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Effect of low oxygen and anaerobic conditions as post-harvest treatment on the quality of sweet cherry fruit [1)]

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*The effect of different storage conditions on the development of anaerobic metabolites and sugars and acids as well was investigated with sweet cherry fruit (*Prunus avium L.*). Three sweet cherry cultivars ('Karešova', 'Kordia' and 'Vanda') were stored in ultra-low oxygen (ULO = 0.9 % O_2, 0.3 % CO_2), anaerobic conditions (AN = 0.2 % O_2, 0.3 % CO_2) and regular atmosphere (RA = 21 % O_2, 0.03 % CO_2), respectively. Afterwards juices were produced and analysed. The effect of anaerobic conditions caused a remarkable production of ethanol, which reached 560 to 750 mg/l within just 16 days. Exposing the fruit from ULO and AN to air resulted in a decrease of ethanol of one third after 30 days, but ethanol contents were still higher than in fruit stored under RA conditions. The different gas mixtures caused only small variations in the ethanal content with a range from 2 to 16 mg/l for all treatments, the highest value was found in 'Karešova' fruit. At an informal tasting carried out during fruit quality evaluation, no noticeable off-flavour was detected in the fruit, not even in the fruit from anaerobic conditions. The effects of treatment and storage time onto firmness of skin and flesh were studied by means of the Anova test. Decrease of firmness was not significantly affected by the oxygen content in the different storage atmospheres and results were comparable for ULO and AN treatment. Only minimal differences were detected between ULO and RA with sucrose, glucose and fructose. In fruit of all cultivars a statistically significant degradation of acids (citric acid and malic acid) occurred; gas mixture of storage and subsequent aerating phase had an influence on acid concentration.*
Key words: Sweet cherries (*Prunus avium L.*), low oxygen storage, anaerobic conditions, ethanol, ethanal, firmness, sugars, acids

Einfluss von sauerstoffreduzierten und anaeroben Lagerbedingungen auf die Qualität von Süßkirschen. *Der Einfluss unterschiedlicher Lagerbedingungen auf die Entwicklung von anaeroben Metaboliten ebenso wie auf Zucker bzw. Säuren bei Süßkirschen (*Prunus avium L.*) wurde untersucht. Früchte von drei Süßkirschensorten ('Karešova', 'Kordia' und 'Vanda') wurden unter ULO-Lagerbedingungen (ULO = 0.9 % O_2, 0.3 % CO_2), anaeroben Bedingungen (AN = 0.2 % O_2, 0.3 % CO_2) und unter Normalatmosphäre (RA = 21 % O_2, 0.03 % CO_2) gelagert. Anschließend wurden aus den Früchten Säfte hergestellt und analysiert. AN-Bedingungen bewirkten beträchtliche Ethanolgehalte, welche innerhalb von nur 16 Tagen 560 bis 750 mg/l erreichten. Wurden die Früchte aus ULO- bzw. AN-Bedingungen wieder in Normalatmosphäre gebracht, sanken die Ethanolgehalte innerhalb von 30 Tagen um ein Drittel, waren aber immer noch höher als in Früchten aus RA-Lagerbedingungen. Die unterschiedlichen Gasmischungen verursachten nur geringe Unterschiede in den Ethanalgehalten (2 bis 16 mg/l für alle Varianten), die höchsten Gehalte zeigte die Sorte 'Karešova'. Bei informellen Verkostungen wurden keine Fehlgeschmäcker festgestellt, auch nicht bei Früchten aus AN-Lagerbedingungen. Die Einflüsse von Lagerbedingungen und Lagerdauer auf Schalen- und Fruchtfleischfestigkeit wurden mittels Anova-Test untersucht. Minderungen der Festigkeit wurden nicht signifikant durch die Sauerstoffgehalte der unterschiedlichen Lageratmosphären beeinflusst und waren für ULO und AN vergleichbar. Nur minimale Unterschiede zwischen ULO und RA wurden bei den Gehalten an Suc-*

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rose, Glucose und Fructose festgestellt. Bei allen Sorten gab es statistisch signifikante Säureabnahmen (Zitronen- und Äpfelsäure), die Gaszusammensetzung der Lagerphase und der folgenden Belüftungsphase beeinflussten die Säurekonzentration.
Schlagwörter: Süßkirsche (*Prunus avium* L.), CA-Lagerung, ULO-Lagerung, Fruchtfleischfestigkeit, Ethanol, Ethanal, Zucker, Säuren

L'influence des conditions réduites en oxygène et anaérobies sur la qualité des cerises douces après la récolte. *L'influence des différentes conditions de stockage sur le développement de métabolites anaérobies, de sucres et d'acides dans des cerises douces (*Prunus avium L.*) a été examinée. Trois variétés de cerises douces ('Karešova', 'Kordia' et 'Vanda') ont été stockées dans des conditions de type ultra-low oxygen (= ULO; 0.9 % O_2; 0.3 % CO_2), anaérobies (= AN; 0.2 % O_2; 0.3 % CO_2) et sous atmosphère normale (= RA; 21 % O_2; 0.03 % CO_2). Par la suite, des jus ont été produits et analysés. Le stockage dans des conditions anaérobies ont causé une formation remarquablement élevée d'éthanol dont la teneur a atteint 560 à 750 mg/l en l'espace de 16 jours seulement. L'exposition des fruits à l'air après le stockage sous ULO et AN a entraîné une baisse de la teneur en éthanol d'un tiers au bout de 30 jours, mais les teneurs en éthanol étaient encore plus élevées que dans les fruits stockés dans des conditions RA. Les différents mélanges de gaz n'ont causé que de faibles variations de la teneur en éthanal, allant de 2 à 16 mg/l pour tous les traitements, la teneur la plus élevée ayant été trouvée dans les fruits de la variété 'Karešova'. A l'occasion d'une dégustation informelle dans le cadre d'une évaluation de la qualité des fruits, aucune flaveur étrangère perceptible n'a été constatée dans les fruits, même pas dans ceux stockés dans des conditions anaérobies. L'influence du traitement et du temps de stockage sur la fermeté de la peau et de la pulpe a été étudiée à l'aide du test de Tukey ($P < 0.05$) avec les fruits de la variété 'Karešova'. La diminution de la fermeté n'a pas été influencée de manière significative par la teneur en oxygène des différents atmosphères de stockage, et les résultats ont été comparables pour les traitements ULO et AN. Quant à la teneur en sucrose, glucose et fructose, on n'a détecté que des différences minimales entre ULO et RA. Dans les fruits de toutes les variétés, une dégradation statistiquement significative des acides (acides citrique et malique) a eu lieu ; le mélange du gaz de stockage et la phase d'aération ultérieure ont exercé une influence sur la concentration d'acides.*
Mots clés : cerises douces (*Prunus avium* L.), stockage dans des conditions réduites en oxygène, conditions anaérobies, éthanol, éthanal, fermeté, sucres, acides

Introducing an efficient cooling system is crucial to ensure sweet cherry quality during storage and marketing. It is necessary to combine low temperatures with high relative humidity in the storage atmosphere to obtain satisfactory results in sweet cherry storage. The presence of rotten fruit increased far more rapidly at higher temperatures (12 and 20 °C) than at lower temperatures (0 and 4 °C) (SEKSE, 1988). A significant improvement of the storage performance of cherry fruit was obtained with the introduction of controlled atmosphere technology.

The use of low oxygen atmosphere in postharvest fruit preservation is an important technique to reduce losses and maintain quality and so considerably extending the possibilities of low temperature storage. Once the fruit tolerance to high CO_2 levels and low O_2 concentrations has been determined, the search for optimum parameters of ambient atmosphere composition may be assisted by physical and chemical analyses. For instance they can be used to describe temporal changes in the production and content of anaerobic metabolites like ethanol and ethanal. It is known that the optimum composition of storage atmosphere for any given temperature is at an oxygen concentration above the point at which accumulation of anaerobic products results in off-flavours. Low oxygen levels of 0.25 % (KE and KADER, 1992; VIDRICH et al., 1998), as well as high CO_2 levels can result in off-flavours and physiological disorders, which are enhanced at higher temperatures (KADER, 1989). PETERSEN and POLL (1999) confirmed that the levels of off-flavour compounds like acetic acid and fermentation alcohols increased at higher temperatures, but CO_2-enriched atmosphere (20 % CO_2) did not affect the different factors significantly. CHEN et al. (1981) used a low oxygen concentration in storage atmosphere, which strongly inhibited fruit respiration. Although the development of diseases was not significantly affected, the fruit stored at 0.5 to 2.0 % O_2 maintained a higher portion of very green stems, brighter fruit colour, and higher levels of titratable acidity than those stored in air at -1.1 °C for 35 days.

Remón et al. (2000) reported that fruit in low-density polyethylene bags can be kept at a marketable stage for three weeks at gas compositions of 9 to 12 % CO_2 and 1 to 3 % O_2. During model studies (Salvator et al., 2002), the optimum O_2 concentration values for modified atmosphere packing of 'Burlat' cherries were predicted. Experimental results confirmed the predicted values satisfactorially when the O_2 concentration was higher than 2 %.

Oxygen concentration did not significantly affect respiration rates by accumulation of CO_2 (up to 16 %), but respiration rate was drastically reduced when O_2 concentration was below 10 % (Jaime et al., 2001).

Kappel et al. (1996) postulated that for optimum cherry quality the minimum soluble solid concentration (SSC) should be between 17 % and 19 % and the optimum pH of the juice is 3.8. Optimum sweet-sour balance was found to be between 1.5 and 2.0 (SSC / ml NaOH as 0.1 NaOH to pH 8.1).

Cherry fruit are susceptible to mechanical damage caused by impact or compression. Low soluble solid concentrations, low fruit temperatures and small fruit size have been associated with greater susceptibility to mechanical damage in cherries (Grant and Thomson, 1997; Thomson et al., 1997). Dark spots on the fruit surface are due to previous mechanical damages caused by other objects. Bruise resistance coefficient and bruise sensitivity increased with increasing absorbed energy (Blahovec, 1996; Blahovec, 1999).

Microwave energy may provide an alternative non-chemical preserving treatment against codling moth (*Cydia pomonella* L.), but it is necessary to optimize the treatment protocol for insect control and fruit quality (Ikediala et al., 1999). Heat stress by microwave, prior to cold storage, reduces damages incurred during cold storage (Perdue et al., 1998), and a combination of controlled atmosphere with hot forced air is an alternative quarantine treatment for sweet cherries (Neven and Drake, 2000). For long-distance transportations, harvesting the cherries at the red colour stage can be used, followed by chilling and keeping a constant temperature during the storage period.

Recent commercialisation of ULO small storage containers and modified atmosphere packing technologies for use in the cherry industry prompted investigation of sweet cherry response to low O_2 storage. This study is focused on the influence of minimum oxygen concentration in the critical stage, when physiological damage has not yet been observed. Oxygen stress was measured by analysing the ethanol and ethanal contents in the tissue of fruit of three cherry varieties which were stored at three different gas mixtures in cold storage.

Material and methods

Sample supply and preparation

Cherry fruit were harvested in the orchards of the horticultural farm Agro Stošíkovice in South Moravia on July, 10th. Defect fruit were removed and sound fruit from each variety ('Karešova', 'Kordia', 'Vanda') were prepared for air cooling before closing the storage chambers. Harvest time for two varieties ('Kordia' and 'Vanda') was at optimum maturity stage, but 'Karešova' was harvested three days earlier. Each chamber containing 15 kg of cherries of uniform colour and weight was sealed when the cooling temperature was 3 °C.

Preparation of storage chambers and gas mixture

Cherry samples were placed in hermetically sealed metal chambers (450 l) equipped with rubber sampling ports. Small sampling containers were connected with a circulating pump to obtain samples from bigger chambers without disturbing the given atmosphere in the big chambers. To eliminate the possible influence of CO_2 as a respiration inhibitor, the big chambers were connected with absorption tubes filled with solid tablets of KOH, which were mixed with inert material (polystyrene).

There were three oxygen levels: 0.2 % O_2 = anaerobic atmosphere (AN), 0.9 % O_2 = ultra-low oxygen (ULO), and 21 % O_2 = regular atmosphere (RA), each concentration maintained to $\pm$ 0.1 % O_2. CO_2 levels were 0.3 % in ULO and AN, and 0,03 % in RA, variation of concentration was within $\pm$ 0.1 %. Gas mixtures were monitored using a dual CO_2/O_2 analyser (Arelco, ARC, France). Gas concentrations were verified every hour. Flushing with N_2 was carried out to achieve the end concentration of O_2. The storage in the gas mixture lasted for 16 days, beginning when the fruit were stored in ventilated air.

Ethanol and ethanal contents

Cherry fruit were defrosted and the produced juice was filtrated (25 mm diameter syringe filter, 0.2 mm nylon

		cv. 'Karešova'		
Treatment	Time	Sucrose (g/l)	Glucose (g/l)	Fructose (g/l)
IN	0	0.16 ± 0.03ab	52.6 ± 0.8a	62.1 ± 0.1a
ULO	16	0.29 ± 0.03abc	56.1 ± 0.4a	69.4 ± 0.9ab
AN	16	0.20 ± 0.06ab	58.6 ± 4.0a	70.6 ± 4.2ab
RA	16	0.35 ± 0.01bc	59.9 ± 1.3a	74.6 ± 2.3ab
ULO	30	0.32 ± 0.01bc	52.7 ± 1.3a	69.2 ± 1.3ab
AN	30	0.07 ± 0.01a	54.9 ± 3.3a	70.6 ± 4.2ab
RA	30	0.48 ± 0.11c	52.7 ± 0.8a	79.5 ± 0.9b
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		**	*	*
Time		ns	*	ns
Treatment x time		*	ns	ns
		cv. 'Kordia'		
Treatment	Time	Sucrose (g/l)	Glucose (g/l)	Fructose (g/l)
IN	0	0.21 ± 0.05ab	64.6 ± 2.6a	77.0 ± 4.2c
ULO	16	0.42 ± 0.11bc	60.7 ± 1.9bcd	73.0 ± 2.9abc
AN	16	0.18 ± 0.07ab	50.4 ± 2.7abc	60.2 ± 2.8ab
RA	16	0.42 ± 0.11c	62.2 ± 1.5cd	74.9 ± 2.2bc
ULO	30	0.18 ± 0.00ab	48.0 ± 4.2a	62.5 ± 5.6abc
AN	30	0.02 ± 0.00a	45.5 ± 1.3a	57.0 ± 1.3a
RA	30	0.53 ± 0.04c	49.5 ± 2.3ab	64.2 ± 3.3abc
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		**	*	*
Time		*	**	*
Treatment x time		ns	ns	ns
		cv. 'Vanda'		
Treatment	Time	Sucrose (g/l)	Glucose (g/l)	Fructose (g/l)
IN	0	0.23 ± 0.13a	61.9 ± 1.9c	74.6 ± 2.5a
ULO	16	0.221 ± 0.04a	61.4 ± 0.6bc	73.9 ± 0.7a
AN	16	0.29 ± 0.05a	62.2 ± 1.6c	72.6 ± 2.6a
RA	16	0.24 ± 0.06a	61.6 ± 0.4bc	73.4 ± 2.1a
ULO	30	0.30 ± 0.10a	53.9 ± 1.7b	69.3 ± 2.5a
AN	30	0.22 ± 0.02a	43.9 ± 2.8a	65.7 ± 5.4a
RA	30	0.40 ± 0.09a	57.5 ± 0.9bc	75.3 ± 0.7a
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		ns	**	ns
Time		ns	**	ns
Treatment x time		ns	**	ns

Table 1:
Sugar content (g/l) in sweet cherries cv. 'Karešova', 'Kordia' and 'Vanda' during different atmosphere storage
Mean ± SE for 6 replicants; storage time 16 days in gas mixture, from 16th to 30th day ULO and AN treatments, the fruits were in ventilated air. Variants are indicated by common letters (a,b,c,d) with Tukey's HSD.

with glass (Alltech Associates Inc., Belgium). 1 ml aqueous samples were injected onto a sample block fitted with Teflon and analysed with a gaschromatograph 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, and an FID was used for analysis. The column was maintained at 92 °C.
Ethanal and ethanol were quantified by external standards and expressed in mg/l for each compound.

Analytical methods

The soluble solid concentration (SSC) was determined with homogenized frozen pulp using an Abbé refractometer (Jena Werk, Germany). Skin and flesh firmness of intact fruit were measured with a universal testing machine which recorded compression and rate of loading. A steel plunger with a 5 mm diameter was pressed into the fruit at a rate of 8 mm per minute and the resulting force-deformation curve was plotted by x-y recorder of the testing machine connected to the software programme. The break in the curve is an indication of the puncture point in which the plunger breaks the skin (skin firmness) and sudden decrease in force is observed as flesh firmness. The area under deformation curve is numerically indicated as firmness (work of compression by loading to rupture point).
Sugar content (sucrose, glucose and fructose) and organic acids (malic acid, citric acid, succinic acid and acetic acid) were determined by HPLC technique from the aqueous extract of the homogenized frozen pulp, but only malic acid and citric acid were calculated.

Table 2:
Citric (mg/l) and malic (g/l) acid content and soluble solids at the beginning of storage in different gas mixture and poststorage in air for cultivars of sweet cherries

		cv. 'Karešova'		
Treatment	Time	Citric acid	Malic acid	Soluble solid
IN	0	79.5 ± 21.2a	11.5 ± 1.1a	14.5 ± 0.4a
ULO	16	41.3 ± 3.4ab	9.7 ± 0.2ab	14.5 ± 0.1ab
AN	16	20.6 ± 0.6b	9.7 ± 0.4ab	14.8 ± 0.4ab
RA	16	44.3 ± 3.4ab	8.7 ± 0.1ab	15.2 ± 0.4ab
ULO	30	7.3 ± 0.0b	8.1 ± 0.5a	14.0 ± 0.5a
AN	30	5.5 ± 1.1b	8.7 ± 0.5ab	15.9 ± 0.6b
RA	30	10.9 ± 2.1b	7.8 ± 0.8b	15.5 ± 0.1ab
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		***	*	*
Time		***	ns	ns
Treatment x time		***	ns	ns
		cv.'Kordia'		
Treatment	Time	Citric acid	Malic acid	Soluble solid
IN	0	38.8 ± 21.9a	10.4 ± 1.0a	15.2 ± 0.7a
ULO	16	29.7 ± 6.0a	8.4 ± 0.5ab	15.2 ± 0.1a
AN	16	13.3 ± 1.2a	7.7 ± 0.4b	13.5 ± 0.1a
RA	16	41.3 ± 2.2a	8.4 ± 0.4ab	15.2 ± 0.3a
ULO	30	6.7 ± 3.0a	7.1 ± 0.5b	13.5 ± 0.7a
AN	30	8.5 ± 1.2a	7.4 ± 0.2b	13.8 ± 0.6a
RA	30	6.1 ± 1.2a	6.6 ± 0.3b	13.3 ± 0.7a
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		**	ns	ns
Time		**	**	*
Treatment x time		**	ns	ns
		cv.'Vanda'		
Treatment	Time	Citric acid(mg/l)	Malic acid (g/l)	Soluble solid (°RF)
IN	0	37.0 ± 7.7c	7.6 ± 0.2b	15.1 ± 0.6a
ULO	16	24.9 ± 2.2bc	7.2 ± 0.3ab	15.0 ± 0.0a
AN	16	9.1 ± 1.8ab	6.1 ± 0.4a	15.5 ± 0.2a
RA	16	37.0 ± 4.4c	7.2 ± 0.2ab	14.9 ± 0.6a
ULO	30	4.9 ± 2.2a	5.9 ± 0.1ab	14.0 ± 0.4a
AN	30	9.7 ± 0.6ab	5.5 ± 0.6ab	15.5 ± 0.4a
RA	30	6.7 ± 1.6a	6.9 ± 0.7ab	15.3 ± 0.3a
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		**	**	ns
Time		**	**	ns
Treatment x time		**	ns	ns

Cherry damage level

Fruit samples (100 fruit) of various storage treatments were collected for damage evaluation. Samples were evaluated after 16 days for pitting and bruising observation. The internal browning was evaluated. Microbiological spoilage was calculated by subtracting the percentage of damage after storage in gas mixture for the next ventilated phase.

Evaluation of fruit and stem freshness

Quality evaluation consisted of subjective defects such as pitting, bruising and stem browning. Subjective visual fruit and stem scores were evaluated at the end of storage time and after the ventilated phase.
Subjective colour was determined using two laboratory staff-members familiar with cherry colour grades. Fruit and stems were rated individually for overall appearance on a scale of 1 to 3 (1 = best; 3 = worst) and the values were recorded.

Statistical evaluation

Six replicates were provided for each measurement, means and standard errors are reported in tables 1 - 3. In order to determine the effect of storage conditions and storage time, Tukey's HSD significance test was performed with all physical and chemical parameters.

Results and discussion

Shelf life at different storage conditions

In general visually evaluated colour of fruit and stems was influenced by gas mixture treatment, but there was no difference in stem colour for AN and ULO storage in contrast to RA after 16 days of cold storage. Enhanced browning of stem colour was very evident for RA storage. Visual assessment of stem colour scored 1.4 ± 0.1 for fruit stored un-

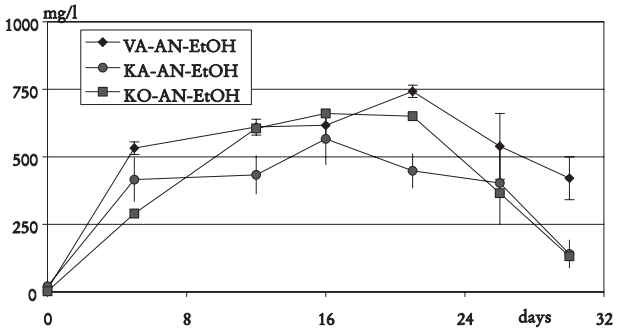

Fig. 1: Time pattern of ethanol (EtOH) concentration in ambient atmosphere (RA) under anaerobic conditions (AN=0.2 % O_2) for 'Karešova' (KA), 'Kordia' (KO) and 'Vanda' (VA). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

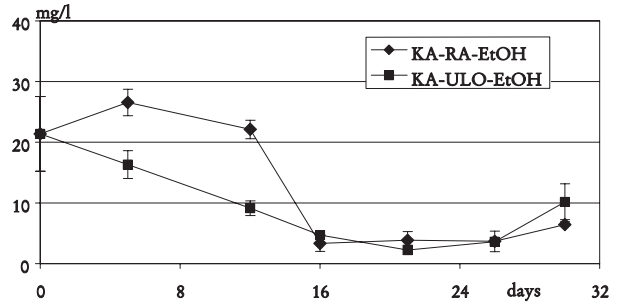

Fig. 2: Time pattern of ethanol (EtOH) concentration in ambient atmosphere under ultra low oxygen conditions (ULO) (0.9 % O_2) and regular atmosphere (RA) (21 % O_2 and 0.03 % CO_2) for 'Karešova' (KA). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

der the highest relative humidity (AN, ULO), in comparison to RA (2.5 $\pm$ 0.2), indicating lower stem quality for both storage periods (in gas mixture and in ventilated air).

However, there were no differences in the number of shrivelled fruit between the variants with reduced oxygen levels and the RA variant at the middle (16^{th} day) and the end of the storage period. Comparison of fruit quality with fruit from cold storage showed that gas

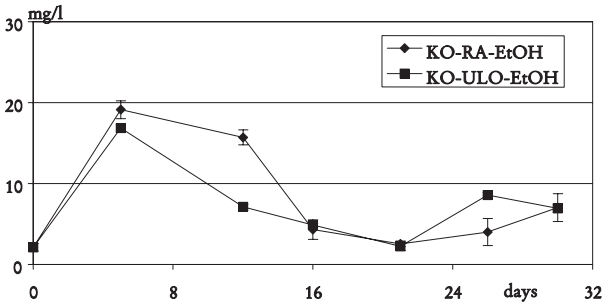

Fig. 3: Time pattern of ethanol (EtOH) concentration in ambient atmosphere under ultra low oxygen conditions (ULO) (0.9 % O_2) and regular atmosphere (RA) (21 % O_2 and 0.03 % CO_2) for 'Kordia' (KO). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

mixtures with reduced oxygen provide a better overall quality after immediate ultra low oxygen action followed by exposure to air condition.

Weight loss was determined immediately and ranged from 0.1 % to 0.3 % for fruit from AN and ULO and 0.5 % from RA. There were no fruit infected by molds during initial ULO and AN treatments; a following ventilated air storage caused an infection up to 3 %.

Ethanol and ethanal levels during and after storage

Storage atmosphere shall not initiate anaerobic metabolism like fermentation, therefore occurrence of products from anaerobic metabolism and resulting off-flavours are a critical point. The lowest level of oxygen concentration at which anaerobic products and ethanol production are still suppressed, accomplishes the fermentation threshold. Ethanol concentration is also suitable for estimating the oxygen minimum. Ethanol traces inside the pulp are normally identified at the beginning of storage, in tested fruit ethanol contents ranged from 2 to 16 mg/l. Ethanol levels were dramatically different after AN storage compared to ULO and RA (Fig. 1). During the anaerobic phase (0.2 % O_2) in prepared atmosphere, the critical low oxygen level lasted for 16 days and the ethanol content reached 600 mg/l. During the aeration phase, in normally ventilated air after storage, the content of ethanol was decreased with

Table 3:
Firmness of skin and flesh of cv. 'Karešova', 'Kordia' and 'Vanda' storred in different storage atmospheres

Treatment	Time	Skin (MPa)	Flesh (MPa)	Toughness (MPa.s)
		cv. 'Karešova'		
IN	0	0.54 ± 0.02a	0.39 ± 0.01a	10.07 ± 0.87a
ULO	16	0.44 ± 0.01ab	0.22 ± 0.02b	8.21 ± 0.38a
AN	16	0.43 ± 0.03ab	0.20 ± 0.03ab	8.30 ± 0.71a
RA	16	0.50 ± 0.02ab	0.20 ± 0.02ab	9.20 ± 0.56a
ULO	30	0.48 ± 0.04ab	0.19 ± 0.01ab	8.16 ± 0.73a
AN	30	0.42 ± 0.03b	0.19 ± 0.01ab	7.32 ± 0.59a
RA	30	0.40 ± 0.00b	0.13 ± 0.01c	7.30 ±0.18a
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		ns	ns	ns
Time		ns	*	ns
Treatment x time		*	ns	ns
		cv. 'Kordia'		
Treatment	Time	Skin (MPa)	Flesh (MPa)	Toughness (MPa.s)
IN	0	0.50 ± 0.08a	0.14 ± 0.02a	9.18 ± 1.2 a
ULO	16	0.53± 0.02a	0.13 ± 0.01a	8.24 ± 0.44a
AN	16	0.47 ± 0.03a	0.14 ± 0.01a	7.90 ± 0.69a
RA	16	0.41 ± 0.01a	0.14 ± 0.01a	7.07 ± 0.20a
ULO	30	0.51 ± 0.05a	0.18 ± 0.03a	8.55 ± 0.85a
AN	30	0.53 ± 0.02a	0.18 ± 0.02a	9.87 ± 5.50a
RA	30	0.53 ± 0.03a	0.16 ± 0.02a	10.44 ± 0.57a
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		ns	ns	ns
Time		**	ns	**
Treatment x time		ns	ns	ns
		cv. 'Vanda'		
Treatment	Time	Skin (MPa)	Flesh (MPa)	Toughness (MPa.s)
IN	0	0.42 ± 0.02abc	0.13 ± 0.01ab	8.43 ± 0.79ab
ULO	16	0.38 ± 0.01abc	0.09 ± 0.01a	6.42 ± 0.24a
AN	16	0.35 ± 0.01ab	0.10 ± 0.01a	6.00 ± 0.62a
RA	16	0.34 ± 0.02a	0.07 ± 0.00a	6.30 ± 0.44a
ULO	30	0.44 ± 0.02c	0.13 ± 0.02ab	9.74 ± 0.77b
AN	30	0.42 ± 0.02abc	0.12 ± 0.01a	7.70 ± 0.21ab
RA	30	0.43 ± 0.01bc	0.18 ± 0.01b	9.45 ± 0.75b
Two-way ANOVA: ** P < 0.01,* P <0.05, ns = not significant				
Treatment		ns	ns	ns
Time		*	**	**
Treatment x time		ns	**	ns

the only exception of fruit from the cultivar 'Vanda', where there was found a continued ethanol formation during the next five days in the second phase of storage.
Measurements of ethanal in fruit pulp showed only very low levels with no principal difference between RA, ULO and AN treatment. Comparing the cultivars, 'Karešova' had a generally higher ethanal concentration (Fig. 5 to 7) under all storage conditions.

Effect of low oxygen levels on the production of ethanol and ethanal

Prolonged ULO storage of sweet cherries can result in a small production of anaerobic metabolites and formation of off-flavours. This ULO effect continues after the transfer of fruit into ventilated air and reduces softening of skin and flesh of fruit (Table 3).
The time-temperature effect on selected aroma compounds (Petersen and Poll, 1999) increased dramatically at higher temperatures as a result of alcoholic fermentation. Increases of this phenomenon may have been associated with aroma concentrate deterioration. When cherry fruit were stored at cold temperature with additional effect of low oxygen levels there was no rise in ethanol concentration (Fig.2 and 3).
Measurements of ethanol and ethanal in fruit pulp showed very low levels of these metabolites, with no significant differences observed between RA and ULO treatments. In addition, at informal tastings of fruit after storage in low oxygen gas mixtures (AN, ULO), no noticeable off-flavours were detected in any fruit (Fig. 3, 4 and 6).

Changes in physical and chemical composition

Soluble solids and titratable acidity are other maturity indices of cherries, which, in addition to firmness, are considered important harvest and postharvest factors. There was no difference in the refrac-

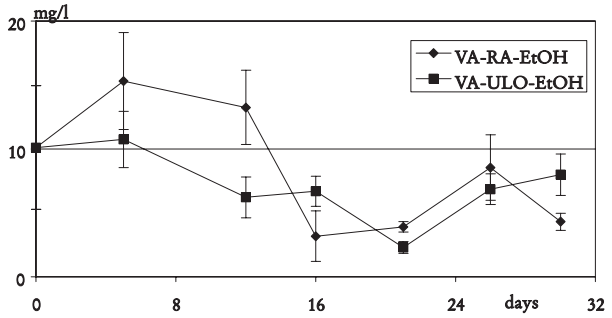

Fig. 4: Time pattern of ethanol (EtOH) concentration in ambient atmosphere under ultra low oxygen conditions (ULO) (0.9 % O_2) and regular atmosphere (RA) (21 % O_2 and 0.03 % CO_2) for 'Vanda' (VA). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

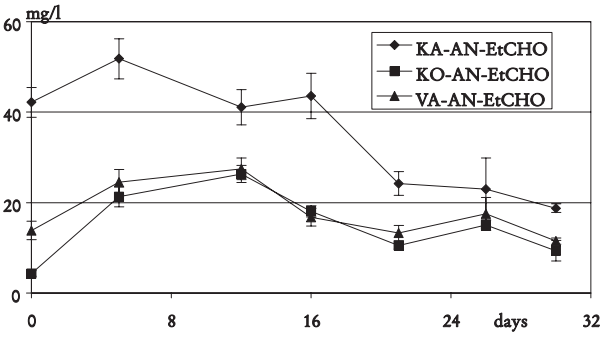

Fig. 5: Time pattern of ethanal (EtCHO) concentration in ambient atmosphere under ultra low oxygen conditions (ULO) (0.9 % O_2) for 'KareÜova' (KA), 'Kordia' (KO) and 'Vanda' (VA). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

tometrically determined values of soluble solid content (SSC) (Table 2) between the treatments, storage duration and cultivars. REMÓN et al. (2000) reported that 'Burlat' cherries showed a low, but statistically significant decrease in soluble solids contents as a result of modified atmosphere storage. However, most studies

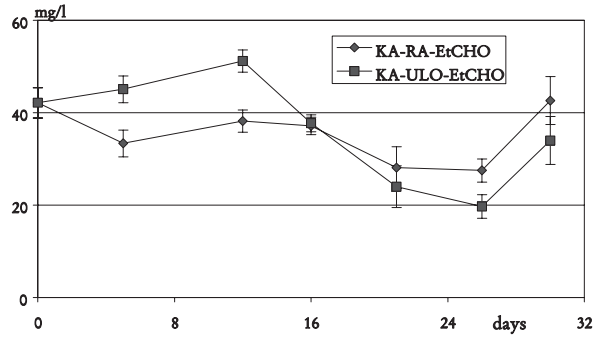

Fig. 6: Time pattern of ethanal (EtCHO) concentration in ambient atmosphere under ultra low oxygen conditions (ULO) (0.9 % O_2) and regular atmosphere (RA) (21 % O_2 and 0.03 % CO_2) for 'KareÜova' (KA). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

have shown no change in SSC level during storage periods (VIDRIH et al., 1998; NEVEN and DRAKE, 2000).
Organic acids are important components of cherry fruit, predominantly citric acid, which can be two to four times higher concentrated than malic acid (Table 2). Higher acid contents in 'Karešova' fruit were probably caused by lower ripeness at harvest time. Degradation of acids is statistically significant for all cultivars, differences between storage under low oxygen and subsequent aerating phase were monitored. The results obtained by HPLC analysis showed a metabolic degradation of malic and citric acids especially during the second storage phase in ventilated air. A statistical significance was found by means of Anova test predominantly for citric acid in all cultivars. Few changes were seen in malic acid, which is more stable than citric acid.

Firmness of cherry fruit at various gas mixtures

Three parameters were identified on the basis of curve deformation obtained by stressing an intact fruit with slow deformation. A destructive fruit device was used to press the penetrometer tip (5 mm diameter) into the cherry flesh. A maximum force applied to the fruit was defined as fruit firmness, and occurred momentarily prior to the collapsing of flesh beneath the penetrometer tip. In the force-deformation curve of cherries with intact skins the puncture point is reached when

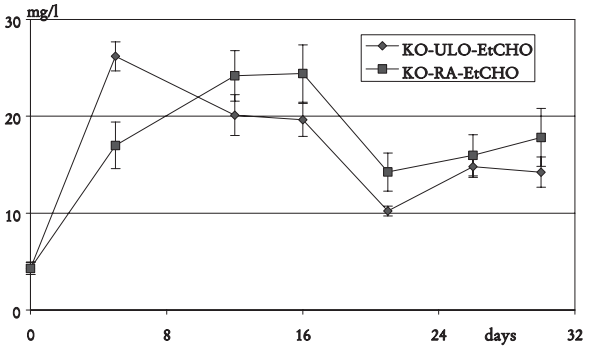

Fig. 7: Time pattern of ethanal (EtCHO) concentration in ambient atmosphere under ultra low oxygen conditions (ULO) (0.9 % O_2) and regular atmosphere (RA) (21 % O_2 and 0.03 % CO_2) for 'Kordia' (KO). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

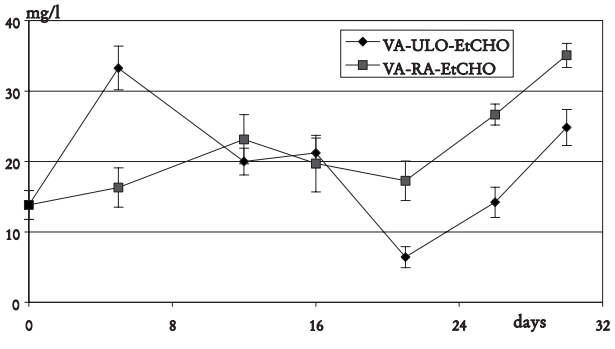

Fig. 8: Time pattern of ethanal (EtCHO) concentration in ambient atmosphere under ultra low oxygen conditions (ULO) (0.9 % O_2) and regular atmosphere (RA) (21 % O_2 and 0.03 % CO_2) for 'Vanda' (VA). This phase lasted 16 days, subsequently the fruits were stored at cold-storage temperature and in normal composed air. Each value represents 6 fruits and vertical bars indicate $P < 0.05$

the plunger breaks the skin. It is responsible for mechanical properties of fruit, but it does not indicate the „bioyield point" as seen in apples (Table 3). Significance of differences between storage conditions and storage duration were not established by Anova test with all cultivars. The statistically significant losses of firmness were not affected by oxygen content in each of applied storage conditions.

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