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The effect of modified atmosphere packaging on the quality of Honeoye and Korona strawberries

Tim Nielsen [a,*], Anders Leufvén [b]

[a] *SIK – The Swedish Institute for Food and Biotechnology, Ideon, 223 70 Lund, Sweden*
[b] *SIK – The Swedish Institute for Food and Biotechnology, P.O. Box 5401, 402 29 Gothenburg, Sweden*

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Abstract

Strawberries (cultivars Honeoye and Korona) were stored in perforated polypropylene bags at 5 °C for 10 days. Unpackaged strawberries were used as a reference. Several quality parameters were monitored during the storage period. The packaged strawberries retained their weight throughout the experiment as opposed to the unpackaged samples which lost 1.5% of their weight per day because of dehydration. The aroma profile of Honeoye strawberries was not affected by storage in modified atmospheres. In Korona fruits, on the other hand, there was a considerable increase in ethyl acetate levels, indicating unwanted metabolism caused by the altered gas composition. The production of potential off-odours was, however, not possible to distinguish in the sensory analyses of the strawberries. The results indicated that storage in a modified atmosphere (11–14% O_2 and 9–12% CO_2) can be used to maintain the quality of Honeoye and Korona strawberries for a longer time, than if kept in air in open containers.

Keywords: Strawberry; Packaging; Atmosphere; Aroma; Quality

1. Introduction

Strawberries have a very short shelf life, the length of which is dependent on the cultivar, degree of ripeness, harvesting conditions, handling and storage. The limiting factors regarding the shelf life of strawberries are a combination of appearance, taste, texture and microbial growth. Within the berry industry there is a strong wish to be able to retain the quality at the original level over a longer period.

It is inevitable that a certain period of time passes between harvest and consumption and during this time sensitive products, such as strawberries, undergo a whole range of quality-damaging processes. It is therefore of vital importance that the negative course of events is slowed down. The obvious solution is to store the commodity at its optimal temperature. Another technique which can be used in combination with low temperature, in order to obtain an even longer shelf life, is storage in an atmosphere suitable for the products (Rooney, 2000; Zagory, 1997).

The effects that are achieved, both at low temperatures and in conjunction with storage in a modified atmosphere, are due to the fact that the respiration of the product is reduced. In doing so, all processes, including the ripeness and damaging reactions, proceed at a slower rate. The respiration of the strawberries falls with the temperature and also during storage with a reduced oxygen and increased carbon dioxide content.

Presently, strawberries in Sweden are almost exclusively sold in open containers, that is the product is kept in air. The use of closed packaging could be used in order to provide the berries with more suitable surroundings and thereby prolonging shelf life. As a result of produce respiration, matching of the film permeability to the commodity characteristics can result in the passive evolution of an appropriate atmosphere within a sealed package.

* Corresponding author. Tel.: +46 462868823; fax: +46 46188765.
E-mail address: tn@sik.se (T. Nielsen).

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Apart from affecting respiration, storage in a modified atmosphere can prevent microbial growth, discolouration and cell destruction and can reduce the risk of infection (Day, 2001; Farber et al., 2003; Gil, Holcroft, & Kader, 1997; Holcroft & Kader, 1999; Kader, 1999). It has, however, been reported that modified atmosphere packaging (MAP) or controlled atmosphere packaging (CAP) can also have a negative consequence on strawberry quality as it might alter the flavour of the product (Ke, Goldstein, O'Mahony, & Kader, 1991; Larsen & Watkins, 1995; Mawele Shamaila, Powrie, & Skura, 1992; Pelayo, Ebeler, & Kader, 2003; Sanz, Perez, Olias, & Olias, 1999; Ueda & Bai, 1993; Zhang & Watkins, 1998).

Strawberry aroma is a complex mixture of esters, aldehydes, ketones, alcohols, acids and terpenes – somewhere in the region of 360 different compounds have been identified in the aroma of strawberries (Zabetakis & Holden, 1997). It has been suggested that 15–25 of these volatiles are the most important contributors to the aroma, including methyl and ethyl esters, furanones, C_6 aldehydes and other C_6 derivative compounds (Pelayo et al., 2003; Ulrich, Hoberg, Rapp, & Kecke, 1997). In addition, strawberries may produce metabolites, such as acetaldehyde, ethanol and ethyl acetate during storage, which can disrupt the taste experience.

Most investigations of MAP or CAP storage of strawberries have indicated that such treatment extends the shelf life as regards the appearance and textural quality but its effect on the flavour characteristics is not so well documented. The recommended gas composition for strawberry storage varies a great deal between different reports (Day, 2001; Fernandez-Trujillo, Nock, & Watkins, 1999; Holcroft & Kader, 1999; Mawele Shamaila et al., 1992; Smith & Skog, 1992; Wszelaki & Mitcham, 2000; Zhang & Watkins, 1998). This can partly be attributed to the fact that different cultivars have been studied. Furthermore, growing conditions, degree of ripeness, storage temperature and crucially, the choice of quality parameter that is being considered, play an important role in determining the most appropriate storage atmosphere.

Smith and Skog (1992) stated that a majority of strawberries were significantly firmer after two days' storage at 15% CO_2 than those stored in air. However, 4 out of 25 cultivars remained unaffected. The colour, sugar content and pH was not altered in any of the cultivars when kept at 15% carbon dioxide.

On the other hand, Holcroft and Kader (1999) reported that storage at 20% CO_2 greatly affected the colour and also affected the acidity. In general, sugar and acid content is reduced during storage. In atmospheres with enhanced CO_2 levels it has been observed that the degradation of acids proceed at a higher rate, which can result in an altered flavour experience.

In yet another study (Fernandez-Trujillo et al., 1999) it was indicated that storage at 20% carbon dioxide increased the firmness of strawberries while it also reduced the microbial decay. However, off-flavours, caused by acetaldehyde, ethanol and ethyl acetate, were detected in some of the strawberry cultivars included in the experiment. Other cultivars did not produce the fermentative metabolites in detectable amounts and the cultivars were therefore divided into CO_2-sensitive and CO_2-insensitive cultivars.

Other investigations have reported similar findings, where strawberries kept in atmospheres with elevated carbon dioxide concentrations produced off-flavours (Ke et al., 1991; Larsen & Watkins, 1995; Mawele Shamaila et al., 1992; Pelayo et al., 2003; Sanz et al., 1999; Ueda & Bai, 1993; Zhang & Watkins, 1998). Watkins, Manzano-Mendez, Nock, Zhang, and Maloney (1999) also suggested that this response was cultivar-dependent.

It has also been confirmed that carbon dioxide can have an inhibiting effect on mould growth and, hence, that mould attacks on strawberries can be delayed by MAP (Zhang & Watkins, 1998).

The objective of the present study was to elucidate how the two most important strawberry cultivars grown in Sweden, Honeoye and Korona, responded to storage in different atmospheres, considering a number of quality parameters, with special attention being paid to the flavour of the product.

2. Materials and methods

2.1. Raw material

Strawberries grown in Olofström, Sweden (cultivar Honeoye) and Bärby, Sweden (cultivar Korona) were harvested and immediately cooled to 2 °C. They were transported in air-conditioned vans to the laboratory the next morning. The strawberries were sorted to eliminate unripe and overripe berries as well as any samples with obvious defects.

2.2. Packaging material

Polypropylene bags, supplied by Amcor Flexibles, Ledbury, England, were used in the study. The bags had been laser treated to provide small holes, facilitating gas exchange between the packaging and the atmosphere. Two packaging materials were used, the difference between them being the number of holes and thereby their permeability. The properties of the bags are displayed in Table 1. The sealed bags had the dimensions 30 × 25 cm and the headspace volume inside the packages was approximately 1.6 L.

2.3. Experimental design

Fifteen strawberries, approximately 250 g, were accurately weighed and placed in a single layer in polypropylene trays. The trays were then inserted into the polypropylene bags described above. The bags were either heat-sealed immediately or flushed with a gas mixture prior to sealing. Samples that were not placed in a packaging

Table 1
Packaging conditions used in the study

Sample	Polymer	Thickness	Oxygen permeation rate (cc O_2/bag/day/atm)	Initial gas composition
A	Antimist coated oriented polypropylene	35 μm	1560	Air, that is 20.9% O_2 + 0% CO_2
B	Antimist coated oriented polypropylene	35 μm	1560	9.5% O_2 + 10.9% CO_2
C	Antimist coated oriented polypropylene	35 μm	6750	Air, that is 20.9% O_2 + 0% CO_2
D	Antimist coated oriented polypropylene	35 μm	6750	14.2% O_2 + 5.0% CO_2
E	No packaging			Air, that is 20.9% O_2 + 0% CO_2

were also prepared, that is they were kept in open trays. The different packages are described in Table 1. Honeoye strawberries were subjected to packaging conditions A, C and E, while the Korona cultivar were stored in all five packaging types, A, B, C, D and E. The samples were placed in a storage room at 5 °C and 75% relative humidity for 10 days.

2.4. Atmosphere

The concentration of oxygen and carbon dioxide inside the packages were monitored using an OxyBaby (HTK, Hamburg, Germany). Analyses were performed by inserting the test probe through a rubber seal (Toray Engineering Co. Ltd., Osaka, Japan) attached to the outside of the packaging. The instrument was calibrated towards air. Measurements were performed day 0, 1, 3, 7 and 10. The atmospheric composition was measured in three replicate packages at each sampling time.

2.5. Weight

The net weight of each sample was registered on day 0, 1, 3, 7 and 10. Three replicate packages were analysed.

2.6. Sugar

All 15 strawberries from each of two replicate packages were homogenised by a mixer for 15 seconds. The homogenate was used for analysing sugar and acid content as well as pH and colour. The Brix value of the homogenate was measured by a refractometer (Atago Co. Ltd., Tokyo, Japan). Five measurements were made on each sample on day 0, 3 and 7.

2.7. Acid

The total titratable acidity was evaluated by diluting the homogenate ten times in distilled water and then titrate the solution with 0.1 M NaOH to pH 8.0. Duplicate titrations were carried out on day 0, 3 and 7.

2.8. pH

The pH of the strawberry homogenate was analysed by a pH meter (Metrohm, Herisau, Switzerland) in duplicate measurements on day 0, 3 and 7.

2.9. Colour

The homogenate was poured into petri dishes and the colour was measured using a colour meter (Minolta Spectramatch, Tokyo, Japan). Triplicate samples were analysed and three measurements were made on each sample. Analyses were performed day 0, 3 and 7.

2.10. Mould

In order to study if the modified atmospheres had any inhibiting effects on mould growth on the strawberries, the samples were inoculated by *Botrytis cinerea* prior to sealing the packages. The development of moulds was followed during 10 days of storage. Duplicate samples were prepared. One of the two replicates was transferred from the cold storage room at 5 °C to ambient temperature, that is 23 °C, after day 7. The mould analysis was performed only for the Korona cultivar.

2.11. Aroma

Volatile compounds were collected from strawberries stored under the different packaging conditions on day 0, 3 and 7. Samples were taken from two packages of each packaging condition. The strawberries were divided into quarters and placed in 500 mL glass bottles that were sealed, 100 g going into each bottle. Each sample was allowed to equilibrate for 30 min at 35 °C. Subsequently 1000 mL of helium was fed through the bottle at a rate of 40 mL/min, and allowed to pass a Tenax trap (Tenax 60–80 mesh, 150 mg), where the volatiles were trapped. The sample collection was performed in duplicate.

The aroma compounds accumulated in the packages during storage were analysed on day 7. Samples were taken by withdrawing 100 mL from the headspace by a syringe and trapping the volatiles on a Tenax trap connected to the needle inserted into the packages.

The adsorbent tubes were transferred to an ATD 400 automatic injector (Perkin–Elmer, Norwalk, CT, USA) where the volatiles were desorbed for 5 min at 250 °C and subsequently injected into a gas chromatography–mass spectrometry (GC–MS) system. The gas chromatograph used was a ThermoQuest Trace GC 2000 (ThermoQuest CE Instruments, Milan, Italy) equipped with a 30 m × 0.32 mm capillary column with a 1.0 μm thick film of DB-1 (J&W Scientific Inc., Folsom, CA, USA). The mass spectrometer used was an Automass Solo (ThermoQuest). The initial temperature of the GC oven was 25 °C and it was kept at that temperature for 5 min. Subsequently, the temperature was raised by 4 °C/min until a final temperature of 180 °C was reached, then by 50 °C/min until 220 °C was reached, which was held for 15 min. Helium was used as a carrier gas at a flow rate of 3 mL/min. The identification and integration of the GC peaks was carried out using computer software Xcalibur™ (Thermoquest). The compounds were identified on the basis of their mass spectra. Quantification of the compounds was undertaken by the means of a response factor, that is the relationship between the external standard (nonane) and the volatile.

In order to identify and characterise the aroma compounds, of the greatest importance, to the flavour of strawberries, samples that were freshly harvested as well as those stored for three days were evaluated using GC-olfactometry (GC-O). The collection and desorption of volatiles was performed similarly as above. However, the effluent from the capillary column was split 1:1 between a flame ionisation detector (FID) and a sniffer-port. In the latter, the column effluent was mixed with humidified air in order to facilitate sensory evaluation. Each sample was evaluated by a trained assessor. The signal from the FID was split, so that the signal could be registered by a computer software Xcalibur™ (Thermoquest) and a printer. The assessor was instructed to describe the odour of each substance detected, as well as the intensity, on a scale from one to five, with five being the maximum, and to make a note beside the GC peak on the paper from the printer. The result was an aromagram used to select the impact compounds of strawberry aroma.

2.12. Sensory evaluation

A quantitative descriptive analysis was used to evaluate the sensory properties of each strawberry. The analyses were carried out on day 3 and 7 for each cultivar and were performed by an external, analytical panel (SIK, Gothenburg, Sweden) consisting of 8 assessors. The panel members were trained to evaluate smell, flavour, taste and texture attributes as well as the appearance of the strawberries in three training sessions. A number of sensory attributes were developed and described in words by comparing strawberries that had large differences in sensory quality. In the training, a reference sample of fresh strawberries was used. The sensory attributes and their definitions are presented in Table 2.

Table 2
Definition of the investigated sensory attributes

Sensory attribute	Definition
Total odour	Intensity of odour regardless of the character of the odour
Strawberry odour	Intensity of strawberry odour
Off-odour	Intensity of off-odours
Total flavour	Intensity of flavour regardless of the character of the flavour
Strawberry flavour	Intensity of strawberry flavour
Off-flavour	Intensity of off-flavours
Sweetness	Intensity of sweetness
Acidity	Intensity of acidity
Juiciness	Degree of juiciness
Firmness	Degree of firmness
Redness	Intensity of red colour
Lustre	Intensity of lustre

Each serving contained 4–5 strawberries, which were served at room temperature and each sample was evaluated in triplicate. For each sensory attribute the assessors were asked to make a mark on a 100 mm continuous line scale anchored with low intensity at 10 mm and high intensity at 90 mm. In the training, the assessors were also trained in how to use the scale. In addition, the panelists were asked to make comments on off-flavours or any other anomalies they experienced during the evaluation. A data collecting system, FIZZ network version 2.10A, was used and the results were subjected to statistical evaluation with Tukeys test.

Furthermore, the personnel preparing the samples, 3 persons, smelled the headspace that had developed inside the packages and that was released upon opening. On the basis of this smelling they provided a description of the odour.

3. Results and discussion

The results from each separate type of analysis are reported and discussed under its respective sub-heading. A general discussion is presented at the end of the section.

3.1. Atmosphere

Strawberries of the cultivar Honeoye were simply placed in the two packaging types, that is in air, prior to sealing. During the storage period of 10 days the produce respiration resulted in a modification of the internal atmospheres, see Fig. 1. According to the manufacturer, the packaging material used for sample C was roughly 4 times more permeable to oxygen than the material used for sample A. However, there were only minor differences in the atmospheric conditions developed inside the bags. Already after one day of storage, the oxygen content had fallen by 4–5% and the carbon dioxide levels had increased similarly. At the end point, after 10 days, the gas concentrations were 11.4% O_2 + 11.2% CO_2 and 13.7% O_2 + 9.2% CO_2 in samples A and C, respectively.

For the Korona variety the experiment was expanded and also included samples to which a gas mixture was introduced into the bags prior to sealing. This was done in order to see if keeping the strawberries in a fairly constant modified atmosphere from day 0, instead of having

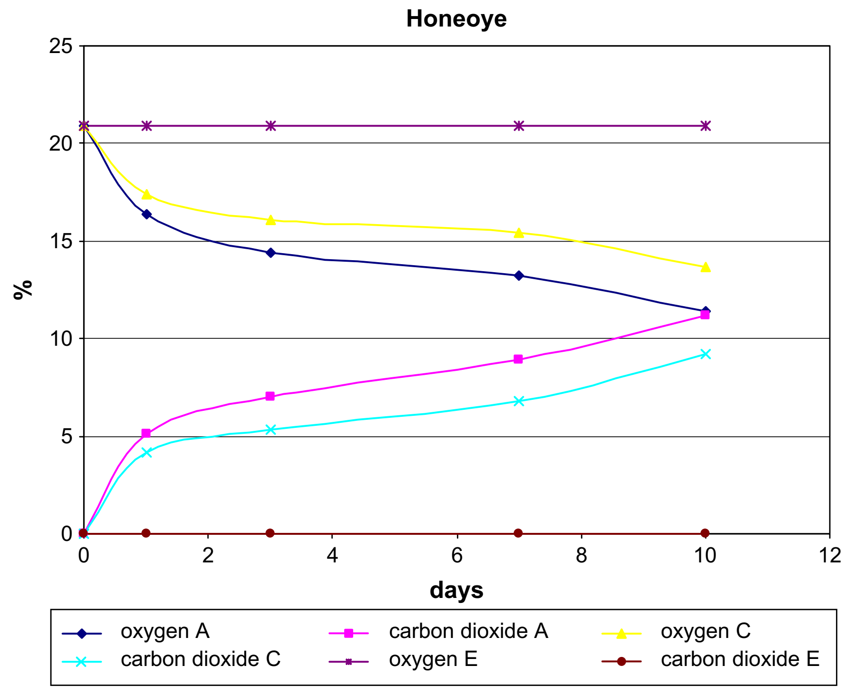

Fig. 1. Gas composition in packages containing Honeoye strawberries.

the modified atmosphere developing during storage, had any additional effect on the quality, be it positive or negative. Gas mixtures that were believed to have the same composition as expected at equilibrium were therefore flushed into the bags before sealing. For sample B that meant 9.5% O_2 and 10.9% CO_2 and for sample D 14.2% O_2 and 5.0% CO_2. The atmospheric changes during storage are displayed in Fig. 2. In sample B the oxygen levels increased slightly to 12.4% after 10 days while the carbon dioxide remained almost constant throughout the storage

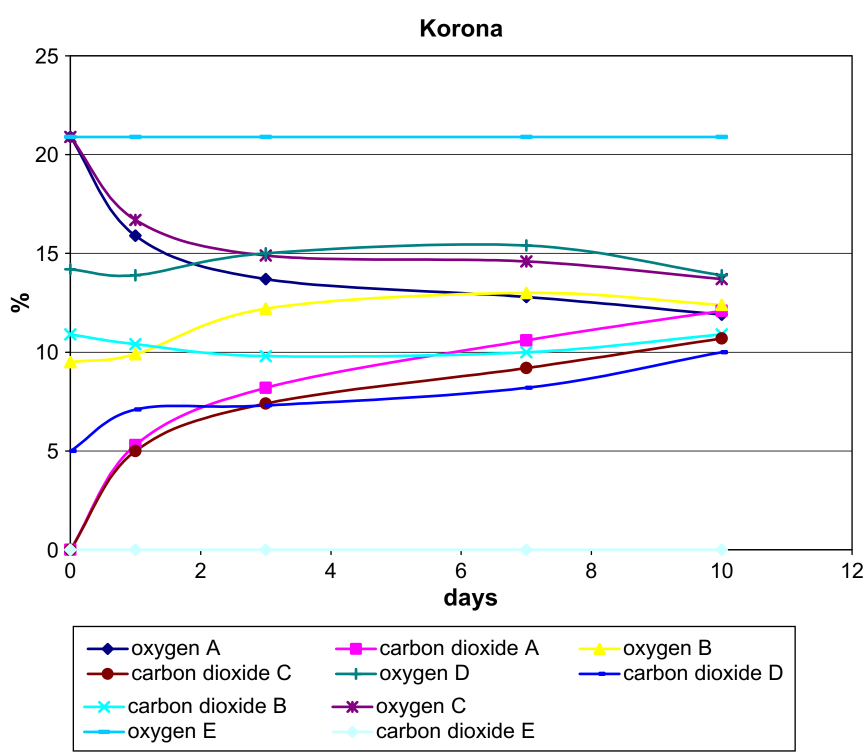

Fig. 2. Gas composition in packages containing Korona strawberries.

period. In sample D, on the other hand, the oxygen concentrations remained at around 14% during storage while the CO_2 level steadily increased until it had been doubled to 10% after 10 days. There were no significant differences in the obtained gas levels for samples A and C for the two cultivars, that is Honeoye and Korona exhibited similar respiration patterns.

The atmospheric compositions that were obtained in the study were well within the, admittedly broad, ranges that are recommended for strawberry storage that can be found in the literature. At no point during storage did the oxygen levels fall so low that anaerobic conditions threatened. Also, the carbon dioxide concentration did not exceed 12% at any given moment.

3.2. Weight

The packaged strawberries lost very little weight during storage, approximately 0.5%, regardless of cultivar and packaging type. The weight of the unpackaged samples, however, was greatly reduced. Already after the first day of storage they had lost 1.4–1.7% weight. The weight loss was as good as linear and at the end of storage, after 10 days, the weight of the Honeoye strawberries was reduced by 14.7% whereas the weight of the Korona cultivar decreased by 18.3%. The reason for the considerable loss is dehydration and could be somewhat alleviated by storage in a higher relative humidity. However, the conditions that were selected for this study were chosen in order to simulate real-life conditions during handling and distribution, and a relative humidity of 75% was therefore considered to be appropriate.

3.3. Sugar

The results from the sugar analyses are presented in Table 3. The initial sugar concentrations were 8.9% in Honeoye and 11.4% in Korona. During storage the sugar levels in all the packaged samples dropped slightly. This can be explained by sugars being consumed through respiration. The odd exception was Honeoye stored under packaging condition A, where the sugar concentration recovered to its original level between day 3 and day 7 – an observation to which no plausible explanation can be put forward. The minor rise in sugar concentration in the unpackaged Korona is probably due to water loss, that is the total amount of sugars did not increase but sugars made up a larger percentage of the weight as the strawberries became dehydrated.

3.4. Acid

The total titratable acidity (TTA) calculated as citric acid, which is the dominant acid in strawberries, for the different samples are displayed in Table 4. For both cultivars, the initial TTA value was 1.0%. The acidity in Korona was unaltered throughout storage while a slight increase could be detected in the Honeoye variety. However, there were no differences between the different packaging conditions.

3.5. pH

The pH of all the samples remained constant at 3.4 at all sampling times throughout the entire experimental period.

3.6. Colour

The colour of the homogenised samples were measured recording L value, chroma value and hue angle. The L value is a measure of the lightness of the sample, the chroma value describes its brightness while the hue angle represents a coordinate in a standardised colour space. The results are presented in Table 5. Honeoye strawberries were lighter (larger L value) after three days of storage than at the time of packaging. Another four days of storage resulted in the L values declining, almost back to the original values for samples A and E, while strawberries packaged under condition C remained lighter. Similar observations were made for the chroma value and the hue angle, indicating more vivid (larger chroma value) and less red (larger hue angle) strawberries after 3 days and close to the initial levels after 7 days storage for samples A and E. Again, sample C differed, as the chroma value and hue angle for Honeoye strawberries kept under this condition were slightly higher after 7 days than samples A and E.

The pattern repeated itself for the Korona cultivar as regards the lightness of the samples, that is an increase after 3 days before the levels became similar to their original levels after 7 days of storage. The chroma values also

Table 3
Sugar concentrations (Brix values) in strawberries

Cultivar	Packaging condition	Day 0	Day 3	Day 7
Honeoye	A	8.9	7.9	8.7
Honeoye	C	8.9	8.2	8.2
Honeoye	E	8.9	8.6	8.9
Korona	A	11.4	10.7	10.5
Korona	B	11.4	11.3	11.3
Korona	C	11.4	10.9	11.0
Korona	D	11.4	10.8	10.6
Korona	E	11.4	11.8	12.5

Table 4
Total titratable acidity (expressed as percent citric acid) in strawberries

Cultivar	Packaging condition	Day 0	Day 3	Day 7
Honeoye	A	1.05	1.36	1.24
Honeoye	C	1.05	1.31	1.23
Honeoye	E	1.05	1.35	1.28
Korona	A	0.98	0.96	1.02
Korona	B	0.98	0.99	0.93
Korona	C	0.98	0.99	0.93
Korona	D	0.98	0.98	0.97
Korona	E	0.98	1.00	1.07

Table 5
Colour of strawberries expressed as L value (*a*), chroma value (*b*) and hue angle (*c*)

Cultivar	Packaging condition	Day 0	Day 3	Day 7
(*a*)				
Honeoye	A	29.4	32.3	30.5
Honeoye	C	29.4	32.4	31.7
Honeoye	E	29.4	32.0	30.2
Korona	A	32.2	34.2	32.3
Korona	B	32.2	34.8	33.4
Korona	C	32.2	33.9	32.8
Korona	D	32.2	34.1	32.2
Korona	E	32.2	33.0	32.5
(*b*)				
Honeoye	A	21.3	26.4	22.6
Honeoye	C	21.3	25.6	22.4
Honeoye	E	21.3	26.4	23.9
Korona	A	24.5	26.5	23.6
Korona	B	24.5	25.6	23.4
Korona	C	24.5	25.8	23.5
Korona	D	24.5	25.5	22.1
Korona	E	24.5	24.5	23.5
(*c*)				
Honeoye	A	29.7	31.7	29.3
Honeoye	C	29.7	33.2	31.4
Honeoye	E	29.7	31.4	29.1
Korona	A	29.9	29.5	28.6
Korona	B	29.9	29.8	28.1
Korona	C	29.9	30.0	27.6
Korona	D	29.9	29.6	28.5
Korona	E	29.9	27.7	27.4

increased initially for all samples. However, they had dropped below the starting values at the end point of storage, especially sample D was less bright (lower chroma value). Korona strawberries became more red (lower hue angle) during the storage period, with the unpackaged sample, E, showing the largest difference.

3.7. Mould

Carbon dioxide can have an inhibiting effect on mould growth and experiments were therefore carried out to establish if the CO_2 levels obtained inside the packaging could prevent moulds from growing. The samples were inoculated with *Botrytis cinerea*, which is the most common mould appearing on strawberries but other moulds may have been naturally present. No mould growth was detected after 3 days of storage. After 7 days, however, spores and some mould growth was observed in all the packaged samples. There was no difference between packaging conditions A, B, C and D. The unpackaged samples were not attacked by mould. This was probably due to the dehydration of the samples resulting in such a low water activity that the moulds were not able to grow. Another 3 days storage at 5 °C led to further growth in the packaged samples. In addition to the mould that was inoculated on the strawberries, *Rhizopus* was also identified. After 7 days some samples were placed at ambient temperature. These samples were heavily attacked by mould growth after the transfer. This was also reflected in the atmospheric condition inside the packages. Carbon dioxide is produced during mould growth and in the samples kept at room temperature the gas composition changed from 10–15% O_2 and 7–12% CO_2 to 1–2% O_2 and 25–37% CO_2, within 3 days.

3.8. Aroma

Approximately 50 volatile substances were identified in the strawberries. The majority of the aroma compounds were present in both cultivars, albeit at very different levels. However, there were also some volatiles that were found in one variety but was not observed in detectable amounts in the other cultivar. By using olfactometry it was possible to determine the odour intensity and the characteristic of the odour of each aroma substance. On the basis of the results from these studies, selections of the most prominent odorous compounds for each variety were made. The aroma substances and a description of their odour are presented in Table 6.

The selected substances were quantified during storage in the different packaging conditions. Also, the production of three substances – that is acetaldehyde, acetone and ethyl acetate – known to be the result of fermentative metabolism, which might occur in produce kept in unfavourable atmospheres, were also followed during storage. The results from the analyses of Honeoye are displayed in Table 7.

There were only minor changes of the aroma composition in the Honeoye strawberries during storage. The small differences in the levels of the selected substances were unlikely to affect the aroma profile. The fermentative metabolites remained at low levels throughout the storage. Any difference between the different packaging conditions could not be observed.

Korona strawberries reacted in a different manner to modified atmosphere storage, as can be seen in Table 8.

Table 6
Aroma substances selected for quantification and a description of their odour

Aroma substance	Odour description
Acetaldehyde	Pungent, penetrating
Acetone	Sweet, pungent
Ethyl acetate	Ether-like, pineapple
Methyl butyrate	Apple
Dimethyl disulfide	Onion, cabbage
Ethyl butyrate	Fruity, pineapple
Butyl acetate	Fruity
1-Methyl-ethyl butyrate	Apple
2-Hexenal	Green, leaf
Heptanone	Banana
Methyl hexanoate	Ether-like, pineapple
Butyl butyrate	Fruity, pear
Ethyl hexanoate	Fruity
Hexyl acetate	Fruity, apricot

Table 7
Amount of selected volatiles (expressed as μg/L headspace over 100 g sample) in Honeoye strawberries

	Day 0	Day 3			Day 7		
		Packaging condition			Packaging condition		
Aroma substance		A	C	E	A	C	E
Acetaldehyde	0.40	0.76	0.20	0.43	0.61	0.60	1.2
Acetone	7.5	7.2	9.4	8.6	11	11	8.1
Ethyl acetate	0.26	0.78	0.60	0.65	1.4	1.1	0.67
Methyl butyrate	0.46	0.99	1.3	1.0	0.67	1.6	0.35
Dimethyl disulfide	0.02	0.04	0.09	0.07	0.12	0.06	0.02
Ethyl butyrate	0.18	0.43	0.57	0.32	0.25	0.18	0.28
Butyl acetate	1.6	4.7	6.5	5.8	5.0	4.6	5.3
2-Hexenal	0.12	0.16	0.09	0.10	0.08	0.07	0.09
Heptanone	0.31	0.85	0.95	0.74	1.2	0.88	0.71
Butyl butyrate	0.19	0.16	0.32	0.24	0.07	0.07	0.08
Ethyl hexanoate	0.25	0.22	0.32	0.28	0.23	0.11	0.26
Hexyl acetate	13	14	14	19	15	14	14

Table 8
Amount of selected volatiles (expressed as μg/L headspace over 100 g sample) in Korona strawberries

	Day 0	Day 3					Day 7				
		Packaging condition					Packaging condition				
Aroma substance		A	B	C	D	E	A	B	C	D	E
Acetaldehyde	0.29	0.89	0.88	0.99	0.53	0.67	0.39	0.50	0.50	0.19	1.6
Acetone	6.6	12	9.7	11	8.9	9.3	10	14	8.0	10	8.1
Ethyl acetate	2.8	15	57	3.1	45	3.0	68	251	168	175	13
Methyl butyrate	55	70	56	62	66	63	50	21	31	35	72
Dimethyl disulfide	0.41	0.36	0.35	0.47	0.48	0.57	0.61	0.20	0.22	0.28	0.58
Ethyl butyrate	8.6	56	51	30	67	45	35	160	220	131	138
Butyl acetate	2.1	6.6	4.5	5.5	11	5.3	3.3	8.0	4.8	9.2	6.2
1-Methyl-ethyl butyrate	5.0	11	5.8	12	8.3	14	8.4	44	22	8.8	14
Heptanone	0.41	0.53	0.25	0.59	0.42	1.0	0.26	0	0	0	0.82
Methyl hexanoate	3.0	4.8	3.2	3.4	4.9	4.9	3.7	2.2	4.7	3.4	9.5
Butyl butyrate	1.2	8.0	6.3	6.5	12	14	3.3	20	30	15	54
Ethyl hexanoate	1.1	5.0	3.8	4.1	7.1	7.1	1.6	10	15	7.7	27
Hexyl acetate	7.7	7.3	7.5	6.7	8.7	5.0	9.0	14	13	12	9.8

The amounts of most aroma compounds were considerably higher in Korona than in Honeoye strawberries. This finding was well in accordance with the general opinion that Korona is the tastier of the two cultivars. During storage the levels of some of the selected substances, for example the two esters ethyl butyrate and butyl butyrate, increased to a large extent. This held true both for packaged and unpackaged strawberries and is the result of the metabolism in the fruit tissue. The most interesting finding, however, was the production of ethyl acetate, that is one of the substances indicating that fermentative metabolism took place, in the packaged samples. The increase of ethyl acetate in unpackaged products was minor while the amounts increased almost hundred-fold in sample B after 7 days. In samples B and D – where the initial gas composition was modified from the time of packaging – the ethyl acetate levels had risen to approximately 20 times their original value after 3 days of storage, while the levels in samples A and C – initially containing air – were much lower. This indicated that the modified atmosphere affected the aroma production in an unwanted manner.

Analyses of the aroma compounds accumulated inside the packages during storage were also performed. The results for these measurements are displayed in Table 9.

Fewer substances were identified in the samples of the internal gas than in those that were performed on the strawberries. This was partly due to a lower sample volume and partly due to the sample preparation. However, it was still possible to distinguish the difference between the two varieties, that is that Korona contained much larger amounts of the aromas. The difference between packaging alternative B and D as opposed to A and C for Korona could be observed again, indicated by the ethyl acetate levels.

3.9. Sensory evaluation

The sensory analyses were performed to establish any sensorial differences between the different packaging conditions after 3 and 7 days of storage of the two strawberry varieties. Twelve attributes, see Table 2, were judged by the assessors. For half of the studied attributes – total

Table 9
Amount of selected volatiles (expressed as μg/L) in the headspace of strawberry packages on day 7

	Honeoye		Korona			
	Packaging condition		Packaging condition			
Aroma substance	A	C	A	B	C	D
Acetaldehyde	2.2	1.3	2.7	3.0	2.3	2.3
Acetone	17	16	14	20	24	17
Ethyl acetate	0.30	0.22	67	329	130	192
Methyl butyrate	nd	nd	13	11	27	14
Ethyl butyrate	0.030	0.021	13	70	70	50
Butyl acetate	0.50	0.52	0.91	3.9	4.0	3.5

nd = not detected.

smell, strawberry smell, off-odour, total taste, off-taste and juiciness – no significant differences were observed at any sampling time.

For Honeoye there were significant differences in the appearance of strawberries kept in the different packaging conditions. The unpackaged sample, E, had a higher value for red colour, that is it was darker red, than samples A and C after 3 and 7 days of storage. Furthermore, sample E had less lustre than the packaged strawberries. These differences can be observed in Fig. 3, where it is obvious that the packaged strawberries maintained their colour and lustre much better than the unpackaged samples. The unpackaged Honeoye strawberries were also regarded as less acidic and less firm than the packaged products.

The only significant sensorial difference in Korona after 3 days was sample A having lower values for the attribute red colour than sample E, that is in similarity with the observations for Honeoye. The reason that unpackaged samples were a darker shade of red than packaged samples in the sensory analyses but that this observation was not made in the colour measurements was that the sensory analyses were performed on whole fruits while the colour measurements were carried out using homogenised strawberries.

After 7 days a few more differences were observed for Korona. Samples A and B had more lustre than the unpackaged sample. Sample E had significantly higher values in strawberry taste and a higher sweetness than sample B while the unpackaged samples, E, were less firm than those stored under condition A and C.

Thus, there were no differences between the different packaging conditions A, B, C and D. The few significant differences that were observed were exclusively found between unpackaged and packaged strawberries. The differences were mainly in appearance but the firmness was also affected. Unpackaged strawberries were judged to be darker red, having less lustre and being less firm. The acidity was also lower in unpackaged samples, even if this difference was not statistically significant for Korona.

The two cultivars differed on some accounts. Korona had higher values for total smell, red colour and sweetness while Honeoye was considered to be more acidic and having more lustre. These observations were well in accordance with the findings from the sugar, acid and aroma analyses. The largest difference between the two varieties was, however, the considerably higher values for Korona in the off-odour attribute. The values for Korona were roughly 30 as opposed to 5 for Honeoye on the scale from 0 to 100 that the assessors utilised. This difference was also mirrored in the descriptions of the off-odour that the panelists offered for the two cultivars. Many more words were used to describe the off-odour in Korona, for example melon, plastic, cheese, petrol, manure, paper and packaging, than in Honeoye, for example melon, caramel, rubber and carton. The observed off-taste was not as strong as the off-odour. Off-taste in Korona was described by words such as water, solvent and metallic while water and metallic were used for Honeoye.

There were no differences in the perception of the odour assembled in the package headspace that was released

Fig. 3. Honeoye strawberries stored unpackaged (the 4 berries to the left) and packaged (the 4 berries to the right) for 7 days.

upon opening. However, there was a difference between samples of the two varieties. The odour released from the Honeoye packages was described by the following words; sweet, cream, strawberry, grass and pungent, while the Korona packages were considered to release odours reminiscing of sweet, sour, acetic acid, butanoic acid, marzipan, compost, musty, and chewing gum. In some cases the odour in the Korona packages was described as unpleasant.

3.10. General discussion

It was apparent that packaging could be used to maintain strawberry quality on a higher level during extended storage. The packaging material reduced weight loss by preventing dehydration and also helped maintain the appearance of the fruits. However, storage in a modified atmosphere affected the aroma development in Korona strawberries. Ethyl acetate, a substance that indicates fermentative metabolism, was produced in large amounts in packaged Korona, especially if the atmosphere was modified from day 0. This finding indicated that the altered gas composition induced the process that resulted in accumulation of ethyl acetate in the strawberry tissue. The aroma production in Honeoye was not affected in a similar manner. Previous studies (Fernandez-Trujillo et al., 1999) have reported that strawberry cultivars can be divided into such that are sensitive or insensitive to carbon dioxide exposure. The results from the present work indicated that Korona and Honeoye belong to the former and latter group, respectively.

Even if the aroma profile of Korona strawberries was affected during storage, it was not altered to such an extent that it caused significant changes with regard to the sensory attributes odour and taste, that is the strawberries still tasted and smelled the same way. A negative consequence was, however, that there were some indications that the trapped gas inside the packages that was released upon opening of Korona packages, in some cases, was considered to be unpleasant.

It is not reasonable to suggest that all strawberries being sold in the future should be packaged, not even the cultivars responding well to modified atmosphere treatment, as it is hardly of any use if the produce is sold within a day after harvest. Packaging of strawberries might, however, be a very attractive alternative for producers that for some reason are in need of a few more days shelf life, for example to facilitate longer transportation in order to expand the market or to minimise the costly picking at weekends that many producers experience.

4. Conclusions

Strawberries kept in modified atmosphere maintained their weight and appearance better than those that were unpackaged.

The fear that the altered atmosphere might disturb the aroma profile was unfounded for strawberries of the Honeoye variety.

Korona strawberries produced considerable amounts of ethyl acetate during storage. This did not, however, affect the smell and taste of the product, but an odour that could be described as mildly unpleasant developed inside the packaging and was released upon opening.

Packaging of strawberries is a viable alternative if there is a desire to extend their shelf life. However, it is essential to ensure that the cultivar in question responds well to modified atmosphere storage as it is evident that there can be large differences between cultivars, especially with regard to the aroma development.

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References

Day, B. P. F. (2001). Modified atmosphere packaging of fresh fruit and vegetables – an overview. *Acta Horticulturae, 553*(2), 585–590.

Farber, J. N., Harris, L. J., Parish, M. E., Beuchat, L. R., Suslow, T. V., Gorney, J. R., et al. (2003). Microbiological safety of controlled and modified atmosphere packaging of fresh and fresh-cut produce. *Comprehensive Review of Food Science and Food Safety, 2*(S1), 142–160.

Fernandez-Trujillo, J. P., Nock, J. F., & Watkins, C. B. (1999). Metabolic changes associated with strawberry cultivars with different tolerances to high carbon dioxide during storage. *HortScience, 34*(3), 537–538.

Gil, M. I., Holcroft, D. M., & Kader, A. A. (1997). Changes in anthocyanins and other polyphenols in response to carbon dioxide treatments. *Journal of Agricultural and Food Chemistry, 45*(5), 1662–1667.

Holcroft, D. M., & Kader, A. A. (1999). Controlled atmosphere-induced changes in pH and organic acid metabolism may affect colour of stored strawberry fruit. *Postharvest Biology and Technology, 17*(1), 19–32.

Kader, A. A. (1999). Fruit maturity, ripening and quality relationships. *Acta Horticulturae, 485*, 203–208.

Ke, D., Goldstein, L., O'Mahony, K., & Kader, A. A. (1991). Effects of short-term exposure to low O_2 and high CO_2 atmospheres on quality attributes of strawberries. *Journal of Food Science, 56*(1), 50–54.

Larsen, M., & Watkins, C. B. (1995). Firmness and concentrations of acetaldehyde, ethyl acetate and ethanol in strawberries stored in controlled and modified atmospheres. *Postharvest Biology and Technology, 5*(1–2), 39–50.

Mawele Shamaila, M., Powrie, W. D., & Skura, B. J. (1992). Analysis of volatile compounds from strawberry fruit stored under modified atmosphere packaging (MAP). *Journal of Food Science, 57*(5), 1173–1176.

Pelayo, C., Ebeler, S. E., & Kader, A. A. (2003). Postharvest life and flavour quality of three strawberry cultivars kept at 5 °C in air or air +20 kPa CO_2. *Postharvest Biology and Technology, 27*(2), 171–183.

Rooney, M. (2000). Active and intelligent packaging of fruit and vegetables. In B. P. F. Day, *Proceedings of the international conference of fresh-cut produce*, 1999 September 9–10, Chipping Campden, Gloucestershire (UK), Campden & Chorleywood Research Association.

Sanz, C., Perez, A. G., Olias, R., & Olias, J. M. (1999). Quality of strawberries packed with perforated polypropylene. *Journal of Food Science, 64*(4), 748–752.

Smith, R. B., & Skog, L. J. (1992). Postharvest carbon dioxide treatment enhances firmness of several cultivars of strawberry. *HortScience, 27*(5), 420–421.

Ueda, Y., & Bai, J. H. (1993). Effect of short-term exposure of elevated CO_2 on flesh firmness and ester production of strawberry. *Journal of the Japanese Society for Horticultural Science, 62*, 457–464.

Ulrich, D., Hoberg, E., Rapp, A., & Kecke, S. (1997). Analysis of strawberry flavour – discrimination of aroma types by analysis of volatile compounds. *Zeitschrift fur Lebensmittel-Untersuchung und-Forschung, 184*, 277–282.

Watkins, C. B., Manzano-Mendez, J. E., Nock, J. F., Zhang, J., & Maloney, K. E. (1999). Cultivar variation in response of strawberry fruit to high carbon dioxide treatments. *Journal of the Science of Food and Agriculture, 79*(6), 886–890.

Wszelaki, A. L., & Mitcham, E. J. (2000). Effects of superatmospheric oxygen on strawberry fruit quality and decay. *Postharvest Biology and Technology, 20*(2), 125–133.

Zabetakis, I., & Holden, M. A. (1997). Strawberry flavour: Analysis and biosynthesis. *Journal of the Science of Food and Agriculture, 74*(4), 421–434.

Zagory, D. (1997). Advances in modified atmosphere packaging (MAP) of fresh produce. *Perishables Handling Newsletter, 90*, 2–5.

Zhang, J. J., & Watkins, C. (1998). Molecular responses of strawberry fruit to high carbon dioxide. *HortScience, 33*(3), 516–517.