Europ.J.Hort.Sci., **68** (1), 14–19, 2003, ISSN 1611–4426. © Verlag Eugen Ulmer GmbH & Co. Stuttgart

Effects of Ultra Low Oxygen Storage on Postharvest Quality of Onion Bulbs (*Allium cepa* L. var. *cepa*)

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Summary.

The effect of ultra low oxygen concentration on the storability of onions (*Allium cepa* L. var. *cepa*) was studied. Onions (cv. 'Sherpa', type Rijnsburger) had been kept during 9, 18, 27 and 36 weeks at 2 °C in atmospheres with 0.5, 1 and 21 % O_2. Quality assessment was effected after each storage time and the following period of 3 weeks of shelf-life. After storage in 1 % O_2, quality maintenance of the onion bulbs was much better than after storage in 21 % O_2, which was characterised by less weight loss, reduced respiration intensity and inhibited sprouting in spring. Lowering the O_2-concentration to 0.5 % in the storage atmosphere led to similar results concerning respiration intensity and sprout inhibition, but weight loss was accelerated during the last storage period between March and May. Some onion bulbs were covered by a slight mould layer after storage until March or May, which arose presumably from high humidity in some of the storage containers. In none of the bulbs internal injury or off flavour due to fermentation metabolism were noticed.

Zusammenfassung.

Wirkung von ULO-Lagerung auf die Nacherntequalität von Speisezwiebeln (*Allium cepa* L. var. *cepa*). Es wurde der Einfluss sehr niedriger Sauerstoffkonzentration auf die Lagerfähigkeit von Speisezwiebeln (*Allium cepa* L. var. *cepa*) untersucht. Die Zwiebeln (Sorte 'Sherpa', Typ Rijnsburger) wurden 9, 18, 27 und 36 Wochen lang bei 2 °C in Atmosphären mit 0,5, 1 und 21 % O_2 gelagert. An jedem Auslagertermin und nach einer dreiwöchigen „shelf-life"-Phase erfolgte eine Qualitätsbeurteilung. Lagerung in 1 % O_2 führte zu erheblich besserer Qualitätserhaltung als Lagerung in Luft, was sich besonders an geringerem Gewichtsverlust, reduzierter Atmungsintensität und verzögertem Austrieb im Frühjahr zeigte. Absenkung der O_2-Konzentration in der Lageratmosphäre auf 0,5 % führte zu ähnlichen Ergebnissen bezüglich Atmungsintensität und Austriebsverzögerung, aber der Gewichtsverlust wurde in der Lagerzeit von März bis Mai beschleunigt. Einige Zwiebeln zeigten leichten Pilzbefall nach Lagerung bis März oder Mai, der vermutlich durch hohe Feuchte in den Lagerbehältern verursacht wurde. Es wurden weder innere Gewebeschädigungen der Zwiebeln noch Fremdgeruch auf Grund von Gärungsreaktionen festgestellt.

Key words. Postharvest quality – storage – vegetable – onion, ultra-low-oxygen – controlled atmosphere

Introduction

Onions can be kept in cold-storage rooms under suitable conditions between 6 and 8 months. Longer storage periods lead to quality loss mainly because of rot and sprouting or rooting. In plant cells, oxygen participates in more than 200 different reactions (HENDRY 1994). Respiration is the major aspect of cellular oxygen consumption (BABCOCK 1999). Reduced O_2-concentrations and raised CO_2-concentrations in the atmosphere extend storability of onions (ADAMICKI and KEPKA 1974; SMITTLE 1988). High CO_2-levels (>5 %) inhibit neck rot, but can cause internal browning or watery scales (SITTON et al. 1997; HOFTUN 1993).

The recommended favourable concentrations are variable, for O_2 between 0.7 and 2 %, for CO_2 between 0 and 10 %. The benefit of CA-storage to prolong market life of onions is evaluated differently. While SALTVEIT (2001) does not attach great importance to commercial use, ADAMICKI (1997) describes ULO-storage of onions with low CO_2-concentrations (2 %) as very effective to extend storability. Possibly the reason for these various recommendations are different genetic or environmental influences.

The objective of this study was to investigate the influence of low O_2-concentrations on quality changes of onions during CA-storage and a subsequent shelf-life period in air. Previous investigations about O_2-diffusion in onion bulbs exposed to atmospheres with reduced O_2-concentrations showed equal O_2-distribution inside the bulbs (unpublished). Owing to these results there are reasons for the assumption that onions can tolerate low O_2-levels without fermentation injuries.

Materials and Methods

Plant material and storage conditions

In September 1999 cured onions cv. 'Sherpa' (type 'Rijnsburger') from commercial field production were furnished from south east Bavaria and kept under CA-con-

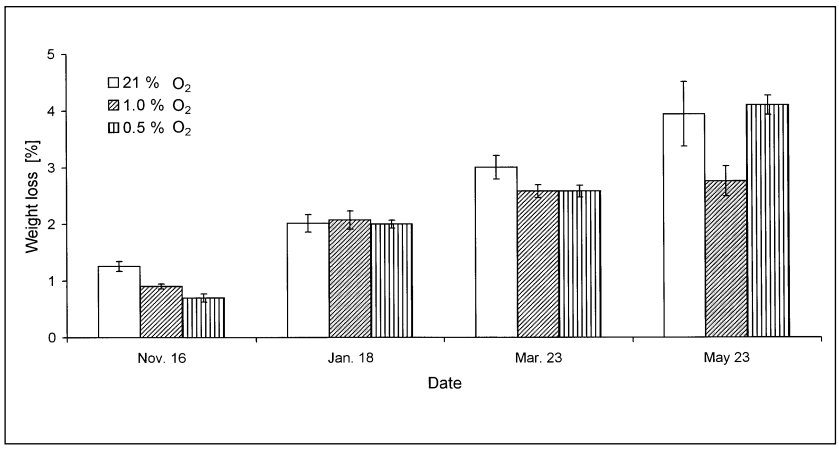


Fig. 1. Weight loss of onion bulbs cv. 'Sherpa' after storage in different O_2-concentrations (the lines indicate standard deviation).

ditions at 2 °C immediately after transport. O_2-concentrations in the storage containers were 0.5, 1 and 21 %, the CO_2-concentration for all treatments was below 0.3 %. For each treatment 25 kg of onions were stored, split up into 4 boxes per storage container. Gas concentrations were measured and regulated continuously using a paramagnetic analyser for O_2 (model Oxor 600, Maihak), an infrared analyser for CO_2 (model Unor 600, Maihak). Humidity was higher in containers with 21 % O_2 (85–89 %) than in the storage containers with low O_2-concentrations (78–82 %). At intervals of 9 weeks (Nov. 16, Jan. 18, Mar. 23, May 23) onions were taken out of the storage containers to evaluate quality changes. Additionally, on each of these dates shelf-life of the onions during 3 weeks at 18 °C was observed.

Determination of weight loss

After each storage period the onions of each box (4 repetitions per treatment) were weighed separately and weight loss was calculated in percentage of fresh weight at the beginning of the storage experiment.

Dry matter

The dry leaves above the necks of 20 onions were removed and bulbs were cut in small parts including the skin. For dry matter determination 3 samples (each 100 g) of the mixed material was used. After drying the onions for three days (at 60/90/105 °C) dry matter was weighed and determined in percentage of the fresh weight.

Respiration measurement

CO_2-production of the onions was measured in a flow-through system (20l/h gas flow) using an infrared analyser (model Uras 10 E, Hartmann & Braun) at 10 °C in air during 2 days at the beginning of the storage experiment and after each storage period. For each treatment respiration was determined in 3 repetitions with 1 kg of onions per measuring vessel. To compare CO_2-production of different treatments the average measurement values of the second day were used when respiration was stable. After the longest storage period (36 weeks) respiration measurement was extended to 5 days.

Determination of skin colour

Skin colour was measured by means of a chromameter (CR 200, Minolta) according to the L–a–b–system (Hunter). Lightness of colour is expressed by the L-value in a range from 0 to 100. With rising L-values lightness of the sample increases. For each treatment skin colour of 20 onions was measured once per onion in the middle between the neck and the roots.

Determination of bulb sprouting

According to a method described by TUCKER (1989) and ERNST et al. (1999) initial sprouting can be determined by measuring the ratio between the leaf blade length and the leaf sheath length because the leaf blade elongates earlier than the leaf sheath. The leaf ratio was measured in ten onion bulbs for leaves with a sheath length of approximately 3 mm after each CA-storage period (except Jan. 18) and three times during shelf-life period. Externally visible sprouting and rooting of bulbs, beginning with raised root plates was evaluated in March (March 23) and May (May 23) and after 3 weeks shelf-life respectively.

Statistical analysis

The analysis of variance was conducted with statistic software SPSS 10.0 using the ANOVA procedure and Tukey's studentized range test ($P \leq 0.05$).

Results

Weight loss

During storage in air (21 % O_2) the onion bulbs lost about 1 % of their fresh weight every 9 weeks. Storage in 1 % O_2 delayed weight loss, resulting in 2.8 % loss after a storage period of 36 weeks. Lowering the O_2-concentration to 0.5 % O_2 led to the same weight loss as in 1 % O_2 until March, but strongly accelerated the loss of fresh matter between March and May (Fig. 1). A significant difference between the average weight loss of all storage periods was observed after storage in air (2.6 %) and in 1 % O_2 (2.1 %). The mean weight loss after storage in 0,5 % O_2 (2,3 %) did not differ significantly from the other treatments.

Table 1. Dry matter of onion bulbs after storage in different O_2-concentrations (mean values with different letters are significantly different).

	Dry matter [%]					
O_2-concentrations [%]	Sep. 15	Nov. 16	Jan. 18	Mar. 23	May 23	Mean values
21	10.9	11.0	10.9	10.4	10.0	10.6 b
1		11.6	10.3	10.3	10.5	10.7 b
0.5		11.7	11.7	11.1	10.8	11.3 a
Mean values		11.3 a	11.0 a	10.6 b	10.4 b	

Dry matter

The average dry matter concentration decreased from 11.3 % in November to 10.4 % in May. After storage in 0.5 % O_2 dry matter percentage was significantly higher than after storage in air or in 1 % O_2 (Tab. 1).

Respiration

CO_2-production of the onions was slightly decreasing during the measurement period at the beginning of the storage experiment, after storage in air during 9, 18, 27 or 36 weeks the courses of respiration were rather increasing (Fig. 2). Mean respiration after storage in air was increasing from 3.1 kg CO_2 kg^{-1} h^{-1} in September to 8.9 kg CO_2 kg^{-1} h^{-1} in May. Lowering the O_2-concentration in the atmosphere to 0.5 % O_2 or 1 % O_2 reduced CO_2-production significantly after all storage periods (Fig. 3).

During the shelf-life measurement beginning May 23, respiration after storage in air and in low O_2-concentrations was nearing slowly (Fig. 4). Nevertheless CO_2-production after storage in air after 6 days was still about 2 mg kg^{-1} h^{-1} above CO_2-production after storage under ULO-conditions.

Skin colour

During the storage time the onion skin became slightly darker in all atmospheres. This effect was most evident between March and May after storage in air. Considering the mean values of all storage periods there was no significant influence of the CA-conditions (Fig. 5).

Sprouting of onion bulbs

In November, there were only minor differences between leaf ratios after different storage conditions. In March and May, immediately after storage, onions

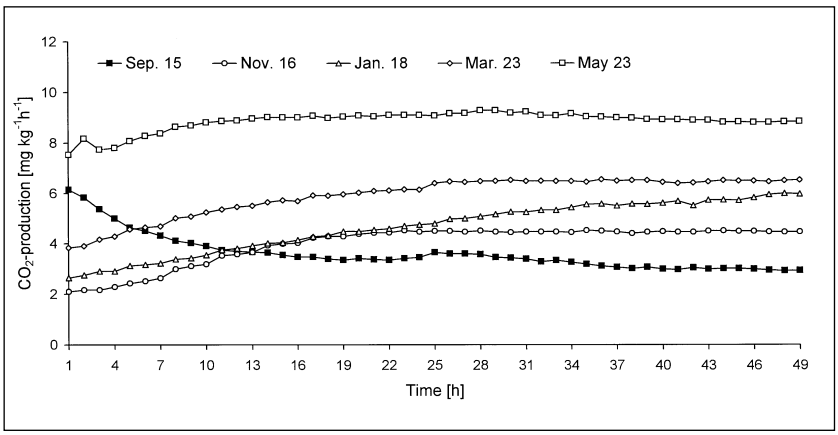


Fig. 2. Shelf-life respiration in air of onion bulbs cv. 'Sherpa' during 48 h at 10 °C after different storage periods in 21 % O_2.

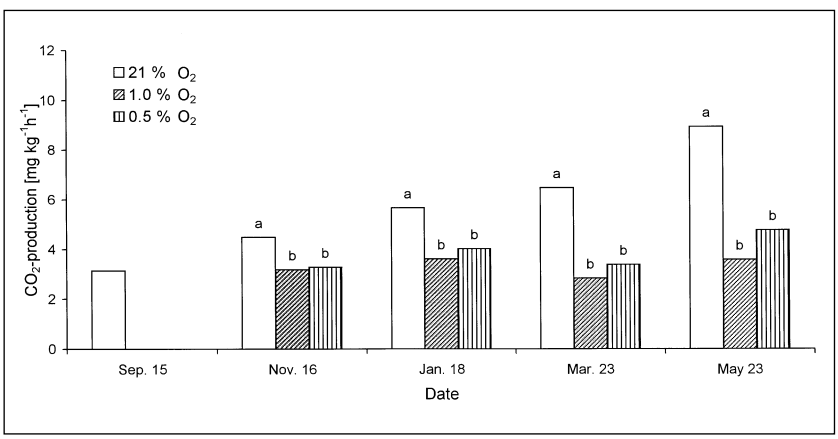


Fig. 3. CO_2-production of onion bulbs cv. 'Sherpa' at 10 °C in air after storage in different O_2-concentrations (statistical analysis was done separately for each storage period ($P \leq 0.05$)).

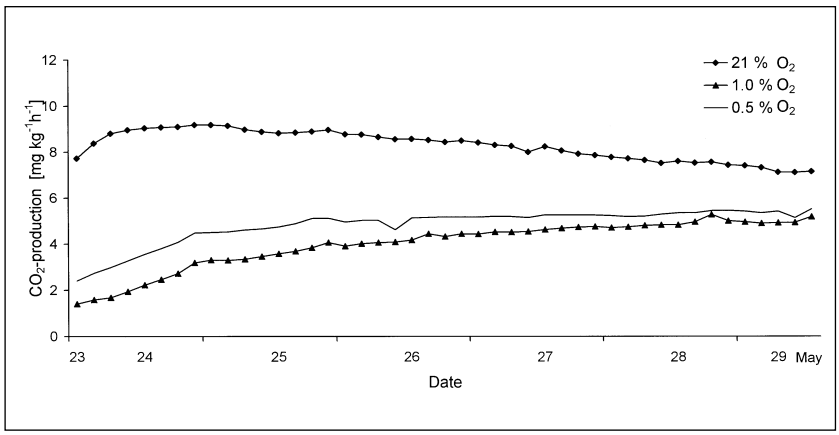


Fig. 4. Shelf-life respiration of onion bulbs cv. 'Sherpa' during 6 days at 10 °C after a storage period of 36 weeks in different O_2-concentrations.

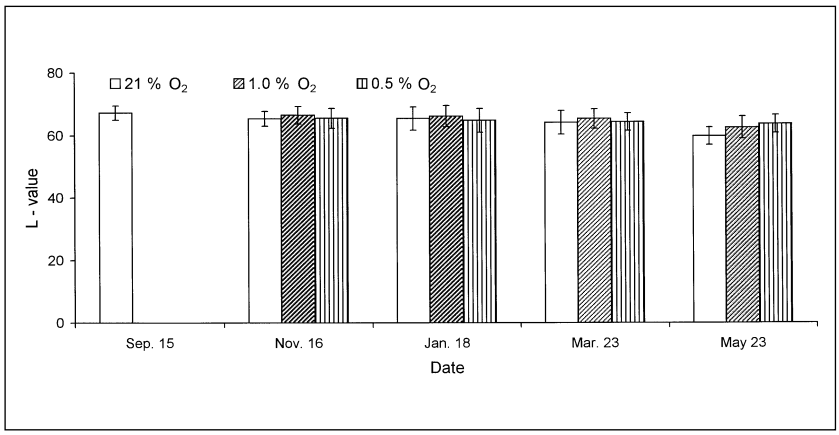


Fig. 5 Lightness of onion skin 'Sherpa' after storage in different O_2-concentrations (the lines indicate standard deviation).

Table 2. Development of leaf ratio in onion bulbs during 3 weeks at 18 °C after storage in different O_2-concentrations.

	Leaf ratio			
O_2-concentration [%]	**Nov. 16**	**Nov. 16 + 1 week**	**Nov. 16 + 2 weeks**	**Nov. 16 + 3 weeks**
21	0.54 ± 0.22	0.75 ± 0.33	1.42 ± 0.17	0.96 ± 0.08
1	0.39 ± 0.08	0.69 ± 0.17	1.09 ± 0.2	0.93 ± 0.21
0.5	0.49 ± 0.11	0.70 ± 0.28	0.86 ± 0.26	0.95 ± 0.12
	Mar. 23	**Mar. 23 + 1 week**	**Mar. 23 + 2 weeks**	**Mar. 23 + 3 weeks**
21	1.53 ± 0.38	–	2.21 ± 0.42	2.19 ± 0.51
1	0.85 ± 0.16	–	1.21 ± 0.30	1.46 ± 0.37
0.5	0.75 ± 0.10	–	1.25 ± 0.41	1.81 ± 0.24
	May. 23	**May 23 + 1 week**	**May 23 + 2 weeks**	**May 23 + 3 weeks**
21	2.70 ± 0.71	2.66 ± 0.37		
1	1.17 ± 0.17	2.09 ± 0.76	2.10 ± 0.43	2.16 ± 0.59
0.5	0.95 ± 0.16	1.65 ± 0.65	2.45 ± 0.58	2.52 ± 0.96

stored in air showed a higher leaf ratio than those stored in low O_2-concentrations. This tendency was continued in the following three weeks at 18 °C in March. In May, leaf ratio of the air stored onions was not determined 2 and 3 weeks after CA-storage because leaf sheaths were too long. There was no clear difference of leaf ratio between onions which were stored in 1 or 0.5 % O_2 (Tab. 2).

Regarding external appearance sprouting was strongly inhibited after storage under ULO-conditions (Tab. 3). This effect was incessant during the 3 weeks

Table 3. Visible sprouting of onion bulbs after storage in different O_2-concentrations during 27 and 36 weeks.

	Sprouted bulbs [% of weight]		
Date	21 % O_2	1 % O_2	0.5 % O_2
Mar. 23	47	0	0
Mar. 23+3 weeks	94	41	29
May 23	100	0	0
May 23+3 weeks	100	24	31

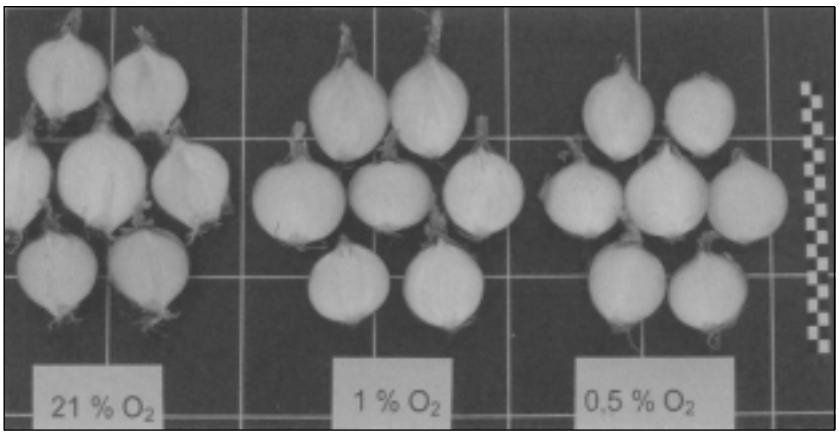


Fig. 6. Onions (cv. 'Sherpa') after 36 weeks storage at different atmospheres.

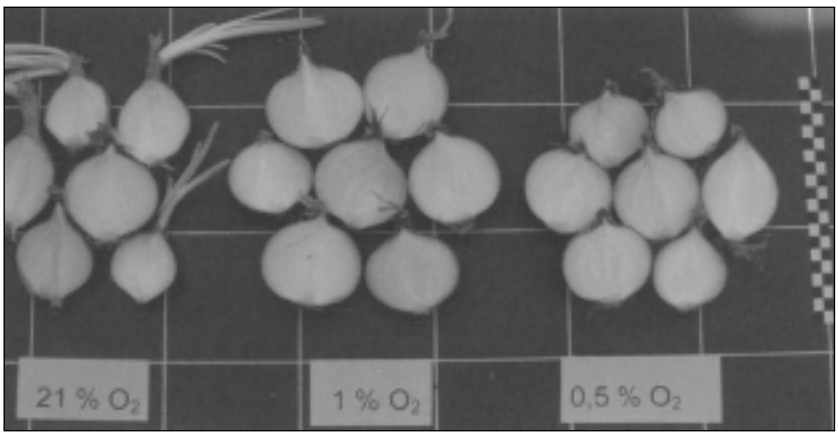


Fig. 7. Onions (cv. 'Sherpa') after 36 weeks storage at different atmospheres and 3 weeks shelf-life.

shelf-life period (Fig. 6 and 7). The difference between bulbs which were stored in air and in low O_2 levels was more obvious than the difference between storage in atmospheres of 1 or 0.5 % O_2.

None of the onions showed symptoms of internal browning or other colour changes inside the bulbs after long time storage under ultra low oxygen conditions. Onions which were stored in low O_2-concentrations appeared considerably firmer than those which were stored in air. After leaving the storage containers in March and May a remarkable percentage of the onion bulbs was covered by a slight mould layer, which mostly went dry during shelf-life period.

Discussion

The slight mould layers on the surface of the bulbs result rather from too high humidity inside some storage containers than from unsuitable composition of the atmosphere. For example humidity in the container of the control variant (21 % O_2) rose to 89 % during 36 weeks. 86 % of the bulbs stored in this container had mould layers on the surface. The percentages of onions with mould layers were between 15 % and 64 %, when humidity in the storage containers was between 78 and 80 %.

Presumably the darker colour of the outer bulb skin after storage in air can also be explained by high humidity in the storage container of this variant (98 %) in contrast to 78 % in the containers with 0.5 or 1 % O_2, because it is known that humidity may cause dark staining of the skins in harvested onions (BREWSTER 1994).

Lowering the O_2-concentration to 1 % in the storage atmosphere of onions clearly delayed weight loss (2.8 % after 36 weeks) in comparison to storage in air. Similar positive effects were reported by ADAMICKI (1997) who determined 3.7 % weight loss of onions in atmospheres with 1 % O_2 and 2 % CO_2 after a storage period of 33 weeks.

The increased weight loss from March to May in 0.5 % O_2 atmosphere indicates that respiration metabolism switched over to fermentation. But nevertheless, CO_2-production directly after storage in 0.5 % O_2 was not intensified and the carbohydrate content in the onions was highest after storage in 0.5 % O_2 in May (data not shown).

Dry matter concentration was decreasing during storage in all atmospheres but less in 0.5 % O_2. In agreement with our results, SMITTLE (1988) observed higher dry weight of onions after storage in 3 % O_2 and 5 % CO_2 than after storage in air. Perhaps increased water loss led to this elevated weight loss in storage atmosphere with 0.5 % O_2, although we cannot explain this effect. Similar results were reported by YANG and HENZE (1987) who observed increased water loss of broccoli stored in 1.5 % O_2 compared to storage in air.

The reason cannot be different water vapour pressure deficit in the storage containers because average water vapour pressure deficit for the storage period of 36 weeks (calculated from mean storage temperature and humidity) was equal (155 Pa) for the variants with 0.5 and 1 % O_2 in the atmosphere.

Our observations concerning better maintenance of bulb firmness and delayed sprouting after storage un-

der ULO-conditions and after the three weeks shelf-life period at 18 °C confirm the observations of ADAMICKI (1997) and YOO and PIKE (1996).

The correlation between delayed sprouting of the bulbs and respiration is not yet clear. Respiration intensity is also diminished by other factors which delay sprouting of onions, such as treatments with maleic hydracide (WARD and TUCKER 1976), but the inhibited respiration intensity is not necessarily the reason for suppressed sprouting. CO_2-production of onions stored in air or in low oxygen concentrations until May was almost the same after one week during the shelf-life period while after 3 weeks only one third of the onions, which were stored in low O_2-levels, began to sprout.

Contrary to our results, SITTON et al. (1997) found accelerated sprouting during shelf-life after storage of onion bulbs cultivar 'Walla Walla' in low O_2- and CO_2-concentrations. Only elevated CO_2-concentrations (>4 %) suppressed sprouting during shelf-life. Different shelf-life behaviour after CA-storage of onions with a short storage life (cv. 'Walla Walla') and the cultivar 'Sherpa' with long dormancy could be subject of further investigations.

In agreement with other authors we found that low O_2- and CO_2-concentrations in the storage atmosphere did not spoil the bulbs internally (ADAMICKI and KEPKA 1974; SITTON et al. 1997), although according to PRAEGER (2001) the O_2-concentration inside onion bulbs decrease to 0 % at a temperature of 10 °C in surrounding atmosphere with 0.5 % O_2. Possibly O_2-consumption due to respiration in the tissue at storage temperature of this experiment (2 °C) is reduced far enough so that anoxic conditions inside the bulbs do not arise.

Several mechanisms of plant tissue adaptation and extension of viability during postharvest life under hypoxic conditions are known (CHERVIN et al. 1996). Fermentation metabolism and enhanced glycolysis of onions under ULO conditions can be excluded for our experiment (see above). Maybe high fructan levels in onions play a role in tolerance of oxygen shortage (data not shown). Further investigations would be necessary to get knowledge about possible adaptation reactions to low energy levels inside the cells which result from low respiration in an atmosphere with 0.5 % O_2.

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Received December 16, 2002 / Accepted January 23, 2003

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