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Storage and Shelf-life of Apples Grown in Norway I. Effects of Controlled Atmosphere Storage on 'Aroma'.

Lagerung und Haltbarkeit von Äpfeln produziert in Norwegen I. Der Einfluss der Lagerung in Kontrollierter Atmosphäre auf die Sorte 'Aroma'.

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Summary

In a three year study on storage, apples of the cultivar 'Aroma' grown in the south-eastern part of Norway were kept in controlled atmosphere at 1.5%–2.5% O_2 + 1.5%–2.5% CO_2 or normal air at 2 °C (±1 °C) until March. At specific times during December, January, and March samples were removed from storage and apples were kept one week at room temperature, simulating shelf-life. Physical and chemical tests as well as sensory evaluation were conducted at the time of harvest, upon removal of fruit lots from storage, and after shelf-life trials. The data, treated by means of principal component analysis (PCA), showed three principal components (PC), accounting for 86% of the total variation. PC1 explained 55% of the total variation caused by storage time and storage method, PC2 explained 17% of the total variation caused by years, while a third component explained another 14% of the total variation as due to weight loss, soluble solids, and taste.

In general, it was found that apples could be stored for a longer period of time and still maintain good quality when controlled atmosphere was used. The results showed a positive effect of reduced oxygen both immediately after storage and after shelf-life trials. Firmer fruit with better skin colour, higher soluble solids content as well as lower pH were some of the important advantages of controlled atmosphere storage compared to normal air storage.

Zusammenfassung

Äpfel der Sorte 'Aroma' aus dem Südosten Norwegens, wurden in dreijährigen Versuchen im CA-Lager bei 1.5%–2.5% O_2 + 1.5%–2.5% CO_2 und normaler Atmosphäre bei 2 °C (±1 °C) auf ihre Qualitätseigenschaften überprüft. Im Anschluß an die Lagerungsversuche wurden zusätzliche einwöchige Haltbarkeitsversuche bei Raumtemperatur im Dezember, Januar und März durchgeführt. Fruchtqualitätsanalysen und die Beurteilung des Geschmacks wurden sowohl zum Erntezeitpunkt als auch nach der Lagerung durchgeführt. Die statistische Bearbeitung des Zahlenmaterials mit Hilfe der „principal component analysis" (PCA) ergab drei „principal components" (PC), die 86% der Gesamtvariation erklärten. PC1 erklärte 55% der gesamten Schwankungen, verursacht durch Lagerungsdauer und Lagerungsmethode. PC2 stand für die Erklärung von 17% der Gesamtvariation verursacht durch die Versuchsjahre. Eine dritte Komponente erklärte weitere 14% der Gesamtvariation bezüglich Gewichtsverlust, lösliche Trockensubstanz und Geschmack. Insgesamt konnten die Früchte für eine längere Lagerungsperiode bei guter Qualitätserhaltung im CA-Lager aufbewahrt werden. Die Ergebnisse zeigen einen positiven Effekt der CA-Lagerung auf die untersuchten Qualitätseigenschaften. Früchte mit höherer Fruchtfleischfestigkeit, besserer Schalenfarbe, höheren Refraktometerwerten und Säuregehalten bei niedrigeren pH-Werten, bestätigten die Vorteile der CA-Lagerung für die Sorte 'Aroma'.

Introduction

Long-term storage of apples in controlled atmosphere may affect fruit quality (DRAKE and EISELE 1997, GOFFINGS and HERREGODS 1994, LAU 1983, LAU 1985, MANSEKA and VASILAKAKIS 1993). However, little is known about apple cultivars in Norway in controlled atmosphere storage. Almost no systematic research on controlled atmosphere storage has been done in Norway. The Swedish apple cultivar 'Aroma' ('Ingrid Marie' × 'Filippa') has become one of the most important cultivars in Norway (FGS MELDING 84/98 1998), and is presently the most interesting cultivar for long-term storage. As described by LANDFALD (1988), the major problems with storage of 'Aroma' involve its susceptibility to postharvest water loss (HAFFNER 1990) and to *Gloeosporium* rot (*Phlyctaena vagabunda* – syn. *Gloeosporium album* and *Cryptosporiopsis curvispora* – syn. *Gloeosporium perennans*), even though beneficial effects of controlled atmosphere storage have been shown (HAFFNER 1993).

Retarding ripening is one of the main benefits of controlled atmosphere storage (KADER 1980). Oxygen concentration has to be lowered < 8% to influence fruit ripening, and oxygen concentration below 8 and above 2% improve the effect (KADER 1980). However, there are limits beyond which physiological injury outweigh the benefits of ripening prevention (KADER 1980), the most important detrimental effect being fermentation and the development of an alcoholic off-flavour (KE et al. 1991). Although elevated carbon dioxide levels can also retard fruit ripening, at levels

which can be tolerated by most fruits (i.e. < 5 %), CO_2 is generally less effective than reduced O_2 in preventing ripening (KADER 1980). The optimum external concentration of oxygen varies between apple cultivars (HARDENBURG et al. 1986). The objective of this work was to study the effects of low oxygen and elevated carbon dioxide concentrations in storage air on quality parameters of apples of the cultivar 'Aroma'. Another aim of the study was to examine shelf-life by observing the effects of one week of storage in normal air at 20 °C and 25–30 % RH after the cold storage period.

Materials and methods

Fruit material and storage conditions

Apples of the cultivar 'Aroma' were harvested near optimum harvest date from 8–13 year old trees at the Agricultural University orchards in Norway (September 6–9, 1993, September 26–27, 1994 and October 2–4, 1995). No chemical treatments against *Gloeosporium* rot were used. Premium quality apples were placed in polystyrene boxes (40 × 60 × 17 cm) which were weighed before storage in either controlled atmosphere (CA) or in normal atmosphere (NA) at 2 °C (±1 °C) and 95-100 % RH. The CA-conditions were 1.5 %–2.5 % O_2 + 1.5 %–2.5 % CO_2 while the NA-conditions were 21 % O_2 + 0.2 %-0.5 % CO_2. The apples were stored to the middle of March during each of the three years, with removal of samples for quality analysis in December (Dec. 8 in 1993, Dec. 14 in 1994 and Dec. 5 in 1995), in January (Jan. 12 in 1994, Jan. 20 in 1995 and Jan. 31 in 1996) and in March (Mar. 9 in 1994, Mar. 14 in 1995 and Mar. 14 in 1996). Twelve of the apples from each storage regime were analysed within two days and the other 12 apples were stored for an additional week at room temperature (20 °C (±1 °C), 25–30 % RH), simulating shelf-life.

Storage equipment

Gas tight (230 l) chambers were employed for CA storage, except in normal air during the first season, when smaller chambers (100 l) were used. A CO_2/O_2 gas analyser was connected to the control system by a recirculating gas pump.

Quality evaluation

Firmness, weight loss, surface colour, soluble solids, pH, titratable acidity, starch and L-ascorbic acid were measured after harvest and after storage. Sensory evaluation was performed by a sensory panel after harvest, storage and after shelf-life trials about 20 hours after removal from CA/NA-storage by 5–6 panellists who evaluated taste using a sensory scale from 1–9 where 1 = poor taste and 9 = very good taste. The panellists also evaluated ground colour of the skin by use of the "Kleuren-kaart" (HERREGODS 1972). Shrinkage was noted in December, January and March after storage and shelf-life trials.

For analyses of internal fruit quality, 10 apples were used per treatment. Fruit firmness was measured, after peeling, with a pressure tester FT 327 (Effegi fruit tester, 11 mm plug, kg/cm²). The apples were thereafter cut in two and one half was used for measuring starch content by the starch iodine test using a scale from 0–5 where 0 = no blue/black colour on apple flesh and 5 = 100 % blue/black covering on the flesh surface. The remaining half of each apple was used for preparation of juice samples for measuring % soluble solids (Atago refractometer model PR-1 CO, LTD), pH (691 pH-meter, Metrohm) and % titratable acidity (Radiometer End Point Titration System, ETS 822, Copenhagen). Ten ml juice was titrated with 0.1 N NaOH to pH 8.1 and results were calculated as % malic acid. High Performance Liquid Chromatography (Perkin Elmer HPLC-system) was used to determine the content of L-ascorbic acid expressed as mg/100 g of fresh fruit (RÜCKMANN 1980) based on standard L-ascorbic acid (Merck). Fifty g apple slices were stabilised in 100 ml metaphosphoric acid (5 %), homogenised, filtered through paper, membrane filtered and then injected into the HPLC.

Data analysis

To test differences between storage treatments and sampling time, factorial analysis of variance was applied. Storage seasons were used as replicates. Statistically significant results ($p \leq 0.05$) are reported, but because information from ANOVA-tests with slightly higher p-values ($0.05 \leq p \leq 0.08$) might be valuable, slightly significant results are also reported.

To get an overview of the main results, principal component analysis (PCA), (Unscrambler, Windows version 6.11, 1997, Camo A/S, Trondheim) was applied. The PCA is a multilinear modelling method given an interpretable overview of the main information in a multidimensional data table. All attributes were mean centred and scaled to unit variance prior to analysis. The calibration model was validated by full scale cross validation (MARTENS and NÆS 1989).

Results

Using PCA, the most important information was given in the variation between the dates of removal from the storage and the differences between CA and NA, shown by principal component 1 (PC1) and explaining 55 % of the total variation. The second most important cause of variation was found in the differences between the years (storage seasons) which explained 17 % of the total variation (Figure 1A and B, Table 1). A third component (PC3) explained 14 % of the total variation, being mostly related to the content of soluble solids, taste preference and weight loss.

PC1 was best described by high values for titratable acidity, soluble solids, firmness and L-ascorbic acid content at the start of the storage season, while the last removal of samples from the store was described by high values for ground colour, pH, weight loss and a high ratio soluble solids/titratable acidity (Figure 1B).

The variation between the storage seasons (PC2) showed in 1993/94 apples with high values for firmness, L-ascorbic acid, weight loss and the ratio soluble solids/ titratable acidity. Apples from the two remaining seasons (1994/95 and 1995/96) showed high values

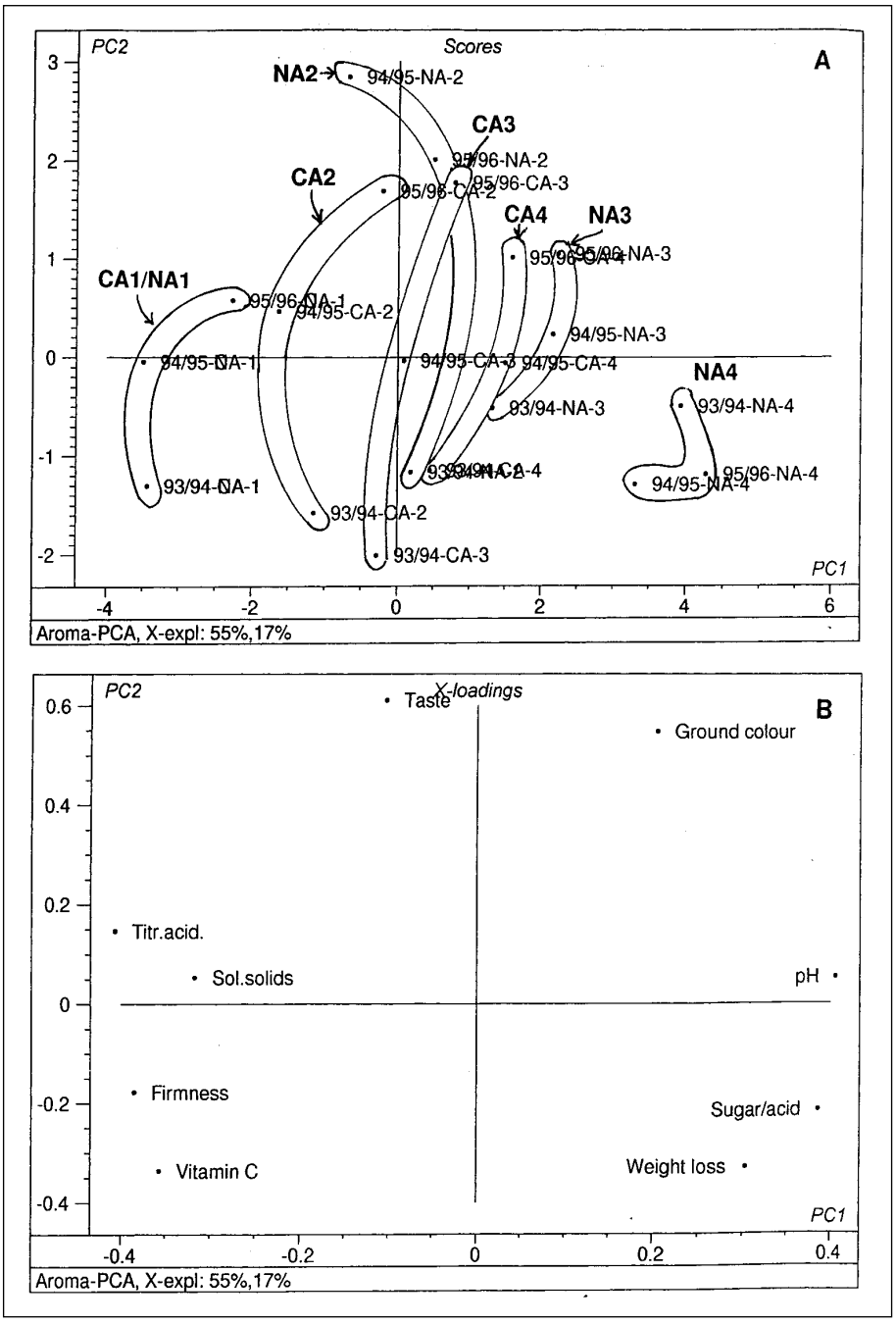


Fig. 1. (A) PCA score plot for principal component (PC) 1 and 2 for storage of apples in controlled atmosphere versus normal atmosphere. Sample signatures: 93/94 = year, NA = normal atmosphere, CA = controlled atmosphere, 1–4 = removal from storage. (B) PCA-loadings for PC1 and PC2.
(A): PCA plot Zeichenfläche für Komponenten (PC) 1 und 2 für Äpfel, gelagert im CA- oder Normallager. Probenbenennungen: 93/94 = Versuchsjahr, NA = Normallager, CA = CA-Lager, 1–4 = Zeitpunkt der Probennahme aus dem Lager. (B) PCA-Ladungsplot der Principal Component Analyse für PC1 und PC2.

for titratable acidity, soluble solids, pH, and high scores for ground colour and taste (Table 1).

Storage in CA versus NA.

The general impression of external quality for both apples stored in CA (CA-apples) and apples stored in NA (NA-apples) was satisfactory in December and January. In March NA-apples looked quite poor compared to CA-apples, as a result of severe attack by *Gloeosporium* rot on NA-apples. In both storage regimes, the rot spots were increasing in size and number as storage continued.

Shrinkage symptoms could not be observed either in December, January or March.

Table 1. Explained variances, (%) for the first three components in principal component analysis.
Erklärte Varianzen (%) für die ersten drei Komponenten der „principal component"-Analyse.

	PC1	PC2	PC3
Soluble solids	48.6	–6.7	44.2
Titratable acidity	88.5	2.8	2.3
Sugar/acid	78.7	6.7	2.3
pH	88.2	–1.0	0.8
L-ascorbic acid	64.9	18.8	–0.9
Ground colour	13.2	50.3	15.6
Taste	–6.0	63.1	34.3
Weight loss	43.7	14.7	22.6
Firmness	77.1	4.1	2.2
Mean	55.2	17.0	13.7

Table 2. Effects of controlled atmosphere (CA) storage versus normal air (NA) storage of Norwegian grown apples of the cultivar 'Aroma'. Quality factors measured were weight loss (%), sensory scores: 1–9 (Sens. Scores) and L-ascorbic acid: mg/100 g fresh weight (L-asc. Acid).
a. The measurements were conducted at harvest (September/October) and in December, January, and March after storage in either a controlled atmosphere (1.5%–2.5% O_2 + 1.5%–2.5% CO_2) or in normal air at 2 °C (±1 °C).
b. Shelf-life trials were conducted after one week of additional storage in normal air at high temperature (20 °C) and low relative humidity.
Einflüsse der CA-Lagerung verglichen mit der Normallagerung in Luft (NA) von in Norwegen produzierten Äpfeln der Sorte 'Aroma'. Die Qualitätseigenschaften: Gewichtsverluste (%), sensorische Beurteilung, bewertet nach einer Skala 1–9 (Sens. Scores) und L-Ascorbinsäuregehalte, gemessen in mg/100g Frischgewicht, (L-asc. Acid).
a. Die Analysen wurden zur Erntezeit (September/October), sowie im Dezember, Januar und März, nach der Lagerung im CA-Lager (1.5%–2.5% O_2 + 1.5%–2.5% CO_2) oder Normallagerung in Luft bei 2 °C (±1 °C) durchgeführt.
b. Zusätzliche Analysen wurden nach einwöchiger Nachlagerung in Luft bei hohen Temperaturen (20°C) und niedriger relativer Luftfeuchtigkeit, nach der Auslagerung durchgeführt („shelf-life").

Quality factors		Start		December		January		March	
	Storage conditions	a	b	a	b	a	b	a	b
Weight loss	CA	0.0	–	0.7	4.4	1.1	3.7	1.3	4.9
	NA	0.0	–	0.7	4.3	1.0	4.1	1.7	5.4
Sens. Scores	CA	5.6	–	6.1	5.9	5.8	4.9	5.7	5.1
	NA	5.6	–	6.5	5.9	5.6	4.3	4.8	4.4
L-asc. acid	CA	9.8	–	5.4	5.5	5.5	4.3	4.3	3.3
	NA	9.8	–	4.6	3.5	3.5	3.4	3.6	3.0

Weight loss and firmness

Weight loss increased during storage ($p = 0.000$), but total weight loss at the end of storage period was less than 1.8%. No significant effect of storage methods was found (Table 2).

Firmness declined during storage as Figure 3A shows ($p < 0.000$), but CA-storage maintained firmness better than NA-storage ($p = 0.043$).

Skin colour

Compared to NA-storage, CA-storage slightly depressed yellowing of the ground colour, though the differences were not statistically significant (Figure 3B). Yellow colour increased only slightly in both CA- and NA-apples, but statistically significant interactions between storage method and storage time indicated that the values were higher and increased faster in NA- than in CA-apples ($p = 0.006$).

Sensory evaluation

Taste scores changed during the storage period (Table 2). When data from both storage conditions were pooled, these changes were slightly significant ($p = 0.062$). There was no significant difference between CA- and NA-apples, but 'Aroma' stored in CA had almost no variation in sensory scores during storage, while NA-apples were given highest scores in December and were no longer acceptable in March.

Starch, soluble solids, titratable acidity, and pH

The starch index score at harvest was about 3, while no starch could be detected in December.

More soluble solids (Figure 3C) were found in apples stored in CA compared to apples stored in NA ($p = 0.051$) and there was a tendency for better retention of titratable acidity in CA-apples compared with NA-apples ($p = 0.060$). Soluble solids (Figure 3C) and titratable acidity (Figure 3D) both declined significantly during the storage period ($p = 0.026$ and $p < 0.000$, respectively). However, the decline under CA-storage was slower than the decline under NA-storage.

The pH of apples stored in CA was significantly lower than in apples stored in NA ($p = 0.024$). The increase in pH during storage period was found to be statistically significant ($p < 0.000$), but the pH increased more rapidly in apples stored in NA than in apples stored in CA (Figure 3F).

The ratio of soluble solids/titratable acidity increased significantly during storage ($p < 0.001$), but the differences between apples stored in CA and NA were not statistically significant (Figure 3E).

L-ascorbic acid

No statistically significant differences were found between apples stored in CA versus NA. The value of L-ascorbic acid decreased significantly during the storage period ($p < 0.000$) from 9.8 to 3.9 mg L-ascorbic acid/ 100 g fresh weight. The greatest loss in L-ascorbic acid was found during the storage period from harvest until December, both in CA- and NA-apples. From December to March, concentrations remained relatively stable around 3.5–5.5 mg L-ascorbic acid/ 100 g fresh weight, but still the highest concentrations were found in CA-apples (Table 2).

Shelf-life -trials

The PCA of shelf-life trials showed a similar pattern as the PCA of CA- and NA-storage (Figure 2A and B), but the differences between CA and NA became more pronounced after one week of storage at room temperature. The first PC, showed the differences between CA- and NA-samples and the removal of samples from storage (50% explained), while PC2 showed the differences between the years (14% explained). PC3

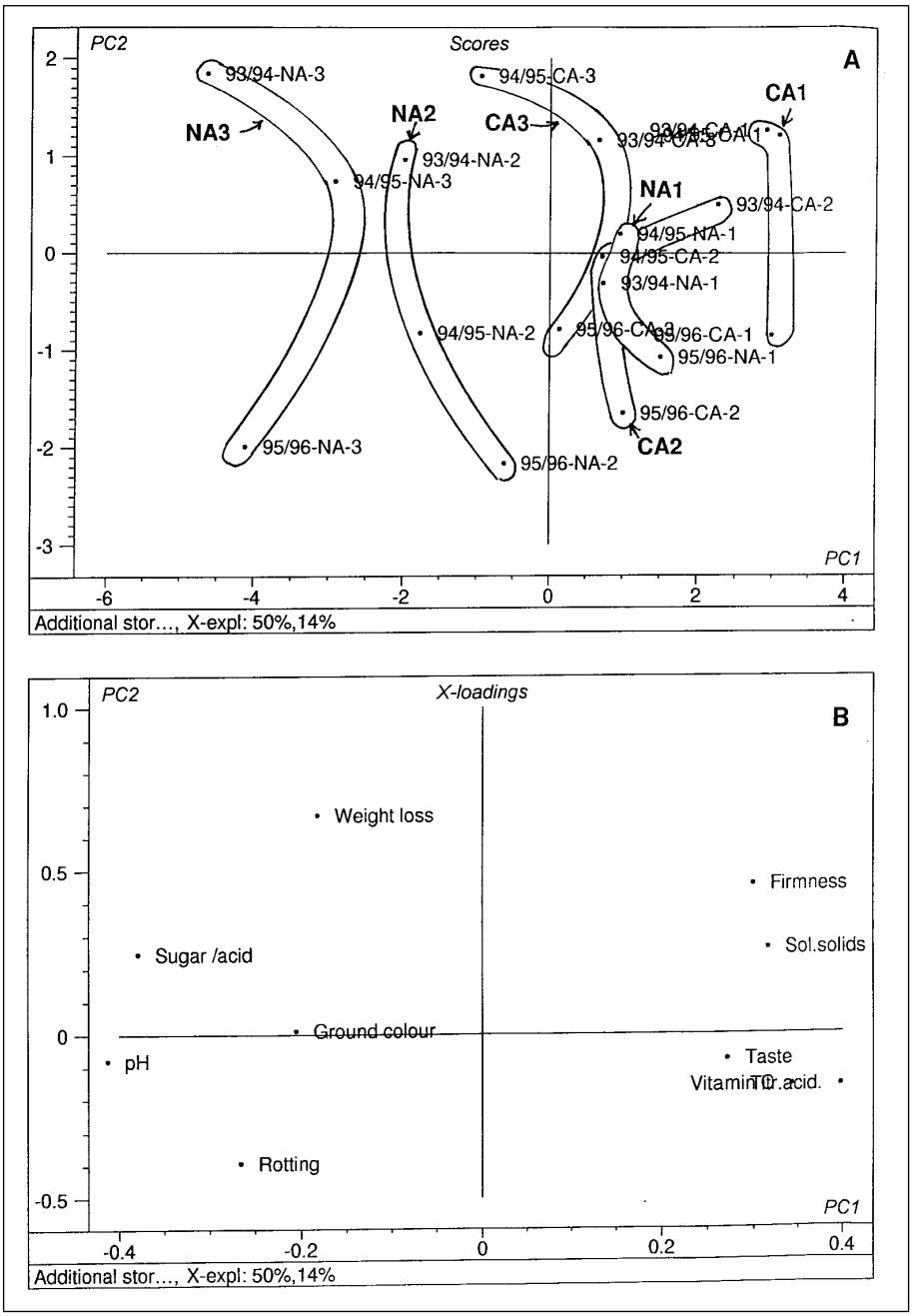


Fig. 2. (A) PCA score plot for principal component (PC) 1 and 2 for shelf-life trials. Sample signatures: 93/94 = year, NA = normal atmosphere, CA = controlled atmosphere, 1–3 = removal from storage. (B) PCA-loadings for PC1 and PC2.
(A): PCA plot Zeichenfläche für Komponenten (PC) 1 und 2 für die Nachlagerung bei Raumtemperatur. Probenbenennungen: 93/94 = Versuchsjahr, NA = Normallager, CA = CA-Lager, 1–3 = Zeitpunkt der Probennahme aus dem Lager. (B) PCA-Ladungsplot der Principal Component Analyse für PC1 und PC2.

could be related to ground colour, weight loss and taste (13 % explained).

Weight loss and firmness

Storage method did not affect weight loss during shelf-life trials significantly, but weight loss varied significantly ($p = 0.002$) between shelf-life trials in December, January and March (Table 2).

Fruit firmness decreased when apples were kept one additional week at room temperature (Figure 3A). Apples that had been stored in CA were firmer compared to apples that had been stored in NA ($p = 0.041$). Firmness values decreased from 6.2 kg/cm² in December to 5.4 kg/cm² in March when all data were pooled ($p = 0.002$).

Rot and shrinkage symptoms

A decrease in the incidence of *Gloeosporium* rot was recorded for CA-apples, compared to NA-apples, although this result was not statistically significant. Rot was most severe in NA-apples at the end of the storage trial (March) when 34.8 % of the apples were attacked, while only 11.7 % of the apples stored in CA had rot spots. Shrinkage symptoms could be registered after shelf-life trials (December, January and March) in both CA- and NA-stored apples.

Skin colour

Apples stored in CA were slightly greener compared to apples stored in NA. As shown in Figure 3B, only small, not significant differences were found between

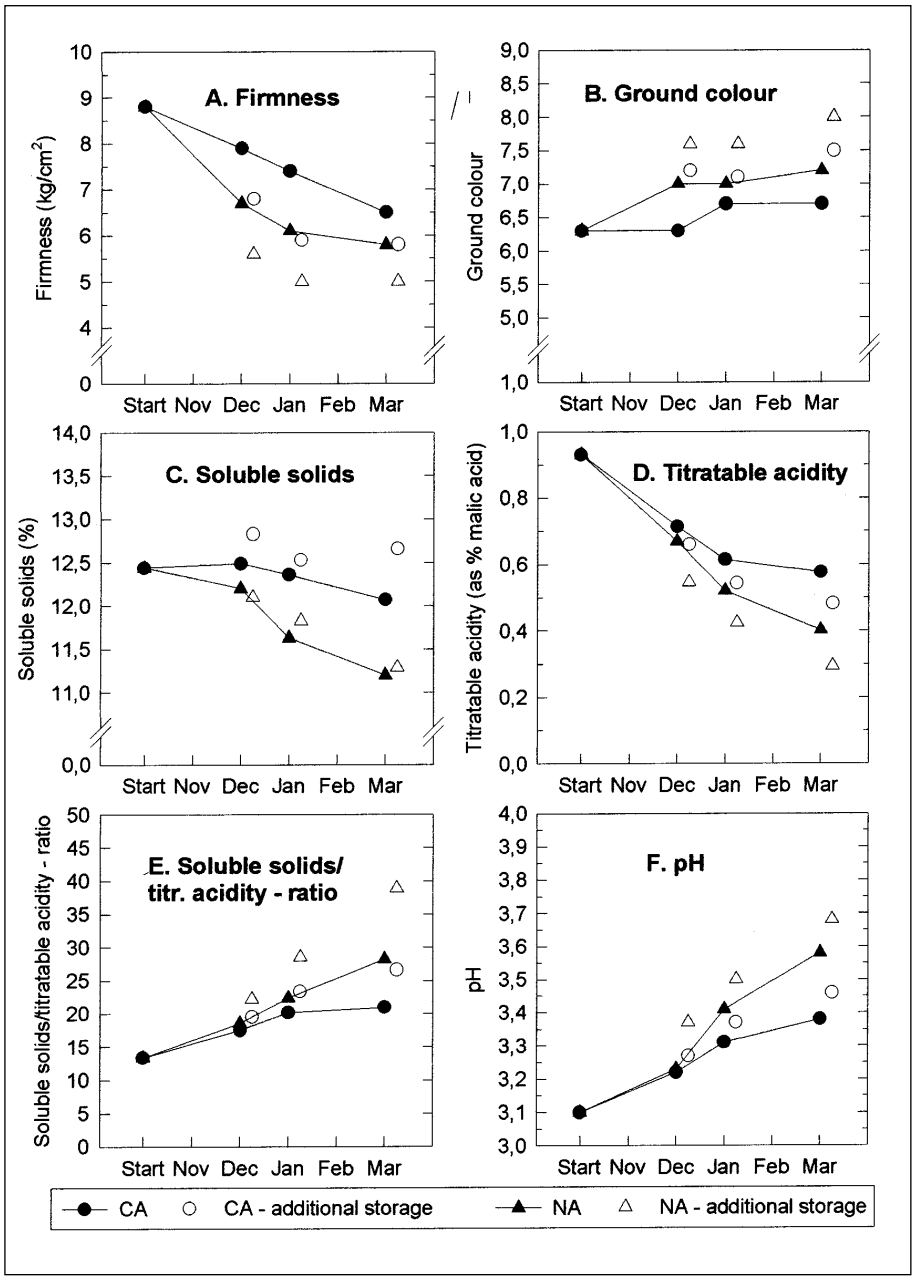


Fig. 3. A–F. Quality evaluation of apples ('Aroma') measured as: A. Firmness (kg/cm²), B. Ground colour (1–8), C. Soluble solids (%), D. Titratable acidity (% malic acid), E. Soluble solids/ titratable acidity-ratio, and F. pH. The measurements were conducted at harvest (September/October) and in December, January, and March after storage in either a controlled atmosphere (1.5%–2.5% O_2 + 1.5%–2.5% CO_2) or in normal air at 2°C (±1°C). Additionally, after removal from storage apples were further kept for one week, at high temperature (20°C) and low relative humidity, and the quality evaluations (A-F) were repeated (shelf-life trials).
A–F: Qualitätsanalysen für Äpfel der Sorte 'Aroma': A. Fruchtfleischfestigkeit (kg/cm²), B. Grundfarbe (1–8), C. gelöste Trockensubstanz (%), D. titrierbare Säure (% Apfelsäure), E. Verhältnis der gelösten Trockensubstanz/titrierbare Säure, und F. pH-Wert. Die Analysen wurden zur Erntezeit (September/October), im Dezember, Januar und März, nach der Lagerung im CA-Lager (1.5%–2.5% O_2 + 1.5%–2.5% CO_2) oder Normallagerung in Luft bei 2°C (±1°C) durchgeführt. Zusätzliche Analysen wurden nach einwöchiger Nachlagerung in Luft bei hohen. Temperaturen (20°C) und niedriger relativer Luftfeuchtigkeit, nach der Auslagerung durchgeführt („shelf-life").

the three storage periods (December, January and March).

Sensory evaluation

Scores given by the sensory panel after shelf-life period were lower than immediately after CA/NA-storage (Table 2). Differences in scores given in December, in January and in March were statistically significant ($p = 0.043$). The sensory panel rated both CA- and NA-apples highest in December. No significant differences in taste preference were found between CA- and NA-stored apples.

Starch, soluble solids, titratable acidity and pH

No starch was detected in apples after the shelf-life period in December, January or March, using the starch iodine test. The decreases of soluble solids (Figure 3C) and titratable acidity (Figure 3D) in CA-apples were slower than for NA-apples, and there was a slower increase in pH (Figure 3F) when storage periods were compared ($p = 0.049$, $p < 0.000$ and $p < 0.000$, respectively). CA-apples contained significantly more soluble solids, titratable acidity and had a lower pH compared to apples stored in NA ($p = 0.041$, $p = 0.023$ and $p = 0.039$, respectively).

No statistically significant differences in soluble solids/titratable acidity-ratios were found between CA- and NA-apples (Figure 3E), but the ratios increased during the three shelf-life trials ($p = 0.000$). Interactions between storage methods and shelf-life indicate a more rapid increase of the soluble solids/titratable acidity-ratio in NA-apples compared to CA-apples during the shelf-life periods ($p = 0.040$).

L-ascorbic acid

No significant differences in L-ascorbic acid concentrations were found in apples stored in either CA or NA after one week at room temperature (Table 2). Values after the shelf-life period in December were 4.4 mg/100 g fresh weight L-ascorbic acid, while values of 3.9 and 3.2 mg/100 g fresh weight were observed in January and March, respectively ($p = 0.007$).

Discussion

CA-storage appeared to be beneficial compared to storage in NA for the apple cultivar 'Aroma'. In general, apples stored in CA had higher internal and external quality compared to apples stored in NA. Higher scores for skin colour, firmness, higher soluble solids concentrations as well as lower pH were also observed for apples stored in CA compared to the apples stored in NA. Similar differences were found after the shelf-life trials. In addition, better retention of titratable acidity and reduced damage from *Gloeosporium* rot were observed for apples stored in CA after the shelf-life trials. This is in good agreement with earlier results (HAFFNER 1993 and LANDFALD 1988).

Yellowing of the fruit (loss of chlorophyll and biosynthesis of carotenoids and anthocyanins) may be slowed down in apples kept in CA, though the tendency for CA-storage to reduce yellowing was not significant in the conducted trials. GOFFINGS and HERREGODS (1994) found that an increase of CO_2 and a decrease of O_2 levels (0.7% O_2–1.0% O_2) depressed yellowing of the skin colour. The lower the oxygen concentration, the slower the skin colour turned yellow. BEN-ARIE et al. (1993) discovered that the yellowing of 'Golden Delicious' was inhibited when the oxygen level was reduced from 15% to 3% and that yellowing was virtually unaffected by the CO_2-level. HAFFNER (1993) found that 'Aroma' apples stored in 2% O_2 + 2% CO_2 kept their green colour longer than apples stored in NA. The apples were more yellow after one additional week of storage at room temperature than when they were taken directly from CA/NA-storage. This may be due to the accelerated rate of ripening as a consequence of temperature rise.

It is generally known that fruits lose firmness during storage (BEN-ARIE et al. 1993, GOFFINGS and HERREGODS 1994, SIDDIQUI et al. 1996). Because flesh firmness is an important aspect of the quality of apples, retention of firmness is a major objective of storage. LANDFALD (1988) and HAFFNER (1993) concluded that firmness was better preserved in 'Aroma' stored in CA compared to NA, which is confirmed in the present experiments. SIDDIQUI et al. (1996) found that the decrease in total pectin and hemicellulose content during the storage period was least in 3% CO_2 + 1% O_2, while it was greatest during storage in air. The firmness of apples was clearly reduced after shelf-life period. The fact that no shrinkage and low weight loss occurred during the storage period indicates that a relative high humidity existed during storage. This is in agreement with HENZE and HANSEN (1988).

Even though the soluble solids concentration decreased during storage when data from both CA- and NA-apples were pooled, the concentrations in CA-apples were quite stable during storage and also in shelf-life trials compared to apples from NA. HAFFNER et al. (1998) found only small differences between CA- and NA-apples, while HAFFNER (1993) found a slight increase in the concentration of soluble solids in apples stored in CA and a decrease in soluble solids in NA-apples.

There was a continuous decrease in titratable acidity during storage as has been shown earlier (BEN-ARIE et al. 1993, HAFFNER 1993, LANDFALD 1988, MANSEKA and VASILAKAIS 1993). During shelf-life trials, a marked decline of titratable acidity occurred, especially in apples stored in NA.

Keeping apples in CA may reduce loss of L-ascorbic acid as reported by DRAKE and SPAYD (1983) and KADER (1988). On the other hand, no differences between L-ascorbic acid concentration were found in apples from CA compared to NA, in good agreement with HAFFNER (1993). HAFFNER et al. (1998) found that the loss of L-ascorbic acid was slightly higher in CA-apples (2.0–3.0% O_2 + 0.5–1.0% CO_2, 2–3 °C) compared to apples stored in NA.

Concerning sensory evaluation of the apples, which in these trials did not result in large differences between apples stored in CA compared to NA, varying research results have been reported. KNEE and SHARPLESS (1981) suggested that CA-storage suppressed apple flavour, and YAHIA et al. (1990) found that CA caused residual suppression of three volatiles; propyl butanoate, butyl hexanoate and hexyl hexanoate, which is found to be important to apple flavour (CUNNINGHAM et al. 1986). However, as noted by HAFFNER (1993), apples stored in CA had a considerably better flavour than apples from NA at the end of the storage period.

Conclusions

In Norway apple growers have to comply with legal requirements for a minimum use of chemical treatments during the outdoor season and no chemical post-harvest treatments of fruits. To be able to compete with imported apples, it is necessary to examine the possibilities of producing and offering consumers apples with good quality and competitive and stable prices. With the use of CA-storage, the consumer is ensured a supply of good quality Norwegian apples over a longer period of the year. Advantages in CA-technology may permit the increased use of controlled atmospheres during temporary storage or long-term storage of apples destined for fresh consumption or processing.

The results of the reported experiments show a positive effect of storage on Norwegian grown 'Aroma', both immediately after removal from storage and after shelf-life trials. This apple cultivar is therefore of special interest for long time storage in controlled atmospheres. To accomplish changes in storage technology, there is a requirement for increased production of apples in Norway, and in particular the cultivar 'Aroma'. There must also be a beneficial effect and a distinct financial gain in using CA-storage technology. Storage in controlled atmospheres may become more important in the future. If new technology for creating low O_2-levels is considered, there are good reasons to believe that advantages in higher quality obtained by modern storage techniques would lead to increased apple consumption. Commercially, CA-storage of

apples and other horticultural commodities in Norway is at an early stage. CA-storage of Norwegian grown apples proved to be profitable for the cultivar 'Aroma' and is a good alternative to traditional cold store.

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