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Quality and consumer acceptability of gooseberry fruits (*Ribes uva-crispa*) following CA and air storage

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SUMMARY
For two successive years gooseberries, 'Achilles' were stored at 1°C in regular air (control) and under six various CA conditions (%CO_2+ %O_2: 6+18; 12+18; 18+18; 12+2; 18+2 and 24+2). Results showed that air storage is not appropriate to handle gooseberries due to a drastic reduction in fruit firmness (25% lower than CA-treatments), darkening of fruit colour, mealy texture, and lower acidity level. Low oxygen storage in combination with high CO_2 concentrations (18% or more) of gooseberries also gave bad results, mainly due to the development of off-flavours in fruits. However, results showed that increasing CO_2-concentration up to 12% did not induce the development of off-flavour. It seems that the tolerance concentration for gooseberries in respect to CO_2 lies between 12-15%, since fruits stored under 18% CO_2 combined with 18% O_2 were evaluated to be good fruits, although a slight off-flavour was noticed by panelists. Consequently, the storage of gooseberries 'Achilles' under 12-15% CO_2 combined with 18% O_2 for up to seven weeks can be recommended.

Gooseberry (*Ribes uva-crispa* L.) is popular in Europe as fresh fruit and as processed product, primarily into pies or preserves. Outside Europe, gooseberries are not so well known and the main limitation to this crop appears to be consumer education and acceptance. The importance of gooseberry lies partially in its content of non-anthocyanin phenolic compounds, which are known to have health-promoting effects as antioxidants and anticarcinogens (Häkkinen, 2000). Concerning postharvest handling, gooseberries are to be picked when berries are firm and have a transparent greenish-yellow flesh and darkened seeds. Although amounts produced in various parts of Europe are small, it comes to price depressions at high seasons; air-stored gooseberries get softer rapidly which narrows the marketing window. Accordingly, the berry industry demand other ways of extending the storage period of gooseberries for longer than regular cold storage. Both modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage, which are used to store other fruits for extended periods, may prove beneficial in extending the marketing span of gooseberries. Controlled atmosphere storage that involves high CO_2 in combination with low O_2-concentrations has many positive effects such as reduced ethylene production and respiratory activity, better flavour retention, slower softening rates, slower green colour loss, and maintenance of organic acid levels (Wills *et al.*, 1998).

Literature available about MAP and CA-storage of gooseberries is very rare. Therefore, the aim of this study was to investigate the influence of modifying atmosphere around fruits, in particular increasing CO_2-concentration and/or decreasing O_2-concentration, on the quality parameters and the consumer acceptability of gooseberries kept up to eight weeks under the designed conditions.

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MATERIAL AND METHODS

Fruit material and storage conditions

Gooseberry fruits ('Achilles') were obtained for the consecutive years 2001 and 2002 from a cooperative packing house in the Lake Constance area, Southwest Germany. Fruits were picked and selected for uniformity without decay or external injuries, and stored at the same day of picking. In the first year, fruits were stored under air and the following six CA-conditions (%CO_2+ %O_2): 6+18; 12+18; 18+18; 12+2; 18+2 and 24+2. In the second year the treatment 24+2 was replaced with 24+18. Storage temperature was 1°C ± 0.5. The required gas compositions inside chambers were achieved within 12 h. In the first year, two sub-samples from each treatment were enclosed in glass jars and subjected to the same gas composition as in the corresponding chambers. These jars served to measure the respiration rate at 0°C as indicated below.

Determination of quality parameters

At harvest time and at 10 d intervals, three sub-samples from each storage condition, which serve as three replicates, were obtained and analysed for the following parameters: a) fruit firmness using a nondestructive analyzer (FirmTech 2) designed for soft fruits, that measure the maximum weight needed to compress the fruit tissues for a specific distance. Readings obtained are in g mm^{-1}; b) total soluble solids % (TSS) determined in fruit juice by digital refractometer (Atago, Japan); c) titratable acidity (TA): 10 ml of fruit juice were diluted with 100 ml distilled water and titrated with 0.1 N NaOH to pH 8.1 using a pH-meter; d) Colour: The fruit colour attributes (CIE L*a*b*) were measured from ten fruits per each replicate using a chromameter (CR 300, Minolta). Additionally, hue (°h) values were calculated as (arctan b*/a*) and chroma values as $(a^2 + b^2)^{1/2}$

Respiration measurements

Respiration measurements at 1°C were performed only in the first year. Two glass jars (1.2 l volume) for each treatment were filled with 300 g fruits (for each jar) and flushed continuously at a rate of 100 ml min^{-1} with a gas mixture of N_2, O_2, and CO_2 corresponding to the concentrations used for the different CA-treatments. All jars were placed in a thermostatic water bath at a constant temperature of 1°C +/- 0.3°C. At ten-day intervals, glass jars were detached from the gas supply and closed for 8 h; the respiration rate of CO_2-production and O_2-uptake was calculated from the difference in concentration of both gases before and after the enrichment period. In both years, and after five weeks in store, fruit samples were removed from the chambers and exposed to air condition for 48 h. After that, respiration rates were measured and termed as respiration rate after 2 d shelf-life at 20°C. All respiration measurements were conducted through a micro-GC (Chrompack, CP 2002 P) with a thermal conductivity detector (TDC). The following columns specifications for gas detection were used. O_2: Molsieve, 20 m, 0.15 mm i.d., 40°C (isothermal); CO_2: Haysep, 25 cm, 45 °C (isothermal).

Sensory test

A taste panel with a minimum of four people conducted this test on fruit samples stored for seven weeks under different CA-treatments. The panelists looked for both visual quality criteria, such as fruit colour, and taste criteria, such as sweetness, acidity, crispness, and off-flavour. All tests were performed after a shelf-life period of 8 h at 20°C in air. The visual properties (appearance, colour, injuries) and or organoleptical impression were judged by numerical scores between 1 and 5 as follows: for decay: 1= no decay, 2= slight decay, 3= one fourth to one third of fruits were infected, 4= more than one third but less than half of fruits were infected, and 5= severe infection (more than half the fruits were infected); for colour: 1= green-red, fresh as at harvest time, 2= slight darkening, 3= red , 4= red and overripe, and 5 = dark red and overripe; for taste: 1= very good, 2= good, 3= satisfactory, 4= poor, and 5= very poor. After that a detailed discussion was conducted to evaluate the quality of stored gooseberries. Therefore, results concerning sensory test will be shown in both numerical as well as descriptive manner.

Weight loss and internal injury evaluation

During storage, the weight loss due to transpiration and respiration of fruits was followed by weighing the same sample of fruits both at the beginning of storage period and at sampling date for each treatment. At the end of the storage period 20 fruits from each treatment and replicate were halved and estimated visually for decay and storage disorders. Decay was recorded as a percentage of damaged fruits.

Statistical analysis

All results, except those of sensory tests, were subjected to analysis of variance (ANOVA) using the CoStat-software. Mean separations were calculated by Student-Newman-Keuls range test at $P \leq 0.05$. Results of the sensory tests were subjected to natural logarithm transformation (*ln*) and further to analysis of variance. Subsequently, mean separation of the transformed data were conducted with Student-Newman-Keuls range test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Due to the absence of scientific reports about the impact of CA-storage, in particular of low oxygen storage, on quantitative as well as qualitative criteria of gooseberries, the results of these experiments cannot be compared with other studies. Consequently, the assumption that gooseberries respond to various CA-storage conditions in a manner similar to other fruits prevails in the current interpretation. Moreover, and due to great similarity in results for both years, results of the second year (2002) will be presented here, unless mentioned otherwise.

Quality parameters

Fruit firmness: During storage, softening proceeded in all treatments, in particular with air-stored gooseberries. Among treatments, air-stored fruits significantly registered the lowest values throughout the entire storage period (Figure 1). Increasing CO_2-concentration and/or decreasing O_2-concentration resulted in a partial preservation of fruit firmness, mainly in the second half of the storage period. But no significant differences were evident between all CA-treatments. The observed loss of firmness is in agreement with findings of Prange *et al.*

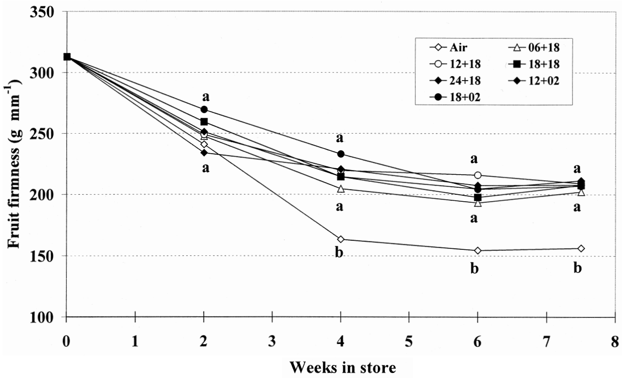

FIG. 1
Influence of storage conditions (%CO_2 + %O_2) at 1°C on the fruit firmness (g m^{-1}) of gooseberries 'Achilles' during the entire storage period in 2002. Means followed by different letters indicate significant differences between treatments at $P \leq 0.05$, Student-Newman-Keuls range test.

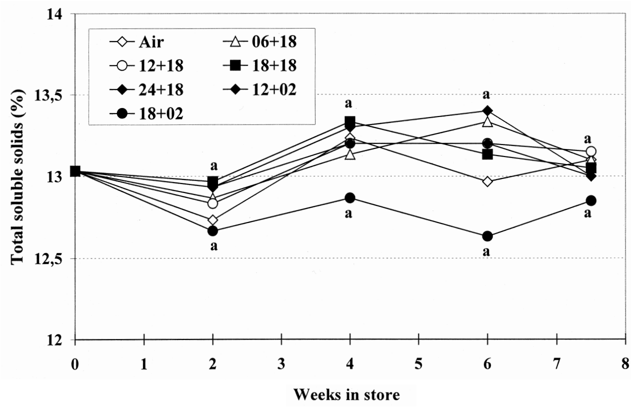

FIG. 2
Influence of storage conditions (%CO_2 + %O_2) at 1°C on the total soluble solids (TSS) of gooseberries 'Achilles' during the entire storage period in 2002. Means followed by different letters indicate significant differences between treatments at $P \leq 0.05$, Student-Newman-Keuls range test.

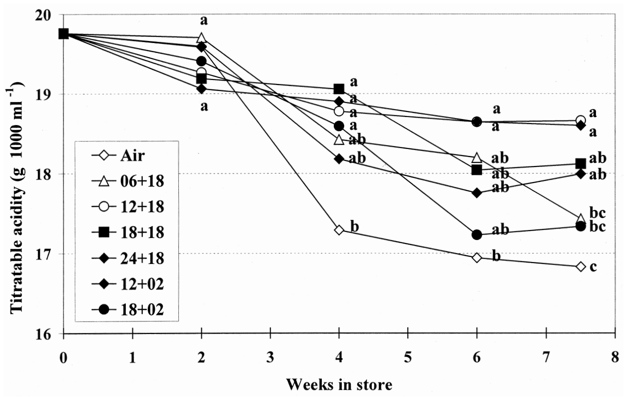

FIG. 3
Influence of storage conditions (%CO_2 + %O_2) at 1°C on the titratable acidity (TA) of gooseberries 'Achilles' during the entire storage period in 2002. Means followed by different letters indicate significant differences between treatments at $P \leq 0.05$, Student-Newman-Keuls range test.

(1995) with lowbush blueberries. Further, Agar *et al.* (1991) found that red and black currants remained firmer under both high CO_2 and CA-storage (high CO_2-concentrations combined with low O_2-concentrations).

Total soluble solids (TSS): No significant differences among all treatment in respect to TSS at all sampling dates were registered (Figure 2). Moreover, increasing storage time did not influence the TSS of fruits. It is difficult to get a clear response of TSS to various CA-storage conditions, mainly due to strong fluctuations in measured data. Perkins-Veazie and Collins (2002) reported also that CA-storage (10% O_2, 15% CO_2) of blackberry gave inconsistent TSS-readings over a storage period of 14 d, with no significant differences between CA- and air-stored berries at the end of the storage period. Moreover, Haffner *et al.* (2002) found that storing raspberries in normal atmosphere or in CA-conditions (15% CO_2+10% O_2, or 31% CO_2+10% O_2) resulted in non-significant differences among these treatments in respect to soluble solids over a 7 d storage period. However, it seems that storing fruits under 18% CO_2 with 2% O_2 may have an impact; readings were lower, although non-significant. The reason behind that may be that fermentation rate was higher with these fruits.

Titratable acidity (TA): During the entire storage period TA-concentrations were highly influenced by storage conditions. Air stored-fruits gave significantly the lowest values throughout the storage period (Figure 3). Haffner et al. (2002) reported a decrease in titratable acidity with raspberries stored under air condition compared with those stored under CA (CO_2-concentrations were 15 or 31%). Concerning other treatments, it can be noticed that increasing CO_2-concentration (12, 18 or 24 at 18% O_2, or 12% CO_2-concentration in combination with 2% O_2 resulted in better retention of acidity. However, there was an accelerated catabolism of acids with 18% CO_2 combined with 2% O_2, and 6% CO_2 combined with 18% O_2. The reasons could be that 6% CO_2 is not sufficient to impose a retarding effect on respiration, particularly on enzymes responsible for breakdown of organic acids. McGlasson and Wills (1972) reported for bananas that two specific reactions in TCA-cycle are influenced by atmosphere of only 3% O_2, namely those between pyruvate and citrate, and between 2-oxyglutarate and succinate. Monnig (1983) also reported for apples that high CO_2-concentration retarded glycolysis, the activity of succinate dehydrogenase, and the synthesis of citrate/isocitrate and α-ketoglutarate. However, it is more difficult to explain the result with 18+2. One explanation could be that this very stressful condition may result in decompartmentation of cell structure that leads to an accelerated catabolism of organic acids.

Fruit colour: Changes in colour (CIE L*, a*, b*), hue (h°), and chroma (C)) of gooseberries were the most obvious among all quality parameters (Figure 4 and Table I). Air-stored fruits became red more rapidly over the entire storage period than CA-stored fruits, followed by fruits stored under high O_2 combined with moderate CO_2-concentration (6% CO_2+18% O_2) (Figure 4). By reaching the end of storage period (after 7.5 weeks) air-stored fruits were darker (lower L*), more intense in red (higher a*), less intense in yellow (lower b*), and had a more red, bluish hue (lower °h) (Table I). According to Moore (1997), both hue angle and b*/a* were parameters sufficiently accurate for screening populations for anthocyanin concentrations of raspberry fruits, it can be suggested that air-stored gooseberries in the present study synthesized and contained more anthocyanin by the end of storage period. Kalt and McDonald (1996) reported such increase in anthocyanin synthesis with lowbush blueberries, where concentration of anthocyanin increased by 18% after two weeks storage period in air at 0°C. Haffner *et al.* (2002) showed that pigment level of red raspberries increased during storage in air, while no significant changes were registered under CA-conditions with high to very high CO_2-concentrations. In our study, increasing CO_2-concentration to 12% drastically retarded the colour change. Decreasing O_2-concentration to 2% also resulted in the preservation of green colour at harvest time, even after 7.5 weeks in store. It is obvious from results of the present study that a combination of very high CO_2 and low O_2-concentration is highly effective in retardation of colour change, which is considered as an advantage to the marketability of gooseberries. However, increasing CO_2-concentration to very high concentrations (18% or more) without O_2

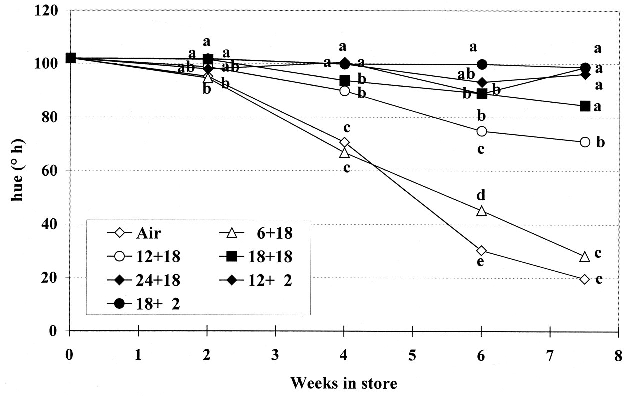

FIG. 4
Influence of storage conditions (%CO_2 + %O_2) at 1°C on the hue values (h°) of gooseberries 'Achilles' during the entire storage period in 2002. Means followed by different letters indicate significant differences between treatments at $P \leq 0.05$, Student-Newman-Keuls range test.

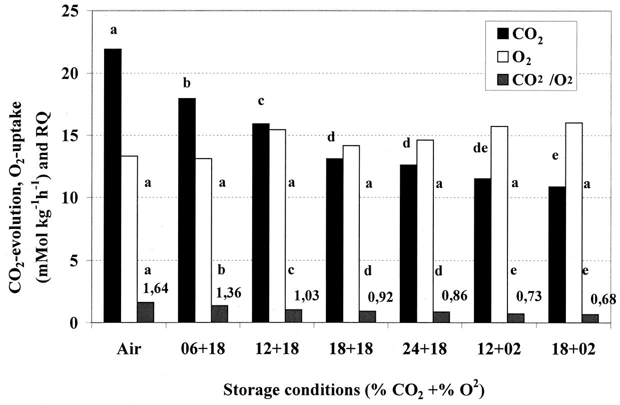

FIG. 5
Respiration behaviour (CO_2-evolution, O_2-uptake, and respiratory quotient (RQ)) of gooseberries stored for five weeks under various CA-conditions (%CO_2 + %O_2) at 1°C and kept under shelf life condition (20°C, 60% relative humidity, and in air) in 2002. Means within each column followed by different letters indicate significant differences between treatments at $P \leq 0.05$, Student-Newman-Keuls range test.

reduction gave the same effect (Figure 4). This has been reported by Gil *et al.* (1997), and Holcroft and Kader (1999) who found in strawberry that treatment with CO_2 inhibits the postharvest increase in anthocynanin concentration. Further, they found that the activities of pheylalanine ammonia lyase (PAL) and UDP glucose : flavonoid glucosyltransferase (GT) decreased during storage in air enriched with 20% CO_2. These findings are important, since the biosynthesis of anthocyanins involve the production of cinnamic acid from phenylalanine by the action of phenylalanine ammonia lyase and UDP glucose : flavonoid glucosyltransferase, resulting in the production of anthocyanin (Holton and Cornish, 1995). Consequently, it seems also for gooseberries that increasing CO_2 concentration and decreasing O_2 has a cumulative effect in retarding colour changes, although increasing CO_2 up to 6% has no influence on all measured chromatic attributes. Moreover, decreasing O_2 concentration to 2% highly retarded colour development; increasing CO_2 concentration up to 24% had the same impact.

Respiration rate

In both years, CA-storage conditions resulted in a differential impact upon both respiration rate and respiratory quotient (RQ) (Figure 5 and Table II). Air-stored fruits respired much higher than fruits from other treatments at all sampling dates in both years. This trend persisted even after a shelf-life of 48 h at 20°C. Increasing CO_2-concentration and/or decreasing O_2-concentration resulted in a significant reduction in respiration rate that persisted also even after 24 or 48 h. Elevated CO_2 may affect respiratory metabolism via effects on glycolysis, fermentative metabolism, the tricarboxylic (TCA) cycle and/or the electron transport chain. Agar and Streif (1996) rerported that storing raspberries under high CO_2 concentration reduced their rate of respiration. However, it is obvious that decreasing O_2-concentration to 2% was more effective than increasing CO_2-concentration (compare treatments 18+12 with 2+12 and 18+18 with 2+18), although a 48 h shelf-life in the first year ended with non-significant differences between these treatments. On the other hand, RQ-value for air-stored fruits reached 1.64 at the end of storage period (Figure 5). Increasing CO_2-concentrations resulted in much lower values; decreasing O_2-concentration resulted in lowering the RQ-value further down to 0.68. Consequently, it is obvious that air-stored fruits consumed much more organic acids due to their higher respiration rate. That led to higher RQ. It is known that RQ-value reaches 1.3 when malate is used as a substrate for respiration in fruits. (Wills *et al.* 1998). On the other hand, when RQ is less than one, fat metabolism prevailed; long-chain fatty acids served here as the substrates for respiration.

TABLE I
Influence of storage conditions (%CO_2 + %O_2) at 1°C on the colour attributes (L, a, b*) and chroma (C) of gooseberries 'Achilles' after 51 d in storage in 2002. Means followed by different letters indicate significant differences between treatments at* $P \leq 0.05$, *Student-Newman-Keuls range test*

CA-condition	colour attributes			
(%CO_2 + %O_2)	L*	a*	b*	C
Harvesttime	46.4	-3.7	17.6	17.9
Air	30.8 c	9.2 a	03.3 c	09.8 c
06+18	31.8 c	8.0 a	04.3 c	09.1 c
12+18	37.3 b	2.9 b	08.4 b	08.9 c
18+18	39.4 a	1.0 c	10.5 ab	10.5 be
24+18	41.6 a	-1.4 c	12.9 a	13.0 a
12+02	40.4 a	-1.7 c	11.1 ab	11.1 ab
18+02	40.5 a	-1.9 c	12.4 a	12.5 ab

TABLE II
Respiration rate (CO_2-evolution) of gooseberries under various CA-conditions (%CO_2 + %O_2) at 1°C and after a shelf life period of 48 h at 20°C in 2001. Means within each column followed by different letters indicate significant differences between treatments at $P \leq 0.05$, *Student-Newman-Keuls range test*

CA-Condition (%CO2 + %O2)		harvest time	day 13	day 25	day 37	day 37 + 48 h at 20ºC
Air		0.11 a	4.22 a	4.18 a	5.11 a	65.84 a
18 +	06	0.11 a	2.91 b	2.86 b	3.29 b	56.31 b
18 +	12	0.11 a	2.56 bc	2.34 bc	2.15 c	42.67 c
18 +	18	0.11 a	2.09 c	1.93 c	2.94 b	37.50 cd
02 +	12	0.11 a	1.14 d	1.69 c	1.16 d	40.23 cd
02 +	18	0.11 a	1.04 d	2.05 c	1.10 d	37.67 cd
02 +	24	0.11 a	1.18 c	2.13 c	1.30 d	35.98 d

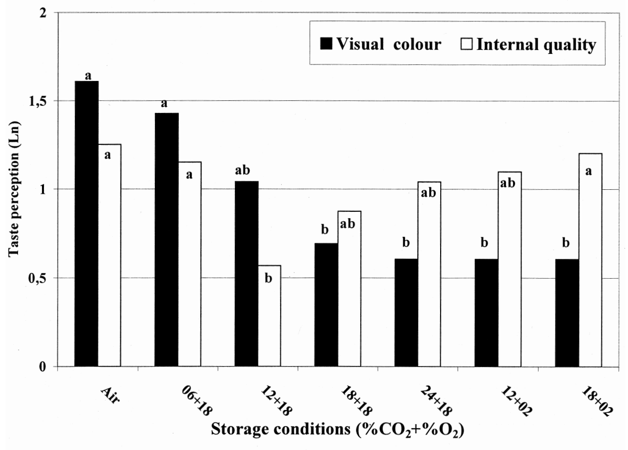

FIG. 6
The perception of taste panel of gooseberries 'Achilles' stored for 7.5 weeks under various storage conditions (%CO_2 + %O_2) at 1°C in 2002. Tests were performed after a shelf-life period of 8 h at 20°C in air. Data were subjected to natural logarithm transformation (*ln*) and further to analysis of variance. Mean separation of the transformed data were conducted with Student-Newman-Keuls range test at $P \leq 0.05$; means followed by different letters indicate significant differences.

Consumer acceptability

The taste panel has evaluated gooseberries after 7.5 weeks in storage (Figure 6). Concerning the external quality, colour seems to be the only possible criterion for gooseberries. Air-stored fruits received the least evaluation mainly due to the senescent appearance of fruits (overripe and dark). Fruits stored under 6+18 also received lower evaluation for the same reasons, although they appeared slightly better than the air- stored fruits. Increasing CO_2-concentration (12% or more) and/or decreasing O_2-concentration resulted in a much better evaluation of external quality, primarily due to fresh appearance (the green colour of fruits). All panelists described gooseberries stored under 18+18 as fresh as the newly harvested fruits. Concerning internal quality, panelists determined that firmness, sweetness/acidity balance and off-flavour as the determining criteria. Air-stored fruits received the least evaluation beside fruits stored under 6+18. Fruits from both treatments were criticized to be too soft and mealy. Moreover, air-stored fruit were described to have too low acidity. Better acceptance was received for fruits stored under 12+18 and 18+18, since fruits were firmer, had more acidity, and did not exhibit off-flavour/off-taste. Panelist described the taste of fruits stored under 12+18 as fresh as newly-harvested fruits. Fruits stored under 18+18 were criticized by some panelists to have mild fermentation taste, which slightly reduced their acceptance. Storing gooseberries under very high CO_2-concentrations, particularly when combined with low O_2-concentration resulted in bad acceptance, mainly due to abnormal taste (off-flavour), which usually reflects an accelerated fermentation process. It was mentioned previously that accumulation of acetaldehyde and ethanol is a common response to CO_2 treatments (Kader, 1986). Our preliminary results (to be described in another article) with odour-volatiles clearly indicate the formation of the fermentation products upon the storage of gooseberries under very high CO_2-concentrations, particularly when combined with low O_2-concentration.

Weight loss

Gooseberries stored under all conditions lost part of their initial weight. Air-stored fruits significantly registered the highest loss, followed by fruits stored under 2+12 (data not shown). However, weight loss of all treatments remained in the acceptable range (less than 2-3%). Perkins-Veazie and Collins (2002) found that weight loss of blackberries stored either in air or in CA-condition (high in CO_2) was less than 1.3%, with no significant differences between treatments.

This research which extended for two years shows that gooseberries 'Achilles' could be safely stored for 7.5 weeks under 12-18% CO_2 combined with 18% O_2. The organoleptic tests in both years confirmed the suitability of fruits for marketing, although panelists noticed a slight off-flavour that did not impair the taste of fruits when gooseberries were kept under 18% CO_2.

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