Mitteilungen Klosterneuburg 56 (2006): 157-165

Release of anaerobic metabolites from intact sweet cherries stored in low oxygen atmospheres

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Acetaldehyde and ethanol accumulated in the flesh of cherries and also permeated through the skin into the surrounding atmosphere. A permeability constant for both fermentation metabolites was calculated for the whole storage period. The permeability constant was 0.145 x 10^{-4} µg/kg/h for ethanol, and 20.9 x 10^{-4} µg/kg/h for acetaldehyde, after 33 days of storage in anaerobic conditions and following 19 days in cold storage with normal air. The levels of these metabolites in the cherry flesh after 33 days of storage were 2.21 mg/l for acetaldehyde and 1.58 mg/l for ethanol. For other treatments, such as ultra-low oxygen and controlled atmosphere, levels were about half these values. Fruit stored in 1.0% O_2 + 7.0% CO_2 had approximately identical ethanol levels to the ultra-low oxygen fruit and no additional effects of higher CO_2 levels on the fermentation metabolism were detected. High CO_2 levels in the atmosphere maintained fruit firmness more effectively than other treatments. Both the cultivars studied had better skin firmness, with the cultivar 'Vanda' superior to 'Van'. Off-flavours were detected only in the anaerobic treatments (O_2 < 1 %) with an undesirable taste and aroma being more pronounced in 'Van'.
Keywords: sweet cherry, storage, ethanol, acetaldehyde, firmness, off-flavour

Freisetzung anaerober Metaboliten aus unbeschädigten Süßkirschen unter LO-Lagerbedingungen. *Acetaldehyd und Ethanol wurden im Fruchtfleisch der Kirschen akkumuliert und diffundierten durch die Schale nach außen. Eine Permeabilitätskonstante für beide Gärungsmetaboliten wurde für die gesamte Lagerperiode berechnet. Die Permeabilitätskonstante betrug nach 33 Tagen Lagerung unter anaeroben Bedingungen und anschließender 19-tägiger Kühllagerung bei Normalatmosphäre 0.145 x 10^{-4} µg/kg/h für Ethanol und 20.9 x 10^{-4} µg/kg/h für Acetaldehyd. Die Gehalte dieser Metaboliten im Fruchtfleisch betrugen nach 33 Tagen Lagerung 2,21 mg/l für Acetaldehyd und 1,58 mg/l für Ethanol. Unter anderen Lagerbedingungen (ULO, CA) waren die Gehalte ungefähr halb so hoch. Früchte, die unter einer Atmosphäre von 1,0% O_2 + 7,0% CO_2 gelagert wurden, hatten ungefähr identische Ethanolgehalte wie die aus ULO-Lagerung, es wurden keine zusätzlichen Auswirkungen der höheren CO_2-Anteile auf die Gärungsmetaboliten festgestellt. Durch hohe CO_2-Anteile in der Atmosphäre blieb die Fruchtfleischfestigkeit besser erhalten als durch andere Lagerungsmethoden. Beide Sorten zeigten eine bessere Schalenfestigkeit, wobei die Sorte 'Vanda' der Sorte 'Van' überlegen war. Fehlgeschmack wurde nur bei den anaeroben Varianten (O_2 < 1 %) festgestellt, wobei unerwünschte Geschmackstöne und Aromen bei der Sorte 'Van' stärker ausgeprägt waren.*
Schlagwörter: Süßkirsche, Lagerung, Ethanol, Acetaldehyd, Festigkeit, Fehlgeschmack

La libération de métabolites anaérobies de cerises non endommagées dans des conditions de stockage LO. *L'acétaldéhyde et l'éthanol s'accumulent dans la pulpe de fruit des cerises et se diffusent vers l'extérieur à travers de la peau. Une constante de perméabilité a été calculée pour les deux métabolites de fermentation et pour toute la durée du stockage. Après 33 jours de stockage dans des conditions anaérobies et un stockage au frais subséquent pendant 19 jours dans une atmosphère standard, les constantes de perméabilité s'élevaient à 0,145 x 10^{-4} µg/kg/h pour l'éthanol*

et à 20,9 x 10^{-4} mg/kg/h pour l'acétaldéhyde. Après un stockage de 33 jours, la teneur de la pulpe en ces métabolites s'élevait à 2,21 mg/l d'acétaldéhyde et à 1,58 mg/l d'éthanole. Dans d'autres conditions de stockage (ULO, CA), les teneurs étaient d'environ la moitié. Les fruits stockés sousá une atmosphère de 1,0% O_2 + 7,0% CO_2 présentaient des teneurs en éthanol à peu près identiques à celles des fruits stockés dans des conditions ULO ; on n'a pas constaté d'autres effets des teneurs plus élevées en CO_2 sur les métabolites de fermentation. Grâce aux portions élevées de CO_2 dans l'atmosphère, le fermeté de la pulpe s'est mieux conservée que dans les autres conditions de stockage. Les deux variétés présentaient une meilleure fermeté de la peau, la variété 'Vanda' étant supérieure à la variété 'Van'. Un mauvais goût n'a été constaté que dans les variantes anaérobies (O_2 < 1 %), les nuances de goût et les arômes non désirés étant plus prononcés dans la variété 'Van'.
Mots clés : merise, stockage, éthanol, acétaldéhyde, fermeté, mauvais goût

Sweet cherry fruits deteriorate rapidly after harvest due to water loss, surface pitting, stem browning and decay. Cool storage of fruit retards respiration and ripening, negative changes in texture and colour and also moisture losses (Chen et al., 1981; Bernalte et al., 2003; Estia et al., 2002; Toivonen et al., 2004). Postharvest treatment with low O_2 and/or high CO_2 concentrations in sealed bags is an attractive alternative for controlling fungal decay, maintaining fruit quality and extending the postharvest life of fruit (Sekse, 1988; Meheriuk et al., 1997; Remon et al., 2003). Maintenance of fruit firmness is important for the fruit quality (Santerre et al., 1991; Mitcham et al., 1998). Atmospheres with decreased O_2 or increased CO_2 levels produce some differences in the ripening process, such as firmness, colour and gas production, depending on the particular gas composition. A knowledge of the lower oxygen limits is critical for controlling the production of fermentation metabolites. Extreme concentrations of both gases cause an accumulation of acetaldehyde and ethanol in fruit tissue. Furthermore a part of the ethanol can be converted into undesired ethyl acetate. The basic physiological action of these compounds, due to their important storage implications, have been extensively studied in the majority of stored fruits. The behaviour of sweet cherries during the ripening process, when stored under oxygen atmospheres with less than 1% was evaluated by measuring flesh metabolite concentrations (Tian et al., 2000; Tian et al., 2004; Spotts et al., 2002). The volatile metabolites diffused through the skin of the intact fruit and increased the concentration in the ambient atmosphere.

At relatively low concentrations, these volatiles in the fruit may be benefical for flavour development or as substrates for the biosynthesis of other characteristic aromas (Ke et al., 1994), but the accumulation of high levels of acetaldehyde, ethanol and ethyl acetate in the flesh of sweet cherries imparts off-flavours (Tian, 2004). Combinations of modern substance-enrichment and analytical techniques can be used to capture the small quantities of volatiles released from intact fruit. For instance trace compounds can be concentrated by sorption in a short column packed with a suitable sorbent, released by thermal desorption and purged into the gas chromatograph. An alternative is the complete trapping of trace compounds obtained from the parent material (intact fruit) in a sorbent (e.g. Tenax-GC®) without changing their original proportions (so-called conservation trapping) (Novák, 1988).

The objective of this research was to study the production and release of acetaldehyde and ethanol from intact sweet cherry fruit during storage at very low oxygen concentrations. Furthermore the effect on firmness and fruit quality was evaluated. The results were compared with other storage gas conditions: regular air (RA), ultra-low oxygen (ULO) and controlled atmosphere (CA).

Materials and methods

Plant material

Sweet cherries (*Prunus avium* cv. 'Van', 'Vanda') harvested at marketable maturity were obtained from a commercial orchard of Agro Stošíkovice on June 30 2004, and transported to the laboratory within 6 hours after harvest. Fruit of uniform size (25 to 27 mm in diameter), disease-free and without any other obvious defects were selected. Cherry fruits were assessed on the basis of a subjective estimation of fruit colour, taste, appearance of stem and size.

Storage conditions

The next day the fruit was put into gas containers and held under special gas mixture conditions for 33 days

in hermetically sealed chambers with a volume of 450 litres.

Gas storage variants:
Var. 1: Ultra-low oxygen (ULO) storage: 1.0 to 1.2% O_2 and 1.0 to 1.4% CO_2
Var. 2: Anaerobic (AN) storage: 0.1 to 0.2% O_2 and 0.8 to 1.0 %CO_2
Var. 3 : Controlled atmosphere (CA) storage: 1.0 to 1.4% O_2 and 6.6 to 7.0% CO_2
Var. 4 : Regular (normal) air (RA): 21% O_2 and 0.03% CO_2
Preparation of atmospheres: Immediately after cooling, the final atmosphere composition was obtained by flushing the chambers with nitrogen. To eliminate the possible influence of excessive CO_2 as a respiration inhibitor, the chambers were connected with absorption tubes filled with solid tablets of KOH, which were mixed with an inert material (polystyrene). The composition of the gas mixtures were monitored using a dual CO_2/O_2 analyser (Arelco, ARC, France), and were adjusted twice a day.
All variants were exposed to a subsequent cold storage period (equivalent to a shelf-life period) for 20 days at 3.0 to 3.3 °C with regular (normal) air.

Determination of ethanol and acetaldehyde released from intact fruit

The following analytical method was developed for the quantification of the volatile compounds diffusing through the skin of sweet cherry fruit. About 0.120 kg (W) of fruit were immediately transferred from the cool storage room to a hermetically sealed, spherical jar, with a volume of about 0.5 l at a temperature of 20 °C. The volatile compounds released from the fruit were washed out by a stream of gas percolating at a flow rate of 30 ml/min (F) and then trapped in a concentrating column with Tenax-GC® as a sorbent. After one hour, the incoming flow in the concentration column had created a total volume (V) of three litres. The compounds deposited in the Tenax-GC® trap were recovered by thermal desorption (Scientific Instrument Services, Inc., Ringoes, NJ, USA) and transferred to gas chromatographic (GC) columns using a stream of carrier gas (He). A gas chromatograph with FID (4890D; Agilent Technologies, Inc. Wilmington, USA) was employed. Substances were separated on a fused silica capillary GC column (30 m x 0.25 mm; I.D., 0.25 µm; J & W Scientific). The GC column was kept at 35 °C for four minutes and then the temperature was raised by 3 °C/min. to 200 °C. The inlet port and detector were kept at 250 °C. The pressure of the carrier gas He, H_2 and air was 270 kPa, 120 kPa and 270 kPa, respectively. The peak areas were processed by a data station (CSW 1.7).

The concentration of analysed compounds in the percolating gas (c_i) is given by following equations (1,2):

$$c_i = (A_i/A_s)c_s v_{(s)}/V \quad [\mu g/l] \quad (1)$$

where

A_i peak area of analysed compound i [mV.s]
A_s peak area of standard for compound i [mV.s]
c_s concentration of standard calibration material (defined i-compound solutions) [µg/µl]
$v_{(s)}$ dosed volume of calibration material [µl]
V volume of in-flowing gas passing over the concentrating column [l]

The production, G_i , of the given compounds is expressed as a function of the velocity of the percolating gas, (F - [l/h]), and weight of fruit (W- [kg]) placed in the spherical jar.

$$G_i = c_i F/W \quad [\mu g/kg/h] \quad (2)$$

Ethanol and acetaldehyde determined in the fruit flesh

After the storage experiments the cherries were temporarily stored in a freezer and then defrosted prior to analysis. The juice produced was filtered (25 mm diameter syringe filter, 0.2 µm nylon with glass Alltech Associates Inc., Belgium). 1 µl aqueous samples were injected into a sample block fitted with Teflon and analysed with a gas chromatograph equipped with a FID (Chrom 5, Laboratory Equipment, Prague). Separation was achieved on a packed column (Porapak P, 3 mm i.d., 120 cm length), gas flow rates were 50 ml/min for H_2, 12 ml/min for He and 300 ml/min for air respectively. The column was maintained at a temperature of 92 °C. Peaks of ethanol and acetaldehyde were quantified using commercial standards and expressed in mg/l.

Firmness measurement

Skin and flesh firmness of the intact fruit were measured using a universal testing machine (Texan 2000, constructed at Mendel University, Brno) which recorded

the degree of compression and rate of loading. The testing machine was equipped with a load cell of 30 kPa. A steel plunger with a diameter of 5 mm was pressed into the fruit at a rate of 8 mm per minute and the resulting force-deformation curve was plotted by an x-y recorder connected to the software program. The break in the curve indicates the puncture point at which the plunger breaks the skin (skin firmness) and the sudden decrease in force measures flesh firmness. The area under the deformation curve is a measure of the compactness of the fruit (the work of compression done by loading to the rupture point).

Assesment of quality of fruit

For the sensory tests, the cherry samples were evaluated at room temperature in duplicate by a panel of 12 judges. The quality of the fruit was assessed by a visual evaluation of stem browning, berry browning and shrivelling, as well as taste, and freshness and marketability. These parameters were evaluated on a scale from 1 to 9, where 1 means a very poor and 9 a very good quality. Off-flavour was simply assessed as being present or absent (detectable or undetectable).

Statistical analysis

The experiment was analysed as a completely random design with storage duration and storage treatments as factors for the ANOVA. Mean comparisons were carried out by Tukey's multiple range test.

Results and discussion

Measurement of a permeability constant

When acetaldehyde and ethanol accumulate in the flesh of fruit only a part of the gas is released through the skin into the ambient atmosphere. Analyzing this atmosphere provides a method of indirectly analysing the intact fruit, since the release of volatiles through the skin depends on the different concentrations inside and outside the fruit.

In equilibrium, the intensity of gas transport is apparently dependent on the production rate, as a consequence of enzymatic processes and spontaneous chemical reactions, and the concentration of the substances in the cell structure. When the flow rate of a percolating gas over intact fruit is constant, the concentration of volatiles in the percolating gas is proportional to the production rate of the gas. Intact sweet cherries are regarded as being a source of volatiles which have a resistance to moving into the ambient atmosphere, compared to the same movement from a simple liquid phase. (Compared to simple liquid phases the transport of volatile compounds from the inside of intact cherries out into the ambient atmosphere is strongly reduced (Equation 3).

$$G_i = c_i F/W = c_i^L - c_i / R \quad (3)$$

G_i production rate of i-compound [µg/kg/h]
c_i concentration of i-compound in percolating gas [µg/l]
F volume rate in percolating gas [ml/h]
W weight of sample in spherical jar [kg]
c_i^L concentration of i-compounds in flesh of fruit [µg/l]
R resistance

The relation of the permeability constant (k) to the tissue resistance is expressed in Equation 4.

$$k = ci/ (c_i^L - c_i) (F/W) \quad [\mu g/kg/h] \quad (4)$$

Enrichment of the ambient atmosphere with fermentation volatiles

The production of acetaldehyde and ethanol in the flesh of fruit which is stored under anaerobic conditions increases continuously from the time of harvest to the end of storage. The permeability constants (Equation 4) for both fermentation metabolites have an approximately uniform value throughout the whole storage period (Table 1). The values of acetaldehyde are about two orders of magnitude higher than ethanol values (Table 1). During the whole period of storage, including the full anaerobic phase and the subsequent cold storage period with ventilation of air, the permeability constants were for ethanol in the range from 0.130×10^{-4} to 0.145×10^{-4} µg/kg/h and for acetaldehyde from 20.9×10^{-4} to 34.3×10^{-4} µg/kg/h, in spite of the concentrations analysed

Table 1: Permeable constant of intact sweet cherry cv. 'Van' expressed as µg/kg/h during the whole storage time for acetaldehyde (Act) and ethanol (EtOH)

Time (days)	EtOH	Act
0	$0.022.10^{-4}$	$5.4.10^{-4}$
11	$0.145.10^{-4}$	$34.3.10^{-4}$
22	$0.130.10^{-4}$	$32.6.10^{-4}$
33	$0.145.10^{-4}$	$20.9.10^{-4}$

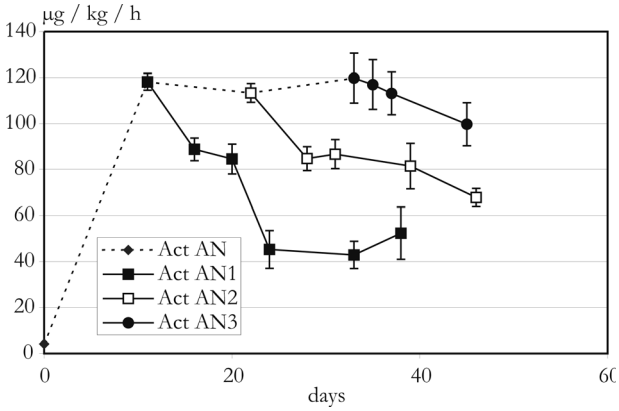

Fig. 1: Acetaldehyde volatiles expresed as production (µg/kg/h) released across skin of intact fruit stored at AN condition (0.1 - 0.2 % O_2 and 0.8 - 1.0 % CO_2). After 11 (AN1), 22 (AN2) and 33 (AN3) days were a part fruit tranfered in air atmosphere and futher stored at 3.0 - 3.3°C. Each point is the mean of 5 repetitions. Vertical bars indicate standard error

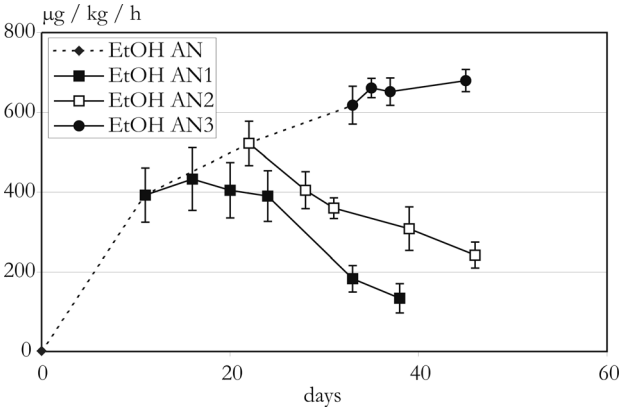

Fig. 2: Ethanol volatiles expresed as production (µg/kg/h) released across skin of intact fruit stored at AN condition (0.1 - 0.2 % O_2 and 0.8 - 1.0 % CO_2). After 11 (AN1), 22 (AN2) and 33 (AN3) days were a part fruit tranfered in air atmosphere and futher stored at 3.0 - 3.3°C. Each point is the mean of 5 repetitions. Vertical bars indicate standard error

in the flesh being very different. The permeability constants were lowest at the start of the storage period, coinciding with the start of anaerobic processes, when the concentration of both compounds was also very low in the fruit. After 33 days of storage under anaerobic conditions the concentration of acetaldehyde reached 2.21 mg/l in fruit of 'Van' (Fig. 3), but the concentration of ethanol at the same time and in the same cultivar was 1.580 mg/l (Fig. 6). After the subsequent exposure of fruit to normal air conditions, concentration of both metabolites in the flesh decreased due to diffusion through the skin into the surrounding atmosphere and enzymatic oxidation leading to the production of CO_2 and H_2O.

This reduction of ethanol and acetaldehyde by oxidation, diffusion out of the fruit and dissipation of the ester, which is sufficiently volatile to evaporate into the surrounding atmosphere, has already been mentioned by MATTHEIS et al. (1991). The reduction of ethanol in the flesh, however, never reaches a concentration of zero (Fig. 1 and 2).

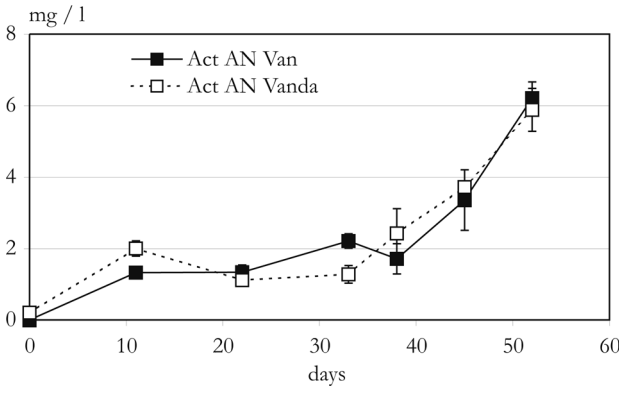

Fig. 3 :Changes over time in acetaldehyde (Act) concentration in pulp of cv. 'Vanda' and 'Van' sweet cherries,exposed to AN (0.1% O_2 and 0.5% CO_2). Each point is the mean of 6 repetitions. Vertical bars indicate standard error

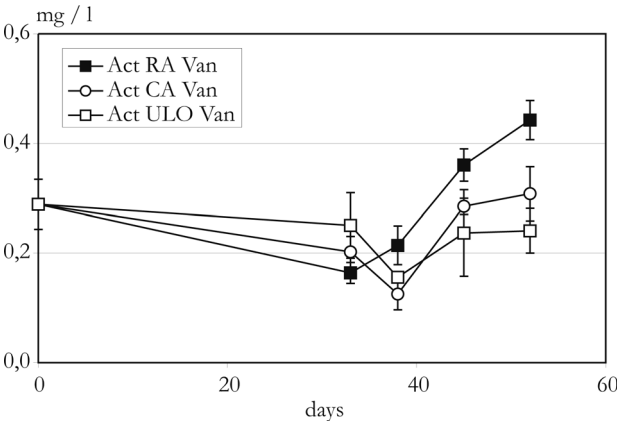

Fig. 4 :Effect of O_2 level on the acetaldehyde (Act) in pulp of cv.'Van' by RA (regular atmosphere 21% O_2 and 0.03% CO_2), CA (1.0 - 1.4 % O_2 and 6.6-7.0 % CO_2) and ULO (1.0 - 1.2 % O_2 and 1.0 - 1.4 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 6 repetitions. Vertical bars indicate standard error

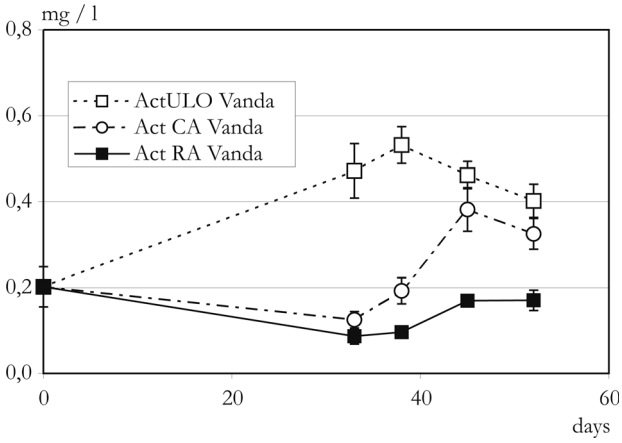

Fig. 5 :Effect of O_2 level on the acetaldehyde (Act) in pulp of cv.'Vanda' by RA (21% O_2 and 0.03% CO_2), CA (1.0 - 1.4 % O_2 and 6.6 - 7.0 % CO_2) and ULO (1.0 - 1.2 % O_2 and 1.0 - 1.4 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 6 repetitions. Vertical bars indicate standard error

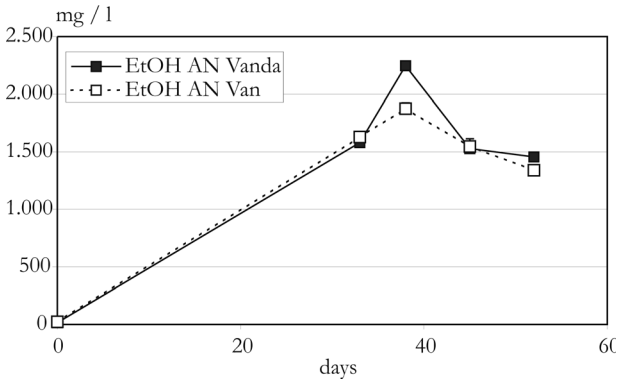

Fig. 6 :Effect of O_2 level on the ethanol (EtOH) in pulp of cv.'Vanda' and 'Van' by AN (0.1 - 0.2 % O_2 and 0.8 - 1.0 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 6 repetitions. Vertical bars indicate standard error

Acetaldehyde concentration in stored sweet cherries

Acetaldehyde can be already detected in fruit at harvest, being 0.20 mg/l and 0.28 mg/l for 'Van' and 'Vanda', respectively. During storage under anaerobic conditions the acetaldehyde level increases. Gas composition with oxygen levels below 1% caused a significant accumulation of acetaldehyde (and ethanol) in sweet cherries (Fig. 3), producing nearly constant values at the end of the storage period. Acetaldehyde and ethanol were formed in regular air-stored fruit (RA) after 33 to 52 days being an indication of over-ripeness. The physiological responses of both cultivars under anaerobic conditions (AN) were identical. In the other atmospheres (ULO, CA) the acetaldehyde content was about one order lower compared to those seen under anaerobic conditions (Fig. 4 and 5). The response of fruit under ultra-low oxygen conditions (ULO, Var. 1) was higher for 'Vanda' than for 'Van'. Acetaldehyde probably accumulates because the oxygen levels were lowered to the limit of aerobic respiration. The present results show that ethanol may be regarded as the more important volatile compound arising from fermentation processes, since acetaldehyde occurs at very much lower concentrations.

Ethanol concentration in stored sweet cherry fruit

The ethanol concentration of sweet cherry fruit increased rapidly from 14 mg/l for 'Vanda' and 23 mg/l for 'Van' at harvest time, to 1580 mg/l and 1628 mg/l, respectively, after 33 days of storage under anaerobic conditions (AN, Var. 2) (Fig. 6). The subsequent cold storage period with air ventilation demonstrated the slightly reduced ability of the fruit flesh to reduce the ethanol which was already formed. The residual values probably reflect the long period with a complete absence of oxygen. The ethanol content of both 'Van' and 'Vanda' cherries under ULO and CA treatments appeared to decline equally fast after the end of the 33 day storage, while under RA treatment this metabolite continued to decline after harvest to the lowest values (Fig. 7 and 8). During the subsequent storage period at 21 °C (equivalent to shelf-life temperature) a fast reduction of ethanol takes place, falling to a zero concentration in fruit which was earlier exposed to high CO_2 levels, partly by direct oxidation and partly by the production of esters (Mattheis et al., 1997).

Fruit stored under controlled atmosphere (CA) had approximately identical ethanol levels as fruit which were stored under ULO and no additional effects of the higher CO_2-levels on the fermentative metabolism were detected. However, it was previously found, that concentrations of CO_2 higher than 7% in the ambient atmosphere have harmful effects on fruit quality (Goliáš et al., 2006) of sweet cherry fruit.

Firmness of sweet cherries in gas mixtures

The skin firmness of the fruit stored under the high humidity of the hermetically-sealed containers with various storage conditions (ULO, CA, RA and AN) did

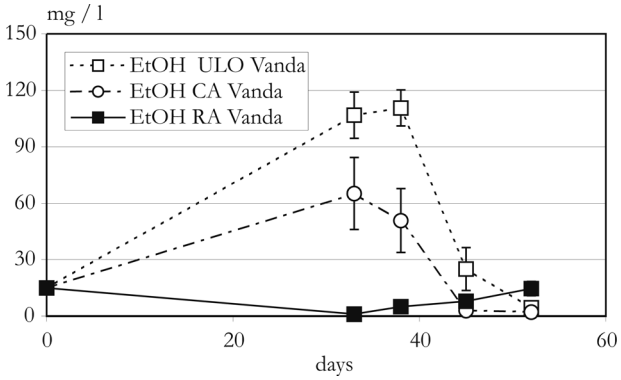

Fig.7 :Effect of O_2 level on the ethanol (EtOH) in pulp of cv.'Vanda' and 'Van' by RA (21% O_2 and 0.03% CO_2), CA (1.0 - 1.4 % O_2 and 6.6 - 7.0 % CO_2) and ULO (1.0 - 1.2 % O_2 and 1.0 - 1.4 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 6 repetitions. Vertical bars indicate standard error

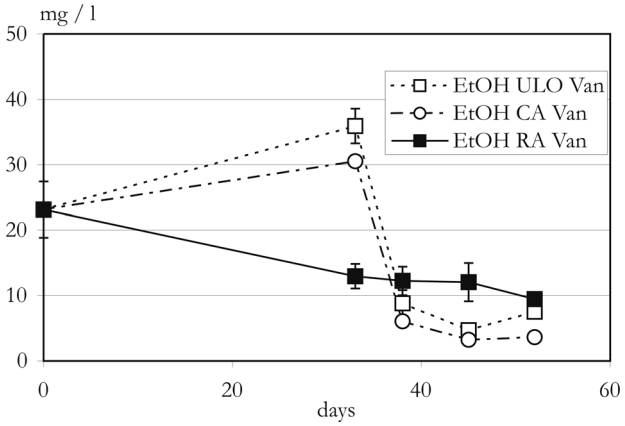

Fig.8 :Effect of O_2 level on the ethanol (EtOH) in pulp of cv. 'Van' by RA (21% O_2 and 0.03% CO_2), CA (1.0 - 1.4 % O_2 and 6.6 - 7.0 % CO_2) and ULO (1.0 - 1.2 % O_2 and 1.0 - 1.4 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 6 repetitions. Vertical bars indicate standard error

not change (Fig. 9 to 11). During the cold-room storage phase at the same temperature, skin and flesh firmness steadily increased. The reason for higher firmness values was the evaporation of moisture from the surface layers of the intact fruit. The values for skin firmness increased much more significantly than those for flesh firmness (Table 2). High CO_2 levels (CA storage) more effectively maintained fruit firmness than did other treatments. The fruit of 'Vanda' had firmer skin than from 'Van' (Fig. 9).

Evaluation of fruit quality

Increased stem browning was the quality characteristic affected the most by low humidity and loss of chlorophyll under RA conditions (Table 3). At the end of the gas mixture storage phase, all treatments, with the exception of RA storage, had stems with a good green co-

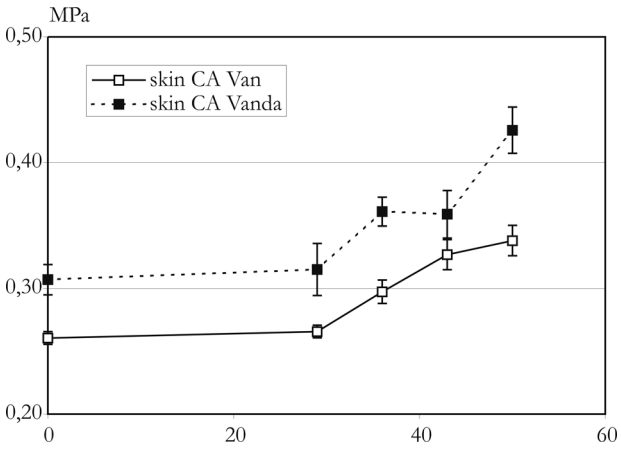

Fig. 9 :Changes over time in skin firmness of cv. 'Vanda' and 'Van' sweet cherries when exposed to CA (1.0 - 1.4 % O_2 and 6.6 - 7.0 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 12 repetitions. Vertical bars indicate standard error

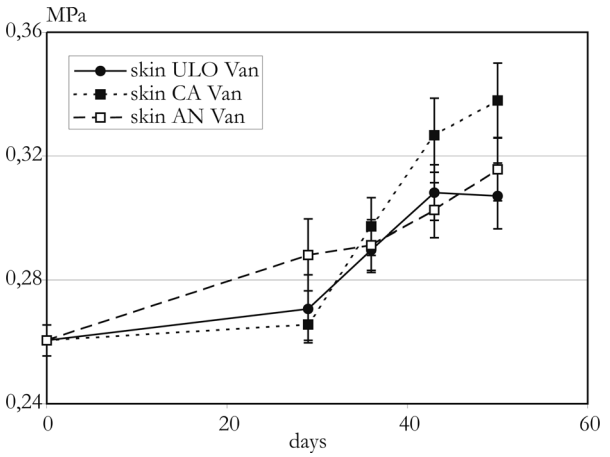

Fig.10 :Changes over time in skin firmness of cv.'Van' sweet cherries when exposed to AN (0.1 - 0.2 % O_2 and 0.8 - 1.0 % CO_2), CA (1.0 - 1.4 % O_2 and 6.6 - 7.0 % CO_2) and ULO (1.0 - 1.2 % O_2 and 1.0 - 1.4 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 6 repetitions. Vertical bars indicate standard error

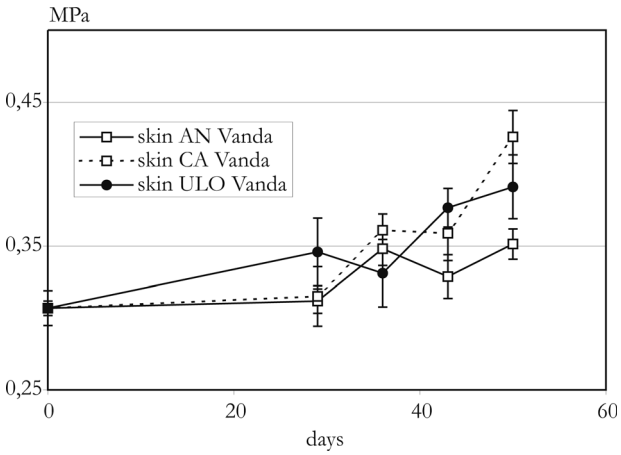

Fig.11 :Changes over time in skin firmness of cv.'Vanda' sweet cherries when exposed to AN (0.1 - 0.2 % O_2 and 0.8 - 1.0 % CO_2), CA (1.0 - 1.4 % O_2 and 6.6 - 7.0 % CO_2) and ULO (1.0 - 1.2 % O_2 and 1.0 - 1.4 % CO_2 at 3.0 - 3.3°C) for 52 days. Each point is the mean of 6 repetitions. Vertical bars indicate standard error

Table 2: Firmness analysis of sweet cherry cultivars 'Vanda' and 'Van'[+)]

Assessed attribute	Skin	Flesh	Toughness
Treatment	**	ns	**
Cultivar	**	ns	**
Time	**	ns	**
Cultivar x treatment	ns	*	ns
Cultivar x time	**	ns	*
Treatment x time	*	*	ns
Cultivar x treatment x time	*	ns	*

[+)] Values are means and standard errors calculated from twenty sweet cherries fruit subjected to treatment RA, ULO, CA, and AN

ANOVA: ** P< 0.01, * P<0.05, ns = not significant

lour which were not shriveled, and this was maintained up to the middle of the cold-storage phase, i.e. for about 45 days of storage. Overall acceptability, like the other sensory parameters, did not significantly change during cold storage. The percentage of rotten fruit was lowest in the AN variant and relatively low in the ULO variant. From these results it can be concluded that the quality of 'Vanda' sweet cherry fruit is maintained during shelf-life storage, but the overall sensory evaluation of all parameters showed a slight decrease in quality during storage for 52 days. From a sensory point of view, overall acceptability depended mainly on the appearance of the cherry stem, followed by the fruit appearance and then freshness.

Off-flavours in stored sweet cherry fruit

The large increases of fermentation volatiles during storage under low O_2 and/or very high CO_2 atmospheres may be detrimental to fruit quality since higher concentrations of these volatiles may cause off-flavours. However, at relatively low concentrations these volatiles may be benefical to flavour development (Ke et al., 1994; Larsen and Watkins, 1995). In this study off-flavours were observed in the AN treatment of both cultivars (Table 3), but were more pronounced in fruit of 'Van' than in 'Vanda'. Only three days after aeration, the fruit that was stored under AN conditions developed characteristic off-flavours, with a marked medicinal flavour and taste. No undesirable appearance or off-flavours were detected in the high CO_2 (CA) treatment or ULO treatment.

Acknowledgements
This research was supported by the Ministry of Agriculture of the Czech Republic, Grant No. QD 1047.

Table 3 :Evaluation of sensory quality of sweet cherry cultivars 'Van' and 'Vanda'*

		Taste	Appearance of stem	Appearance of fruit	Freshness	Off-flavour	Marketing
Van	RA	5.7 a	2.9 a	4.4 a	4.1 a	9.0 b	1.1 a
	AN	5.1 a	4.3 ab	7.4 b	7.0 b	1.0 a	7.3 b
	ULO	7.5 b	5.2 bc	6.2 b	6.8 b	9.0 b	7.7 b
	CA	7.6 b	6.0 c	7.3 b	7.5 b	7.9 b	7.3 b
Vanda	RA	6.8 a	3.8 a	5.0 a	5.4 a	8.4 a	3.9 a
	AN	5.5 a	4.2 a	7.2 b	7.2 b	3.9 b	6.7 ab
	ULO	6.8 a	6.6 b	7.2 b	7.1 b	7.9 a	8.4 b
	CA	7.2 a	7.6 b	7.2 b	7.3 b	8.4 a	9.0 b

* Tukey HSD test; differences between treatment are signed by common letters

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Received July 7, 2006