Quality characteristics of apples preserved under controlled atmosphere storage in a pilot plant scale

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Abstract — Introduction. The controlled atmosphere storage is a modern technique which was developed in many countries during the latest years. The use of a low temperature in combination with a low O_2 and high CO_2 atmosphere affects the physiology of fruit, mainly in respiration and ethylene production for climacteric fruit. **Materials and methods**. The storage performance of 'Starking Delicious' and 'Golden Delicious' apples, varieties grown in Greece, was evaluated during their storage for up to 240 days in 2.5–6.0% O_2 and 1.7–2.5% CO_2 at 0 °C, in a pilot plant scale. **Results and discussion**. Results from a 2-years study indicated that, in both varieties, a better texture retention was observed when a CO_2 level of 1.7 to 2.5% was combined with a low O_2 concentration. The general patterns of changes in soluble solids content, titratable acidity and pH values were not influenced greatly by storage treatment. **Conclusion**. The results suggested that apples have the longest storage life at 0 °C when the atmosphere contains [2.5% O_2 + 2.5% CO_2] for 'Starking Delicious' apples and [3.0% O_2 + 2.5% CO_2] for 'Golden Delicious'. (© Elsevier, Paris)

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Caractéristiques qualificatives de pommes stockées en atmosphère contrôlée, étudiées à l'échelle expérimentale.

Résumé — Introduction. Le stockage des fruits placés en atmosphère contrôlée est une technique moderne qui a été développée dans différents pays, au cours des dernières années. L'utilisation de basses températures combinée avec celle d'atmosphères à teneurs réduites en oxygène et élevées en gaz carbonique a un effet direct sur la physiologie des fruits et surtout sur la respiration et la production d'éthylène par les fruits climactériques. **Matériel et méthodes**. Après leur récolte, des pommes des variétés « Starking Delicious » et « Golden Delicious » cultivées en Grèce ont été stockées à 0 °C, dans diverses compositions d'atmosphères contrôlées, les taux d'oxygène variant de 2,5 à 6,0 % et ceux de gaz carbonique, de 1,7 à 2,5 %. L'évolution de divers paramètres de la qualité du fruit a été suivie pendant 240 d. **Résultats et discussion**. Pour les deux variétés étudiées, les résultats obtenus sur deux années d'études ont montré que la texture du fruit était mieux préservée lorsque le taux de CO_2 ambiant se situait entre 1,7 et 2,5 % et que la concentration en O_2 était limitée. La teneur en extrait sec, l'acidité titrable et la valeur du pH des fruits n'ont pas été affectées de façon significative par les différentes compositions des atmosphères contrôlées testées. **Conclusion**. Les meilleures conditions de stockage des pommes seraient une température de 0 °C, associée à la composition gazeuse [2,5 % O_2 + 2,5 % CO_2] pour la variété « Starking Delicious » et [3,0 % O_2 + 2,5 % CO_2] pour « Golden Delicious ». (© Elsevier, Paris)

Grèce / pomme / stockage en atmosphère contrôlée / température

1. introduction

Controlled atmosphere storage (CA) has been shown both experimentally and commercially to extend the shelf life of many horticultural commodities [1, 2]. It generally results in reduced respiration rates as long as O_2 and CO_2 levels are maintained within levels tolerated by the commodity. Reduced respiration rates, combined with low ethylene (C_2H_4) production and reduced sensitivity to C_2H_4, results in the better retention of texture (less softening) and sensory attributes of fruit and vegetables [3].

Apples are subjected to excessive softening during and after storage. Controlled atmosphere storage reduces this problem but marked softening still occurs over extended storage periods. Higher firmness retention and acid levels indicate an improvement in the expected storage life of the apples [4]. 'Delicious' (Starking and Golden) apples are usually stored in 2–3% O_2 and 1–2% CO_2 at 0–1 °C [5]. Although Blanpied et al. [6] initially reported that C_2H_4 had no effect during CA storage of apples, Liu [7], subsequently, showed that C_2H_4 influenced the rate of softening and loss of acidity whilst apple softening in low temperature air storage can be influenced by prior CA storage [8].

Compositional changes and the incidence of certain physiological disorders have been related to interactions between storage temperature and atmospheric composition for apples [9, 10].

The objective of this research was to determine the effects of exposures to O_2 levels at or below 6%, and to CO_2 levels at or above 1.5%, on quality attributes of apples in a pilot plant scale.

2. materials and methods

The experiment was carried out in a pilot plant scale during two cultivation periods for Starking Delicious (1991–1992 and 1992–1993) and one cultivation period for Golden Delicious (1993–1994).

Fruit was supplied by an Agricultural Association of apple growers in the areas of Naoussa and Larissa, at the North of Greece, and were harvested at the beginning of October at an average soluble solid content of 10.3% (1991–1992), 11.6% (1992–1993) and 13.8% (1993–1994). The fruits were sorted out to eliminate obvious defects, then they were divided into categories A (191–210 g) and B (151–190 g) according to desired colour, size-weight and packed into common plastic boxes (B) with about 20 kg per box of fruit. To minimize decay during storage, the Starking Delicious apples were sprayed, in 1991, with a diphenylamine + thiapendasol solution whilst, in 1992, fruits were sprayed with a combination of $CaCl_2$ and thiophanate methyl.

Immediately after packaging, the fruit was precooled at 4 °C and transferred then to the Institute of Technology of Agricultural Products in Athens, by means of a vehicle with cooling facilities (one day travel). For each cultivation period (1991–1992, 1992–1993 and 1993–1994), two CA storage rooms with a capacity of about 3 500 kg of apples were used. After loading the cold rooms, the temperature was lowered from 4 °C to 0 °C, within 4–5 d, and was maintained at this level during the whole preservation period.

The preservation conditions applied during the three storage periods were the combinations of different percentages of O_2 and CO_2 (*table I*). Control samples were maintained in air at 0 °C. In all treatments the relative humidity was maintained at 95%.

The equipment for the CA rooms consisted of two CO_2 gas absorbers (Delta Gem 20), two ethylene catalytic converters (Swinghterm E-50), one unit (type Swan 15) with fibber membranes for controlling the atmosphere of the rooms, four water atomizers (Crystal R-800), one central analytical unit (Orsat type analyzer) and one automatic analytical unit for O_2 and CO_2.

The Swan unit can be adjusted to produce 97–99% nitrogen and 1-3% oxygen without any CO and CO_2 production.

Table I.
Composition of controlled atmosphere (CA) tested to preserve apple samples, during three storage periods.

Test number	O_2 (%)	CO_2 (%)	Observation	Storage period	Apple cultivar
Control	–	–	Air at 0 °C	–	Starking Delicious
A	5.1	1.7	–	1991–1992 1992–1993	Starking Delicious
B	5.5	2.5	+ Ethylene control (< 0.02 ppm)	1991–1992	Starking Delicious
C	2.5	2.5	–	1992–1993	Starking Delicious
D	6.0	1.5		1993–1994	Golden Delicious
E	3.0	2.5		1993–1994	Golden Delicious

At the initial loading of the rooms, eight sampling positions had been allocated inside each cold room. At periodic intervals of 0, 30, 60, 90, 120, 140, 180 and 225 or 240 d, 25 fruits were removed from storage and evaluated within 2 h for visual quality, firmness, soluble solid content, titratable acidity and pH values. In addition, 25 fruits were removed out of the room for colour and weight measurements and they were then placed back inside the room at the same positions.

Fruit firmness was monitored using a fruit firmness tester of the Food Technology Corporation, U.S.A, with an 8 mm tip. Measurements were carried out after removing the skin of the fruit at each concrete area of the tip immersion, by means of a knife. The rest of the skin was then also removed by means of a knife and the flesh was cut into pieces and homogenized in an equal volume of distilled water. The homogenate was subsequently used for the other analysis: soluble solid content was determined using an optical Abber refractometer, with an automatic temperature compensation; titratable acidity was determined by titrating 10 mL of juice with 0.1 M NaOH to pH 8.2 and expressed as percentage of malic acid (w/v). L, a and b colour parameters of Hunter's method were obtained for Golden Delicious apples by using a Minolta CR-300 colorimeter, with a 8 mm measuring area and diffuse illumination / 0° viewing geometry. A white plate with Y = 92.4, x = 0.3147 and y = 0.3225 was used as reference.

The obtained data at the preservation time of 180 d were subjected to an analysis of variance using the Genstat Program [11]. The comparison of means given in each table of figure was made by using the least significant difference (LSD) test at $p < 0.05$.

3. results

The analysis of variance performed on firmness data indicated that there were significant differences among all treatments for both cultivars, Starking and Golden Delicious (*figures 1, 2*; *table II*).

In Starking Delicious apples, the soluble solid content (SSC) was increased by increasing the storage time, showing lower values when CO_2 concentration was decreased (*figure 3*; *table II*). In Golden Delicious apples, no significant differences regarding the SSC were noticed (*table II*).

The analysis of variance showed also that there were significant differences in the acid content (%) among apples preserved under CA conditions and control sample fruits for both cultivars (*figures 4, 5*; *table II*).

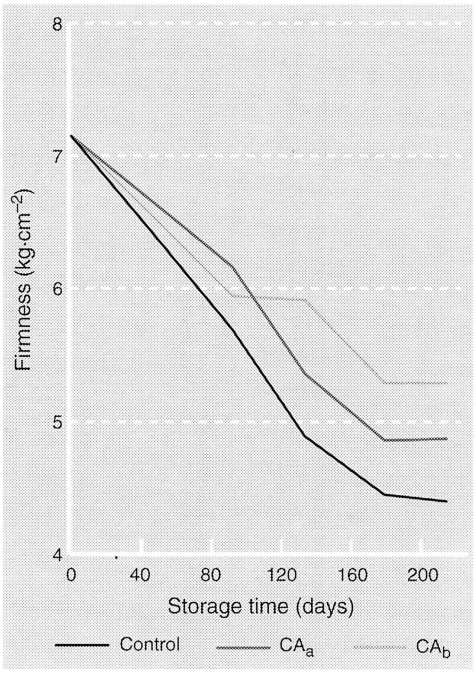

Figure 1.
Texture change of Starking Delicious apples during cold storage in air (control) and controlled atmosphere conditions: CA_a = 5.1% O_2 + 1.7% CO_2; CA_b = 5.5% O_2 + 2.5% CO_2 + ethylene control (storage period: 1991–1992).

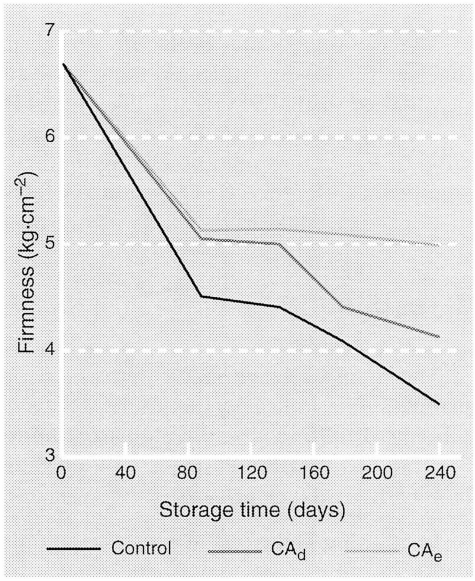

Figure 2.
Texture change of Golden Delicious apples during cold storage in air (control) and controlled atmosphere conditions: CA_d = 6.0% O_2 + 1.5% CO_2; CA_e = 3.0% O_2 + 2.5% CO (storage period: 1993–1994).

The results obtained from pH values indicated that there were significant differences in both cultivars, only in the case between air storage and CA storage procedures but not among CA treatments (*figure 4, 5; table II*).

The weight loss of apples was found to be not significant at all treatments in both varieties while the ethylene concentration had no effect on the quality attributes of apples.

The colour of Golden Delicious apples was significantly affected by the storage conditions applied (*figure 6; table II*).

4. discussion

The firmness loss percentage of control samples (Starking Delicious, 1991–1992) at 90 d of storage was 20.4% whilst, for the CA procedures including 1.7% CO_2 and 2.5% CO_2, it was found to be 13.4% and 16.2%, respectively. For the last 45 days of a 225 d storage, no change in firmness loss was observed, compared with the values obtained after 180 d.

During the storage period 1992–1993, Starking Delicious apples showed a similar trend in firmness with those stored in 1991–1992 when the same CA procedure was applied. Some differences in absolute values obtained are probably due to differences in physiological or biochemical properties that are affected by maturity and climatic conditions. However, a better retention of firmness was observed in apples during the storage period 1992–1993 when O_2 concentration was reduced from 5.1% to 2.5% while the CO_2 concentration (2.5%) remained stable. So the firmness of the apples was not greatly influenced by CO_2 concentration and this agrees with previous findings [12].

In Golden Delicious apples, the firmness loss percentage of control samples at 90 d of storage was 32.8% whilst for the [6.0% O_2 + 1.5% CO_2] and [3.0% O_2 + 2.5% CO_2] CA procedure, it was found to be 25.4% and 23.1%, respectively. The corresponding firmness loss after 180 d of storage was 38.8% for control samples while, for the mentioned above CA procedures, it was 34.3% and 23.9%, respectively. During the last 2 months of storage, the firmness of Golden Delicious apples, in contrast to Starking Delicious apples, was found to be deteriorated, particularly in the case of control samples where a further 14.6% of firmness loss was observed. Golden Delicious

Table II.
Results obtained from preserved under CA conditions apples analysed after 180 d of storage time (preservation limit of control samples). The CA conditions tested are those presented in *table I.*

Storage conditions	Starking Delicious (1991–1992)				Starking Delicious (1992–1993)				Golden Delicious (1993–1994)				
	Firmness ($kg \cdot cm^{-2}$)	Sol. solid content (°Brix)	Titr. acid.[1] (%)	pH	Firmness ($kg \cdot cm^{-2}$)	Sol. solid content (°Brix)	Titr. acid.[1] (%)	pH	Firmness ($kg \cdot cm^{-2}$)	Sol. solid content (°Brix)	Titr. acid.[1] (%)	pH	Hunter a/b ratio
A	4.40	13.40	0.18	4.23	4.51	13.3	0.15	4.29	3.49	14.80	0.22	4.51	0.14
B	5.29	14.00	0.21	4.04	–	–	–	–	–	–	–	–	–
C	–	–	–	–	5.11	12.8	0.21	4.07	–	–	–	–	–
D	–	–	–	–	–	–	–	–	4.13	14.70	0.27	4.02	0.27
E	–	–	–	–	–	–	–	–	4.99	14.60	0.27	3.91	0.30
F value	17.50	8.20	4.40	14.40	9.90	6.80	32.10	25.70	78.20	10.90	29.40	80.60	53.70
$LSD_{0.05}$	0.31	0.43	0.03	0.08	0.27	0.56	0.02	0.06	0.24	0.31	0.02	0.04	0.03

[1] Titratable acid is expressed in percentage of malic acid (w/v). LSD = Least significant difference test at $p < 0.05$.

apples which soften appreciably in air storage responded more to procedure with higher concentration in CO_2 and lower in O_2. This observation agrees with previous findings [13, 14].

During the first 90 d of storage, the CA procedures showed a similar rise in soluble solid content (SSC) and, after this time, they had a constant level in the case of samples stored at [5.1% O_2 + 1.7% CO_2] while, in the samples at [5.5% O_2 + 2.5% CO_2 + ethylene control], SSC was further increased up to 14%. On the contrary, control samples showed a continuous SSC increase for up to 180 d and a slight decrease up to the end of the storage period. During the period 1992–1993, when the O_2 concentration of the CA procedures was reduced from 5.5% to 2.5% with an almost stable CO_2 concentration, the SSC values were found to be lower during storage to those obtained from all other treatments. The acid content followed a similar trend with the firmness values obtained when the same CA procedure was applied. The levels of malic acid in CA stored apples were found to be greater as the CO_2 concentration of the storage atmosphere was increased. This is in general agreement with previous works [12, 15]. When the apples were stored in CA conditions with the highest CO_2 concentration, the acidity values were higher by 16.7% for Starking Delicious apples (1991–1992), 25.8% for Starking Delicious (1992–1993) and 42.6% for Golden Delicious (1993–1994), than in the case with air storage conditions. However, in other fruits, malic acid content has been observed to decrease under high CO_2 concentrations, e.g., citrus [16], pears [17] and kiwifruit [18]. The higher acidity observed in Golden Delicious apples

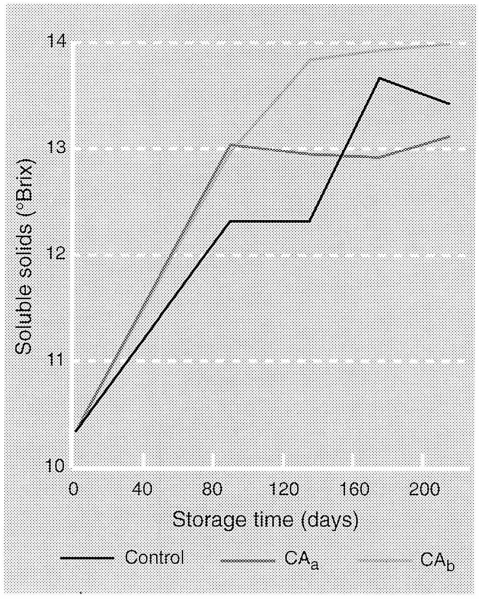

Figure 3.
Total soluble solids of Starking Delicious apples during cold storage in air (control) and controlled atmosphere conditions: CA_a = 5.1% O_2 + 1.7% CO_2; CA_b = 5.5% O_2 + 2.5% CO_2 + ethylene control (storage period: 1991–1992).

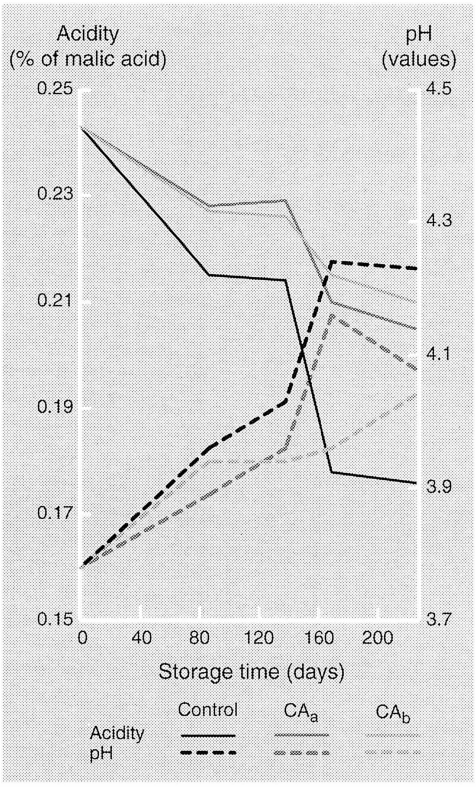

Figure 4.
Acidity and pH change of Starking Delicious apples during cold storage in air (control) and controlled atmosphere conditions: CA_a = 5.1% O_2 + 1.7% CO_2; CA_b = 5.5% O_2 + 2.5% CO_2 + ethylene control (storage period: 1991–1992).

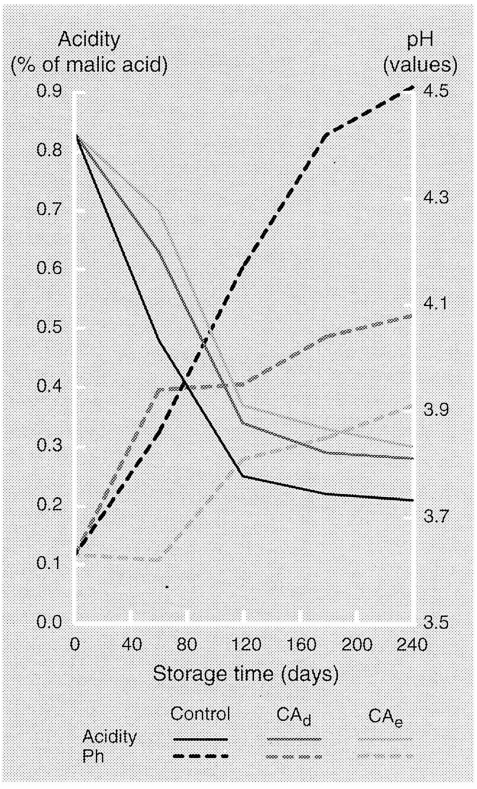

Figure 5.
Acidity and pH change of Golden Delicious apples during cold storage in air (control) and controlled atmosphere conditions: CA_d = 6.0% O_2 + 1.5% CO_2; CA_e = 3.0% O_2 + 2.5% CO_2 (storage period: 1993–1994).

in comparison to Starking Delicious is on line with the previous results [19] whilst a comparison of acidity for 1991–1992 and 1992–1993 apples illustrates that the pattern of change in acidity was to be similar.

The pH values slightly decreased when the CO_2 concentration in the CA storage was increased. So, It can be said, that the pH values were found to be inversely analogous to firmness values obtained. The ethylene concentration, which was controlled to be less than 0.02 ppm in CA conditions, had a little effect on the quality attributes of the apples. This doesn't agree with the results obtained by other researchers [20]. However, some other researchers reported that the ethylene in CA had a negative effect on fruit acidity and on objectively measured firmness [7].

Golden Delicious apples stored in air were significantly less in green colour than those obtained from the other CA treatments. The percentage loss of greenness at 90 d of storage was found to be 29.3% (air), 17.1% [6% O_2 + 1.5% CO_2] and 14.6% [3.0% O_2 + 2.5% CO_2] whilst, after 240 d, it was found to be 60.9%, 24.1% and 26.8%, respectively. Fruits in air storage lost about 34.1% of their initial greenness compared with those in the CA storage with the higher CO_2 and the lower O_2 concentrations. So, the CA treatments above mentioned retarded the loss of green colour in stored apples and the effect of CA storage on reducing chlorophyll degradation established [21, 22].

5. conclusion

The results of this study strongly suggest that treatments with a CO_2 level (1,7–2.5%) combined with a low O_2 level (3–5.5%) for both Starking Delicious and Golden Delicious apples would be beneficial in all commercial CA storage facilities. In addition, a properly managed quality control for selection of high quality fruits of optimum maturity and a short time of loading (4 to 5 d) must always be considered. Under these conditions, apples can be stored about

3 months longer than in normal refrigerated storage conditions, keeping their quality attributes at high levels.

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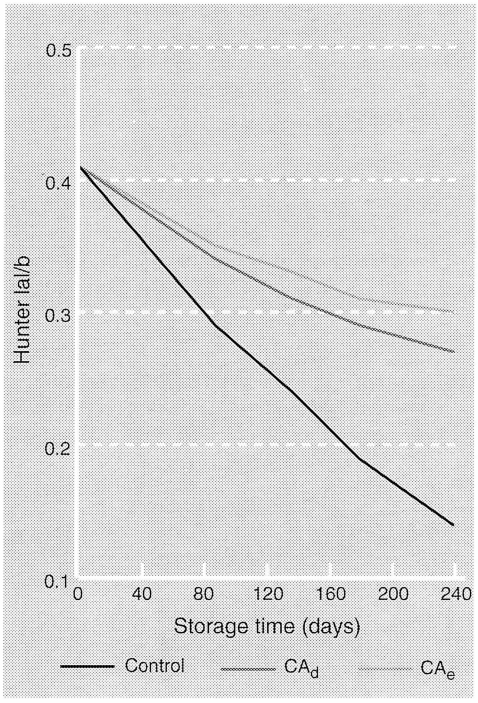

Figure 6.
Colour change of Golden Delicious apples during cold storage in air (control) and controlled atmosphere conditions: CA_d = 6.0% O_2 + 1.5% CO_2; CA_e = 3.0% O_2 + 2.5% CO_2 (storage period: 1993–1994).

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Características calificativas de las manzanas almacenadas en atmósfera controlada, estudiadas a nivel experimental.

Resumen — Introducción. El almacenamiento de los frutos colocados en atmósfera controlada es una técnica moderna que se desarrolló en distintos países, en los últimos años. El uso de bajas temperaturas combinado con la de atmosferas de contenidos reducidos de oxigeno y elevadas de gas carbónico surte un efecto directo en la fisiología de los frutos y sobre todo en la respiración y la producción de etileno por los frutos climatericos. **Material y mêtodos**. Después de cosecharlas, las manzanas de las variedades " Starking Delicious " y " Golden Delicious " cultivadas en Grecia fueron almacenadas a 0 °C, en varias composiciones de atmosferas controladas, las tasas de oxigeno variando de un 2,5 a un 6,0% y los del gas carbónico, de un 1,7 a un 2,5%. Se siguió vigilando la evolución de varios parámetros de la calidad del fruto durante 240 d. **Resultados y discusión**. Para las dos variedades estudiadas, los resultados logrados en dos años de estudios mostraron que la textura del fruto se preservaba mejor cuando la tasa de CO_2 ambiente se situaba entre un 1,7 y un 2,5% y que la concentración de O_2 era limitada. El contenido de extracto seco, la acidez graduable y el valor del pH de los frutos no fueron afectados de manera significativa por las distintas composiciones de las atmosferas controladas sometidas a prueba. **Conclusiones**. Las mejores condiciones de almacenamiento de las manzanas serían una temperatura de 0 °C, asociada con la composición gaseosa [2,5% O_2 + 2,5% CO_2] para la variedad " Starking Delicious " y [3,0% O_2 + 2,5% CO_2] para " Golden Delicious ". (© Elsevier, Paris)

Grecia / manzana / almacenamiento atmósfera controlada / temperatura