

# Harvest Date Influences Superficial Scald Development in Granny Smith Apples During Long Term Storage

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**Abstract:** The effects of harvest dates on superficial scald development and postharvest quality in 'Granny Smith' apples (*Malus domestica* Borkh.) were investigated. Apples were harvested at 15-day intervals during 2 consecutive years (2000-2001) and stored at 0 °C with 90% relative humidity for 8 months. At the end of the 8 – month storage period plus an additional 1 week at 20 °C the percentage of superficial scald was lower (24.4%) in late harvested (November 15) apples than in apples harvested early (October 15), which was 85.4%. The apples harvested late reached a climacteric maximum quicker than those harvested early. The percentage of weight loss, soluble solids, titratable acidity and flesh firmness varied among the different harvest dates. Delaying harvest achieved an increase in soluble solids percentage. Flesh firmness, titratable acidity and soluble solids remained at acceptable levels regardless of harvest dates and storage durations. Loss of chlorophyll was slower in apples harvested late than in those harvested early. The percentage of decay was lower in fruit harvested early. We conclude that 'Granny Smith' apples could be stored for 8 months with minimal scald incidences (0% to 14.2% depending on storage length) if they are harvested in November in Korkuteli, Antalya ecological conditions.

**Key Words:** apple, *Malus domestica*, maturity, respiration, superficial scald, storage

## Granny Smith Elmalarında Derim Zamanının Uzun Süreli Depolama Sürecinde Oluşan Yüzeysel Kabuk Yanıklığı Gelişimi Üzerine Etkileri

**Özet:** Bu çalışmada, farklı derim zamanlarının 'Granny Smith' elmalarında yüzeysel kabuk yanıklığı gelişimi ve meyve kalitesi üzerine etkileri araştırılmıştır. Bu amaçla 2000-2001 deneme yıllarında elmalar 15'er gün aralıklarla derilmiş ve 0 °C sıcaklık ile %90 oransal nemde 8 ay süreyle muhafaza edilmiştir. Denemede, geç derilen (15 Kasım) elmalarda yüzeysel kabuk yanıklığı oranı erken derilen (15 Ekim) elmalara göre daha düşük bulunmuştur. 15 Kasım'da derildikten sonra 8 ay süreyle soğukta muhafaza edilen ve 1 hafta süreyle de 20 °C de bekletilen elmalarda %24.4 olan kabuk yanıklığı oranı aynı süre sonunda 15 Ekim'de derilen elmalarda %85.4 olarak saptanmıştır. Buna karşılık geç derilen elmalar, erken derilenlere göre daha önce klimakterik maksimuma ulaşmışlardır. Ağırlık kaybı, titre edilebilir asit miktarı ve meyve eti sertliği derim zamanları arasında farklılık göstermiştir. Geç derilen elmalarda toplam suda çözünebilir madde miktarı daha yüksek bulunmuştur. Muhafaza periyodu sonunda elmaların meyve eti sertliği, titre edilebilir asit ve toplam suda çözünebilir madde miktarları kabul edilebilir seviyelerde kalmıştır. Erken derilen elmalarda geç derilenlere göre klorofil kaybı daha hızlı gerçekleşmiş, buna karşılık bu meyvelerde 8 ay süren depolama sonunda daha düşük oranlarda çürük meyve saptanmıştır. Sonuçlar, Antalya ekolojik koşullarında üretilen ve Kasım ayı içerisinde derilen 'Granny Smith' elmalarının düşük oranda scald gelişimiyle (depolama süresine bağlı olarak %0 ile %14.2) 8 ay süreyle muhafaza edilebileceğini göstermiştir.

**Anahtar Sözcükler:** elma, *Malus domestica*, olgunluk, solunum, kabuk yanıklığı, depolama

## Introduction

Turkey, producing over 2.5 million tons of apples annually, is one of the most important apple producing countries in the world (FAO, 2002). 'Starking Delicious' and 'Golden Delicious' are the leading apple cultivars in Turkey, but the production of 'Granny Smith' apples has been increasing in recent years because of high consumer demand. However, the fact that 'Granny Smith' is highly susceptible to superficial scald negatively affects the

quality and its expanding production in Turkey, as in other apple producing countries.

Superficial scald, or storage scald, characterized by a brown discoloration of the skin surface of apples, is a physiological disorder that appears during marketing or after storage (Watkins et al., 1995). 'Granny Smith' apples are particularly prone to developing scald, and in some areas of the world the severity of scald reaches 100% after several months of cold storage (Chellew and

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Little, 1995). Scald development is associated with the accumulation of conjugated trienes, and oxidation products of  $\alpha$ -farnesene, and high concentrations of natural antioxidants in the apple peel may reduce scald development (Anet, 1972; Meir and Bramlage, 1988; Gallerani et al., 1990; Manseka and Vasilakakis, 1993; Golding et al., 2001; Diamantidis, 2002).

Many attempts have been made to control superficial scald. One way of controlling scald is to apply chemicals such as Diphenylamine (DPA), still used extensively around the world, or Ethoxyquin, prohibited in most of the world, directly after harvest (Smock, 1957; Lurie et al., 1989; Chellew and Little, 1995; Golding et al., 2001). However, these chemicals appear worldwide on priority lists of chemicals that will be withdrawn from the market in the near future. Controlled atmosphere (CA), especially ultra-low oxygen (ULO) storage, is another common practice for controlling superficial scald and is one of the alternative methods for DPA application and other chemical methods (Little and Taylor, 1981; Lau, 1990; Watkins et al., 1991; Erkan et al., 2004). Other treatments, such as pre-storage heat treatments (Lurie et al., 1991), hot water dip treatments (Ingle and D'Souza, 1989), ethanol vapors (Scott et al., 1995a), vegetable oils (Scott et al., 1995b), intermittent warming (Alwan and Watkins, 1999), stripped corn oil emulsion (Ju and Curry, 2000) and 1-MCP (Fan et al., 1999; Shaham et al., 2003; Zanella, 2003), are other useful methods for controlling superficial scald but are often not as effective as DPA treatment.

Another approach to prevent this disorder is to investigate its biochemical origin. Scald formation is thought to result from the oxidation of  $\alpha$ -farnesene, producing hydroperoxides and peroxides commonly known as conjugated triene hydroperoxides (CTH) (Soria et al., 1999).

The susceptibility of different apple cultivars to this disorder varies greatly with many factors, such as maturity, location and storage conditions. Fruit maturity may be one of the most important criteria for controlling superficial scald. Immature apples scald more rapidly than mature apples (Ingle and D'Souza, 1989; Özelkök et al., 1995; Ingle, 2001). The maximum storage life and highest quality of apples depend both on cultivar and fruit maturity (Özelkök et al., 1995; Drake et al., 2002). It is therefore very important to determine the optimum harvest date for each cultivar, region and country.

The following study was conducted in order to determine the effect of harvest dates on superficial scald development and postharvest quality in 'Granny Smith' apples during long-term storage.

## Materials and Methods

'Granny Smith' apples (*Malus domestica* Borkh.) growing on M9 rootstock were harvested from a commercial orchard in Korkuteli, Antalya, Turkey, in 2 consecutive years (year 1, 2000, and year 2, 2001). The first year, fruit were harvested twice at 15-day intervals (harvest 1 and harvest 2). Harvest 1 was on October 1, and harvest 2 was on October 15. The second year, the apples were harvested 3 times at 15-day intervals (harvest 1, harvest 2 and harvest 3). Harvest 1 was on October 15, harvest 2 was on October 30 and harvest 3 was on November 15. Starch content of the harvested apples was determined by standard procedures using a starch index 1 to 8 (Cornell University, Generic Starch-Iodine Index Chart for Apples). When the average starch index reached 4 (harvest 1), 5 (harvest 2) and 6 (harvest 3) the apples were harvested. After harvesting, all apples were stored without any chemical applications or treatments at 0 °C and 90% relative humidity. During the storage period, 90 apples were removed from storage at 2 – month intervals for analysis and observations. Superficial scald was evaluated just after removal from cold storage and after 7 days' shelf life at 20 °C. Flesh firmness, soluble solids (SS) percentage, titratable acidity (TA) and skin color were analyzed just after storage. Scald incidence was calculated as the number of apples showing any sign of scald (regardless of darkness), divided by the number of apples and multiplied by 100 and expressed as a percentage. Flesh firmness was determined using a hand-held penetrometer (Effegi, Milan, Italy, model FT327) with an 11.1 – mm – measuring head on a pared surface on 3 sides of the apples at the equator. SS percentage and titratable acidity were measured in juice squeezed from whole apples. SS was determined with a hand refractometer, and titratable acidity was determined by titrating 10 ml of fruit juice with 0.1 N NaOH to pH 8.1 and calculating the result as malic acid. Fruit skin color was measured by the 'L\*, a\*, b\*' system using a chromameter (CR-200, Minolta, Osaka, Japan). Expression of color was characterized as L\* (lightness) and a\*, b\* (chromaticity coordinates). The chromaticity coordinates represent color directions as

follows: +a\* (red direction), -a\* (green direction), +b\* (yellow direction), -b\* (blue direction) (Wang, 2000). In addition to the above – stated analyses, changes in the respiration rate of the apples at 20 °C prior to storage and fungi causing deterioration after storage were also recorded.

Analysis of variance was carried out using MSTAT-C with harvest dates as the main plot and storage durations as the subplot. Means were separated using Duncan's multiple range test ( $P \leq 0.05$ ).

## Results

During the first year (2000) of the experiment, superficial scald development was aggravated by an extension of the storage period. The percentage of superficial scald, after 8 – months of storage, reached 73.1% and 51.4% in harvest 1 and harvest 2, respectively (Table 1). The severity of scald was even greater with fruit kept 7 days at 20 °C after removal from 0 °C. Scald incidence of the apples kept at 20 °C for 7 days after 8 – months of cold storage was 100% and 79.6% in harvest 1 and harvest 2, respectively (Table 1). Therefore, during the second year of the experiment, fruit were harvested later than in the first year.

Scald incidence in the apples during the second year (2001) is given in Table 2. The later the harvest was the lower the scald incidence. At the end of the 8 – month storage period scald incidence was 53.0%, 30.8% and 14.2% in harvest 1, harvest 2 and harvest 3, respectively

(Table 2). Scald incidence after storage decreased with advancing harvest date. Scald incidence of the apples kept at 20 °C for 7 days after 8 – months of cold storage was 85.4%, 56.2% and 24.4% in harvest 1, harvest 2 and harvest 3, respectively (Table 2). During both the first and second years of the experiment, statistically significant differences ( $P \leq 0.05$ ) in superficial scald incidence were found between the different harvest dates.

During both the first and second years of the experiment, the respiration rate of the apples stored at 20 °C first increased, and then decreased over time. During the second year of the experiment late harvested apples (November 15) reached the climacteric maximum earlier than those harvested early (October 15) (Figure 1). In 2001, apples harvested on November 15 reached a climacteric peak 18 days after harvest ( $23.1 \text{ ml CO}_2/\text{kg}^{-1} \cdot \text{h}^{-1}$ ), apples harvested on October 30 reached a climacteric peak 21 days after harvest ( $21.4 \text{ ml CO}_2/\text{kg}^{-1} \cdot \text{h}^{-1}$ ) and apples harvested on October 15 reached a climacteric peak 24 days after harvest ( $18.6 \text{ ml CO}_2/\text{kg}^{-1} \cdot \text{h}^{-1}$ ) (Figure 1). A similar pattern was observed during the first year of the experiment in terms of respiration.

During both the first and second years of the experiment, a longer storage period gave a higher weight loss. Late harvested fruit showed lower weight loss than early harvested fruits. In 2001, at the end of 8 – months of storage, while the weight loss of apples harvested on November 15 (harvest 3) was 6.8%, the weight loss was 7.9% and 10.6% in the apples harvested on October 30

Table 1. Influence of harvest dates and storage durations on superficial scald development of 'Granny Smith' apples after storage at 0 °C and 7 days at shelf life conditions at 20 °C (year 1-2000).

Harvest dates	Storage duration (months)	Superficial scald (%)	
		after storage	after additional 1 week
October 1 (year 1-2000)	2	8.2 d <sup>2</sup>	12.4 d
	4	23.5 c	31.6 c
	6	53.6 b	69.4 b
	8	73.1 a	100.0 a
October 15 (year 1-2000)	2	6.6 d	10.4 d
	4	19.4 c	26.8 c
	6	38.9 b	54.8 b
	8	51.4 a	79.6 a

<sup>2</sup>Mean separation within columns by Duncan's multiple range test,  $P \leq 0.05$ .

Table 2. Influence of harvest dates and storage durations on superficial scald development of 'Granny Smith' apples after storage at 0 °C and 7 days at shelf life conditions at 20 °C (year 2-2001).

Harvest dates	Storage duration (months)	Superficial scald (%)	
		after storage	after additional 1 week
October 15 (year 2-2001)	2	7.1 d <sup>2</sup>	11.8 d
	4	17.6 c	24.9 c
	6	34.4 b	49.7 b
	8	53.0 a	85.4 a
October 30 (year 2-2001)	2	4.2 d	7.3 d
	4	10.4 c	18.6 c
	6	19.5 b	34.7 b
	8	30.8 a	56.2 a
November 15 (year 2-2001)	2	0.0 d	0.0 d
	4	3.2 c	5.7 c
	6	8.4 b	14.6 b
	8	14.2 a	24.4 a

<sup>2</sup>Mean separation within columns by Duncan's multiple range test, P ≤ 0.05.

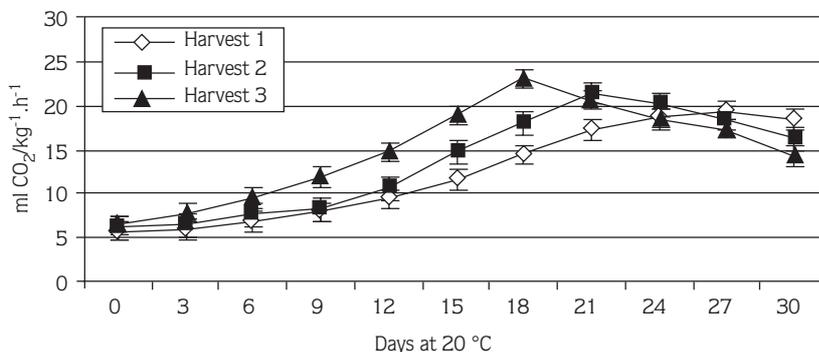


Figure 1. The effect of harvest dates on respiration rate (ml CO<sub>2</sub>/kg<sup>-1</sup>.h<sup>-1</sup>) of 'Granny Smith' apples at 20 °C (year 2-2001). Vertical bars represent standard error of the means.

(harvest 2) and on October 15 (harvest 1), respectively (Table 3).

During the second year (2001) of the experiment, apples were harvested at a firmness of 19.9 lb, 19.1 lb and 18.6 lb in harvest 1, harvest 2 and harvest 3, respectively. Flesh firmness continuously decreased during the 8-month storage period, but the apples harvested in harvest 1 were firmer than those harvested in harvest 3. At the end of storage, the flesh firmness of the apples harvested on October 15 was 15.4 lb, while it

was 14.5 lb and 14.4 lb in harvest 2 and harvest 3, respectively. During the second year of the experiment, statistically significant differences (P ≤ 0.05) in flesh firmness were found among the different harvest dates (Table 3).

At harvest the titratable acidity (malic acid) of the apples was 1.14%, 1.08% and 1.01% in harvest 1, harvest 2 and harvest 3, respectively. Malic acid content of the apples decreased continuously during the storage period in all harvest dates. After 8 – months of storage,

the final amount of malic acid in early harvested fruit (October 15) was 0.88%, and in the fruit harvested on October 30 and on November 15 it was 0.86%; these differences were not statistically significant (Table 3).

The SS percentage of the apples at harvest in 2001 was 11.4%, 12.6% and 13.0% in harvest 1, harvest 2 and harvest 3, respectively. At all harvest dates, first a steady increase, and then a decrease in SS percentage was observed during storage at 0 °C. The SS percentage of the fruit after 8 months of storage was 14.8%, 15.4% and 15.8% in harvest 1, harvest 2 and harvest 3, respectively, but these differences were not statistically significant (Table 3).

During the second year of the experiment, small increases in the L\*, a\* and b\* values of the apples occurred. Fruit color did not consistently differ between harvest dates after 4 months of storage. After 8 months, late harvested fruit had higher L\* and a\* values, indicating that the apples were greener than those harvested early (Table 4).

At the end of the 8-month storage period, the percentage of decayed apples from both harvest seasons was lower in those harvested early than in those harvested late (Table 3). Until the fourth month of storage no decay occurred. At the end of 8 months' storage decayed fruit were 3.1%, 3.5% and 3.7% in harvest 1, harvest 2 and harvest 3, respectively (Table 3). These differences were not statistically significant.

## Discussion

In our study, a high percentage of superficial scald developed in early harvested (harvest 1) fruit in both years. We found that there was a clear relationship between delaying harvest time and superficial scald development during storage. It is widely accepted that maturity stage and harvest date greatly influence superficial scald development in apples during storage and marketing. Fruit maturity at harvest has been considered to be an important factor determining scald susceptibility (Fan et al., 1999). According to Diamantidis et al. (2002), the scald development of 'Starking Delicious' apples was reduced with harvest delay. Our findings were similar to the results of these researchers. It has been suggested that superficial scald in 'Granny Smith' is related to chilling injury (Watkins et al., 1995). The increased scald susceptibility of immature apples has been attributed to a less efficient antioxidant system than that of mature fruit, and mature fruit that have relatively high rates of ethylene production at harvest have low superficial scald susceptibility (Anet, 1972). Our results showed that, harvest time is a major factor for controlling scald development. Özelkök et al. (1995) stated that 190 post-blooming days for long storage eliminates superficial scald development in 'Granny Smith' apples and our findings were similar to the results of these researchers.

According to Thomai et al. (1998), 'Granny Smith'

Table 3. Quality attributes of 'Granny Smith' apples after 8 months in cold storage at 0 °C (year 2-2001).

Harvest dates	Weight loss (%)	Firmness (lb)	SSP <sup>y</sup> (%)	TA <sup>z</sup> (%)	Decayed fruit (%)
		(19.9)	(11.4)	(1.14)	
October 15	10.6 a <sup>x</sup>	15.4 a	14.8 a	0.88 a	3.1 a
		(19.1)	(12.6)	(1.08)	
October 30	7.9 b	14.5 b	15.4 a	0.86 a	3.5 a
		(18.6)	(13.0)	(1.01)	
November 15	6.8 c	14.4 b	15.8 a	0.86 a	3.7 a

<sup>y</sup>SSP = soluble solids percentage, <sup>z</sup>TA = titratable acidity

<sup>x</sup>Means separation within columns by Duncan's multiple range test (P ≤ 0.05).

Numbers in parentheses are initial values of the parameters at harvest

Table 4. Influence of harvest dates and storage durations on peel color of 'Granny Smith' apples (year 2-2001).

Harvest dates	Storage time (months)	L*	a*	b*
October 15	0	69.3 a <sup>2</sup>	-18.7 a	39.4 c
	2	68.1 a	-18.5 a	39.6 bc
	4	68.5 a	-17.8 ab	39.9 bc
	6	68.0 a	-17.3 ab	40.4 b
	8	67.6 a	-16.6 b	41.1 a
October 30	0	70.8 a	-18.5 a	41.2 b
	2	69.9 a	-18.3 a	41.8 ab
	4	69.6 a	-17.9 ab	42.1 ab
	6	68.9 a	-17.4 ab	42.9 a
	8	67.3 a	-16.7 b	43.3 a
November 15	0	73.4 a	-18.1 a	42.7 c
	2	73.1 a	-18.1 a	43.1 bc
	4	72.5 a	-17.7 b	43.9 b
	6	73.0 a	-17.5 ab	44.7 ab
	8	72.2 a	-17.3 ab	45.6 a

<sup>2</sup>Mean separation within columns by Duncan's multiple range test,  $P \leq 0.05$ .

apples from hot climates were more susceptible to scald incidence during storage at 0 °C than apples of the same cultivar from regions with cool climates. Therefore it is necessary to investigate the scald status of apples grown at different elevations.

Scald can also be reduced by CA storage and/or pre-storage treatment with DPA, and both treatments reduce ethylene production (Lurie et al., 1989; Lau, 1990). 1-MCP treatment of 'Granny Smith' and 'Delicious' apples also slows fruit ripening, and 1-MCP treatment prevents or reduces the incidence of superficial scald (Fan et al., 1999; Zanella, 2003). However, increased health concerns from consumers regarding postharvest chemical treatments, as well as pressure from export markets to reduce chemical residue, have caused uncertainty as to the use of these compounds in the future and have hastened the search for alternative approaches to control this disorder (Ju and Curry, 2000). According to Meir and Bramlage (1988), the antioxidant activity of 'Cortland' apples increased with harvest delay in both mature and immature apples. Our results showed that the harvest maturity of 'Granny Smith' apples greatly affected the development of superficial scald during cold

storage and after additional storage at 20 °C for 1 week. Determination of the optimum stage of maturity is therefore important when studying the effect of various treatments on the development of superficial scald in 'Granny Smith' apples and other scald-sensitive apples. The results of this study suggest that harvest time is responsible for the biochemical changes that are involved in scald reduction.

In conclusion, 'Granny Smith' apples have a long storage life. They retain texture, acidity, soluble solids and other quality attributes during long-term storage, but are very susceptible to superficial scald. In our study, harvest maturity seems the key factor to control this physiological disorder. Late harvest (November 15) significantly reduced the development of superficial scald. 'Granny Smith' apples can be stored without any chemical application for up to 8 months with a low percentage of scald incidence if they are harvested in mid-November.

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