Effects of Controlled Atmosphere Storage on Scald Development and Postharvest Physiology of Granny Smith Apples

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Abstract: The effects of different O2 and CO2 concentrations on the scald development and postharvest physiology of Granny Smith apples (Malus domestica Borkh.) were investigated. Apples were harvested at optimal harvest time and stored in 1% CO2/2% O2, 2% CO2/2% O2, 3% CO2/2% O2 and 0% CO2/21% O2 (control) at 0 °C and 90-92% relative humidity for 9 months. At certain intervals, samples were collected from each storage condition for physical and chemical analysis (e.g. weight loss, flesh firmness, amount of titratable acid, total soluble solids, skin color, scald development, respiration rate and decayed fruit). Respiration rates of the apples were measured at 20 °C. The percentage of scald was significantly lower in CA-stored apples than in those stored in a normal atmosphere. In tested CA conditions, 3% CO2/2% O2 was more effective and scald incidence was retained at around 8% after 9 months of storage. There were small differences in scald incidence among the 1% CO2/2% O2, 2% CO2/2% O2 and 3% CO2/2% O2 concentrations. Apples subjected to CA-storage were firmer and had substantially higher levels of titratable acids and soluble solids than apples stored in a normal atmosphere. CA-storage delayed the loss of chlorophyll and yellowing of the skin and also prevented the incidence of decay. The respiration rate of CA-stored apples was lower than that of apples stored in a normal atmosphere at 20 °C. Flesh firmness, soluble solids, titratable acids, skin color and levels of decay were not different at the 3 tested CA concentration levels. Granny Smith apples were able to be stored for up to 9 months under 3% CO2/2% O2 with minimal superficial scald incidence and quality loss.

Key Words: Apple, Malus domestica, Granny Smith, superficial scald, CA-storage, quality

Kontrollü Atmosferde Muhabazanın Granny Smith Elmalarında Kabuk Yanıklıği (superficial scald) ve Derim Sonrası Fizyolojisi Üzerine Etkileri

ÖZET: Bu çalışmada, farklı CO2 ve O2,konsantrasyonlarının Granny Smith elmalarında (Malus domestica Borkh.) kabuk yanıklığı ve derim sonrası fizyolojisi üzerine etkileri araştırılmıştır. Araştırmda Granny Smith elmalar optimal derim zamanında derilmiştir ve %1 CO2,%2 O2, %2 CO2,%2 O2, %3 CO2,%2 O2 ve %0 CO2,%21 O2 (kontrol) konsantrasyonlarında ve 0 °C sıcaklık ile %90-92 oransal nemde 9 ay süreyle muhabaza edilmişlerdir. Farklı muhabaza ortamlarından belirli aralıklarla alınan meyve örneklerinde ağırlık kaybı, meyve eti sertliği, titre edilebilir asit, suda çözünemebilir toplam kuru madde miktarı, kabuk rengi, kabuk yanıklıği (superficial scald) gelişimi, solunum hızı ve çıkar meyve miktarları belirlenmiştir. Kontrollü atmosferde (KA) muhabaza edilen elmalarda, kabuk yanıklıği gelişimi normal atmosferde (NA) muhabaza edilen elmalara göre önemli miktarlarda azalmıştır. %3 CO2,%2 O2, scald oluşumunu önlene bakımdan daha etkili bulunmuş ve 9 aylık muhabaza sonunda scald oluşumu %6 dolayında kalmıştır. Denenen CO2 ve O2 konsantrasyonları arasında scald oluşumu bakımından küçük farklılıklar saptanmıştır. KA'de depolanlan elmalar, muhabaza penyodu sonunda NA'de muhabaza edilenlere göre meyve eti sertliği, %3 CO2,%2 O2, çözünemebilir toplam kuru madde miktarı ve %3 CO2,%2 O2, solunum hızı, normal atmosferde muhabaza edilen elmalara göre daha düşük bulunmuştur. Denenen KA konsantrasyonları arasında ise meyve eti sertliği, %3 CO2,%2 O2, çözünemebilir toplam kuru madde, %3 CO2,%2 O2, solunum hızı ve %3 CO2,%2 O2, scald oluşum oranında önemli bir farkmıştır. Muhabaza edilen elmalarda %3 CO2,%2 O2, cozünemebilir toplam kuru madde ve %3 CO2,%2 O2, çözünemebilir toplam kuru madde miktarı bakımından önemli bir fark olmuştur. %3 CO2,%2 O2, koşullarında muhabaza edilen Granny Smith elmaları minimum scald oluşumu ve kalite kaybıyla 9 aylık süreyle muhabaza edilebilmiştir.

Anahtar Sözcükler: Elma, Malus domestica, Granny Smith, kabuk yanıklıği, KA-muhabaza, kalite

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Introduction

The production of Granny Smith apples in Turkey has been increasing recently. However, superficial scald development during storage and marketing is still the main problem of this apple cultivar and negatively affects its quality. Superficial scald of apples is a physiological disorder following long-term storage, which has the potential to destroy the market value and utility of millions of tons of fresh apples annually (Wang and Dilley, 1999). It is manifested as discolored irregular lesions on the surface of a fruit that destroy its market value. Since scald frequently develops following the transfer of fruit from cold to warm temperatures, the disorder may not be evident until the fruit reaches market (Bramlage and Watkins, 1994).

Scald development in Granny Smith apples was correlated with the oxidation of \( \alpha \)-farnesene to conjugated triene hydroperoxides (Huelin and Coggiola, 1970; Filmer and Meigh, 1971).

The disorder is prevented commercially by postharvest drench treatment with diphenylamine (DPA) (Smock, 1957; Golding et al., 2001; Ju and Curry, 2002). This drench treatment must include a fungicide to prevent decay. Numerous countries have banned the use of DPA or the importation of DPA-treated fruits, which mandates the development of alternative methods to control scald (Wang and Dilley, 2000).

Superficial scald is also reduced by 1-methylcyclopropene (1-MCP) treatment in Granny Smith apples (Fan and Mattheis, 1999; Shaham et al., 2003; Zanella, 2003).

CA-storage is one of the other alternative methods of inhibiting scald development on Granny Smith and other scald sensitive apples (Lau, 1989; Truter et al., 1994). Several studies have demonstrated that the effects of different \( O_2 \) and \( CO_2 \) concentrations on scald incidence are cultivar specific and related to the preharvest environment because of annual variations (Ingle and D’Souza, 1989; Ingle, 2001). Scald incidence fell to nearly zero in Bramley apples after 5.5 months of storage in 12% \( O_2 \) and 9% \( CO_2 \) (Dover, 1997). Superficial scald on Granny Smith apples was largely controlled by an initial low \( O_2 \) stress followed by CA-storage (Little et al., 1982). Under local conditions a low \( O_2 \) stress treatment controlled superficial scald for up to 6 months in Granny Smith apples picked at optimum maturity (Truter et al., 1994). Scald on 5 strains of Cortland grown in Nova Scotia was unrelated to \( O_2 \) concentrations from 1.5 to 4.5% (DeEll and Prange, 1998).

The objective of this study was to investigate the effects of different \( CO_2 \) and \( O_2 \) concentrations on scald development and postharvest quality of Granny Smith apples during long-term storage, which could be used in Turkey.

Materials and Methods

Granny Smith apples were harvested from a commercial orchard at Elmali, in the Antalya region. The fruits were harvested at the end of October, which was a relatively late harvest season for other apple cultivars grown in the region. The harvest date of the apples was determined by using starch pattern indices and flesh firmness. Apples were pre-cooled for 1 day before being placed in CA and NA-storage containers. Only fruits free of damage were used in the experiments. In the research, the effects of 3 different \( CO_2 \) and \( O_2 \) concentrations (1% \( CO_2/2% O_2 \), 2% \( CO_2/2% O_2 \) and 3% \( CO_2/2% O_2 \)) on the scald development and postharvest quality of apples were investigated. Control fruits were kept in normal atmosphere (NA) conditions (0% \( CO_2/21% O_2 \)). All fruit samples were immediately placed in CA and NA containers and stored at 0 °C and 90% relative humidity. Storage atmosphere was established by N\(_2\) flushing, and \( CO_2\) was removed by KOH as a \( CO_2\) absorbing agent. The atmospheres were monitored daily by using \( CO_2\) and \( O_2\) analyzers. The adjustment of the desired storage atmosphere was made by the addition of air or flushing with \( N_2\).

During the storage period, weight loss, flesh firmness, and the amount of soluble solids and titratable acids were tested at certain intervals on fruit samples taken from different CA-storage and NA-storage conditions in 3 replications. In addition to the above analyses, changes in the respiration rates of the apples at 20 °C and the changes in their skin color (\( a^*\) value) were examined.
Physiological and fungi-caused deteriorations were also recorded. Evaluation of superficial scald incidence was performed after 1, 3, 5, 7 and 9 months of storage at 0 °C and an additional week of shelf life at 20 °C. The total number of apples manifesting scald incidence was determined for each concentration and expressed as the scald incidence. Respiration of the apples was determined by using the Claypool-Keefer method (Watada and Pratt, 1963). Weight loss was evaluated by weighing the fruit before and after storage. Flesh firmness of the fruits was measured on opposite sides of each apple using a penetrometer (Fruit Tester-model FT 327). Soluble solids concentration was measured on combined juice collected from the penetrometer probe with an Atago hand refractometer. Titratable acidity was measured by titration with 0.1 N NaOH to pH 8.2, the results being expressed as malic acid. For skin color, individual fruits were marked at the equatorial region (3 opposite regions per fruit) and color was recorded as L*, a* and b* values with a Minolta Chroma Meter CR-200 (Minolta Camera Co Ltd, Japan). Fruit samples were kept at 20 °C after removal from CA and NA-storage containers for evaluation of superficial scald.

The results of the experiments were analyzed using a completely randomized design. One-way variance analysis, comparison of means and calculations of least significance differences (Duncan’s multiple range test) were also performed.

**Results**

Longer storage period produced greater weight loss during storage. At the end of the 9-month storage period, while the lowest weight loss was obtained from the fruits stored in CA conditions, the highest weight loss was obtained from the NA-stored (control) fruits (Figure 1). At the end of the 9-month storage period, there were no statistically significant differences in weight loss among apples stored at different CO2 and O2 concentrations. However, statistically significant (P < 0.05) differences were found between CA-stored apples and NA-stored apples. At the end of storage, while the weight loss in CA-stored apples (all 3 concentrations) was around 1%, the weight loss in NA-stored fruits reached 8% (Figure 1).

Fruits subjected to all treatments were harvested at a firmness of 18 lb. The flesh firmness of the apples continuously decreased during storage, but the apples from the CA-stored groups were firmer than those from the NA-stored group (Figure 2). Although there were statistically significant differences between CA-stored and NA-stored apples, there were no statistically significant differences between tested CO2 and O2 concentrations in terms of flesh firmness. At the end of storage, while the flesh firmness of the CA-stored apples (all 3 concentrations) was around 16 lb, the flesh firmness of the NA-stored fruits decreased to 11 lb (Figure 2).

The incidence of scald significantly decreased on fruits stored in different CO2 and O2 concentrations. During the first 3 months of storage no scald incidence was observed in the apples kept in CA-storage conditions. The lowest scald incidence was observed in the fruits stored in CA at 2% O2 and 3% CO2. After the 9-month storage period the percentage of scald in NA-stored fruits reached 49.56%, whereas scald incidence remained at around 10% in CA-stored apples (Figure 3). CA-stored fruits had lower levels of superficial scald than NA-stored fruits after 9 months of storage plus 1 week at 20 °C. Although there were statistically significant differences between

![Figure 1](image1.png)

**Figure 1.** The effects of different CO2 and O2 concentrations and duration of storage on weight loss (%) in Granny Smith apples. Vertical bars represent standard error of the means.

![Figure 2](image2.png)

**Figure 2.** The effects of different CO2 and O2 concentrations and duration of storage on flesh firmness (lb) of Granny Smith apples. Vertical bars represent standard error of the means.
CA-stored and NA-stored apples, there were no statistical differences in scald incidence among the tested CO₂ and O₂ concentrations.

In all treatments, first a steady increase, and then a decrease in soluble solids content were observed during storage at 0 °C (Figure 4). The soluble solids content of the fruits stored in CA conditions was lower than that of the NA-stored fruits.

At the time of initial storage an average content of 1.18% titratable acid (malic acid) was determined. The malic acid content of the apples decreased continuously during the storage period (Figure 5). After 9 months of storage, while the final amount of malic acid in the fruits stored in CA remained at around 1%, the malic acid content of the NA-stored fruits decreased to 0.68% (Figure 5). While statistically significant (P < 0.05) differences were found between CA-stored apples and NA-stored apples, the differences in malic acid content among apples kept at different CA concentrations were not statistically significant.

During storage, while small increases in the a* values of CA-stored apples occurred, high increases were observed in the NA-stored apples. After the 9-month storage period, the a* values of both CA-stored and NA-stored apples became less negative in terms of skin color. After 9 months, CA-stored fruit had higher a* values, indicating the fruits were greener than the control fruits (Figure 6). Statistically significant (P < 0.05) differences were found in the a* values of the skin color of CA-stored apples and NA-stored apples, but the differences among apples kept at differing CA concentrations were not statistically significant.

During the study, the respiration rates of the Granny Smith apples were measured at 20 °C. The respiration rate of apples at 20 °C first increased, and then decreased, like other climacteric fruits. After 9 months of storage, while the NA-stored apples reached a climacteric peak of 17.4 ml CO₂/kg⁻¹h⁻¹ during the first 6 days, CA-stored apples reached a climacteric peak during the first 12 days after moving the fruits from 0 °C to 20 °C (Figure 7).

Figure 3. The effects of different CO₂ and O₂ concentrations and duration of storage on superficial scald incidence (%) in Granny Smith apples. Vertical bars represent standard error of the means.

Figure 4. The effects of different CO₂ and O₂ concentrations and duration of storage on soluble solids contents (%) of Granny Smith apples. Vertical bars represent standard error of the means.

Figure 5. The effects of different CO₂ and O₂ concentrations and duration of storage on the titratable acid (malic acid) content (%) of Granny Smith apples. Vertical bars represent standard error of the means.

Figure 6. The effects of different CO₂ and O₂ concentrations and duration of storage on skin color (a* value) of Granny Smith apples. Vertical bars represent standard error of the means.
The longer storage period gave a higher amount of decayed fruits in NA-stored apples during storage. At the end of the 9-month storage period, while the percentage of decayed fruits reached 10.4% in NA-stored fruits, it remained at 0% in CA-stored apples.

Discussion

Research on CA-storage conditions for Turkish-grown Granny Smith apples has lagged behind its commercial use. Studies on Granny Smith apples indicate that market differences in fruit quality can occur in response to varying CA storage regimes. The combination of ultra-low oxygen (ULO) storage with low levels of CO₂ was not suitable for some apple cultivars, as scald appeared in Grand Alexander and Granny Smith (Sharples and Stow, 1986). Therefore in our study we did not test ULO-storage. In New Zealand, the most effective CA conditions in preventing scald incidence in Granny Smith apples are 2% O₂ and 2% CO₂, 3% O₂ and 3% CO₂ (Watkins et al., 1991). In the present study there was little to differentiate among 3 different CO₂ and O₂ concentrations, although 2% O₂ and 3% CO₂ had a slight advantage in preventing scald incidence. However, other tested CO₂ and O₂ concentrations were also effective in preventing scald incidence when compared to NA-storage. Similar results were obtained by Watkins et al. (1991). These researchers stated that physiological disorders such as superficial scald could be controlled in a 2% O₂ and 2% CO₂ concentration. Dover (1997) reported that scald incidence fell to nearly zero the as O₂ concentration was reduced from the conventional to 12% O₂ and 9% CO₂ to 1% O₂ or 0.4% O₂ plus 5% CO₂. According to Johnson (1999), a major influence on the choice of CA conditions is the susceptibility of particular cultivars to superficial scald. Little and Taylor (1981) obtained good control of storage scald on later harvested Granny Smith apples with CA-storage.

In our experiment, a low O₂ and high CO₂ concentration was more effective than NA-storage in reducing the levels of acid, soluble solids, and skin color and flesh firmness loss during the storage period in Granny Smith apples. A 2% O₂ and 2% CO₂ level resulted in firmer, greener and more acceptable fruits than did a NA. Soluble solids were higher after 9 months of storage in 2% O₂ and 2% CO₂ levels than in NA. Truter and Eksteen (1987) found beneficial effects of 2% CO₂ and 2% O₂ on skin color, while flesh firmness, though not significantly different, tended to be softer than in fruit stored with 0% CO₂. Lau and Looney (1982) observed similar findings in Golden Delicious apples. However, in Australia and South Africa, the use of low level CO₂ is recommended to lower the risk of core-flush, even though higher CO₂ levels resulted in physical attributes of quality (Little and Taylor, 1981; Truter and Eksteen, 1987).

Our results suggest that the metabolic processes causing fruit softening, soluble solids, titratable acid and skin color loss throughout the storage period are induced shortly after harvest and continue to develop in normal atmosphere storage at 0 °C, unless checked by the establishment of a low O₂ and high CO₂ regime immediately after harvest.

In our experiment, we found that all tested CO₂ and O₂ concentrations significantly reduced the respiration rate of apples at 20 °C. However, there were no significant differences among the tested O₂ and CO₂ concentrations in terms of respiration rate.

Low O₂ (2%) and high CO₂ (3%) storage regimes are being increasingly used world wide to control superficial scald and to obtain further extensions to apple storage periods (Watkins et al., 1991), and we therefore compared this treatment with other CO₂ regimes.

Conclusion

One of the main factors limiting the storage life of apples is superficial scald. Since Granny Smith apples are extremely sensitive to superficial scald, CA-storage should...
be considered as an alternative to chemical methods. In the present study a 2% O₂ and 3% CO₂ concentration eliminated or significantly reduced the development of superficial scald in Granny Smith apples at 0 °C and subsequent ripening at 20 °C for 1 week. A 2% O₂ and 2% CO₂ concentration not only controlled superficial scald but also resulted in improved fruit storage quality in terms of firmness, acidity and soluble solids content. Under a 2% O₂ and 3% CO₂ concentration, this apple cultivar can be stored for up to 9 months with minimal incidence of scald and quality losses. When DPA becomes unavailable for superficial scald control in Turkey, use of CA-storage, 2% CO₂ and 2% O₂, for Granny Smith apples might be warranted, but other studies are needed for different locations in Turkey.

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References


