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Effect of Controlled Atmosphere Storage on Damaged Citrus Fruit Quality

MUHAMMAD AKRAM TARIQ, FAQIR MUHAMMAD TAHIR†, ALI ASGHAR ASI AND MUHAMMAD ASLAM PERVEZ†
Horticulture Section, Ayub Agricultural Research Institute, Faisalabad, Pakistan
†Department of Horticulture, University of Agriculture, Faisalabad–38040, Pakistan

ABSTRACT

Present studies were carried out to evaluate the impact of controlled atmospheric (CA) storage to maintain the quality of citrus fruits which have been damaged through scuffing. The results show that the reduced O_2 and increased CO_2 had no beneficial effects on curing. Different O_2 and CO_2 concentrations had no significant effect on weight loss and on the external and internal fruit quality. The deformation increase and firmness decrease of the damaged part of the fruit held in 2% O_2 with 10% CO_2 and were greater than fruit stored in air (21% O_2 and 0% CO_2) or in other CA combinations. The scuffing damaged part of the fruit completely showed bruising/browning symptoms and became softer due to anaerobic conditions (2% O_2 with 10% CO_2). The bruising/browning and decay symptoms increased with reduced levels of O_2 and increased CO_2 concentration. The atmosphere 2% O_2 with 10% CO_2 was toxic to damaged citrus fruits and, indeed, CO_2 injury was seen as browning symptoms on the scuffing damaged part of the fruit. The fruits held in 10% O_2 with 10% CO_2 showed less CO_2 injury as brown spots on the peel.

Key Words: Citrus; Quality; Controlled atmosphere

INTRODUCTION

The useful storage life of harvested fresh produce can often be extended by a decrease in the O_2 concentration and an increase in the CO_2 content of the surrounding atmosphere, provided such changes are within specific limits for each commodity. Post harvest losses in citrus fruits have been observed too much due to which fruit loses its quality and thus it is a very serious limitation and great loss to the economy of a country. Such losses occur due to non technical methods of harvesting, handling and storage. If damaged fruits are stored under controlled atmosphere (CA), keeping in view the standard limitations, the shelf life of such fruits can be increased and post harvest losses can be minimized.

CA requirements may be precise and that factors other than oxygen and carbon dioxide concentrations, such as maturity, variety, humidity and even techniques, may be involved (Chace *et al*., 1967). Many tests, using various CA storage conditions, demonstrated that CA effectively reduced rind breakdown and often maintained a firm texture of citrus fruits. However, some of these tests showed a substantial increase in fruit decay, generally attributed to an increase in CO_2 concentration (Scholz *et al*., 1960; Rygg & Wells, 1962). The development of anaerobic conditions in the fruit, resulting in off-flavors due to increased internal ethanol, acetaldehyde, has been related to an increase in internal CO_2 and decreased internal O_2 (Cohen *et al*., 1990). This experiment was carried out to test the effect of O_2 and CO_2 concentrations on the fruit quality of scuffing damaged citrus fruits.

MATERIALS AND METHODS

These studies were carried out in Silsoe College Silsoe Cranfield University Bedford MK 45 4DT U.K during 1998-1999. Valencia oranges produced in Spain and obtained from a U.K commercial source and Kinnow mandarin fruits imported from Pakistan were used. The fruits were freshly harvested and were not subjected to any Post harvest treatment. The fruits were damaged by scraping the surface with abrasive paper and then washed with distilled water. The fruits were held in 10 and 2% O_2 concentrations in combination with 0, 5 and 10% CO_2 concentrations and in air (21% O_2 and 0% CO_2) at 35°C with 95-98% RH for 48 hours and subsequent storage at 5°C with 95% RH for 24 days. The gases were mixed (as listed below) and passed through the containers of the fruits at a flow rate of 3 L/minute. Mixed gases were passed through each of the seven containers in sequence for three minutes every 21 minutes. The inlet and outlet gases were analysed each day for O_2 and CO_2 concentration using a Carlo-Erba GC 8000 gas chromatograph fitted with a hot wire detector. The fruits were analysed after 24 days storage. Weight loss percentage, deformation (mm) and firmness (Nmm^{-1}) TSS, acidity, TSS/acid ratio and pH and physiological disorders were measured.

The experiment was a completely randomised design (seven treatments), replicated four times.

Treatments (applied as mixtures)	Actual means of gas mixtures
1. 21% O_2 and 0% CO_2	1. 20.8% O_2 and 0% CO_2
2. 10% O_2 and 0% CO_2	2. 9.8% O_2 and 0% CO_2
3. 10% O_2 and 5% CO_2	3. 9.7% O_2 and 5.2% CO_2
4. 10% O_2 and 10% CO_2	4. 9.7% O_2 and 10.4% CO_2
5. 2% O_2 and 0% CO_2	5. 1.7% O_2 and 0% CO_2
6. 2% O_2 and 5% CO_2	6. 1.8% O_2 and 5.3% CO_2
7. 2% O_2 and 10% CO_2	7. 1.7% O_2 and 10.5% CO_2

RESULTS AND DISCUSSION

Weight loss percentage. The results regarding weight loss percentage of Kinnow mandarin and Valencia oranges are given in Tables I and II, respectively. The decreasing O_2 and increasing CO_2 concentrations had no significant effect on weight loss. Fruits held in air (21% O_2 with 0% CO_2) had a higher weight loss followed by the combinations of 10% O_2 with 0% CO_2, 10% O_2 with 5% CO_2, 10% O_2 with 10% CO_2 and 2% O_2 with 0% CO_2. The fruits held in 2% O_2 with 5% CO_2 had the lowest weight loss followed by those held in 2% O_2 with 10% CO_2 where the weight loss was slightly higher than that of the treated ones (2% O_2 with 5% CO_2). These changes in concentrations (low O_2 and higher CO_2) could, therefore, account for higher weight loss of the fruits held in 2% O_2 with 10% CO_2. At higher CO_2 and lower O_2 levels, the damaged part of the fruit, became softer due to anaerobic conditions, which increased the weight loss. It is possible that a high CO_2 concentration started to damage the tissues and due to this weight loss increased. Respiration of oranges was reported to be a function of O_2 tension in the range of 0-8% O_2 with anaerobic reaction occurring below 2.5% O_2 (Biale, 1961). It has previously been shown that reducing respiration as well as transpiration (Salunkhe *et al*., 1991) can reduce the weight loss of fruits and vegetables in storage. High concentrations of CO_2 (15%) have been shown to result in toxic levels of succinate accumulate in apples causing damage to the tissues (Kays, 1991). Lemons remained in good condition for up to six months under an atmosphere of 6-10% O_2 and essentially no CO_2 at 10°C (Wild *et al*., 1977).

Deformation and Firmness. The deformation increase and

Table I. Effects of different O_2 and CO_2 concentrations on the quality of scuffing damaged Kinnow mandarin fruits after curing for 48 hours at 35°C with 95-98% RH and subsequent storage at 5°C with 95% RH for 24 days

Treatments	T_1 O_2–CO_2 21–0%	T_2 O_2–CO_2 10--0%	T_3 O_2–CO_2 10–5%	T_4 O_2–CO_2 10--10%	T_5 O_2–CO_2 2–0%	T_6 O_2–CO_2 2–5%	T_7 O_2–CO_2 2–10%	LSD (P=0.05)
Weight Loss % (g)	4.36	4.20	4.15	4.02	3.83	3.69	3.81	N. S
Deformation (mm) at 5 N	0.82	0.81	0.81	0.80	0.80	0.81	0.86	N. S
Deformation (mm) at 5 N (damaged part)	0.83	0.82	0.82	0.81	0.81	0.82	0.89	0.05
Deformation (mm) at 5 N (undamaged part)	0.80	0.79	0.79	0.78	0.78	0.79	0.82	N. S
Deformation (mm) at skin failure	7.18	7.06	6.93	6.81	6.73	6.76	7.35	N. S
Deformation (mm) at skin failure (damaged-part)	7.20	7.08	6.95	6.83	6.75	6.78	7.75	0.47
Deformation (mm) at skin failure (undamaged part)	7.15	7.03	6.90	6.78	6.70	6.73	6.95	N. S
Firmness (Nmm^{-1})	4.91	4.97	5.00	5.19	5.13	5.09	4.63	N. S
Firmness (Nmm^{-1}) (damaged part)	4.89	4.94	4.97	5.03	5.10	5.06	4.25	0.25
Firmness (Nmm^{-1}) (undamaged part)	4.93	5.00	5.03	5.34	5.16	5.12	5.01	N. S
TSS	12.18	12.23	12.25	12.30	12.33	12.38	12.28	N. S
Acidity	0.95	0.96	0.96	0.97	0.98	0.98	0.96	N. S
TSS/acid ratio	12.82	12.74	12.76	12.68	12.58	12.60	12.79	N. S
PH	3.71	3.69	3.68	3.66	3.66	3.67	3.70	N. S

Table II. Effects of different O_2 and CO_2 concentrations on the quality of scuffing damaged sweet oranges after curing for 48 hours at 35°C with 95-98% RH and subsequent storage at 5°C with 95% RH for 24 days

Treatments	T_1 O_2–CO_2 21–0%	T_2 O_2–CO_2 10–0%	T_3 O_2–CO_2 10--5%	T_4 O_2–CO_2 10–10%	T_5 O_2–CO_2 2–0%	T_6 O_2–CO_2 2–5%	T_7 O_2–CO_2 2–10%	LSD (P=0.05)
Weight Loss % (g)	2.62	2.47	2.44	2.32	2.18	2.06	2.15	N. S
Deformation (mm) at 5 N	0.69	0.67	0.67	0.66	0.66	0.67	0.71	N. S
Deformation (mm) at 5 N (DP)	0.70	0.69	0.69	0.68	0.68	0.69	0.76	0.05
Deformation (mm) at 5 N (UDP)	0.67	0.65	0.65	0.64	0.64	0.65	0.66	N. S
Deformation (mm) at skin failure	6.08	5.96	5.83	5.69	5.63	5.66	6.41	N. S
Deformation (mm) at skin failure (DP)	6.10	5.98	5.85	5.73	5.65	5.68	6.63	0.47
Deformation (mm) at skin failure (UDP)	6.05	5.93	5.80	5.65	5.60	5.63	6.18	N. S
Firmness (Nmm^{-1})	5.94	5.98	6.20	6.19	6.26	6.30	5.50	N. S
Firmness (Nmm^{-1}) (DP)	5.92	5.97	6.05	6.16	6.24	6.28	5.29	0.43
Firmness (Nmm^{-1}) (UDP)	5.96	5.99	6.34	6.21	6.28	6.32	5.71	N. S
TSS	10.38	10.45	10.45	10.48	10.55	10.55	10.48	N. S
Acidity	1.00	1.01	1.01	1.02	1.03	1.03	1.01	N. S
TSS/acid ratio	10.38	10.35	10.35	10.27	10.24	10.24	10.37	N. S
pH	3.82	3.79	3.76	3.75	3.72	3.73	3.78	N. S

firmness decrease from the damaged part of the fruit held in 2% O_2 with 10% CO_2 were greater than fruit stored in air (21% O_2 and 0% CO_2) or in other CA combinations (Table I & II). There were no differences between fruits held in air (21% O_2 and 0% CO_2) and in other CA combinations. Decreasing O_2 and increasing CO_2 concentrations had a significant effect on deformation and firmness from the damaged part of the fruit. The deformation increased and firmness decreased from the damaged part of the fruit with reduced levels of O_2 and increased CO_2 concentration. It is possible that due to anaerobic conditions the high CO_2 damaged the tissues and fruits became softer and reduced firmness. The atmosphere of 2% O_2 with 10% CO_2 was toxic to damaged citrus fruits and, indeed, CO_2 injury was seen as browning symptoms on the damaged part of the fruit peel. In previous research, it had been shown that the physical examination of fruits at the end of one week's storage under 5% CO_2 indicated no change in appearance and firmness as compared to control (0% CO_2). However, at 10% CO_2, there were traces of CO_2 injury as evidenced by reddish brown spots and softening (Lakshminarayana & Subramanyam, 1970). Exposure of fruits to 10% CO_2 for 1 and 7 days was safe; however, a 14 days exposure resulted in CO_2 injury. The CO_2 injury was manifested as discoloration and physical damage in the form of collapse of the rind cells, which caused softening (Harton *et al*., 1974). The rind injury developed in fruits held at 10% CO_2. This injury was characterised by large areas of soft and grey-brown tissues (Davis *et al*., 1973).

TSS, Acidity, TSS/acid ratio and pH. The TSS and acidity of fruits slightly decreased and TSS/acid ratio and pH increased when fruits were held in air (21% O_2 and 0% O_2) compared to CA storage combinations (Table I & II). It is possible that the fruit held in air had decreased TSS and acidity due to a higher respiration rate. In previous research, it had been shown that no marked differences were found in total soluble solids, total acids, pH and ascorbic acid between Valencia oranges from CA storage and those from air (Chace *et al*., 1967). The storage of fruit in air decreased acidity (Pesis & Avissar, 1989). The juice of Valencia oranges stored at 3% O_2 and 5% CO_2 (3.5^{o}C) lost less acid than oranges held in air storage (0^{o}C) and the concentration of Citric acid and Malic acids in the juice of Shamouti oranges (*Citrus sinensis*, (L) Osbeck) declined with storage time (Kays, 1991).

The TSS and acidity of fruits held in 2% O_2 with 10% CO_2 slightly decreased and TSS/acid ratio and pH increased with increasing CO_2 concentration compared to the remaining CA storage combinations. However, this decrease in acidity, TSS and increase in TSS/acid ratio and pH were lower compared to fruits held in air (21% O_2 and 0% CO_2) treatment. It is possible that this decrease may be due to anaerobic conditions where organic acids may be used as energy production/used as reserve source of energy. Acid levels in the fruits can be affected by CA treatments. Acidity was reduced in stored grape fruit during a 20 hour anaerobic treatment with pure N_2 at 40°C (Bruemmer & Roe, 1969). Controlled atmosphere of apples and some other climacteric fruits (5% CO_2, 2-3% O_2) has been highly successful in maintaining fruit quality and extending storage life at low temperatures (Eckerts & Eaks, 1989). Grierson and Ben-Yehoshua (1986) pointed that it is unreasonable to expect CA storage to provide similar benefits for citrus fruit because they are fully ripe at harvest. The optimum CA conditions for maintaining quality in citrus fruits appear to be a about 0 to 1% CO_2 and 10 to 15% O_2 (Oogaki & Manago, 1977).

Physiological disorders. The effect of different O_2 and CO_2 concentrations on physiological disorders of scuffing damaged fruit was that the bruising/browning symptoms were observed on fruits held in 10 and 2% O_2 concentrations in combination with 0 and 10% CO_2 concentration. Fruits held in air (21% O_2 with 0% CO_2) or in other CA combinations did not show bruising/browning and decay symptoms up to 24 days of storage except the fruits held in 2% O_2 with 10% CO_2 and 10% O_2 and with 10% CO_2 where bruising/browning symptoms were observed in fruits after 24 days of storage. However, the bruising and browning symptoms were less on the peel of the fruits held in 10% O_2 with 10% CO_2 than 2% O_2 with 10% CO_2. If the CO_2 levels are too high and O_2 levels are low, effects similar to those caused by anaerobiosis (lack of oxygen) could be initiated (Wills *et al*., 1989). The CO_2 injury was manifested as discoloration and physical damage in the form of collapse of the rind cells, which caused softening (Harton *et al*., 1974). The rind injury developed when fruits were held in 10% CO_2. This injury was characterized by large area of soft, grey-brown tissues (Davis *et al*., 1973).

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