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Calcium Deficiency Causes Pithiness in Japanese Pear (*Pyrus pyrifolia* cv. Niitaka) Fruit

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칼슘 결핍에 의한 ‘신고’ 배 (*Pyrus pyrifolia* cv. Niitaka) 과실에서의 바람들이

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Received: 7 November 2012 / Revised: 1 May 2013 / Accepted: 4 May 2013

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Abstract

BACKGROUND: Pithy pear fruit are not distinguished externally from sound fruit and thus often cause unexpected economic losses. To find out the cause of pithiness, the pithiness incidence and characteristics of Japanese pear (*Pyrus pyrifolia* cv. Niitaka) fruit picked from a spot frequently produced pithy fruit in an orchard were compared with those of fruit picked from another spot produced sound fruit every year. And the soil chemical properties of the two spots and mineral contents in fruit, shoots, and leaves of Japanese pear trees cultivated in the two spots were also examined.

METHODS AND RESULTS: The pithiness incidence was 0, 8.8, and 11.3% at 7 days before and 0 and 7 days after optimal harvest date, respectively, in the spot frequently produced pithy fruit. Flesh firmness was significantly lower in pithy fruit than in sound fruit, while soluble solids content

was slightly higher in pithy fruit than in sound fruit. Unlike other mineral contents, Ca content was significantly lower in pithy fruit than in sound fruit. These results indicate that Ca deficiency in fruit is closely associated with decrease in flesh firmness and thus pithiness development. Ca content in soil of the spot frequently produced pithy fruit was also significantly lower than that in soil of the spot produced sound fruit. However, shoots or leaves did not exhibit significant difference in Ca and/or other mineral contents between the two spots, indicating that Ca deficiency in fruit is dependent on the translocation of Ca within a plant rather than soil Ca status. Although total-N, available P₂O₅, K, and Ca contents were significantly lower in soil of the spot frequently produced pithy fruit than in soil of the spot produced sound fruit, Mg and Na contents and pH were not different between the soil conditions.

CONCLUSION(S): Fruit maturity and Ca level in fruit are closely related to the incidence of pithiness in ‘Niitaka’ Japanese pear.

Key Words: Calcium deficiency, Flesh firmness, Minerals, Pithiness, *Pyrus pyrifolia*

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Introduction

Pithiness in Japanese pear fruit is a serious physiological disorder that deteriorates flesh texture (Chijiwa *et al.*, 2002). The pithy pear fruit are not distinguished externally from sound fruit and thus unexpected economic losses often occur.

Since the cell membrane permeability of the pithy fruit flesh is higher than that of healthy flesh, pithiness may be associated with an aging process. As pithiness intensifies, affected flesh tissues form cavities, decreasing the specific gravity and the flesh firmness of fruit during their ripening (Chijiwa *et al.*, 2002) and changing flesh color to light-brown or brown. However, flesh decay or core breakdown does not appear in pithy fruit. The affected fruit tissues are as sponge, syndrome of pithiness in radish tuber (Marcelis *et al.*, 1997). Unlikely, there are no fibrous materials in pear fruit.

The pithiness symptom in Japanese pear occasionally arises in the later-picked fruit (Kajiura *et al.*, 1976; Chijiwa *et al.*, 2002). And the incidence of pithiness is affected by cultural practices and preharvest environmental conditions (Franck *et al.*, 2007). For example, the symptom was usually observed in years experiencing cool summers or heavy rain during growing season (Honjo *et al.*, 1994; Franck *et al.*, 2007).

Pithiness as in the case of other physiological disorders in fruit (Bangerth, 1979; Ferguson *et al.*, 1999; Elmer *et al.*, 2007; Manganaris *et al.*, 2007) may also be associated with low Ca, because Ca is involved in maintaining the textural quality of fruit. Ca ions form crosslinks or bridges between free carboxyl groups of the pectin chains, strengthening the cell wall (Garcia *et al.*, 1996; Chardonnet *et al.*, 2003; Martín-Diana *et al.*, 2007) and enhancing cell cohesion (Hatfield and Knee, 1988; Chijiwa *et al.*, 2002). Thus, a loss of Ca from middle lamella and/or a loss of Ca binding site in the pectin molecules could cause fruit softening or pithiness (Knee, 1982; Stow, 1993).

In the present study, the soil chemical properties of one spot frequently produced pithy fruit in a Japanese pear (*Pyrus pyrifolia* cv. Niitaka) orchard were compared with those of another spot produced sound fruit every year. The mineral contents in shoots, leaves, and fruit picked from Japanese pear trees cultivated in the two spots were also analyzed to estimate the cause of pithiness with respect to

plant nutrition.

Materials and Methods

Two spots of an orchard in Ichon, Korea were selected to investigate pithiness incidence and characteristics in fruit of 12-year-old Japanese pear (*P. pyrifolia* cv. Niitaka). One spot had frequently produced pithy fruit, while the other had steadily produced sound fruit for many years. Yearly averages of air temperature and precipitation of Ichon for past 30 years were 11.6°C and 1,370 mm, respectively. In 2006, averages of air temperature and precipitation were 11.2°C and 1,453 mm, respectively.

Chemical properties of soil sampled from the two spots in late July were analyzed with respect to pH, organic matter, and mineral contents including total-N, available P₂O₅, K, Ca, Mg, and Na. The analysis was replicated three times for each spot. Each soil sample was collected from 20 to 30 cm below the soil surfaces of three points at a distance of 1.5 m from a tree. Soil pH of a mixture of soil and water (1:5, w/v) was determined using a pH meter (D-24, Horiba, Kyoto, Japan). Organic matter, total-N, and available P₂O₅ in soil were analyzed according to the methods of Tyurin, micro-Kjeldahl, and Lancaster, respectively (RDA, 1988). The contents of exchangeable cations including K, Ca, Mg, and Na were determined by analyzing eluted solution from soil using an inductively coupled plasma emission spectrometer (ICPS-1000IV, Shimadzu Corp., Kyoto, Japan). Four shoots, 50 leaves, and 5 fruit per tree were also randomly collected from the two spots to examine their mineral contents including total-N, P, K, Ca, and Mg. The analysis of mineral contents in shoots, leaves, and fruit were replicated three times. The shoots and leaves were sampled in late July and the fruit in mid-October. Total-N was analyzed using a Kjeltac auto 1035 analyzer system (Foss Tecator AB, Hoganas, Sweden). The vanadate method was used for P analysis (RDA, 1988). K, Ca, and Mg contents were determined using an atomic absorption spectrophotometer (AA680, Shimadzu, Kyoto, Japan).

At optimal harvest date, October 15, 2006, and 7 days before and after the optimal harvest date, pithiness incidence in fruit picked from the spot frequently produced pithy fruit was examined to find out the correlation with fruit maturity. The optimal harvest date in Ichon, Korea was determined based on the days after full bloom and flesh firmness

(Childers *et al.*, 1995). For monitoring the physiological disorder, randomly picked fruit were cut at the equatorial region transversely and distinguished damaged fruit with cavities of necrotic tissues from sound fruit. The pithiness incidence was expressed by percentage of damaged fruit to a total of 70 to 80 fruit monitored. The five pithy fruit harvested at optimal harvest date were compared with five sound fruit with respect to commercial qualities such as fruit weight, flesh firmness, soluble solids content, and peel color. Fruit firmness was determined using a texture analyzer (TA-XT2i, Stable Micro Systems, Surrey, UK) equipped with a cylinder probe of 5 mm in diameter. A hand refractometer was used for the determination of soluble solids content. Chromaticity of the fruit peel was determined with a chromameter (CR-300, Minolta Co., Ltd., Japan). The chromaticity was expressed as Hunter's L, a, and b color space coordinates. The L value represents the lightness of colors from 0 to 100, being small for dark colors and large for bright colors. The a value is negative for green and positive for red. The b value is negative for blue and positive for yellow. Both a and b scales range from -60 to 60 (Dussi *et al.*, 1995). The experiment was employed to a randomized block design with four replications. Data were subjected to analysis of variance using the SAS package (SAS Institute, Cary, NC, USA). Mean separation was performed with *t*-test at 5% level.

Results and Discussion

Pithy fruit were not found in the spot produced sound fruit every year. In the spot frequently produced pithy fruit, however, pithiness occurred as much as 0, 8.8, and 11.3% at 7 days before and 0 and 7 days after optimal harvest date, respectively (Table 1). These results indicate that targeting the harvest date is very important in 'Niitaka' Japanese pear, because pithiness is known to develop on the tree as well as during storage (Kajiura *et al.*, 1976; Cho *et al.*, 2010). In fact,

Table 1. Incidence of pithiness according to harvest date in spot frequently produced pithy fruit of Japanese pear (*P. pyrifolia* cv. Niitaka)

Harvest date	Incidence of pithiness (%)
7 days before optimal harvest date	0.0
Optimal harvest date (October 15)	8.8
7 days after optimal harvest date	11.3

pithiness is a typical postharvest disorder, induced by adverse storage conditions (Franck *et al.*, 2007).

Fruit weight and Hunter values of pithy fruit were not significantly different from those of sound fruit (Table 2), demonstrating that pithy fruit was not distinguished externally from sound fruit. Flesh firmness, however, was obviously lower in pithy fruit than that in sound fruit, while soluble solids content was slightly higher in pithy fruit than in sound fruit (Table 2). In pears, a decrease in flesh firmness is usually correlated with cell wall degradation during ripening (Hiwasa *et al.*, 2004). Since the cell membrane permeability of pithy fruit is higher than that of sound fruit, pithiness in 'Niitaka' Japanese pear may be associated with an aging process (Chijiwa *et al.*, 2002). The softening or pithiness in Japanese pear fruit has previously been reported to be closely related to the extensive enhancements of cell wall-degrading enzyme activities with ripening or overripening (Yamaki and Matsuda, 1977).

Table 2. Characteristics of pithy and sound fruit of Japanese pear (*P. pyrifolia* cv. Niitaka) harvested at optimal date (October 15)

Fruit type	Fruit weight (g)	Flesh firmness (kg)	Total soluble solid (^o Brix)	Hunter value		
				L	a	b
Pithy	640 a ^z	1.09 b	13.1 a	54.8 a	11.8 a	33.9 a
Sound	637 a	1.19 a	12.7 a	57.2 a	10.1 a	36.0 a

^zMean separation within columns by *t*-test at *P* = 0.05.

The incidence of pithiness on the tree as well as during storage could be modified by preharvest environmental conditions and cultural practices during growing season. The preharvest factors include seasonal characteristics such as temperature during growth and rainfall, orchard characteristics including tree and soil conditions, application of agro-chemicals, irrigation, and geographical position, and the position of the fruit in the tree (Ferguson *et al.*, 1999; Franck *et al.*, 2007). For example, fruit grown during seasons with relatively low mean temperatures are more susceptible to pithy browning in the flesh than those grown during relatively warm seasons (Honjo *et al.*, 1994). However, only a few reports have been published on the effect of preharvest factors causing pithiness (Xuan *et al.*, 2001; Saure, 2005).

Several physiological disorders in fruit have been associated with low Ca and/or with excess of N

(Ferguson *et al.*, 1999; Elmer *et al.*, 2007; Manganaris *et al.*, 2007). Especially, Ca level in fruit, associating structural integrity of fruit tissues, can be an important factor in association with pithiness development (Cho *et al.*, 2010). In the present study, pithy fruit had significantly lower Ca content both in the peel and the flesh than sound fruit, although the mineral contents such as total-N, P, and Mg except K were not significantly different between pithy and sound fruit in both peel and flesh (Table 3). K, antagonizing Ca, were 9.7 and 6.6 g/kg in the peel of pithy and sound fruit, respectively. Ca contents in the peel and the flesh of pithy fruit were 349 and 253 mg/kg, respectively, while sound fruit had Ca of 443 and 357 mg/kg in the peel and flesh, respectively (Table 3). These results confirm that Ca is associated with pithiness development of Japanese pear (Cho *et al.*, 2010). In fact, after long-term storage for 6 months damaged fruit by pithiness had also lower Ca in the flesh than sound fruit (data not shown). Thus, postharvest Ca application could maintain cell turgor, membrane integrity, and tissue firmness during storage and delay membrane lipid catabolism, extending storage life of fresh fruit (Garcia *et al.*, 1996; Piccioni *et al.*, 1998; Manganaris *et al.*, 2007; Martín-Diana *et al.*, 2007). Preharvest Ca sprays could also increase fruit firmness as previously reported in apple (Dris and Niskanen, 1999). However, this increase is slight and may differ from year to year, highly influenced by environmental factors (Saure, 2005; Elmer *et al.*, 2007).

Table 3. Mineral contents in the peel and the flesh of pithy and sound fruit of Japanese pear (*P. pyrifolia* cv. Niitaka) harvested at optimal date (October 15)

Fruit type	Total-N (g/kg)	P (mg/kg)	K (g/kg)	Ca (mg/kg)	Mg (mg/kg)
<i>Peel</i>					
Pithy	4.5 a ²	546 a	9.7 a	349 b	860 a
Sound	4.5 a	509 a	6.6 b	443 a	960 a
<i>Flesh</i>					
Pithy	1.9 a	827 a	8.4 a	253 b	366 a
Sound	2.1 a	805 a	8.3 a	357 a	407 a

²Mean separation within columns of peel and flesh by *t*-test at *P* = 0.05.

High N level in fruit, also influencing structural integrity of fruit tissues, could deteriorate fruit qualities in association with pithiness development. In the present study, sound fruit tended to have higher total-N than pithy fruit, although significant difference

was not observed in pithy and sound fruit in total-N contents (Table 3). Sound fruit, however, showed lower N/Ca ratio than pithy fruit, suggesting that N/Ca ratio as well as N level are important in pithiness development of 'Niitaka' Japanese pear.

Mineral level in a plant can be affected by mineral level in soil. The contents of total-N, available P₂O₅, K, and Ca were significantly lower in soil of the spot frequently produced pithy fruit than in soil of the spot produced sound fruit (Table 4). Mg and Na contents and pH in the two soil conditions were not different (Table 4). Furthermore, the mineral contents including Ca in shoots and leaves were not significantly different between the two spots, having little or no relation to soil mineral status (Table 5). These results suggest that Ca-related physiological disorders in fruit might be due to an inefficient translocation of Ca rather than poor Ca uptake (Bangerth, 1979). This problem is illustrated by the observation that leaves or shoots contain considerably higher Ca than storage organs irrespective of orchard position (Tables 3, 5). Ca differs from other minerals by being imported into fruit only in small amounts, much less than into leaves. However, the translocation of Ca within the tree and the cause of Ca deficiency in fruit are still a matter of conjecture (Scaife and Clarkson, 1978; Ferguson *et al.*, 1999; Saure, 2005; Franck *et al.*, 2007). A number of factors could be associated with movement of Ca into the developing fruit. Saure (2005) reported that the translocation of Ca within a plant might be based on a hormonal control mainly executed by gibberellins (GAs): physiologically active GAs have shown to inhibit Ca translocation. High levels of GAs during vigorous growth could thus be responsible for the often-observed decline in the course of Ca uptake during fruit development. Consequently, varying levels of GAs due to environmental factors could be the cause of the observed difference in the Ca content per fruit between different years and different regions. As only very limited quantities of Ca could be directly supplied to the fruit, reducing excessive GA levels through various means might be the appropriate way to control physiological disorders including pithiness. Further research should focus on a multivariate statistical approach towards analyzing the relationship between pithiness and cultural practices and preharvest environmental factors with respect to GA and Ca level. This will provide a better understanding of the phenomenon and means to

control pithiness incidence.

Consequently, pithiness incidence in 'Niitaka' Japanese pear increased with delay of harvest time. Pithy fruit was lower in flesh firmness and Ca content than sound fruit, indicating fruit maturity and Ca level in fruit are closely related to the incidence of pithiness in 'Niitaka' Japanese pear. Thus, development of means increasing Ca level in fruit might be the appropriate way to reduce pithiness incidence in 'Niitaka' Japanese pear.

Table 4. Chemical properties of soil from spot produced pithy or sound fruits of Japanese pear (*P. pyrifolia* cv. Niitaka)

Orchard type	pH (1:5)	Organic matter (g/kg)	Total-N (g/kg)	Av. P ₂ O ₅ (mg/kg)	Exchangeable cation (cmol/kg)			
					K	Ca	Mg	Na
PFP ^z	6.6 a ^y	19 b	1.3 b	932 b	0.99 b	6.6 b	1.51 a	0.04 a
SFP	7.2 a	22.4 a	2.3 a	1,236 a	1.30 a	14.7 a	1.16 a	0.07 a

^zPithy fruit produced; sound fruit produced.

^yMean separation within columns by *t*-test at *P* = 0.05.

Table 5. Mineral contents per dry weight in shoots and leaves of Japanese pear (*P. pyrifolia* cv. Niitaka) produced pithy and sound fruit

Tree type	Total-N (g/kg)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)
<i>Shoot</i>					
PFP ^z	7.0 a ^y	0.9 a	7.4 a	12.6 a	0.25 a
SFP	7.6 a	1.0 a	11.5 a	12.2 a	0.24 a
<i>Leaf</i>					
PFP	18.5 a	1.6 a	12.5 a	13.6 a	0.20 a
SFP	19.3 a	1.5 a	15.0 a	13.7 a	0.19 a

^zPithy fruit produced; sound fruit produced.

^yMean separation within columns of shoot and leaf by *t*-test at *P* = 0.05.

Acknowledgement

This work was supported by Gyeonggi-do Agricultural Research and Extension Services and Rural Development Administration, Korea.

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