Effect of Different Fertilizer Application Levels on Texture of ‘Hakuho’ Peach (*Prunus persica* Batsch)

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Summary

Effects of different fertilizer application levels on the flesh texture of peach fruits were investigated. Four-year-old ‘Hakuho’ peach trees trained to a central leader system were supplied with complete liquid fertilizers comprising higher (160 ppm), medium (80 ppm), or lower (40 ppm) levels of N. The fertilizer levels were lowered to half for each at the stone hardening stage. The fruit harvested from the H treatment trees reached the shipping maturity stage 4 to 6 days later than the fruits from the L and M treatment trees. The flesh firmness of the H treatment fruit was significantly lower than those from the M and L treatment fruits when compared at the shipping maturity stage in each treatment. The flesh softening was apparently accompanied with increased ethylene emission from the fruit. The flesh of the H treatment fruits contained higher levels of water-soluble pectin and cellulose, and lower levels of HCl-soluble pectin and starch than those from the M and L treatment fruits at the pre-mature stage. In addition to that, a higher level of K and a lower level of Ca were analysed in the flesh of the H treatment fruit than the other treatments. These results indicate that the peach fruit grown under using a high amount of fertilizer application deteriorates the flesh texture at the time of harvest mainly because of the unbalanced mineral nutrition and delayed fruit ripening than the normally fertilized fruits.

Key Words: ethylene, flesh firmness, maturation, peach.

Introduction

Our previous work showed that ‘Hakuho’ peach trees applied with a high level of complete liquid fertilizers produced fruit with lower levels of sugars, anthocyanin, and peachy aromas but higher levels of acids and amino acids. Their flavor deteriorated and the harvest date was delayed 5 to 7 days, compared to the fruit on moderately or lightly fertilized trees (Jia et al., 1999; Jia et al., 2000). Such negative effects of excessive fertilization on the quality of peach fruit were reported by Carter et al. (1958), Schneider et al. (1958), and Okamoto et al. (1989). However, the information about the effect of fertilizer application levels on the texture of harvested fruits is limited. Peach flesh softens rapidly during the late stage of ripening, which affects significantly the fruit taste. The process of fruit softening involves mainly the changes in cell-wall polysaccharides e.g. pectin, hemicellulose and cellulose (Chapman et al., 1990; Fishman et al., 1993; Hedge and Maness, 1998; Ning et al., 1997).

The present study investigated the changes in biochemical and physical properties of ‘Hakuho’ peach

flesh grown under different levels of fertilizer application.

Materials and Methods

1. Plant materials

In early March of 1997, 18 one-year-old ‘Hakuho’ (*P. persica*) peach trees, grafted on wild peach (*P. persica*) seedlings, were planted 1.2 m apart in 3 soil beds, 1 m wide × 7.5 m long × 0.25 m high. They were trained to a central leader system and utilized for this experiment in 1999. From bud burst in mid-March, the trees were supplied with 10 liters of complete liquid fertilizers (OHTSUKA EKIHI #1 and #2) containing 160, 80, and 40 ppm N (high, H, medium, M, and low, L, respectively) plus all essential elements as in our previous paper (Jia et al., 1999). The fertilizer levels in each treatment were reduced to half at the stone hardening stage in late May. Fruits were thinned during late May as usually practiced in Okayama Prefecture and covered with orange colored paper bags to avoid insect and fungus attacks.

2. Fruit sampling

Fruit were sampled from each plot several days before reaching the “shipping mature stage” (Aoyagi et

al., 1976) as determined by the loss of the greenish color of the skin and the firmness to the hand. Three to five fruits per tree, which were harvested 9:00 AM at 2 or 3 day intervals until over ripe, were immediately weighed and analyzed.

3. Ethylene evolution, skin color and flesh firmness

Sampled fruits were put into a 1.5 liter air-tight plastic vessel individually and kept at 25 °C. After 1.5 hr, 1 ml of gas was sampled by a syringe and injected into a FID-GC (SHIMADZU CG-14A) equipped with an activated aluminum column kept at 80 °C; the carrier gas was N₂. Measurements were carried out on 3 fruits per treatment.

After ethylene determination, skin coloration was determined with a color difference meter (NIPPON DENSHOKU, MODEL 1000DP) at the highest and the least colored areas at the equator of each fruit.

For measuring flesh firmness, two square pillars (1.5 mm × 1.5 mm) from the entire thickness of the mesocarp were taken from both cheeks of each fruit and pressed with a penetrometer (TOYO BOLDWIN, STM-T), having a plunger (φ 20 mm), at the rate of 50 mm · min⁻¹. The internal stress was recorded when the height of the pillar was decreased by 5%.

4. Analyses of cell wall substances and minerals in the mesocarp

Analysis for cell wall substances in the mesocarp was conducted by extracting with 80% EtOH 3 times. The residue, alcohol insoluble substances (AIS), was dried at 60 °C overnight and weighed. A 100-mg subsample of AIS was successively extracted with H₂O, 4% sodium hexametaphosphate, and 0.05 N-HCl to yield three types of pectic substances: water-soluble pectin (WSP), hexametaphosphoric acid-soluble pectin (PSP), and HCl-soluble pectin (HSP), respectively. After the 0.05 N-HCl extraction, the residue was treated with 1 M KOH and 4 M KOH to solubilize the hemicelluloses. The final residue consisted of cellulose. The three types

of pectic substances were determined photometrically according to the Carbazol-H₂SO₄ method. The hemicellulose and cellulose fractions were hydrolyzed with HCl (0.5 N) at 100 °C for 2.5 hr to reducing sugars which were determined by Somogyi-Nelson method. The hemicellulose and cellulose contents were calculated from the glucose contents by multiplying 0.9.

For mineral analyses, 2.5 g of flesh were lyophilized and the dried samples were reduced to ashes with 30 ml of nitric acid and 3 ml of perchloric acid by heating for 1 hr. After diluting with H₂O to 1 liter, the concentrations of Ca, Mg, and K were determined with an atomic absorption spectro photometer (SHIMADZU AA-660).

Results

1. Fruit weight and total soluble solids (TSS)

The fruit on the L treatment trees were the first to reach a shipping maturity on July 14, followed by the M treatment 2 days after and the H treatment 6 days after that. The average fresh weight of fruits from the H treatment trees was heaviest but the range varied most compared to those of the M and L treatments (Table 1). TSS was higher in fruits of the M and L treatments than that of the H treatment.

2. Changes in ethylene production, flesh firmness, and skin color

Ethylene evolved from harvested fruits became detectable on July 14 and increased gradually in all treatments (Fig. 1). After July 20, the H treatment fruit yielded less ethylene than the M and L treatment fruits but more on a per kg fruit basis at shipping maturity stage.

The flesh firmness gradually decreased in each treatment as the fruits ripened (Fig. 2); it was highest in the L treatment fruit and lowest in the H treatment fruit at shipping maturity stage.

The "a" value of skin ground color was highest in the L treatment fruit and lowest in the H treatment fruit until July 20 (Fig. 3) but that of the latter increased contin-

Table 1. Effect of fertilizer levels on size and TSS of 'Hakuho' peaches at shipping maturity^z.

Treatment ^y	Fruit weight (g)	Juice TSS (°Brix)	Harvest date ^x
L	170.4 ± 6.7	12.0 ± 0.4a	Jul. 14
M	169.5 ± 7.6	12.5 ± 0.4a	Jul. 16
H	177.6 ± 13.8	11.1 ± 0.3b	Jul. 20

^zMean ± SE (n=12), significant difference by Duncan's multiple range test ($P < 0.05$) for values within each column.

^yLevels of complete liquid fertilizer containing 40 ppm (L), 80 ppm (M), and 160 ppm (H) of N. The levels were lowered to half of each at the end of pit hardening stage.

^xThe day when a half number of the fruits in each treatment reached shipping maturity stage.

Fig. 1. Changes in ethylene evolution by the ripening 'Hakuho' peaches grown under different levels of liquid fertilizers. H, M, and L represent 160, 80, 40 ppm N contained in the fertilizer, respectively. Arrows show the shipping maturity stage in each treatment. Vertical bars indicate SE (n=3).

Fig. 2. Changes in flesh firmness of 'Hakuho' peaches grown under different levels of liquid fertilizers. (See Fig. 1 for meaning of symbols.) Arrows show the shipping maturity stage in each treatment. Vertical bars indicate SE (n=6).

Fig. 3. Changes in "a" and "b" values of ripening 'Hakuho' peaches. (See Fig. 1 for meaning of symbols.) Arrows show the shipping maturity stage in each treatment. Vertical bars indicate SE (n=6).

uously thereafter, while in M and L treatment fruits it became constant. The "b" value of skin ground color was highest in the ripe and overripe H treatment fruit, which indicated that they had a stronger yellowish tint than did those of the M and L treatment fruits. No significant difference in "L" value was found among fruits from different treatments (Data not shown).

3. Cell wall substances and starch

At the pre-mature stage, H treatment fruit flesh contained more WSP than did the M and L treatment fruits, whereas at the full-ripe stage, WSP increased in

Table 2. Effect of fertilizer levels on pectin content ($\text{mg} \cdot \text{gFW}^{-1}$) in pre-mature and ripe 'Hakuho' peach^z.

Pectin type ^y	Treatment ^x	Ripening stage ^w	
		Pre-mature	Full ripe
WSP	L	$2.75 \pm 0.30\text{b}$	$3.01 \pm 0.31\text{b}$
	M	$2.77 \pm 0.40\text{b}$	$3.58 \pm 0.0\text{a}$
	H	$3.42 \pm 0.18\text{a}$	$3.40 \pm 0.43\text{ab}$
PSP	L	0.49 ± 0.02	0.60 ± 0.12
	M	0.56 ± 0.05	0.56 ± 0.06
	H	0.48 ± 0.03	0.49 ± 0.02
HSP	L	$2.54 \pm 0.18\text{ab}$	1.34 ± 0.18
	M	$3.89 \pm 0.05\text{a}$	1.51 ± 0.22
	H	$2.09 \pm 0.32\text{b}$	1.61 ± 0.29
Total (TP)	L	$5.78 \pm 0.15\text{b}$	4.94 ± 0.29
	M	$7.30 \pm 0.46\text{a}$	5.65 ± 0.27
	H	$5.99 \pm 0.45\text{b}$	5.49 ± 0.61

^zMean $\pm$ SE (n=6), significant difference by Duncan's multiple range test ($P<0.05$) for values within each column.

^yWSP, water soluble pectin; PSP, hexamethaphosphoric acid soluble pectin; HSP, HCl soluble pectin.

^xSee Table 1.

^wPre-mature, $1.6-1.8\text{kg} \cdot \text{cm}^{-2}$ of flesh firmness; full ripe, $0.5\text{kg} \cdot \text{cm}^{-2}$.

Table 3. Effect of fertilizer levels on hemicellulose, cellulose, and starch contents ($\text{mg} \cdot \text{gFW}^{-1}$) in pre-mature and ripe 'Hakuho' peach^z.

Constituent	Treatment ^y	Ripening stage ^x	
		Pre-mature	Full ripe
Hemicellulose	L	$1.55 \pm 0.16\text{a}$	0.88 ± 0.11
	M	$1.16 \pm 0.27\text{b}$	1.03 ± 0.34
	H	$1.14 \pm 0.10\text{b}$	0.89 ± 0.16
Cellulose	L	$7.77 \pm 1.03\text{b}$	$7.21 \pm 0.59\text{a}$
	M	$8.66 \pm 0.21\text{ab}$	$7.18 \pm 0.26\text{a}$
	H	$9.28 \pm 0.44\text{a}$	$5.65 \pm 0.72\text{b}$
Starch	L	$3.61 \pm 0.26\text{a}$	$1.47 \pm 0.10\text{b}$
	M	$2.86 \pm 0.25\text{a}$	$2.56 \pm 0.19\text{a}$
	H	$1.93 \pm 0.13\text{b}$	$1.51 \pm 0.20\text{b}$

^zMean $\pm$ SE (n=6), significant difference by Duncan's multiple range test ($P<0.05$) for values within each constituent of each column.

^ySee Table 1.

^xSee Table 2.

the L and M treatment fruits while it remained constant in the H treatment fruit (Table 2). No significant difference was found in PSP content between the treatments and fruit maturation stages, but the HSP content was much higher in the M treatment fruit than it was in the L and H treatment fruits at the pre-mature stage, but the differ-

Table 4. Effect of fertilizer levels on mineral contents (mg · gDW⁻¹) in 'Hakuho' peach flesh^z.

Mineral	Treatment ^y	Ripening stage ^x	
		Pre-mature	Full ripe
K	L	16.0 ± 1.33b	16.3 ± 1.95b
	M	16.9 ± 0.83b	12.5 ± 1.31b
	H	21.4 ± 3.74a	25.7 ± 3.22a
Ca	L	3.04 ± 0.31a	1.29 ± 0.11b
	M	1.63 ± 0.25b	0.72 ± 0.08b
	H	1.30 ± 0.18b	1.99 ± 0.28a
Mg	L	0.62 ± 0.06	0.59 ± 0.05b
	M	0.64 ± 0.05	0.45 ± 0.05b
	H	0.85 ± 0.10	1.08 ± 0.12a

^zMean ± SE (n=6), significant difference by Duncan's multiple range test ($P < 0.05$) for values within each constituent of each column.

^ySee Table 1.

^xSee Table 2.

ence diminished at the full-ripe stage. Total pectin (TP) content was significantly higher in the M treatment fruit than in the L and H treatment fruits at the pre-mature stage, though the high TP level in the M treatment fruit decreased by the full-ripe stage.

Hemicellulose content was highest in the L treatment fruit at the pre-mature stage, but it decreased significantly as the fruit fully ripened, while the cellulose content was lowest in the L treatment fruit at the same stage (Table 3). The cellulose content which was highest in the unripe H treatment fruit markedly decreased by the full-ripe stage, attaining the lowest value among the treatments.

Starch content was highest in the L treatment fruit and lowest in the H treatment fruit at the pre-mature stage. However, the content in the L treatment fruit decreased remarkably by the full-ripe stage.

4. Mineral contents

Significantly higher K and Mg levels were observed in the H treatment fruits than the M and L treatment fruits at the pre-mature and full-ripe stages (Table 4). Ca level was highest in the L treatment fruit and lowest in the H treatment fruit at the pre-mature stage; their levels were reversed at full-ripe stage.

Discussion

Higher contents of leaf N and fruit amino acids, accompanied with delayed fruit ripening were observed in the peach trees applied with high levels of complete liquid fertilizers in our previous works (Jia et al., 1999; Jia et al., 2000). Those fruit also had much wider variation in size with lower levels of juice TSS and skin anthocyanins. These findings agrees with the results of our present experiment.

It is very interesting that the onset of ethylene production by peach fruits occurs approximately at the same rate irrespective of the fertilizer application levels, where the harvesting time was significantly changed. Peach fruit is a climacteric one, which produce abundant ethylene at the final ripening stage (Tonutti et al., 1991; Tonutti et al., 1996), paralleling the softening rate of the peach mesocarp (Valero et al., 1997). Our present data also show that 'Hakuho' peach flesh softens simultaneously with the increase in ethylene evolution from the whole fruit. The higher ethylene level of the H treatment fruits at the shipping maturity stage than that of the M and L fruits is consistent with the lower flesh firmness at the time, which indicates a shorter shelf life.

The softening of fruit flesh is usually accompanied by changes of pectin substances and hemicellulose, which is regulated by various enzymes (Yahata et al., 1998; Bonghi et al., 1998; Hedge and Maness, 1998). The increase in WSP and the decrease in HSP found in the L and M treatment fruit flesh are attributed to the usual ripening process (Ning et al., 1997; Fishman et al., 1993). However, the flesh of the pre-mature H treatment fruit contained more WSP and less HSP than did the M and L treatment fruits, which indicates that the mesocarp tissue in the H treatment fruit was becoming senescent before reaching the shipping maturity stage. This finding is supported by the low level of starch at the pre-mature stage in H treatment fruit. At the same time, the flesh of the H treatment fruits contained the highest level of cellulose at the pre-mature stage which decreased significantly by the full-ripe stage. This indicates that the H treatment fruit initially was fibrous but this condition was rapidly altered during the ripening period.

The Ca and Mg in fruit flesh are largely cross-linked between pectic polymers to retain the rigidity of the flesh cell wall (Alonso et al., 1995; Femenia et al., 1998), whereas high amounts of N and K in fruits prevent the formation of new cross links by competing with Ca and Mg (van Buren, 1979). In our experiment, the flesh K and Ca contents were markedly affected by the fertilizer application levels. The higher K level in the flesh of the H treatment fruit might cause an earlier dissolution of pectic substances. The increased levels of K, Ca, and Mg in the H treatment fruit at the full ripe stage indicate that active mineral accumulation occurs during fruit ripening because of the abundant and continuous supply of nutrients from the liquid fertilizers.

From these results, we conclude that excessively fertilized peach trees produce late ripening fruit of poor quality, e.g. soft texture with a low juice TSS and short shelf life. The earlier softening of the mesocarp after harvest may be caused by the unbalanced mineral nutrition of the fruit flesh and the high level of ethylene evolution by the fruit at the shipping maturity stage.

Literature Cited

- Alonso, J., T. Rodriguez and W. Canet. 1995. Effect of calcium pretreatments on the texture of frozen cherries. *J. Agric. Food Chem.* 43: 1011–1016.
- Aoyagi, M., H. Makino and J. Sato. 1976. Effects of low temperature and maturity at harvest on keeping quality of white flesh peaches during their distribution. *J. Japan. Soc. Hort. Sci.* 45: 89–96.
- Bonghi, C., L. Ferrarese, B. Ruperti, P. Tomutti and A. Ramina. 1998. Endo- β 1,4- glucanases are involved in peach fruit growth and ripening, and regulated by ethylene. *Physiol. Plant.* 102: 346–352.
- Carter, G. H., D. W. Ingalsbe and A. M. Neubert. 1958. Canning quality of Elberta peaches as affected by nitrogen fertilization. *Food Technol.* 12: 174–179.
- Chapman, G. W. and R. J. Horvat. 1990. Changes in nonvolatile acids, sugars, pectin, and sugar composition of pectin during peach (cv. Monroe) maturation. *J. Agric. Food Chem.* 38: 383–387.
- Femenia, A., E. S. Sanchez, S. Simal and C. Rossello. 1998. Developmental and ripening-related effects on the cell wall of apricot (*Prunus armeniaca*) fruit. *J. Sci. Food Agric.* 77: 487–493.
- Fishman, M. L., B. Levaj and D. Gillespie. 1993. Changes in the physio-chemical properties of peach fruit pectin during on-tree ripening and storage. *J. Amer. Soc. Hort. Sci.* 118: 343–349.
- Hedge, S. and N. O. Maness. 1998. Changes in apparent molecular mass of pectin and hemicellulose extracts during peach softening. *J. Amer. Soc. Hort. Sci.* 123: 445–456.
- Jia, H., K. Hirano and G. Okamoto. 1999. Effects of fertilizer levels on tree growth and fruit quality of 'Hakuho' peaches (*Prunus persica*). *J. Japan. Soc. Hort. Sci.* 68: 487–493.
- Jia, H., G. Okamoto and K. Hirano. 2000. Effect of amino acid composition on the taste of 'Hakuho' peaches (*Prunus persica* Batsch) grown under different fertilizer levels. *J. Japan. Soc. Hort. Sci.* 69: 135–140.
- Ning, B., Y. Kubo, A. Inaba and R. Nakamura. 1997. Softening characteristics of Chinese pear 'Yali' fruit with special relation to changes in cell-wall polysaccharides and their degrading enzymes. *Sci. Rep. Fac. Agri. Okayama Univ.* 88: 79–86 (In Japanese with English summary).
- Okamoto, G., Y. Fujii and K. Shimamura. 1989. Effect of levels of fertilizer application tree growth and fruit quality of peach trees on *Prunus tomentosa*. *Environ. Control in Biol.* 27: 83–87 (In Japanese with English summary).
- Schneider, G. W., I. D. Jones and A. C. McClung. 1958. Studies of pruning effects, and rate and time of nitrogen fertilization on certain chemical and physical characteristics of the peach fruit. *Proc. Amer. Soc. Hort. Sci.* 71: 110–115.
- Tonutti, P., P. Casson and A. Ramina. 1991. Ethylene biosynthesis during peach fruit development. *J. Amer. Soc. Hort. Sci.* 116: 274–279.
- Tonutti, P., C. Bonghi and A. Ramina. 1996. Fruit firmness and ethylene biosynthesis in three cultivars of peach (*Prunus persica* L. Batsch). *J. Hort. Sci.* 71: 141–147.
- Valero, D., M. Serrano, M. C. Martinez-Madrid and F. Riquelme. 1997. Polyamines, ethylene, and physico-chemical changes in low-temperature-stored peach (*Prunus persica* L. cv. Maycrest). *J. Agric. Food Chem.* 45: 3406–3410.
- van Buren. 1979. The chemistry of texture in fruits and vegetables. *J. Text. Stud.* 10: 1–23.
- Yahata, D. and M. Awamura. 1996. Varietal differences and changes in cell wall composition in ripening fig fruits. *J. Japan. Soc. Hort. Sci.* 65: 41–47 (In Japanese with English summary).

モモ‘白鳳’果実の肉質に及ぼす施肥濃度の影響

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摘 要

モモ樹に対する施肥濃度が果実の肉質に及ぼす影響を調査するため、4年生の主幹形‘白鳳’樹に、発芽期から窒素 160 ppm(H区), 80 ppm(M区), 40 ppm(L区)を含む総合液肥を与え、硬核期からは各濃度を半分にした。H区の果実は、硬熟期に達するのがM区、L区より4~6日遅れたが、果肉硬度の低下はM区、L区と同時に始まり、ほぼ同じ速度で進行した。果実のエチレン発生量も各区ともほぼ同様に増加し、果肉の軟化と平行した。軟化前の果肉の細胞壁構成成分を比較すると、H区では、

M区、L区に比べて水溶性ペクチンとセルロース含量が高く、塩酸可溶性ペクチンとデンプン含量が低かったが、軟化後はセルロース含量が低かった。また、H区では果肉のK含量が高く、Ca含量が低かった。本実験の結果から、過剰施肥したモモ果実は、果肉の無機成分含量にアンバランスがあることや、糖の蓄積や果皮色の変化などが遅れ、エチレン発生が先行するなどのために、収穫期の肉質が劣ると考察される。