Varietal Differences in the Relationship between Maturation Characteristics, Storage Life and Ethylene Production in Peach Fruit

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Summary

The time courses of fruit weight, ground color of skin (a^* value), flesh firmness, sugar content, titratable acidity and amount of ethylene produced were measured during growth, maturation and senescence of four peach cultivars (*Prunus persica* Batsch) with different keeping qualities. Special emphasis was placed on the relationships and differences among individual indices of maturation and the characteristics of ethylene production. In the melting-type cultivars 'Akatsuki', 'Kushigatahakuto' and 'Nagasawahakuho', increase in fruit size, changes in ground color, rise in sugar content and reduction in titratable acidity gradually proceeded after full bloom. After a cultivar-dependent period, postharvest ethylene production and softening were clearly accelerated. On-tree ethylene production occurred later. However, there were large varietal differences in the relationship between ethylene production and changes in the indices of maturation. In 'Kushigatahakuto', ethylene production and softening proceeded fruit enlargement, completion of changes in ground color, and the rapid rise in sugar content. In contrast, in 'Nagasawahakuho', which showed a slow and late softening, ethylene production started after attaining full size, accumulating near maximum sugar level and loss of ground color. In the stony hard-type cultivar 'Yumyeong', ethylene production and postharvest softening did not occur; the on-tree flesh firmness decreased to about 4.0 kg. However, the trends in increase in fruit size, change in ground color, sugar accumulation and decreased in titratable acidity, were similar to those of the melting-type cultivars. From these results, we conclude that there are large varietal differences in the softening and maturation characteristics of peach fruit and that the genetics is determinant of these differences.

Key Words: ethylene, maturation, peach, softening.

Introduction

During maturation and ripening of fruits, enlargement, softening, changes in skin and flesh colors, accumulation of sugars, and lowering in acid content generally take place, and fruits become ready-to-eat (Gortner et al., 1967). Therefore, characteristics such as fruit size, flesh firmness, ground color of the skin, sugar content and titratable acidity are used as indices of maturity (Thompson, 1996). Flesh textures of peach (*Prunus persica* Batsch) are classified into melting, nonmelting and stony hard types (Connors, 1922; Connors, 1928; Yoshida, 1976). Most peach cultivars that are eaten flesh belong to the melting-type. The fruit of the melting-type cultivars soften rapidly after harvest. Therefore, table peaches are generally harvested at the firm ripe rather than the eating ripe stage on trees. However, as the quality of early-harvested and postharvest-matured peaches is inferior to that of fruit that are fully matured

on trees (Do et al., 1969; Robertson et al., 1992), it is desirable to harvest fruit as near to full maturation as possible. A difficulty arises in that the period suitable for the harvest of peach fruit of near-maturation stage is quite short. Crisosto (1994) indicated that the assessment of maturity from the combination of change in ground color and flesh firmness was a practical technique for the harvest of peach fruit with high eating quality and long storage life. One important breeding objective in peach is the improvement of storage life (Scorza and Okie, 1990; Kanato et al., 1980; Yamaguchi et al., 1996). Hence postharvest keeping quality is one of the important indices of fruit characteristics.

Recently, peach cultivars have changed markedly, and many new cultivars have been released in Japan. Among these newly-released cultivars, there are new types in which the flesh is hard even when ground color has changed. Thus, their maturation characteristics may differ from those of the traditional cultivars. We need to compare additional indices of ripening, beyond the rate of softening, to evaluate the keeping quality of different peach cultivars.

The ripening of fruits can be classified as climacteric

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and nonclimacteric types (Pratt and Goeschl, 1969; Abeles, 1973). In the climacteric type, ethylene is known to have key roles in the process of maturation, such that the control of ethylene has been discussed as a method improving storage life (Tucker, 1993; Grierson, 1998). Peach is a climacteric fruit (Biale and Young, 1981), and stony hard cultivars, which do not show postharvest ethylene production and softening, are sensitive to ethylene; they are subject to ethylene-induced softening (Haji et al., 2003). This suggests that ethylene is involved in the varietal differences in maturation and ripening characteristics of peach fruit. In this study, we compared maturity indices and ethylene production in four table peach cultivars with different storage life characteristics. Several new findings are reported.

Materials and Methods

This study was carried out in 1996, using the peach trees grown at the National Institute of Fruit Tree Science. The cultivars analyzed were 'Akatsuki', 'Kushigatahakuto', 'Nagasawahakuho' and 'Yumyeong'. 'Akatsuki', 'Kushigatahakuto' and 'Nagasawahakuho' are melting-type cultivars bred in Japan. 'Yumyeong' is a cultivar bred in Korea (Kim et al., 1978). It has been known that 'Yumyeong' is a stony hard type as previously reported (Haji et al., 2001).

Fruit of the stage III of development, which are in the processes of enlargement, maturation and senescence, were collected every 4 to 7 days from each cultivar. Fruit weight, change in ground color, flesh firmness, sugar content, titratable acidity and amount of ethylene production were measured on 4 fruit immediately after sampling. The rest of the collected fruit was stored at 25 °C; the amount of ethylene they produced and their flesh firmness were measured every 2 days for 8 days using 3 fruit per sample.

As an index of change in ground color of the fruit skin, the a^* value of the unpigmented area was measured with a spectrophotometer (Minolta, CM-2002). When ground color of peach fruit changed, the a^* value was more than -1.5. After removing the fruit skin in the equatorial area, the flesh firmness was measured with a fruit pressure tester (Italtest, FT011) with a cylindrical plunger (8.0 mm diam.). The amount of ethylene produced was determined by incubating a fruit in a 1.5-liter desiccator for 2 hr at 25 °C. A 1.0-ml gas sample that was withdrawn from the desiccator was injected into a gas chromatograph (Shimadzu, GC-9A) equipped with an activated alumina column and flame ionization detector. Sugar content was determined with a refractometer (Atago, PR-100), whereas, titratable acidity was expressed in malic acid equivalents after titration of acids in the juice with 0.1 N KOH.

Results

The time-courses of ethylene production and flesh firmness in the melting-type cultivars 'Kushigatahakuto', 'Akatsuki' and 'Nagasawahakuho' (Fig. 1, 2, 3) reveal that the on-tree flesh firmness gradually decreased with elapsed time after full bloom. Postharvest softening was not observed in immature fruit. However, postharvest softening became more marked after 75, 91 and 115 days after full bloom (DAFB) in 'Kushigatahakuto', 'Akatsuki' and 'Nagasawahakuho', respectively. After these dates the postharvest softening was clearly accelerated as compared to the on-tree softening. On-tree production of ethylene occurred 82, 109 and 129 DAFB in 'Kushigatahakuto', 'Akatsuki' and 'Nagasawahakuho', respectively. The amount of on-tree ethylene production increased slowly thereafter. In contrast, the postharvest fruit showed a very marked increase in the rate and total amounts of ethylene

Fig. 1. On-tree and postharvest time courses of flesh firmness and amount of ethylene production in the melting-type cultivar 'Kushigatahakuto'.

Fig. 2. On-tree and postharvest time courses of flesh firmness and amount of ethylene production in the melting-type cultivar 'Akatsuki'.

Fig. 3. On-tree and postharvest time courses of flesh firmness and amount of ethylene production in the melting-type cultivar 'Nagasawahakuho'.

produced. The increased ethylene production in the postharvest fruit was generally accompanied with a marked decrease in flesh firmness. Postharvest ethylene production and on-tree ethylene production were accelerated after on-tree flesh firmness decreased to 9.4 kg (75 DAFB) and 6.7 kg (82 DAFB), respectively, for 'Kushigatahakuto'; those factors decreased to 8.5 kg (91 DAFB) and 4.0 kg or less (109 DAFB) in 'Akatsuki'. Postharvest ethylene production did not occur in 'Nagasawahakuho' until flesh firmness dropped to 4.3 kg (115 DAFB); whereas on-tree ethylene production became detectable 14 days later (129 DAFB). On-tree softening was quite slow throughout these periods.

Time-courses of relative fruit weights, a^* values of ground color, relative values of sugar content and titratable acidity in the three cultivars 'Kushigatahakuto',

'Akatsuki' and 'Nagasawahakuho' (Table 1, 2, 3) show that in all the cultivars, the increases in relative fruit weight and relative sugar content became slower as the days elapsed after full bloom, while the change in ground color and the lowering of titratable acidity proceeded. While the relative fruit weight to final weight at the time of onset of on-tree ethylene production was 52.2% in 'Kushigatahakuto', the corresponding value in 'Akatsuki' was 84.4% and that in 'Nagasawahakuho' was 98.2%. In 'Kushigatahakuto', ethylene production started prior to the change in ground color, when the a^* value was -11.9. However, 'Akatsuki' and 'Nagasawahakuho' started ethylene production after the change in ground color, when the a^* values reached 0.5 and 2.5, respectively. While the relative sugar contents in 'Akatsuki' and 'Nagasawahakuho' were higher than

90% of the final level, when the ethylene production started, the corresponding value in 'Kushigatahakuto' was 65.2%. It was 9 days after the onset of ethylene production (91 DAFB) when the relative sugar content in 'Kushigatahakuto' exceeded 85.0%. The flesh firmness at that time was less than 2.0 kg (Fig. 1). The titratable acidity in these cultivars was in the range of 0.20–0.26% when ethylene production started, showing that the process of acid decrease was almost completed. Relative to the other cultivars, onset of postharvest ethylene production was delayed in 'Nagasawahakuho'; fruit enlargement, change in ground color and sugar accumulation at that point were more advanced than those in 'Akatsuki'. Thus, there were large varietal differences in the relationship between ethylene production and the advancement of maturity indices. To clarify

the situation, we compared relative fruit weight, ground color (a^* value), relative sugar content and titratable acidity in three melting-type cultivars when their respective flesh firmness reached 4.0 kg, a stage often regarded as suitable for commercial harvesting (Table 4). At this stage, the titratable acids had decreased in all cultivars. 'Kushigatahakuto' was still growing in size and some of its ground color remained. Moreover, production of a large amount of ethylene was observed even though this stage preceded the rapid increase of sugar content. On the other hand, 'Akatsuki' and 'Nagasawahakuho' had almost reached full size and maximum sugar accumulation. Although 'Akatsuki' started ethylene production with partially remaining ground color, 'Nagasawahakuho' did not evolve ethylene even with the full change in ground color.

Table 1. Relative fruit weight, a^* value, relative sugar content and titratable acidity at different stage of development and maturation in 'Kushigatahakuto'.

Days after full bloom	Relative fruit weight ^z (%)	Ground color (a^* value)	Relative sugar content ^z (%)	Titratable acidity (%)
68	24.1	–15.7	61.6	0.52
75 ^y	32.3	–15.7	61.6	0.52
82 ^x	52.2	–11.9	65.2	0.25
87	65.2	–6.5	68.8	0.15
91	83.3	–3.0	89.1	0.14
96	94.9	–2.8	85.5	0.15
101	100.0 ^w	2.3	100.0 ^v	0.15

^z $100 \times (\text{observed value}/\text{maximum value})$.

^y Start of postharvest ethylene production.

^x Start of on-tree ethylene production.

^w Maximum value of fruit weight was 293.3 g.

^v Maximum value of soluble solid content was 13.8%.

Table 2. Relative fruit weight, a^* value, relative sugar content and titratable acidity at different stage of development and maturation in 'Akatsuki'.

Days after full bloom	Relative fruit weight ^z (%)	Ground color (a^* value)	Relative sugar content ^z (%)	Titratable acidity (%)
84	31.6	–14.4	60.7	0.79
91	34.6	–13.3	70.7	0.46
98 ^y	71.3	–12.0	82.8	0.36
105	84.8	–7.1	91.4	0.28
109 ^x	84.4	0.5	92.1	0.26
114	87.9	0.7	98.6	0.24
119	93.4	1.1	99.2	0.20
125	100.0 ^w	3.1	100.0 ^v	0.15

^z $100 \times (\text{observed value}/\text{maximum value})$.

^y Start of postharvest ethylene production.

^x Start of on-tree ethylene production.

^w Maximum value of fruit weight was 258.7 g.

^v Maximum value of soluble solid content was 13.9%.

Table 3. Relative fruit weight, a* value, relative sugar content and titratable acidity at different stage of development and maturation in ‘Nagasawahakuho’.

Days after full bloom	Relative fruit weight ^z (%)	Ground color (a* value)	Relative sugar content ^z (%)	Titratable acidity (%)
87	20.4	–14.8	61.6	0.76
94	26.2	–14.3	72.9	0.50
101	41.4	–12.8	79.7	0.40
108	61.8	–8.2	78.9	0.36
115 ^y	91.9	–4.6	90.2	0.20
122	90.7	0.7	88.7	0.22
129 ^x	98.2	2.5	99.2	0.21
136	100.0 ^w	3.9	100.0 ^v	0.20

^z $100 \times (\text{observed value}/\text{maximum value})$.^y Start of postharvest ethylene production.^x Start of on-tree ethylene production.^w Maximum value of fruit weight was 275.1 g.^v Maximum value of soluble solid content was 13.3%.**Table 4.** Relative fruit weight, a* value, ethylene production, relative sugar content and titratable acidity in melting-type cultivars at the stage when flesh firmness reached 4.0 kg.

Cultivar	Relative fruit weight ^z (%)	Ground color (a* value)	Ethylene (nl · gFW ⁻¹ · hr ⁻¹)	Relative sugar content ^z (%)	Titratable acidity (%)
Kushigatahakuto	65.2	–6.5	14.1	68.8	0.15
Akatsuki	84.6	–3.3	2.2	91.8	0.27
Nagasawahakuho	90.7	0.7	0.0	88.7	0.22

^z $100 \times (\text{observed value}/\text{maximum value})$. **Fig. 4.** On-tree and postharvest time courses of flesh firmness and amount of ethylene production in the stony hard cultivar ‘Yumyeong’.

The similar results were obtained in the stony hard-type cultivar ‘Yumyeong’ (Fig. 4, Table 5). In this cultivar, unlike ‘Kushigatahakuto’, ‘Akatsuki’ and ‘Nagasawahakuho’, ethylene production and postharvest softening did not occur. The on-tree decrease in flesh firmness was moderate, dropping to about 4.0 kg. On the other hand, the increase in fruit weight, the change in ground color, the increase in sugar content and the drop

in titratable acidity were similar to those of the melting-type cultivars. Fruit enlargement, the change in ground color, the accumulation of sugars and the drop in acidity were almost complete 129 DAFB.

Discussion

Although the level of ethylene production has been regarded as a key factor determining varietal differences

Table 5. Relative fruit weight, a* value, relative sugar content and titratable acidity at different stage of development and maturation in 'Yumyeong'.

Days after full bloom	Relative fruit weight ^z (%)	Ground color (a* value)	Relative sugar content ^z (%)	Titratable acidity (%)
101	39.6	-14.2	76.7	0.60
108	53.1	-9.3	77.5	0.44
115	60.1	-7.3	80.8	0.27
122	81.8	-3.1	88.3	0.31
129	93.0	0.2	91.6	0.27
136	97.4	1.5	95.6	0.25
143	100.0 ^y	2.2	100.0 ^x	0.23

^z $100 \times (\text{observed value}/\text{maximum value})$.

^y Maximum value of fruit weight was 268.0 g.

^x Maximum value of soluble solid content was 12.0%.

in the storage life of melons (Kitamura et al., 1975; Kendall and Ng, 1988) and apples (Yoshioka et al., 1989), our maturity indices did not always advance synchronously and maturation characteristics differed appreciably among peach varieties. In 'Kushigatahakuto' ethylene production started in the early stage of fruit development, the softening of flesh preceded the increase in fruit size, the change in ground color and sugar accumulation. In 'Nagasawahakuho', a late ethylene producer, the softening of flesh started after the increase in fruit size, the change in ground color, sugar accumulation and the drop in acidity occurred. In 'Yumyeong', ethylene production and postharvest softening did not occur, but the increase in fruit size, change in ground color, rise in sugar content and decrease in titratable acids advanced normally. This indicates that for peach, unlike melon and apple, the time of onset of ethylene production varied and determining the keeping quality and maturation characteristics. Therefore, we conclude that the onset of ethylene production is a key criterion in the breeding and selection of new peach cultivars. In 'Yumyeong', the on-tree flesh firmness gradually decreased with increase in fruit size while harvested fruit did not soften, which suggests that in addition to the ethylene-regulated softening, fruit enlargement may also affect when softening of on-tree fruit takes place.

Transgenic plants in which ethylene production is almost completely suppressed have been obtained in tomato (Hamilton et al., 1990; Oeller et al., 1991) and melon (Ayub et al., 1996; Guis et al., 1997). Softening and coloration are strongly inhibited in the fruits of these transgenic plants. Genetic engineering opens a gate to the possibility of longer storage life for fruits, thus, is a focus of much attention. For commercial applications, the development of a technique that suppresses softening but not other maturation processes, is desirable (Grieron, 1998; Bommineni, 2000). On the other hand, this study showed that there are wide varietal differences in

the capacity for ethylene production, and that the time of onset of ethylene production and of softening are closely related. We demonstrated that even when ethylene production is delayed or suppressed, the other major indices of maturation of peach fruit, besides softening, proceeds normally. These findings suggest that the possibility of improving the keeping quality of peach fruit, by genetically controlling the onset of ethylene production exists. It is also expected to be possible to achieve larger fruit size and higher fruit quality by delaying the start of ethylene production, as there are cultivars, such as 'Kushigatahakuto' that start ethylene production and softening during the enlargement of fruit size or before the rapid rise in sugar content.

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モモ果実における成熟特性と日持ち性およびエチレン生成との関係の品種間差異

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摘 要

日持ち性が異なる生食用モモ品種について、果実の肥大、成熟および老化の過程を通して果実重、果皮の地色の a^* 値、果肉硬度、糖度、滴定酸含量、エチレン生成量の推移を調査し、熟度の指標の相互関係すなわち成熟特性の差異とエチレン生成特性との関連を検討した。溶質品種の‘あかつき’、‘橢形白桃’および‘長沢白鳳’はいずれも満開後日数の経過とともに果実肥大、地色の抜け、糖度の上昇、滴定酸含量の低下が進み、特定の日以降収穫によりエチレン生成と軟化が明瞭に促進されるようになった後、樹上でのエチレン生成が認められるようになった。しかしエチレン生成と熟度の指標の進行との間には大きな品種間差異が見出され、‘橢形白

桃’は果実肥大の途中で地色が残り、糖度が急速に増加する前であってもエチレンを多く生成し軟化が進んだのに対して、軟化が遅延する‘長沢白鳳’では果実肥大と糖度の上昇を終え地色が抜けた後にエチレン生成が始まった。また硬肉品種の‘有明’ではエチレン生成と収穫後の軟化が認められず、樹上での果肉硬度は 4.0 kg 前後までしか低下しなかったものの、果実肥大、地色の抜け、糖度の上昇、滴定酸含量の低下は溶質品種と同様に進んでいた。以上の結果から、モモでは果実の軟化特性とともに成熟特性にも大きな品種間差異が認められ、その発現にはエチレン生成開始時期の遺伝的差異が重要な働きをしていると考えられた。