, and 40 days, respectively. The difference was most conspicuous in Stage II, although the other stages also exhibited large differences. Each stage was shortened in early-ripening ‘Saotome’, whereas longest in late-ripening ‘Yuzora’.

Changes in fruit weight, radial cell length and the number of flesh cells during fruit development in 1995 (Fig. 2) reveal that the cell numbers were always approximately 170 in ‘Saotome’ from 26 DAF to ripening, whereas they increased from full bloom to 36 DAF in ‘Akatsuki’ and 46 DAF in ‘Yuzora’ and final attaining 220 and 240, respectively. They reached the maximum before the end of Stage I, and were much smaller in ‘Saotome’ than in the other two cultivars.

The mean RCL of ‘Saotome’ showed a continuous increase throughout the 3 growth periods. The growth rate rapidly increased after 46 DAF when Stage I ended, and the final mean RCL of matured fruit was 240 μm.
In ‘Akatsuki’, the growth in diameter was arrested during Stage II but resumed when Stage III started. The final mean RCL of ‘Akatsuki’ was 240 μm as in ‘Saotome’. Similarly, the diameter of ‘Yuzora’ ceased increasing during Stage II and resumed subsequently rapid growth during Stage III. The final mean RCL of ‘Yuzora’ was, likewise 240 μm. In all of these cultivars, cell division ceased before the onset of Stage II, when the stone hardened. It was confirmed that fruit growth during Stage I was attributable to the increase in the number and size of the mesocarp cells.

RCL in Fig. 3 reveal that the coefficients of correlation, $r$, in all cultivars were highly significant. The inclination of regression line was 0.53 in ‘Saotome’, 0.97 in ‘Akatsuki’, and 1.07 in ‘Yuzora’. The slope of ‘Saotome’ was notably small, indicating that ‘Saotome’ does not increase in fruit weight as fast as the other cultivars even though the cells grew equally well. Hence, the difference in the final size of ‘Saotome’ fruit is attributed to its smaller cell number.

RCL of ‘Akatsuki’ varied slight during Stage I; and its range was relatively small during Stage II but increased notably during Stage III when huge cells of over 500 μm and many cells less than 100 μm appeared (Fig. 4). The mean RCL at different parts of the fruit in Fig. 5 depicts cell length in 10 sections of equal cell numbers from the stone to the exocarp. The fluctuation of RCL for each section shows that before maturation, the sections were uniform. However, as the fruit grew and matured during Stage III, the cells near the stone became longer than the cells in the mesocarp.

Our study on fruit weight, RCL, and cell number (FT/mRCL) confirmed that the peach fruit exhibits a double sigmoid curve. They also showed that 1) the durations of each stage were different among cultivars, 2) the dates of cell division cessation likely differed in each cultivar, 3) the cultivar difference in matured fruit weight is attributable mainly to the difference in cell number, and 4) the cells of a fruit did not grow uniformly; those adjacent to the stone was elongated, whereas in the mid-mesocarp, they were isodiometric.

Tukey and Lee (1936) mentioned that, of the three growth stages of peach fruit, the duration of Stage I was relatively constant for all cultivars and that the duration of Stage II determines the ripening period of a cultivar. However, our study showed that the durations of all
three stages differed considerably with cultivar. The ripening period depends not only on Stage II but also on the duration of the other two stages. Lilleland (1935) monitored the growth of 'Elberta' fruit for five years and showed that Stage I fluctuated 55 to 74 days; Stage II, 23 to 56 days; and Stage III, 18 to 32 days, depending on the year. Lilien-Kipnis and Lavee (1971) who investigated the fruit growth of 'Ventura' peach, which ripens 100 DAF, reported that Stage I was only 35 days; Stage II, 14 days; and Stage III, 51 days. Our study showed that the differences in the growth stage duration among cultivars varied indicating depends not only on the duration of Stage II but also stage I. The short duration of Stage I in early-ripening peaches may be related to their small fruit sizes and short ripening periods.

Tukey and Young (1938) in their studies on sour cherries found that the length of flesh cells depended their position. Reeve (1959) reported a similar phenomenon in peach fruit. Cells adjacent to the stone can only elongated because of the limited area on the pit near face.

Cell growth after the cessation of cell division during Stage I depends on their enlargement before hardening of the stone. Such rapid growth was especially notable in early-ripening 'Saotome', which often lead to pit splitting.

2. Relationship between the duration and rate of cell division after bloom and the size of mature fruit

The changes in fruit thickness of young developing fruit of 'Saotome', 'Akatsuki', 'Yuzora' and 'Ohatsu-momo' from full bloom up to the end of cell division, along with the thickness of their matured fruit are in Table 1, whereas their mean RCLs and cell numbers are listed in Table 2 and 3, respectively.

In all cultivars, the fruit diameter ranged from 1.2 to 1.7 mm at anthesis; 'Ohatsu-momo' and 'Yuzora' ovaries
were slightly smaller than the others. However, six weeks later, 'Saotome' fruit had the biggest diameter whereas 'Ohatsumomo' had the smallest. Mature fruit of 'Ohatsumomo' weighed only 30 g, the smallest of all. Mature fruit of 'Saotome' was apparently smaller than those of 'Akatsuki' and 'Yuzora'.

The mean RCL was about 11 µm in all cultivars at full bloom. The size was stable for one week but gradually increased after the second week, reaching 17 to 18 µm at the end of the third week. The increase of the 'Saotome' fruit cell length was 34 µm at the end of the fifth week, which was much larger than the values of the other cultivars. At the end of the seventh week, 'Ohatsumomo' had the shortest cells than the others. This difference persisted throughout the subsequent fruit growth. The mean RCLs of mature 'Saotome', 'Akatsuki', and 'Yuzora' fruit were 218, 256, and 252 µm, respectively, but that of 'Ohatsumomo' fruit was only 135 µm (Table 2).

The cell numbers at full bloom was 34 to 40 in 'Ohatsumomo', 'Akatsuki', and 'Yuzora', it was 52 in 'Saotome'. It increased slowly in 'Saotome', 'Akatsuki', and 'Yuzora' during the subsequent week; whereas in 'Ohatsumomo' it increased rapidly immediately after full bloom. Cell numbers rapidly rose thereafter in all cultivars. At the end of the fourth week, the cell number in 'Saotome' fruit was 165, which was 8 % less than that of the mature fruit.

Cell numbers of 'Yuzora', 'Akatsuki', and 'Ohatsumomo' continued to increase their cell numbers until the end of the fifth week, although that of 'Ohatsumomo' was slower than the other two cultivars. The cell number
of matured fruit was about 165 in ‘Ohatsumomo’, approximately 180 in ‘Saotome’, and about 230 in ‘Akatsuki’ and 240 in ‘Yuzora’, indicating that ‘Ohatsumomo’ and ‘Saotome’ have fewer flesh cells than the other two (Table 3). Early-ripening ‘Saotome’ had the fewest number of cells because cell division ceased at the end of the fourth week, one week earlier than the other cultivars. The number of mesocarp cells in ‘Ohatsumomo’ was small because its cells divided slowly, although the duration of the cell division period was as long as those of ‘Akatsuki’ and ‘Yuzora’.

The correlation of coefficient between cell number and fruit size in all cultivars before cell division ceased was highly significant (Fig. 6). However, this positive correlation disappeared after the cells ceased dividing, suggesting that the subsequent fruit growth depends not only on an increase in cell number but also on cell enlargement (Fig. 7).

The measurements of cell length and numbers, which were conducted from full bloom to the end of cell division period, showed that 1) mesocarp cells continued dividing for four to five weeks after full bloom, 2) the duration of cell division varied with the cultivar, 3) the cultivar that ceased cell division early had a small final number of mesocarp cells, resulting in small fruit, and 4) the smallest size of wild peach is attributable to slow cell division and poor cell growth.

Various studies have been made on the duration of cell division in fruit but the results are not consistent. Ragland (1934) who examined ‘Phillips Cling’ peach concluded that mesocarp cells developed vacuoles and that cell division ceased in three weeks after full bloom. Ishida et al. (1973) reported that in early-, mid- and late-season peaches cell division in the mesocarp in the
Fig. 6. Correlation between cell number (FT/mRCL) and fruit thickness for immature ‘Saotome’, ‘Akatsuki’, ‘Yuzora’ and ‘Ohatsumomo’ fruit before the cessation of cell division.

Fig. 7. Relationship between cell number (FT/mRCL) and mean RCL from bull bloom to maturation. Observation dates: a, b, c, d, e, f, g and h = 0, 1, 2, 3, 4, 5, 6, 7 weeks after full bloom, respectively, i= 1 week before maturation, j = maturation.
three cultivars ceased at the end of the third week after full bloom, except for the cells around conductive tissues and near the exocarp. Masia et al. (1992) observed fruit growth of 'Redhaven' peach from full bloom to maturation and concluded that cell division was most vigorous for the two weeks following full bloom and that the subsequent fruit growth was attributable to cell development. Our study showed that active cell division continued for four to five weeks after full bloom.

Ishida et al. (1973) determined the timing of cell division cessation by measuring the cell length at 0.5 cm depth from skin, and concluded that cell division ceased when fruit thickness reached 1.0 cm. Our results showed that it took more than four weeks for fruit thickness to reach over 1.0 cm. Ragland (1934) and Masia et al. (1992) estimated the cell division cessation based on vacuole development in cells but the growth of peach mesocarp cells was not equal in all sections. The differences between their conclusions and ours may be due to the sections that were observed and the methods that were used for estimating the cessation of cell division. Our data with 'Akatsuki' and 'Yuzora' in 1995 confirm those of Gage and Stutte (1991) who reported that cell division continued up to the fifth week.

In our study, the differences in flesh cell number among cultivar is attributed to the duration of the cell division period, to wit; 'Saotome', in which ceased cell division early, the cell number was 50 cells less than in 'Akatsuki' or 'Yuzora'. The rate of cell division also differed among cultivars; in 'Saotome', 'Akatsuki', and 'Yuzora', which are commercial cultivars, showed FT/mRCL increased from 40 to 50 cells per week during active cell division but it increased only 20 to 30 cells in 'Ohatsu momo'.

Our study also confirmed that the growth of fruit after Stage I depends on cell enlargement. The mean RCL of mature 'Ohatsu momo' fruit was only 135 μm, and weighed only 30 g, much smaller than those of the other cultivars. 'Saotome' showed a similar number of flesh cells but the final mean RCL was about 220 μm.

We conclude that fruit growth rate varies among cultivars because there are differences of the duration of cell division ranging from four to five weeks after bloom, of the rate of cell division, and the final cell length among cultivars.

**Literature Cited**


その果実発育期における細胞分裂および果実膨大の品種間差異

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摘 要

早生の‘さおとめ’、中生の‘あかつき’および晩生の‘ゆうぞら’の栽培モモ3品種、および野生桃タイプの‘おはじもも’1品種を用いて、開花から成熟に至る果実の膨大経過と、果肉細胞数、果肉細胞径の推移について調査を行った。供試品種の各発育スケジュールの長さは、ステージⅡで最も品種による差異が大きかったが、ステージⅠ、ステージⅢの期間にも品種による差異が認められ、早生品種ではいずれのステージも短かった。細胞分裂停止後の果実は果肉細胞径の増大により膨大していくことが認められたが、果肉内の細胞径はステージⅢに入ると極めて不均一となり、核に近い部分の細胞においてその増大が顕著だった。果肉の細胞分裂は滴開後4~5週間続き、分裂停止後はステージⅠの終了時期まで細胞径の増大が認められた。果肉細胞の分裂停止時期には品種による差異が認められ、分裂停止時期の早い‘さおとめ’では、細胞数が少なく最終的な果実の大きさも明らかに劣った。さらに、野生桃タイプの‘おはじもも’では細胞分裂速度が栽培品種に比して遅く、また中生および晩生品種よりも果肉細胞数が少なく、成熟時の細胞径と果実重が小さかった。