Turk J Agric For
28 (2004) 43-48

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

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Received: 29.04.2003

Abstract: The effects of different O_2 and CO_2 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% CO_2/2% O_2, 2% CO_2/2% O_2, 3% CO_2/2% O_2 and 0% CO_2/21% O_2 (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% CO_2/2% O_2 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% CO_2/2% O_2, 2% CO_2/2% O_2 and 3% CO_2/2% O_2 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% CO_2/2% O_2 with minimal superficial scald incidence and quality loss.

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

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

Özet: Bu çalışmada, farklı CO_2 ve O_2 konsantrasyonlarının Granny Smith elmalarında (*Malus domestica* Borkh.) kabuk yanıklığı ve derim sonrası fizyolojisi üzerine etkileri araştırılmıştır. Araştırmada Granny Smith elmaları optimal derim zamanında derilmiş ve %1 CO_2/%2 O_2, %2 CO_2/%2 O_2, %3 CO_2/%2 O_2 ve %0 CO_2/%21 O_2 (kontrol) konsantrasyonlarında ve 0 °C sıcaklık ile %90-92 oransal nemde 9 ay süreyle muhafaza edilmişlerdir. Farklı muhafaza ortamlarından belirli aralıklarla alınan meyve örneklerinde ağırlık kaybı, meyve eti sertliği, titre edilebilir asit, suda çözünebilir toplam kuru madde miktarı, kabuk rengi, kabuk yanıklığı (superficial scald) gelişimi, solunum hızı ve çürük meyve miktarları belirlenmiştir. Kontrollü atmosferde (KA) muhafaza edilen elmalarda, kabuk yanıklığı gelişimi normal atmosferde (NA) muhafaza edilen elmalara göre önemli miktarda azalmıştır. %3 CO_2/%2 O_2 scald oluşumunu önleme bakımından daha etkili bulunmuş ve 9 aylık muhafaza sonunda scald oluşumu %8 dolayında kalmıştır. Denenen CO_2 ve O_2 konsantrasyonları arasında scald oluşumu bakımından küçük farklılıklar saptanmıştır. KA'de depolanan elmalar, muhafaza periyodu sonunda NA'de muhafaza edilenlere göre meyve eti sertliklerini daha iyi korumuşlar, aynı zamanda daha yüksek seviyelerde titre edilebilir asit ve kuru madde içermişlerdir. KA'de muhafaza, elmaların kabuğundaki klorofil kaybını geciktirmiş ve ortaya çıkan çürümelerin oranını azaltmıştır. 20 °C'de yapılan solunum ölçümlerinde, KA'de muhafaza edilen elmalarda saptanan solunum hızı, normal atmosferde muhafaza edilen elmalara göre daha düşük bulunmuştur. Denenen KA konsantrasyonları arasında ise meyve eti sertliği, suda çözünebilir kuru madde, titre edilebilir asit, kabuk rengi ve çürük meyve miktarı bakımından önemli bir farklılık bulunmamıştır. %3CO_2/%2O_2 koşullarında muhafaza edilen Granny Smith elmaları minumum scald oluşumu ve kalite kaybıyla 9 ay süreyle muhafaza edilebilmiştir.

Anahtar Sözcükler: Elma, *Malus domestica*, Granny Smith, kabuk yanıklığı, KA-muhafaza, 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).

The susceptibility of apples to scald is highly variable. Some cultivars such as Empire and Royal Gala have little or no susceptibility, whereas others such as Granny Smith and Delicious can be at high risk (Bramlage and Watkins, 1994). Typically, early-harvested fruits and less mature fruit are most susceptible, but scald may also develop on fully mature fruits (Watkins et al., 1995).

Scald development in Granny Smith apples was correlated with the oxidation of α-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 Elmalı, 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 CO_2 and O_2 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 CO_2 and O_2 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 CO_2 and O_2 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% O_2 and 3% CO_2. 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

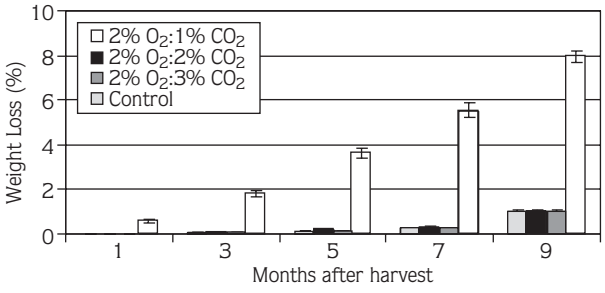

Figure 1. The effects of different CO_2 and O_2 concentrations and duration of storage on weight loss (%) in Granny Smith apples. Vertical bars represent standard error of the means.

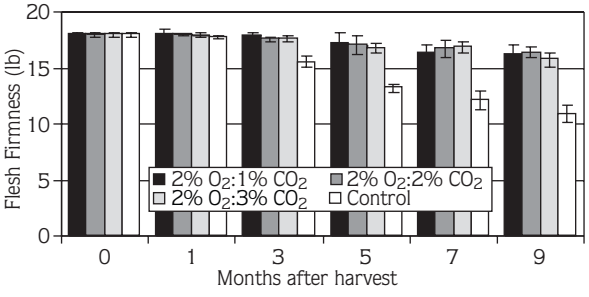

Figure 2. The effects of different CO_2 and O_2 concentrations and duration of storage on flesh firmness (lb) of Granny Smith apples. Vertical bars represent standard error of the means.

CA-stored and NA-stored apples, there were no statistical differences in scald incidence among the tested CO_2 and O_2 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 $CO_2/kg^{-1}.h^{-1}$ 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).

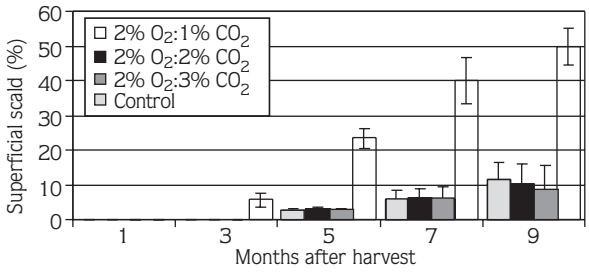

Figure 3. The effects of different CO_2 and O_2 concentrations and duration of storage on superficial scald incidence (%) in Granny Smith apples. Vertical bars represent standard error of the means.

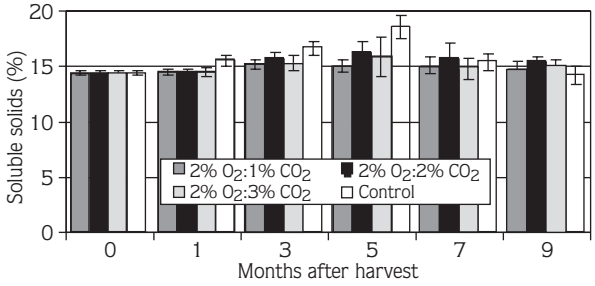

Figure 4. The effects of different CO_2 and O_2 concentrations and duration of storage on soluble solids contents (%) of Granny Smith apples. Vertical bars represent standard error of the means.

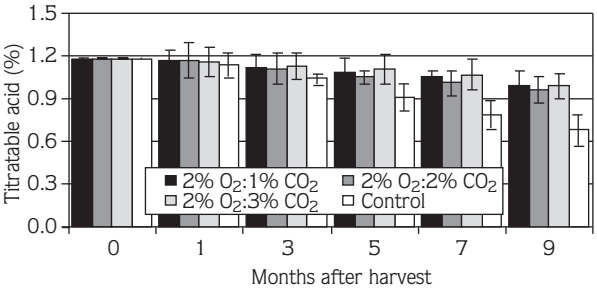

Figure 5. The effects of different CO_2 and O_2 concentrations and duration of storage on the titratable acid (malic acid) content (%) of Granny Smith apples. Vertical bars represent standard error of the means.

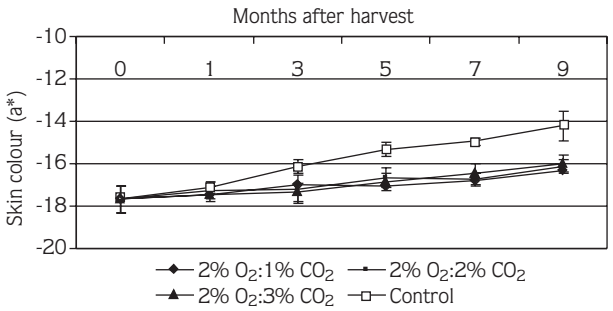

Figure 6. The effects of different CO_2 and O_2 concentrations and duration of storage on skin color (a* value) of Granny Smith apples. Vertical bars represent standard error of the means.

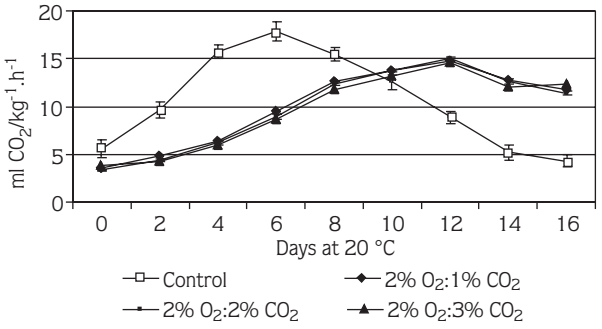

Figure 7. The changes in respiration rate of Granny Smith apples at 20 °C after storing the fruits for 9 months in a NA (control) and CA at 0 °C. Vertical bars represent standard error of the means

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 CO_2 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% O_2 and 2% CO_2, 3% O_2 and 3% CO_2 (Watkins et al., 1991). In the present study there was little to differentiate among 3 different CO_2 and O_2 concentrations, although 2% O_2 and 3% CO_2 had a slight advantage in preventing scald incidence. However, other tested CO_2 and O_2 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% O_2 and 2% CO_2 concentration. Dover (1997) reported that scald incidence fell to nearly zero the as O_2 concentration was reduced from the conventional to 12% O_2, and 9% CO_2 to 1% O_2 or 0.4% O_2 plus 5% CO_2. 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 O_2 and high CO_2 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% O_2 and 2% CO_2 level resulted in firmer, greener and more acceptable fruits than did a NA. Soluble solids were higher after 9 months of storage in 2% O_2 and 2% CO_2 levels than in NA. Truter and Eksteen (1987) found beneficial effects of 2% CO_2 and 2% O_2 on skin color, while flesh firmness, though not significantly different, tended to be softer than in fruit stored with 0% CO_2. Lau and Looney (1982) observed similar findings in Golden Delicious apples. However, in Australia and South Africa, the use of low level CO_2 is recommended to lower the risk of core-flush, even though higher CO_2 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 O_2 and high CO_2 regime immediately after harvest.

In our experiment, we found that all tested CO_2 and O_2 concentrations significantly reduced the respiration rate of apples at 20 °C. However, there were no significant differences among the tested O_2 and CO_2 concentrations in terms of respiration rate.

Low O_2 (2%) and high CO_2 (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 CO_2 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% O_2 and 3% CO_2 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% O_2 and 2% CO_2 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% O_2 and 3% CO_2 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% CO_2 and 2% O_2, for Granny Smith apples might be warranted, but other studies are needed for different locations in Turkey.

Acknowledgements

The fruits used in this research were kindly supplied by Omer Deniz.

References

Bramlage, W.J. and C.B. Watkins. 1994. Influences of preharvest temperature and harvest maturity on susceptibility of New Zealand and North American apples to superficial scald. New Zealand J. Crop Hort. Sci. 22: 69-79.

DeEll, J.R. and R.K. Prange. 1998. Disorders in 'Cortland' apple fruit are induced by storage at 0 °C in controlled atmosphere. HortScience 33: 121-122.

Dover, C.J. 1997. Strategies for control of scald without the use of antioxidants. Postharvest Biol. Technol. 8: 41-43.

Fan, X. and J.P. Mattheis. 1999. Development of apple superficial scald, soft scald, core flush, and greasiness is reduced by 1-MCP. J. Agric. Food Chem. 47: 3063-3068.

Filmer, A.A.E. and D.F. Meigh. 1971. Natural skin coating of the apple and its influence on scald in storage. IV-Oxidation products of α-farnesene. J. Sci. Food Agric. 22: 188-190.

Golding, J.B., W.B. McGlasson and S.G. Wyllie. 2001. Relationship between production of ethylene and α-farnesene in apples, and how it is influenced by the timing of diphenylamine treatment. Postharvest Biol. Technol. 21: 225-233.

Huelin, F.E. and I.M. Coggiola. 1970. Superficial scald, a functional disorder of stored apples: V. Oxidation of α-farnesene and its inhibition by diphenylamine. J. Sci. Food Agric. 21: 44-48.

Johnson, D.S. 1999. Controlled atmosphere storage of apples in the UK. Acta Hort. 485: 187-193.

Ju, Z. and Curry, E.A. 2002. Effects of 6-methyl-5-hepten-2-one vapor on peel browning of 'Delicious' and 'Granny Smith' apples: open vs. closed system. Postharvest Biol. Technol. 25: 265-272.

Ingle, M. and M.C. D'Souza. 1989. Physiology and control of superficial scald of apples: a review. HortScience 24: 28-31.

Ingle, M. 2001. Physiology and biochemistry of superficial scald of apples and pears. Horticultural Review, Vol. 27. p. 227-267.

Lau, O.L. and N.E. Looney. 1982. Improvement of fruit firmness and acidity in controlled-atmosphere-stored 'Golden Delicious' apples by a rapid reduction procedure. J. Amer. Soc. Hort. Sci. 107: 531-534.

Lau, O.L. 1989. Control of storage scald in 'Delicious' apples by diphenylamine, low oxygen atmosphere and ethylene scrubbing. Proceedings of the 5th International Controlled Atmosphere Research Conference, Wenatchee, WA, USA, Vol. 1-Pome Fruits, 177-184.

Little, C.R. and H.J. Taylor. 1981. Orchard locality and storage factors affecting the commercial quality of Australian 'Granny Smith' apples. J. Amer. Soc. Hort. Sci. 56: 323-329.

Little, C.R., J.D. Faragher and H.J. Taylor. 1982. Effects of initial low oxygen stress treatments in low oxygen modified atmosphere storage of 'Granny Smith' apples. J. Amer. Soc. Hort. Sci. 107: 320-323.

Shaham, Z., A. Lers and S. Lurie. 2003. Effect of heat or 1-MCP on antioxidative enzyme activities and antioxidants in apples in relation to superficial scald development. J. Amer. Soc. Hort. Sci. 1128: 761-766.

Sharples, R.O. and J.R. Stow. 1986. Recommended conditions for the storage of apples and pears. Rep. E. Malling Res. Stn for 1985, pp. 165-170.

Smock, R.M. 1957. A comparison of treatments for control of the apple scalds disease. J. Amer. Soc. Hort. Sci. 69: 91-100.

Truter, A.B. and G.J. Eksteen. 1987. Storage potential of apples under controlled atmosphere storage at ultra-low oxygen concentrations. Deciduous fruit grower 37: 141-145.

Truter, A.B., J.C. Combrink and S.A. Burger. 1994. Control of superficial scald in 'Granny Smith' apples by ultra-low and stress levels of oxygen as an alternative to diphenylamine. J. Hortic. Sci. 69: 581-587.

Wang, Z. and D.R. Dilley. 1999. Control of superficial scald of apples by low oxygen atmosphere. HortScience 34: 1145-1151.

Wang, Z. and D.R. Dilley. 2000. Initial low oxygen stress controls superficial scald of apples. Postharvest Biol. Technol. 18: 201-213.

Watada, A.E. and A.K. Pratt. 1963. Adaptation of the Calypool-Keefer colorimetric method for carbon dioxide determination in vegetables crops laboratory. Univ. of California. Veg. Sec. Lectures (unpublished).

Watkins, C.B., K.L. McMath, J.H. Bowen and C.J. Brennan. 1991. Controlled atmosphere storage of 'Granny Smith' apples. New Zealand J. Crop Hort. Sci. 19: 61-68.

Watkins, C.B., W.J. Bramlage and A.B. Cregoe. 1995. Superficial scald of 'Granny Smith' apples are expressed as a typical chilling injury. J. Amer. Soc. Hort. Sci. 120: 88-94.

Zanella, A. 2003. Control of apple superficial scald and ripening–a comparison between 1-methylcyclopropene and diphenylamine postharvest treatments, initial low oxygen stress and ultra low oxygen storage. Postharvest Biol. Tecnol. 27: 69-78.