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FRUITS OTHER THAN APPLES AND PEARS

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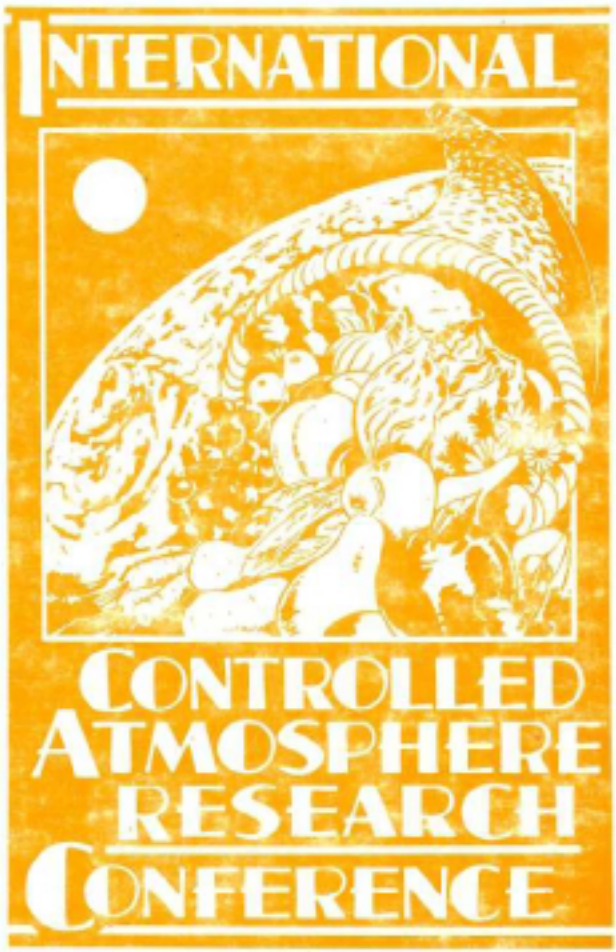

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A SUMMARY OF CA REQUIREMENTS AND RECOMMENDATIONS FOR FRUITS OTHER THAN APPLES AND PEARS

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General Summary

	Commodity	Temperature Range[1] (°C)	CA[2] % O_2	CA[2] % CO_2	Commercial use as of June, 1997
1	Apricot	0-5	2-3	2-3	
2	Avocado	5-13	2-5	3-10	Used during marine transport
3	Banana	12-16	2-5	2-5	Used during marine transport
4	Blackberry	0-5	5-10	15-20	Used within pallet covers during transport
5	Blueberry	0-5	2-5	12-20	Limited use during transport
6	Cherimoya & Atemoya	8-15	3-5	5-10	
7	Cherry, sweet	0-5	3-10	10-15	Used within pallet covers or marine containers during transport
8	Cranberry	2-5	1-2	0-5	
9	Durian	12-20	3-5	5-15	
10	Fig	0-5	5-10	15-20	Limited use during transport
11	Grape	0-5	2-5 or	1-3	Incompatible with SO_2
			5-10	10-15	Can be used instead of SO_2 for decay control up to 4 weeks
12	Grapefruit	10-15	3-10	5-10	
13	Kiwifruit	0-5	1-2	3-5	Expanding use during transport and storage; C_2H_4 must be maintained below 20 ppb
14	Lemon	10-15	5-10	0-10	
15	Lime	10-15	5-10	0-10	
16	Lychee (litchi)	5-12	3-5	3-5	
17	Mango	10-15	3-7	5-8	Increasing use during marine transport
18	Nectarine	0-5	1-2 or	3-5	Limited use during marine transport
			4-6	15-17	Used to reduce chilling injury (internal breakdown) of some cultivars

	Commodity	Temperature Range[1] (°C)	CA[2] % O_2	CA[2] %CO_2	Commercial use as of June, 1997
19	Olive	5-10	2-3	0-1	Limited use to extend processing season
20	Orange	5-10	5-10	0-5	
21	Papaya	10-15	2-5	5-8	
22	Peach, clingstone	0-5	1-2	3-5	Limited use to extend canning season
23	Peach, freestone	0-5	1-2 or	3-5	Limited use during marine transport
			4-6	15-17	Used to reduce incidence and severity of internal breakdown (chilling injury) of some cultivars
24	Persimmon	0-5	3-5	5-8	Limited use of MA packaging
25	Pineapple	8-13	2-5	5-10	Waxing is used to create MA and reduce endogenous brown spot
26	Plum	0-5	1-2	0-5	Limited use for long-term storage of some cultivars
27	Pomegranate	5-10	3-5	5-10	
28	Rambutan	8-15	3-5	7-12	
29	Raspberry	0-5	5-10	15-20	Used within pallet covers during transport
30	Strawberry	0-5	5-10	15-20	Used within pallet covers during transport
31	Sweetsop (custard apple)	12-20	3-5	5-10	

[1]Usual and/or recommended range; a relative humidity of 90-95% is recommended.

[2]Specific CA combination depends on cultivar, temperature, and duration of storage. These recommendations are for transport and/or storage beyond 2 weeks. Exposure to lower O_2 and or higher CO_2 concentrations for shorter durations may be used for control of some physiological disorders, pathogen, and/or insects.

COMMODITY: Apricot

OPTIMUM TEMPERATURE: -0.5° TO 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-3 %	2-3%
Benefits:	Delayed ripening	Firmness retention
Potential for benefits:	Moderate	Moderate
Injurious level:	< 1%	> 5%
Injury symptoms:	Off-flavor development	Loss of flavor, flesh browning
Potential for injury:	Slight to moderate	Slight to moderate

Commercial use or potential: Very limited use on apricots destined for canning

REMARKS: The addition of 5-10% CO, as a fungistat, may improve the potential for benefit from CA. Prestorage treatment with 20% CO_2 for 2 days may reduce incidence of decay during subsequent storage in CA or air.

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COMMODITY: Avocado

OPTIMUM TEMPERATURE: 10°C, expected range: 5° to 13°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-5 %	3-10%
Benefits:	Delayed ripening, reduced rates of CO_2 and C_2H_4 production	Delayed softening, reduced chilling injury symptoms
Potential for benefits:	Good	Good
Injurious level:	< 1%	> 15%
Injury symptoms:	Off-flavor, internal flesh browning	Skin browning, off-flavors
Potential for injury:	Moderate	Moderate

Commercial use or potential: Use during long-distance transport is expanding.

REMARKS: Exclusion and/or removal of ethylene to below 1 ppm from air or CA storage are recommended. Exposure to 25-30% CO_2 for 2-3 days can delay decay incidence during subsequent storage in air or CA.

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COMMODITY: Banana

OPTIMUM TEMPERATURE: 14°C, expected range: 12° to 16°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-5 %	2-5%
Benefits:	Delayed ripening	Delayed ripening
Potential for benefits:	Very good	Very good
Injurious level:	< 1%	> 7%
Injury symptoms:	Dull yellow or brown skin discoloration, failure to ripen, off-flavors	Green fruit softening undesirable texture & flavor
Potential for injury:	High	Moderate to high

Commercial use or potential: About 30%of the bananas are shipped in CA during long-distance transport. Modified atmospheres (1-5% O_2 and 4-6% CO_2) and/or ethylene-absorbents are also used commercially during transport and distribution.

REMARKS: Cooking bananas and plantains have similar CA responses to those shown above.

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COMMODITY: Blackberry

OPTIMUM TEMPERATURE: -0.5 to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	5-10%	15-20%
Benefits:	Reduced respiration rate	Reduced decay, firmness retention
Potential for benefits:	Moderate	Very good
Injurious level:	< 2%	> 25%
Injury symptoms:	Off-flavors	Off-flavors
Potential for injury:	Slight to moderate	Moderate

Commercial use or potential: Limited use during transport within pallet covers

REMARKS: Prompt cooling to near 0°C should be done before modification of the atmosphere

SELECTED REFERENCES:

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COMMODITY: Blueberry

OPTIMUM TEMPERATURE: -0.5° to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-5 %	12-20%
Benefits:	Reduced respiration rate	Reduced decay
Potential for benefits:	Moderate	Very good
Injurious level:	< 1.5%	> 25%
Injury symptoms:	Off-flavors	Skin browning, off-flavors
Potential for injury:	Slight to moderate	Moderate

Commercial use or potential: Limited use during transport within pallet covers

REMARKS: Prompt cooling to near 0°C before MA is established and maintenance of such temperature during transport are essential to reduction of postharvest losses.

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COMMODITY: Cherimoya and Atemoya

OPTIMUM TEMPERATURE: 10°C, expected range: 8° to 15°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-5 %	5-10%
Benefits:	Lower respiration and ethylene production rates, retarded ripening, firmness retention	Delayed ripening
Potential for benefits:	Good	Moderate
Injurious level:	< 1%	?
Injury symptoms:	Off-flavors	?
Potential for injury:	High	?

Commercial use or potential: Cherimoyas can be kept for up to 6 weeks at 10°C in 5% O_2, then ripened with good flavor at 20°C.

REMARKS: Ethylene removal can be helpful in retarding ripening.

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COMMODITY: Cherry, sweet

OPTIMUM TEMPERATURE: -1° to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-10%	10-15%
Benefits:	Firmness retention	Decay control, maintenance of fresh appearance
Potential for benefits:	Moderate	Very good
Injurious level:	< 1%	> 30%
Injury symptoms:	Skin pitting, off flavors	Brown discoloration of skin, off-flavors
Potential for injury:	Moderate	Moderate to high

Commercial use or potential: Increasing use during transport, especially for export marketing

REMARKS: Elevated CO_2 may provide a satisfactory alternative to postharvest fungicides for decay control

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COMMODITY: Cranberry

OPTIMUM TEMPERATURE: 3°C, expected range: 2° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	1-2 %	0-5%
Benefits:	Reduced respiration, reduced decay	Firmness retention
Potential for benefits:	Slight to moderate	Slight
Injurious level:	< 1%	?
Injury symptoms:	Off-flavors	?
Potential for injury:	Slight	?

Commercial use or potential: None at this time

REMARKS: Further research is needed to identify potential benefits and limits of tolerance to CO_2

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COMMODITY: Durian

OPTIMUM TEMPERATURE: 15°C, expected range: 12° to 20°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-5 %	5-15 %
Benefits:	Lowered CO_2 and C_2H_4 production rates, retarded ripening	Retarded ripening if combined with 10% or lower O_2
Potential for benefits:	Good	Moderate
Injurious level:	< 2%	> 20%
Injury symptoms:	Failure to ripen, Grey discoloration of pulp	?
Potential for injury:	High	?

Commercial use or potential: None at this time (July 1997)

REMARKS: Modified atmosphere packaging and waxing can reduce CO_2 and C_2H_4 production rates and sulphurous odor characteristic of ripe durian.

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COMMODITY: Fig

OPTIMUM TEMPERATURE: -1 °C to 0 °C, expected range: 0° to 5 °C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	5-10%	15-20%
Benefits:	Reduced respiration and ethylene production	Decay control, firmness retention
Potential for benefits:	Moderate	Good
Injurious level:	< 2%	> 25%
Injury symptoms:	Off-flavors	Loss of flavor
Potential for injury:	Moderate	Moderate

Commercial use or potential: Limited use during transport within pallet covers.

REMARKS: Further research is needed to understand the reasons for loss of flavor of fresh figs after storage in 15 - 20% CO_2 for more than 2 weeks.

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COMMODITY: Grape

OPTIMUM TEMPERATURE: -1° to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-5%	1-5%
Benefits:	Delayed senescence	Reduced decay
Potential for benefits:	Moderate	Slight
Injurious level:	< 1%	> 5% (for longer than 6 weeks)
Injury symptoms:	Off-flavors	Browning of berries and stems
Potential for injury:	Slight to moderate	Moderate
Commercial use or potential:	Incompatible with SO_2 fumigation	

REMARKS: CO at 5-10% can be combined with CA to provide decay control (equally effective to SO_2). Also, CO_2 at 10-15% in air can be used for control of grey mold for up to 2-4 weeks (depending on cultivar) and 45% CO_2 in air can be used for insect control for up to 2 weeks without detrimental effects on the grapes.

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6. Uota, M. 1957. Preliminary study on storage of Emperor grapes in controlled atmospheres with and without sulfur dioxide fumigation. Proc. Amer. Soc. Hort. Sci. 69:250-253.

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COMMODITY: Grapefruit

OPTIMUM TEMPERATURE: 13°C, expected range: 10° to 15°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-10%	5-10%
Benefits:	Delayed senescence, firmness retention	Reduced pitting and other chilling injury symptoms at 7 to 12°C, reduced stem-end breakdown
Potential for benefits:	Slight to moderate	Moderate
Injurious level:	< 3%	> 10%
Injury symptoms:	Off-flavors due to increased ethanol and acetaldehyde contents	Scald-like areas on the rind, off-flavors
Potential for injury:	Moderate	Moderate

Commercial use or potential: Very limited use of CA + 5 to 10% CO, as a fungistat, for export shipments

REMARKS: Prestorage treatment with 10-20% CO_2 for a few days may reduce chilling injury during subsequent handling at 7 to 10°C

SELECTED REFERENCES:

1. Artés, F., J. Aparicio, A.J. Escriche and J.G. Marin. 1994. Cold storage of 'Red blush' grapefuit under normal and controlled atmosphere and carbon dioxide treatments, p. 149-157. In: P.E. Zerbini et al., (eds.). Proc. Cost 94 Workshop on CA Storage of Fruit and Vegetables; April 22-23, 1993, Milan, Italy.

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COMMODITY: Kiwifruit

OPTIMUM TEMPERATURE: 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	1-2%	3-5%
Benefits:	Delayed ripening	Firmness retention
Potential for benefits:	Excellent	Excellent
Injurious level:	< 1%	> 7%
Injury symptoms:	Off-flavors	Internal breakdown of the flesh
Potential for injury:	Moderate	Moderate

Commercial use or potential: Increasing commercial use during both transport and storage

REMARKS: CA must be established within 2 days after harvest to maximize benefits; ethylene concentration should be kept below 20 ppb to avoid accelerated flesh softening and incidence of white core inclusions.

SELECTED REFERENCES:

1. Arpaia, M.L., F.G. Mitchell, A.A. Kader, and G. Mayer. 1985. Effects of 2% O_2 and varying concentrations of CO_2 with or without C_2H_4 on storage performance of kiwifruit. J. Amer. Soc. Hort. Sci. 110:200-203.

2. Arpaia, M.L., F.G. Mitchell, A.A. Kader, and G. Mayer. 1986. Ethylene and temperature effects on softening and white core inclusions of kiwifruit stored in air or controlled atmospheres. J. Amer. Soc. Hort. Sci. 111:149-153.

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4. Ben-Arie, R. and L. Sonego. 1985. Modified-atmosphere storage of kiwifruit (Actinidia chinensis Planch) with ethylene removal. Scientia Hort. 27:263-273.

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COMMODITY: Lemon

OPTIMUM TEMPERATURE: 13°C, expected range: 10° to 15°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	5-10%	0-10%
Benefits:	Delayed senescence	Delayed loss of green color
Potential for benefits:	Moderate	Moderate
Injurious level:	< 5%	> 10%
Injury symptoms:	Off-flavors	Increased susceptibility to decay, decreased acidity
Potential for injury:	Moderate to high	Moderate to high
Commercial use or potential:	Very limited use of 5% O_2 + 5% CO_2 + 5 to 10% CO (for decay control) during export shipment of lemons	

REMARKS: Removal of ethylene from lemon storage facilities can reduce rate of degreening (senescence) and decay incidence.

SELECTED REFERENCES:

1. Artes, F., A.J. Escriche, and J.G. Marin. 1993. Treating 'Primofiori' lemons in cold storage and intermittent warming and carbon dioxide. HortScience 28:819-821.

2. Bertolini, P., G. Lanza, and G. Tonini. 1991. Effects of pre-storage carbon dioxide treatments and storage temperatures on membranosis of `Femminello comune' lemons. Scientia Hort. 46:89-95.

3. Grierson, W., H.M. Vines, M.F. Oberbacher, S.V. Ting, and G.J. Edwards. 1966. Controlled atmosphere storage of Florida and California lemons. Proc. Amer. Soc. Hort. Sci. 88:311-318.

4. Harding, P.R., Jr. 1964. Effect of low oxygen and low carbon dioxide combination in controlled atmosphere storage of lemon, grapefruit and oranges. Plant Dis. Reptr. 53:585-588.

5. McDonald, R.E. 1986. Effects of vegetable oils, CO_2, and film wrapping on chilling injury and decay in lemons. HortScience 21:476-477.

6. Rygg, G.L. and A.W. Wells. 1962. Experimental storage of California lemons in controlled atmospheres. USDA, AMS Rept. 475, 11 p.

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COMMODITY: Lime

OPTIMUM TEMPERATURE: 13°C, expected range: 10° to 15°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	5-10%	0-10%
Benefits:	Retarded senescence	Retarded degreening
Potential for benefits:	Moderate	Slight to moderate
Injurious level:	< 5%	> 10%
Injury symptoms:	Scald-like injury, decreased juice content	Increased susceptibility to decay
Potential for injury:	Moderate	Moderate to high

Commercial use or potential: Very limited use of CA + 5 to 10% CO (for decay control) during marine transport.

REMARKS: Removal of ethylene from lime storage facilities can be beneficial in retarding degreening and reducing decay

SELECTED REFERENCES:

1. Hatton, T.T. and W.F. Reeder. 1968. Quality of Persian limes after different packinghouse treatments and storage in various controlled atmospheres. Proc. Trop. Reg. Amer. Soc. Hort. Sci. 11:23-32.

2. Spalding, D.H. and W.F. Reeder. 1974. Quality of 'Tahiti' limes stored in a controlled atmosphere or under low pressure. Proc. Trop. Reg. Amer. Soc. Hort. Sci. 18:128-134.

3. Spalding, D.H. and W.F. Reeder. 1976. Low pressure (hypobaric) storage of limes. J. Amer. Soc. Hort. Sci. 101:367-370.

4. Wardowski, W.F., W. Grierson, and G.J. Edwards. 1973. Chilling injury of stored limes and grapefruit as affected by differentially permeable packaging films. HortScience 8:173-175.

COMMODITY: Lychee (Litchi)

OPTIMUM TEMPERATURE: 7°C, expected range: 5° to 12°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-5%	3-5%
Benefits:	Reduced skin browning and polyphenoloxidase activity	Slower rates of losses of ascorbic acid, acidity, and soluble solids
Potential for benefits:	Good	Moderate
Injurious level:	< 1%	> 15%
Injury symptoms:	Off-flavors	Off-flavors, dull gray appearance of the pulp
Potential for injury:	Moderate	Moderate

Commercial use or potential: Modified atmosphere packaging is used to a limited extent

REMARKS: Maintenance of high relative humidity is essential for reduction of water loss and browning.

SELECTED REFERENCES:

1. Chen, W.X., M.X. Su, and P.M. Lee. 1982. A study of controlled atmosphere storage of litchi. Journal of South China Agricultural University 3:54-61.

2. Paull, R.E. and J.N. Chen. 1987. Effect of storage temperature and wrapping on quality characteristics of litchi fruit. Scientia horticulturae 33:233-236.

3. Paull, R.E., M.E.Q. Reyes, and M.U. Reyes. 1995. Litchi and rambutan insect disinfestation: treatments to minimize induced pericarp browning. Postharvest Biol. Technol. 6:139-148.

COMMODITY: Mango

OPTIMUM TEMPERATURE: 13°C, expected range: 10° to 15°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-7%	5-8%
Benefits:	Delayed ripening	Firmness retention
Potential for benefits:	Moderate	Slight to moderate
Injurious level:	< 2%	> 10%
Injury symptoms:	Skin discoloration, off-flavors	Off-flavors, softening, grayish flesh color
Potential for injury:	Moderate	Moderate

Commercial use or potential: Increasing use of 5% O_2 + 5% CO_2 during marine transport.

REMARKS: Avoiding chilling injury is important when CA is used. Use of heat treatments to reduce anthracnose is highly recommended.

SELECTED REFERENCES:

1. Bender, R.J., J.K. Brecht, and C.A. Campbell. 1994. Responses of 'Kent' and 'Tommy Atkins' mangoes to reduced O_2 and elevated CO_2. Proc. Fla. State Hort. Soc. 107:274-277.
2. Bender, R.J., J.K. Brecht, and S.A. Sargent. 1995. Inhibition of ethylene production in mango fruit by elevated CO_2 and recovery during subsequent air storage. Proc. Fla. State Hort. Soc. 108:279-285.
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5. Maekawa, T. 1990. On the mango CA storage and transportation from subtropical to temperate regions in Japan. Acta Hort. 269:367-374.
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9. Spalding, D.H. and W.F. Reeder. 1977. Low pressure (hypobaric) storage of mangos. J. Amer. Soc. Hort. Sci. 102:367-369.
10. Yahia, E.M. and l. Vasquez-Moreno. 1993. Responses of mango to insecticidal oxygen and carbon dioxide atmospheres. Lebersm. Wiss. u. Technol. 26:42-48.

COMMODITY: Nectarine

OPTIMUM TEMPERATURE: -0.5°C to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	1-2%	3-5%
Benefits:	Delayed ripening, firmness retention	A slight reduction in internal breakdown
Potential for benefits:	Moderate	Moderate
Injurious level:	< 1%	> 10%
Injury symptoms:	Failure to ripen, skin browning, off-flavors	Flesh browning, loss of flavor
Potential for injury:	Moderate	Slight to moderate

Commercial use or potential: Limited use of CA during marine transport

REMARKS: Cultivars differ greatly in their postharvest-life potential. Internal breakdown is the limiting factor in long-term storage of many nectarine cultivars. Use of intermittent warming in combination with CA or exposure to 15-17% CO_2 + 4-6% O_2 may overcome this problem in some cultivars.

SELECTED REFERENCES:

1. Anderson, R.E. 1982. Long-term storage of peaches and nectarines intermittently warmed during controlled atmosphere storage. J. Amer. Soc. Hort. Sci. 107:214-216.
2. Anderson, R.E., C.S. Parsons, and W.L. Smith, Jr. 1969. Controlled atmosphere storage of eastern-grown peaches and nectarines. USDA, Mktg. Res. Rpt. 836, 19 p.
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6. Olsen, K.L., and H.A. Schomer. 1975. Influence of controlled-atmosphere on the quality and condition of stored nectarines. HortScience 10:582-583.
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10. Tonini, G., S. Brigati, and D. Caccioni. 1989. CA storage of nectarine: influence of cooling delay, ethylene removal, low O_2 and hydrocooling on roots, overripening, internal breakdown and taste of fruits. Acta Hort. 254:335-340.

COMMODITY: Olive

OPTIMUM TEMPERATURE: 7°C, expected range: 5° to 10°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-3%	0-1%
Benefits:	Delayed senescence	Firmness retention
Potential for benefits:	Good	Slight
Injurious level:	< 2%	> 5%
Injury symptoms:	Off-flavors, lower oil quality	Increased severity of chilling injury on olives kept at <7°C
Potential for injury:	Slight	Moderate

Commercial use or potential: Very limited use on olives destined for processing.

REMARKS: Exposure to chilling temperatures (<7°C) should be avoided if olives are kept in CA.

SELECTED REFERENCES:

1. Garcia, J.M., F. Gutierrez, J.M. Castellano, S. Perdiguero, A. Morilla, and M.A. Albi. 1994. Storage of olives destined for oil extraction. Acta. Hort. 368:673-681.

2. Garcia, J.M. and J. Streif. 1991. The effect of controlled atmosphere storage on fruit and oil quality of `Gordal' olives. Gartenbauwissenschaft 56:233-238.

3. Gutierrez, F., S. Perdiguero, J.M. Garcia, and J.M. Castellano. 1992. Quality of oils from olives stored under controlled atmosphere. J. Amer. Oil Chem. Soc. 69:1215-1218.

4. Kader, A.A., G.D. Nanos, and E.L. Kerbel. 1989. Responses of `Manzanillo' olives to CA storage. Proc. 5th Intl. CA Research Conf., Wenatchee, WA, vol. 2, pp. 119-125.

5. Kader, A.A., G.D. Nanos, and E.L. Kerbel. 1990. Storage potential of fresh `Manzanillo' olives. Calif. Agr. 44(3):23-24.

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COMMODITY: Orange

OPTIMUM TEMPERATURE: 7°C, expected range: 5° to 10°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	5-10%	0-5%
Benefits:	Delayed senescence, firmness retention	May reduce chilling injury symptoms
Potential for benefits:	Slight	Slight
Injurious level:	< 5%	> 5%
Injury symptoms:	Off-flavors	Off-flavors
Potential for injury:	Moderate	Moderate

Commercial use or potential: Very limited use of 5% O_2 + 5% CO_2 + 5 to 10% CO (as a fungistat) during marine transport

REMARKS: Decay control is the limiting factor to long-term storage of oranges. Removal of ethylene from orange storage facilities can help in reducing decay.

SELECTED REFERENCES:

1. Davis, P.L., B. Roe, and J.H. Bruemner. 1973. Biochemical changes in citrus fruits during controlled-atmosphere storage. J. Food Sci. 38:225-229.

2. Eaks, I.L. and W.A. Ludi. 1960. Effects of temperature, washing, and waxing on the composition of the internal atmosphere of orange fruits. Proc. Amer. Soc. Hort. Sci. 76:220-228.

3. Ke, D. and A.A. Kader. 1990 Tolerance of `Valencia' oranges to controlled atmospheres as determined by physiological responses and quality attributes. J. Amer. Soc. Hort. Sci. 115:779-783.

4. Shaw, P.E., M.G. Moshonas, M.O. Nisperos-Carriedo, and R.D. Carter. 1991. Controlled-atmosphere treatment of freshly harvested oranges at elevated temperature to increase volatile flavor components. J. Agr. Food Chem. 40:1041-1045.

5. Shaw, P.E., M.G. Moshonas, and E. Pesis. 1991. Changes during storage of oranges pretreated with nitrogen, carbon dioxide and acetaldehyde in air. J. Food Sci. 56:469-474.

6. Smoot, J.J. 1969. Decay of Florida fruit stored in controlled atmosphere and in air. Proc. 1st Intl. Citrus Symp. 2:1283-1293.

COMMODITY: Papaya

OPTIMUM TEMPERATURE: 12°C, expected range: 10° to 15°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-5%	5-8%
Benefits:	Delayed ripening (degreening and softening)	Firmness retention
Potential for benefits:	Slight to moderate	Slight to moderate
Injurious level:	< 2%	> 8%
Injury symptoms:	Off-flavors, failure to ripen	Off-flavors, may aggravate chilling injury at < 12°C
Potential for injury:	High	Moderate

Commercial use or potential: None at this time; waxing may be used to modify internal O_2 and CO_2 concentrations.

REMARKS: Chilling injury should be avoided when CA is used. Prestorage treatments to minimize decay during storage are essential to successful storage.

SELECTED REFERENCES:

1. Akamine, E.K. 1969. Controlled atmosphere storage of papayas. Univ. Hawaii Ext. Misc. Publ. 64:23-24.

2. Alvarez, A.M. 1980. Improved marketability of fresh papaya by shipment in hypobaric containers. HortScience 15:517-518.

3. Chen, J.N. and R.E. Paull. 1986. Development and prevention of chilling injury in papaya fruit. J. Amer. Soc. Hort. Sci. 111:639-643.

4. Hatton, T.T., Jr. and W.F. Reeder. 1969. Controlled-atmosphere storage of papayas. Proc. Trop. Reg. Amer. Soc. Hort. Sci. 13:251-256.

5. Maharaj, R. and C.K. Sankat. 1990. Storability of papayas under refrigerated and controlled atmosphere. Acta Hort. 269:375-385.

6. Nazeeb, M. and W.J. Broughton. 1978. Storage conditions and ripening of papaya 'Bentong' and `Taiping'. Scientia Hort. 9:265-277.

7. Paull, R.E. and N.J. Chen. 1989. Waxing and plastic wraps influence water loss from papaya fruit during storage and ripening. J. Amer. Soc. Hort. Sci. 114:937-942.

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COMMODITY: Peach, clingstone

OPTIMUM TEMPERATURE: -0.5°C to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	1-2%	3-5%
Benefits:	Delayed ripening	Firmness retention
Potential for benefits:	Good	Good
Injurious level:	< 1%	> 5%
Injury symptoms:	Off-flavors in the canned product	Internal flesh browning severity increases with CO_2 concentration and time
Potential for injury:	Moderate	Moderate

Commercial use or potential: Limited use for pre-processing storage of late-season cultivars to extend the canning season

REMARKS: Cultivars differ greatly in their storage potential in CA or air

SELECTED REFERENCES:

1. Brecht, J.K., A.A. Kader, C.M. Heintz, and R.C. Norona. 1982. Controlled atmosphere and ethylene effects on quality of California canning apricots and clingstone peaches. J. Food Sci. 47:432-436.

2. Claypool, L.L. and L.D. Davis. 1959. Effect of cold and modified atmosphere storage on the canning quality of cling peaches. Food Technol. 13:208-212.

3. Kader, A.A. 1985. Cold storage potential of cling peach varieties. Cling Peach Quarterly 21(1):18-19.

4. Kader, A.A., S. Briggs, and A. Chordas. 1986. Genotypic variation in postharvest behavior and cold storage potential of clingstone peaches. Progress Report, Department of Pomology, University of California, Davis.

COMMODITY: Peach, freestone

OPTIMUM TEMPERATURE: -0.5 °C to 0 °C, expected range: 0° to 5 °C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	1-2%	3-5%
Benefits:	Delayed ripening and softening	Slight reduction in internal breakdown of some cultivars
Potential for benefits:	Moderate	Moderate
Injurious level:	< 1%	> 10%
Injury symptoms:	Failure to ripen, skin browning, off-flavors	Flesh browning, off-flavors
Potential for injury:	Moderate	Slight to moderate

Commercial use or potential: Limited use of CA during marine transport

REMARKS: Cultivars differ greatly in their postharvest-life potential. Internal breakdown is the limiting factor to long-term storage of many peach cultivars. Use of intermittent warming in combination with CA or exposure to 15-17% CO_2 + 4-6% O_2 may overcome this problem in some cultivars.

SELECTED REFERENCES:

1. Anderson, R.E., R.W. Penny, and W.L. Smith, Jr. 1977. Peach storage in a controlled atmosphere with intermittent warming: A pilot test using inexpensive flowmeters and plastic bags as CA chambers. HortScience 12:345-346.
2. Crisosto, C.H., D. Garner, and G. Crisosto. 1997. Evaluating the relationship between controlled atmosphere storage, peach fruit size and internal breakdown. Perishables Handling 90:7-8.
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6. Rushing, J.W. and A. Dinamarca. 1993. Simulated shipment of peaches, plums, and nectarines under controlled atmospheres. p. 202-222. In: Proc. Int'l CA Res. Conf., NRAES-71, Cornell University, Ithaca, NY.
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8. Wade, N.L. 1981. Effects of storage atmosphere, temperature, and calcium on low temperature injury of peach fruit. Scientia Hort. 15:145-154.

See also the references listed for nectarines

COMMODITY: Persimmon

OPTIMUM TEMPERATURE: -1° to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-5%	5-8%
Benefits:	Delayed ripening	Firmness retention, reduced chilling injury symptoms on `Fuyu' persimmons
Potential for benefits:	Good	Good
Injurious level:	< 3%	> 10%
Injury symptoms:	Failure to ripen, off-flavors	Off-flavors, brown discoloration
Potential for injury:	Moderate	Moderate

Commercial use or potential: Limited use of MA packaging

REMARKS: CO_2 at 60-90% for 24 hours at 17° to 20°C can be used to remove astringency while maintaining firmness of `Hachiya' and other astringent cultivars of persimmon.

SELECTED REFERENCES:

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COMMODITY: Pineapple

OPTIMUM TEMPERATURE: 10°C, expected range: 8° to 13°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	2-5%	5-10%
Benefits:	Delayed senescence, reduced respiration	Delayed degreening, reduced chilling injury
Potential for benefits:	Slight to moderate	Moderate
Injurious level:	< 2%	> 10%
Injury symptoms:	Off-flavors	Off-flavors
Potential for injury:	Moderate	Moderate

Commercial use or potential: Very limited use during marine transport.

REMARKS: Waxing may be used to modify O_2 and CO_2 concentration within the fruit enough to reduce incidence and severity of endogenous brown spot (chilling injury).

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COMMODITY: Plum

OPTIMUM TEMPERATURE: -0.5°C to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	1-2%	0-5%
Benefits:	Delayed ripening	Firmness retention
Potential for benefits:	Good	Moderate to good
Injurious level:	< 1%	> 15%
Injury symptoms:	Failure to ripen, off-flavors	Flesh browning
Potential for injury:	Moderate	Moderate
Commercial use or potential:	Limited use for storage (>1 month) of some cultivars, such as Angeleno, Casselman, Santa Rosa, Laroda, and Queen Ann.	

REMARKS: Cultivars differ greatly in their storage potential in air or in CA. CA can be used to delay ripening at 10°C of some "slow-ripening" cultivars (such as Casselman, Late Santa Rosa, and Roysum), and thus allow storage at this non-chilling temperature. For other cultivars, 10-15% CO_2-enriched atmospheres can be used during transport at 0-2°C to reduce chilling injury.

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COMMODITY: Pomegranate

OPTIMUM TEMPERATURE: 5°C, expected range: 0° to 10°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-5%	5-10%
Benefits:	reduced chilling injury	retarded decay
Potential for benefits:	Good	Good
Injurious level:	< 2%	> 10%
Injury symptoms:	Off-flavors	Aggravation of husk scald caused by chilling injury; loss of red color
Potential for injury:	Moderate	Moderate

Commercial use or potential: None as of June, 1997; potential is good for long-term storage

REMARKS: Additional research is needed before the optimum temperature-time-CA combination can be identified.

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COMMODITY: Rambutan

OPTIMUM TEMPERATURE: 10°C, expected range: 8° to 15°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-5%	7-12%
Benefits:	Retardation of senescence, lower respiration rate	Retarded red color loss, extended postharvest life to about one month if water loss is minimized
Potential for benefits:	Slight	Moderate
Injurious level:	< 1%	> 20%
Injury symptoms:	Increased decay incidence	?
Potential for injury:	High	?

Commercial use or potential: Modified atmosphere packaging has potential for maintaining quality.

REMARKS: Maintenance of high relative humidity is essential to minimizing water loss and preventing skin darkening.

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COMMODITY: Raspberry

OPTIMUM TEMPERATURE: -0.5°C to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	5-10%	15-20%
Benefits:	Reduced respiration rate	Reduced decay, firmness retention
Potential for benefits:	Moderate	Very good
Injurious level:	< 2%	> 25%
Injury symptoms:	Off-flavors	Off-flavors, brown discoloration
Potential for injury:	Slight to moderate	Moderate

Commercial use or potential: Increasing use within pallet covers during transport

REMARKS: Proper temperature management is prerequisite for successful handling of raspberries

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COMMODITY: Strawberry

OPTIMUM TEMPERATURE: -0.5° to 0°C, expected range: 0° to 5°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	5-10%	15-20%
Benefits:	Reduced respiration rate	Firmness retention, reduced decay
Potential for benefits:	Good	Very good
Injurious level:	< 2%	> 25%
Injury symptoms:	Off-flavors	Off-flavors, purple and brown discoloration
Potential for injury:	Slight to moderate	Moderate

Commercial use or potential: About 60% of the strawberries shipped out of California are treated with 15-20% CO_2 within pallet covers following cooling to near 0°C.

REMARKS: Proper temperature management is essential for maintaining quality of strawberries.

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COMMODITY: Sweetsop (custard apple)

OPTIMUM TEMPERATURE: 15°C, expected range: 12° to 20°C

MODIFIED ATMOSPHERE CONSIDERATIONS:

	REDUCED O_2	INCREASED CO_2
Beneficial range:	3-5%	5-10%
Benefits:	Reduced ethylene production and respiration, delayed ripening	Delayed ripening
Potential for benefits:	Good	Moderate
Injurious level:	< 1%	15% and higher
Injury symptoms:	Failure to ripen	Flat taste and uneven ripening
Potential for injury:	High	Moderate

Commercial use or potential: None at this time (July, 1997)

REMARKS: Ethylene removal can be helpful in retarding ripening.

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Molecular Responses of Strawberry Fruit to Carbon Dioxide

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Strawberry fruit respond beneficially to 20% carbon dioxide treatment as indicated by enhanced flesh firmness and increased resistance to decay. However, carbon dioxide treatment also can cause detrimental effects, such as development of off-flavor, depending on factors such as concentration and length of exposure to the gas, temperature and cultivar. To characterize molecular responses of the fruit to high carbon dioxide treatment, the mRNA differential display technique has been used to identify and clone genes expressed in carbon dioxide-treated fruit compared with air-treated fruit at both 2°C and 20°C. Forty-eight cDNA bands have been selected and grouped into four families: carbon dioxide-induced at both temperatures, induced only at low temperature, or induced at warm temperature, when carbon dioxide-treated and inhibited by carbon dioxide. These cDNA bands are being cloned and sequenced. Genebank database search found that most of them have homology with known genes. Tentative identification indicates that genes induced by carbon dioxide include alcohol dehydrogenase, spermidine-binding protein and rbcl intergene. We have also tentatively identified carbon dioxide-repressed genes such as ACC synthase. Full length clones are being obtained by the 5' RACE technique. Possible function(s) of the genes in responses of strawberry fruit to carbon dioxide will be discussed.

Effect of Carbon Dioxide on Anthocyanin Biosynthesis During Storage of Fresh Strawberry

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Although carbon dioxide-enriched atmospheres are used to reduce the incidence and severity of decay and extend the postharvest life of strawberries, they can adversely affect color. Initial experiments showed a decrease in anthocyanin concentration of external and internal tissues of 'Selva' strawberry stored in elevated CO_2 atmospheres. We hypothesized that this effect could be explained, at least partially, by a reduction in biosynthesis of anthocyanins. This experiment was repeated on 'Camerosa' strawberries which were placed in jars ventilated continuously with air or air enriched with 10% or 20% CO_2 at 5°C for 10 days. Samples were taken initially, and after 5 and 10 days of storage, and color (L* a* b* color space), pH, titratable acidity (TA), soluble solids content (SSC) and firmness were measured. Anthocyanins were quantified in the internal and external fruit tissue by HPLC. pH of the external tissues did not change significantly but pH of the internal tissues increased during storage, particularly in fruit stored in CO_2-enriched atmospheres. TA was stable in the external tissues but decreased in the internal tissues of all fruit during storage. Fruit stored in CO_2-enriched atmospheres were paler, particularly in the internal tissues. Again a reduction in anthocyanin biosynthesis in both external and internal tissues of fruit stored in elevated CO_2 was observed. External tissues contained cyanidin 3-glucose, pelargonidin 3-glucose and pelargonidin 3-rutinoside, while internal tissues only contained pelargonidin derivatives. The activities of phenylalanine ammonia lyase (PAL) and UDP-glucose:flavonoid 3-O-glucosyltransferase (GT) were measured.

Development of High Concentration Carbon Dioxide Modified Atmosphere Packaging Systems to Maintain Peach Quality

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Additional index words. Chilling injury, flesh browning, flesh mealiness, internal breakdown

Abstract. **Evaluation of different modified atmosphere packaging (MAP) systems were studied in 'Elegant Lady' and 'O'Henry' peach cultivars. Different carbon dioxide (CO_2) and oxygen (O_2) concentrations were attained by using bag box liners made with different film permeabilities to enhance CO_2 accumulation. Internal box liner CO_2 and O_2 atmospheric composition was monitored during a 21 day storage period at 1°C. Fruit quality, with an emphasis on evaluation for flesh browning and mealiness, was measured after cold storage on ripe fruit. CO_2 level varied from 10 to 25% and O_2 levels from 1.5 to 10%. A reduction in flesh browning and mealiness was measured on the MAP treatment with the highest CO_2 levels. As a follow up to this screening test, the best MAP treatments in maintaining peach quality were tested in a semi-commercial scale shipment from Valparaíso (Chile) to Los Angeles (USA). After 30 days shipment, fruit firmness, decay incidence, soluble solids concentration, flesh browning and mealiness were measured on ripe 'O'Henry' peaches. The rate of fruit softening was slow and flesh browning was reduced on all of the high CO_2-MAP treatments. Mealiness was reduced only in the high CO_2 and low O_2 MAP treatments, which resulted in off flavors due to high ethanol formation. This suggests that more detailed work on the development of MAP with high CO_2 and low O_2 concentrations should be pursued.**

Flesh browning and mealiness are the main symptoms of internal breakdown of peaches. Many attempts have been approached to prolong the storage life of peaches. Delayed cooling (Nanos and Mitchell, 1991, Dodd et al., 1986), intermittent warming (Anderson and Penney. 1975, Ben-Arie et. al., 1970), and controlled atmosphere storage (CA) (Lurie 1992, Kajiura 1975, Retamales et. al., 1992) have been tried although, other problems such as softening, decay and off flavor usually appeared.

CA storage has been reported, from different parts of the world, to reduce the internal breakdown of stone fruit. However, the optimum CO_2 and O_2 concentration varies in relation to the cultivar and growing conditions. Haller (1952) working with different peach varieties found injury with a CO_2 concentration above 10%. Kajiura (1975) retarded the manifestation of internal breakdown in 'Okubo' white flesh peach using a combination of 3% CO_2 and 3% O_2 but, he did produce similar results with 3% O_2 without CO_2. Wade (1981) got total control of internal breakdown without "off

flavor" in 'J.H. Hale' peach, when a 20% CO_2 in air was used. Other researchers have reported the beneficial effect of working with high levels of CO_2 in nectarines (Retamales et al. 1992, Lurie 1992).

The beneficial effects of high level of CO_2 (>10%) while maintaining a high level of O_2 (7%) to avoid fermentation is an approach to controlling internal breakdown. Under Chilean conditions, controlled atmosphere has to be developed during transportation. The use of modified atmosphere during this transportation period is an interesting possibility for the Chilean peach export market as long as a high CO_2 concentration remains inside the liner. The possibility of developing a modified atmosphere with high levels of CO_2 in an aerobic condition has been difficult to obtain. Deily and Rizvi (1991) could not find a liner available to reach the optimum concentration inside the package CO_2 (15 - 25%) and O_2 (10 - 15%) for peaches at a calculated steady state. Rij and Ross (1987) while working with overwrapped peaches with different polyvinylchloride (PVC) concluded that CO_2 transmission could not get a CO_2 concentration higher than 4.5 % CO_2 and 4% O_2 when the peaches were stored for 14 days at 1°C. Lurie (1992) extended the storage life of peaches and nectarines using low density polyethylene (PE) liners and reached levels of 4-5% CO_2 and 11-12% O_2 after 6 weeks of storage. The highest CO_2/O_2 ratio was 10/8, obtained with 'Fantasia' nectarines packed in PE films.

Different MAP systems which included polyethylene and physical perforation films were evaluated to match the optimum high carbon dioxide concentration to maintain peach quality.

Materials and Methods

'Elegant Lady' peach was harvested from an orchard in the central valley of Chile (Maipo), following the standard maturity for USA: Firmness= 56.3 N, total soluble solids= 12.6%, titratable acidity= 0.57% malic acid. The fruit was treated with 1,000 ppm Iprodione (Rhone Poulenc Agro) and packed in different types of bags. The size of the bags was 27 x 34 cm with 9 fruits per bag, with 30% remaining free space. The films were prepared by San Jorge (Santiago, Chile) Company from Dow chemical resins and different nomenclatures were assigned to the films: PUC 961, 962, 963, 964, 965, 966. The films 961 and 962 consisted of three perforations of 0.2 mm^2 on the same film characteristics of 964 and 963 respectively.

The oxygen and vapor transmission rates of polymeric films were obtained by ASTM method D3985-81 and F1249-90, respectively (ASTM, 1979) and summarized in Table 1.

The bags were heat sealed and the fruit was cooled overnight reaching an average pulp temperature of 1°C. The fruit was evaluated after 21 days storage at 1°C and after 3 or 4 days of ripening at 20°C. Fruit quality parameters evaluated were firmness with a penetrometer (effegi) using 11 mm tip, soluble solids content with a temperature compensated refractometer (Atago) and titratable acidity. Titratable acidity was determined by titrating 5 mL of juice to an end point of pH 8.2 with 0.1 N NaOH and expressing the acidity as percent malic acid. Flesh browning of each fruit was accessed as healthy= 0%, low= <10%, moderate= 10-50%, and severe= > 50%; mealiness was rated as juicy or not juicy fruit.

CO_2 and O_2 concentration were measured at 2, 7, 14, 21 days from the internal atmosphere of the bags, 2 ml were extracted with two 1 ml syringes and injected into the chromatograph (Fyson 8500) with a thermal conductivity detector separated into two columns, one for O_2 and the other for CO_2 using helium as carrier gas.

Ethanol and acetaldehayde were determined after 21 days storage by distillation of a known

amount of frozen fruit in a vapor stream using propanol as an internal standard. The gas sample was injected into the chromatograph (Fyson 8500) with a flame ionization detector.

Five replications were evaluated in a randomized experiment. Mean separation was done by Analysis of Variance (ANOVA) and LSD test with the arsin %/100 transformed data.

Commercial validation. 'O'Henry' peach was harvested following the maturity standard for export: total soluble solids concentration= 12.9%, titratable acidity= 0.54% malic acid, firmness= 62 N.

The fruit was hydrocooled to 3°C and stored for one day at 0°C following commercial processing which included washing, waxing, manual selection and mechanical calibration. The fruit was packed in a size 40 tray with an average of 175 g/fruit, and sealed inside a 56 x 50 cm bag with 53.9% remaining free space. Different bags were selected from the 'Elegant Lady' experiment PUC 961 (PUC 964 with 12 holes of 0.2 mm^2), 962 (PUC 963 with 12 holes of 0.2 mm^2), 963, 964, 966. The control fruit were packed in a polyethylene liner without sealing. The postharvest period was 30 days, divided into a storage time of 10 days at 1°C in Chile and a transportation period of 20 days by vessel .

At California's Los Angeles port, the fruit were transported by a refrigerated truck and loaded in Irvine, where it was picked up and transported in a unrefrigerated truck during the night to the Kearney Agricultural Center, Parlier, California.

The fruit were evaluated after a 10 day postharvest period, before loading, and after arriving in Los Angeles using the same parameter as in the 'Elegant Lady' experiment. The CO_2 and O_2 was quantified by a Carle AGC-111 chromatograph. The pulp temperature was recorded during the postharvest period using data logger sensor (Stow Away XTI, Onset Computers Corporation).

Four replications were evaluated in a randomized experiment. Mean separation was done by Analysis of Variance (ANOVA) and LSD test with the arsin %/100 transformed data.

Results and Discussion

Elegant Lady. A high incidence of internal breakdown was observed in 'Elegant Lady' fruit. Mealiness and flesh browning affected approximately 76% and 60% of the fruit respectively (Table 1). The liners evaluated, modified the air composition inside the bag, increasing the CO_2 and reducing the O_2 concentration. At two days of storage, the CO_2 concentration reached a range of 6 to 8% CO_2 depending on the film material. After seven days, it was possible to distinguish the three groups of films from each other in relation to CO_2 accumulation: one group in the range of 8 to 10% CO_2 for the perforated bag (PUC 961 and PUC 962), 15% for PUC 965 and 966, the third group was higher than 15% CO_2 (PUC 963, 964). The oxygen concentration, however, stabilized in two groups, one in the range of 8 to 10 % (PUC 961, 962) and the other between 1.8 to 2.7% (PUC 963, 964, 965, 966) (Figure 1).

The perforated films were the most effective way to obtain a high oxygen level (10%) with 15% CO_2 inside the bag without any negative effect or "off flavor" development. These films significantly reduced mealiness incidence by 60%. The perforated 962 film reduced flesh browning from 60% to 8%. The use of perforated film has been proposed (Edmond et al., 1990) as a system to change the permeability ratio CO_2/O_2 of the film from four to six to approximately 1 allowing the storage of fruit with high CO_2 but without reaching the low critical level of oxygen.

Better control of internal breakdown was attained by using a more impermeable film. Ninety and one hundred percent reduction of mealiness and flesh browning respectively, was obtained with

the films PUC 965 and 966, these films were considered to have intermediate CO_2 accumulation (20%). However, these positive results contrasted with symptoms of surface skin discoloration and accumulation of ethanol and acetaldehyde found in the pulp of fruit packed in the more impermeable films (Table 2).

Commercial Validation. 'O'Henry' sent to Los Angeles, California following a semi-commercial scale validation of different MAP systems, reduced the expression of mealiness and flesh browning at two evaluation times. After ten days storage plus ripening, mealiness incidence in the control fruit was 15% compared to almost 0 % in the most impermeable films (PUC 963, 964 and 966). No off flavor was detected in fruit with any of the films at this time. After a total 30 days postharvest, at arrival in Los Angeles, plus a period of ripening the fruit developed a high incidence (88%) of mealiness or flesh browning (Table 3).

Although a high final CO_2 (15%) and low O_2 (4%) level was obtained with the perforated film (PUC 961), it was not enough to reduce the mealiness condition of 'O'Henry' peach (Table 4). Semi-permeable (PUC 966) and film with greater impermeability (PUC 963, 964) were more effective in the reduction of mealiness and controlled flesh browning better done any of the other films. The best treatments PUC 963 and 964, reduced the mealiness in a 70 and 58 % compared to the control, respectively. (Table 3). A significant and negative correlation ($r= -0.92$ $p<0.05$) was found between high CO_2 concentrations and the development of mealiness (Figure 2).

Decay and rate of softening were inhibited with high CO_2 and low O_2 concentration inside the bags. In the perforated bag PUC 961 the CO_2 / O_2 15/4 ratio was not enough to control decay in that high condensation situation (Table 5).

Flesh browning was more feasible to control with the film. The most permeable films, 961 and 962, controlled flesh browning by about 50%, however almost 90% of the flesh browning was inhibited when high CO_2 and low O_2 remained inside the bag (PUC 963, 964 and 966). The reduction of oxygen is involved in the lower browning capacity of the phenols and enzymes to participate in the manifestation of the flesh browning.

The positive effect of high CO_2 found to reduce mealiness and flesh browning agreed with the research done in controlled storage system. The potential for maximum control of internal breakdown was found in a range of high CO_2 (30%) and low O_2 (1%) concentration for 'O'Henry' peach. This level of stress, however, produced an anaerobic condition that generated other symptoms of low quality fruit. To achieve those levels of CO_2 and O_2 can be very dangerous using MAP system therefore, other factors such low temperature management and delayed cooling can be combined with MAP to get a better response using safer CO_2 / O_2 concentrations.

Table 1. Polymeric film characteristics.

Film	Oxygen transmission rate[1]	Vapor Transmission rate[2]	Thickness (mil)[3]
PUC 963	242.0	2.32	2.50
PUC 964	246.5	2.75	2.44
PUC 965	376.5	5.15	2.90
PUC 966	326.5	3.39	2.10

[1] cc-mil/100in^2 C day C atm at 23°C
[2] g-mil/100in^2 C day
[3] 1 mil= 0.00254 cm

Table 2. Influence of modified atmosphere packaging (MAP) systems on the development of flesh browning and mealiness of 'Elegant Lady' peach stored for 21 days at 1°C plus a period of ripening.

Treatments	Mealiness (%)	Flesh Browning (%)
Control	75.6 b	60.0 c
PUC 961	33.3 a	22.2 b
PUC 962	27.7 a	8.3 ab
PUC 963	25.0 a	11.1 ab
PUC 964	11.1 a	0.0 a
PUC 965	8.3 a	0.0 a
PUC 966	5.6 a	0.0 a

Means followed by different letter are significantly different for LSD test ($p< 0.05$).

Table 3. Influence of modified atmosphere packaging systems (MAP) on the concentration of acetaldehyde and ethanol in the tissue of flesh 'Elegant Lady' peach after storage for 21 days at 1°C plus a period of ripening.

Treatments	Acetaldehyde ug/g f.w.	Ethanol Mg/g f.w.
Control	0.0 c	0.012 c
PUC 961	0.0 c	0.15 c
PUC 962	0.98 c	0.26 c
PUC 963	4.3 ab	1.20 a
PUC 964	4.2 a	1.30 a
PUC 965	1.02 a	0.88 b
PUC 966	5.0 a	1.50 a

Means followed by different letter are significantly different for LSD test ($p < 0.05$)
f.w.=FreshWeight

Figure 1. Oxygen and Carbon Dioxide concentrations inside bags according to different films for 'Elegant Lady' peaches stored for 21 days at 1°C.

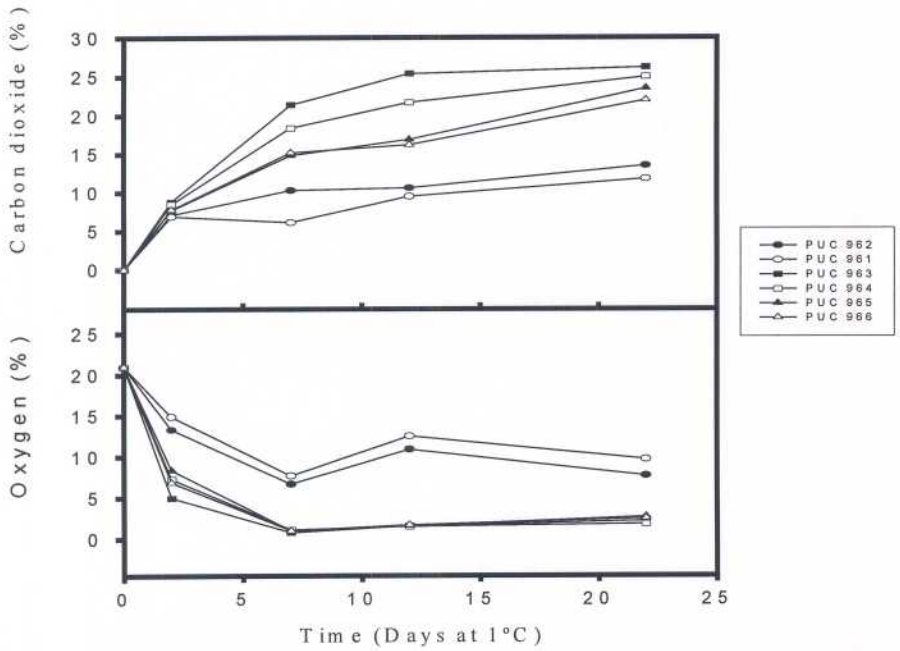


Table 4. Influence of modified atmosphere packaging (MAP) systems on the development of mealiness and flesh browning of 'O'Henry' peach after 10 days storage before loading plus a period of ripening and after 30 days postharvest period (10 days storage before loading + 20 days of transportation to Los Angeles, California) plus ripening.

	Mealiness %		Flesh Browning %	
	Days at 1°C plus ripening			
	10	30	10	30
Treatments				
Control	14.9	87.4 d	3.3	88.4 c
PUC 961	4.8	85.8 cd	0.0	43.3 b
PUC 962	9.3	77.4 c	0.0	45.0 b
PUC 963	0.0	26.2 a	0.0	4.5 a
PUC 964	0.0	37.1 a	0.0	8.3 a
PUC 966	2.2	45.4 b	0.0	9.6 a

Means followed by different letter are significantly different for LSD test ($p < 0.05$).

Table 5. Oxygen and carbon dioxide concentrations inside the modified atmosphere bag for 'O'Henry' peaches measured 10 days before load and after 30 days postharvest period upon arrival in Los Angeles, California.

	Oxygen (%)		Carbon dioxide (%)	
Treatments	10 days	30 days	10 days	30 days
Control	21.0	21.0[1]	0.0	0.0[1]
PUC 961	6.0	3.4 b	10.6	16.9 a
PUC 962	4.6	4.1 b	11.9	14.8 a
PUC 963	2.0	0.6 a	22.2	29.3 c
PUC 964	1.6	0.7 a	25.4	28.7 c
PUC 966	1.5	0.7 a	17.2	23.7 b

Means followed by different letter are significantly different for LSD test ($p < 0.05$)
[1]The control treatment was not considered in the analysis.

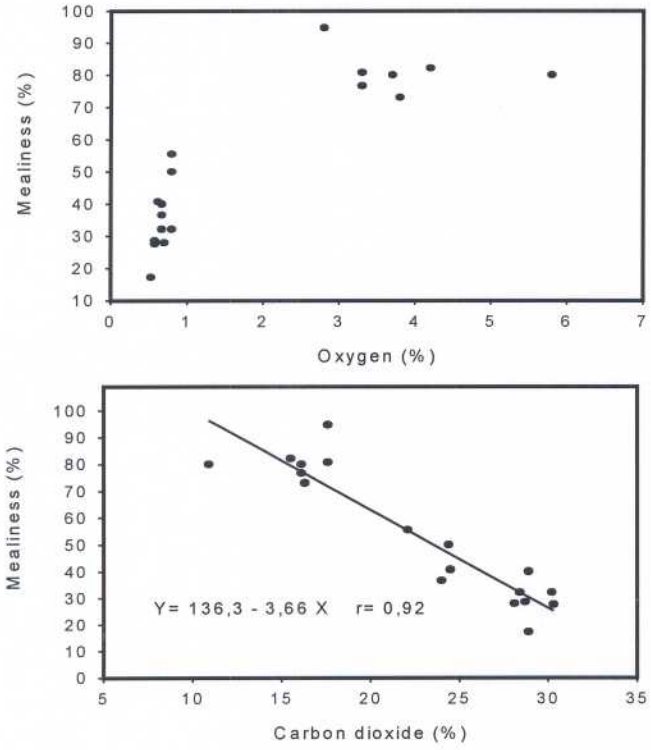
Table 6. Influence of modified atmosphere packaging (MAP) on firmness retention and decay development of 'O'Henry' peaches measured at arriving to Los Angeles (USA) after 30 days of postharvest period.

Treatments	Firmness (N)	Decay[1] (%)
Control	29.0 b[2]	3.3 ab
PUC 961	37.0 b	22.7 c
PUC 962	33.0 b	10.2 bc
PUC 963	50.6 a	5.1 ab
PUC 964	52.8 a	4.4 ab
PUC 966	52.4 a	3.5 a

[1] Fruit evaluated after ripening.

[2] Means followed by different letter are significantly different for LSD test ($p < 0.05$).

Figure 2. Relationship between the Carbon Dioxide, Oxygen and the development of mealiness by using different films for 'O'Henry' peaches.



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High CO_2 Modified Atmosphere Can Be Effective in Preventing Woolliness in Nectarines

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Abstract. **Physiological disorders, mainly woolliness, are the most limiting factors in prolonged storage of many cultivars of peaches and nectarines [*Prunus persica* (L). Batsch] grown in Chile. Based on our previous work, in which CA with high CO_2 content gave control of woolliness, experiments were set up aiming at obtaining similar conditions through MAP. Trials were performed using modified atmosphere obtained through use of sealed plastic bags. In the 1995-96 season, Fantasia and Flamekist nectarines were packed using different films with or without injection of CO_2 at different concentrations (with nitrogen as balance gas) to replace partially the air inside. In the 1996-97 season, July Red, Flamekist and August Red nectarines together with Calred peach were packed using two low permeability films with or without CO_2 injections (with oxygen as balance gas). Fruit was cold-stored for 20 or 30 days and kept afterwards for 5 days at room temperature for ripening (shelf life). After each period, fruit was evaluated for firmness and physiological disorders. In the 1995-96 season, good control of woolliness was obtained in both nectarine cultivars only in the treatments where high CO_2 concentrations (above 10%) were reached. In 1996-97, a reduction in woolliness incidence was obtained in nectarines through MAP, but no control was apparent in Calred peach. In general, high CO_2 treatments resulted in less pronounced softening after cold storage.**

Prolonged storage of peaches and nectarines can be impaired by occurrence of physiological disorders, termed as "chilling injury" or "internal breakdown" (Lill et al., 1989). Susceptibility to these disorders is determined by a number of factors, with cultivar being decisive (Von Mollendorf, 1987). Unfortunately many mid-season and late season cultivars, including most of those exported by Chile to distant markets, are highly susceptible to these problems, especially woolliness.

Previous work carried out in Chile has shown that controlled atmosphere with high CO_2 levels can be very beneficial in preventing these disorders in nectarines after prolonged cold storage (Retamales et al., 1992; Streif et al., 1994). Thus, based on such work, a technology using CA containers has been developed and used successfully in shipping peaches and nectarines to distant markets. The availability of such type of containers, though, is restricted and cannot suffice the entire Chilean production destined to such markets. Therefore, it would be very advantageous to develop a MAP (modified atmosphere packaging) system that could provide the same benefits as CA for prolonged storage of peaches and nectarines. Consequently, a set of experiments were carried out in the 1995-96 and 1996-97 seasons aiming at such an objective.

Materials and Methods

Mid-size Fantasia and Flamekist nectarines (count 36-40) in 1995/96 and July Red, Flamekist, August Red nectarines and Calred peaches in 1996/97, harvested from the same orchard near Rancagua (100 km south of Santiago de Chile), were used for the experiments. Bags made from different films, i.e. low permeability (LP1, low density polyethylene, 70 *u* thick; LP2, low density polyethylene, 75 *u* thick) and high permeability (HP, low density polyethylene, 35 *u* thick, only for Fantasia in 1995/96), were filled with fruit and sealed using a PAC Vacuum Impulse Sealer (Packaging Aids Corporation, San Rafael, CA). Bags were filled with different gas injections either of air or CO_2 with N_2 as balance gas in 1995/96 season and with O_2 in 1996/97 to provide MAP treatments; a control treatment without bags was available in each cultivar. Bags with fruit were put in 5 kg cartons and submitted to forced-air cooling before cold storage for 30 days. Afterwards, bags were opened and put at ambient temperature for 5 days (shelf life) prior to evaluation.

CO_2 and O_2 concentration in the inside of four bags per treatment were determined by sampling with a 5 ml syringe and injecting into a Maptest 4000 gas analyzer (Hitech Instruments Ltd., Luton, England). Fruit firmness was evaluated in 20 fruits at harvest, on four fruits per box in shelf life. The same fruits were used for soluble solids determination. Physiological disorders were determined only in shelf life on all the fruits of each box by classifying them according to the following criteria: woollines, as sound, degree 1 (mealy with some juice by hand pressing) or degree 2 (severe mealy without any juice), internal browning and reddish discoloration as percentage of fruit affected.

Treatments were completely randomized with four boxes per treatment as replicates. Results were analyzed by ANOVA and Duncan´s multiple range test.

Results

Fantasia nectarines (95/96). Different levels of both O_2 and CO_2 were established by initial injections of CO_2 (with nitrogen as balance gas), resulting simultaneously in increased CO_2 and reduced O_2 (Table 1). However, after just 5 days, fruit respiration combined with restricted permeability of the LP film resulted in low O_2 and high CO_2 concentrations for all the three treatments in such bags for most of the storage period. The higher permeability of the HP film, on the other hand, resulted in very little modification of the air inside the bags during the cold storage period.

As a consequence of adequate maturity of the fruit when harvested and appropriate cold storage conditions, little, if any, softening occurred until fruit was removed for ripening (shelf life) and no differences between treatments were apparent (Table 2). After 5 days at ambient temperature following cold storage, though, all the treatments using the LP film bags, which, thus, resulted in high CO_2 content during cold storage, produced firmer fruit than control and HP treatment (Table 3). No differences in soluble solids between treatments and a total absence of internal browning and reddish discoloration were determined for this cultivar (data not shown).

During shelf life, after 30 days cold storage, a high incidence of woolliness ocurred for both LP and control treatments, amounting to 45 and 65%, respectively, whereas absolute control of the problem was achieved through all LP treatments (Table 3). No incidence of decay was found during shelf life (data not shown). Further, no visible damage, both externally or internally, owing to high CO_2 was apparent.

Flamekist nectarines (95/96). As for Fantasia, CO_2 injection (100% CO_2) led to an initial reduction in O_2 content. After only 2 days, however, no differences in O_2 content within both LP treatments were apparent, whereas differences in CO_2 concentration were still discernible after 5 days of cold storage, attaining levels of about 10% CO_2 and 4-8% O_2 inside the sealed bags for most of the period (Table 4). No softening was apparent for any treatment over the entire cold storage period (Table 5), while normal softening accompanying ripening occurred during shelf life, without differences between treatments (Table 6).

While internal browning was almost absent with all treatments, some reddish discoloration occurred, mostly with the control treatment (Table 4). Decay was low and only present in the control treatment. Woolliness was prevalent in the control treatment affecting about 50% of the fruit after 30 days of cold storage. Both LP treatments gave a very good control of the disorder, reducing substantially its incidence without producing symptoms of CO_2 damage.

July Red nectarines (96/97). Although both MAP treatments (LP1 and LP2), including initial CO_2 addition, resulted in high CO_2 and low O_2 levels after 5 days cold storage, use of LP2 film led to further reductions of O_2 levels (Table 7). The latter treatment resulted also in firmer fruit after 30 days cold storage (Table 8), but no differences were established after shelf life (Table 9). LP2 treatment resulted in a reduction of decay after 30 days. Similarly, this treatment reduced incidence of internal browning relative to control and LP1 treatments, whereas both MAP treatments were effective in reducing woolliness.

Flamekist nectarines (96/97). Injection of 60% CO_2 (with O_2 as balance gas) led to initial high levels of both CO_2 and O_2 (Table 10), but active fruit respiration together with low permeability of both films resulted in low O_2 levels irrespective of air or CO_2 injection. Similarly, after just 4 days, CO_2 in all MAP treatments attained very high levels (about 27%) for most of the period thereafter. This could be a consequence of the advanced maturity stage of the fruit as judged from the firmness at harvest (Table 11) and marked softening along the cold storage period, even with MAP treatments. A marked contrast can be drawn, thus to the behavior of the same cultivar in the previous season, when a gradual increase of CO_2 concentration and no softening ocurred during cold storage as a consequence of less advanced maturity. A definite trend to firmer fruits with the MAP treatments was present in shelf life (Table 12), while no differences in decay were determined. Internal browning was again extremely low in this cultivar (data not shown), posing no limitation to fruit quality.

Incidence and severity of woolliness was extremely high in the control treatment, affecting 99% of the fruit after 30 days. Therefore, advanced maturity cannot be considered as a deterring factor in the development of woolliness in this case, but rather the opposite. All the MAP treatments were effective in reducing woolliness to a large extent, agreeing with the results of the previous season.

Calred peaches (96/97). High respiratory rates led to reduced O_2 levels and high CO_2 levels (data not shown). Even when fruit was harvested still firm (12.8 lbs), marked softening ocurred in the control treatment that could be partially counteracted by MAP treatments during cold storage (Table 13). This effect, with firmer fruits from the MAP was still apparent after shelf time (Table 14). Decay was not a problem except in control treatment after 30 days cold storage (Table 14). Woolliness was extremely severe in this cultivar with all the fruit being affected. MAP treatments were not effective in preventing the incidence of the disorder. Clearly, there is a limitation with Calred peaches for the use of this technology, as already demonstrated by others using CA.

August Red nectarines (96/97). The differences in content of the gases between MAP

treatments with low permeability (LP2) film can be attributed mainly to the composition of the initial injections (Table 15). MAP treatments were able to counteract partially the marked softening suffered by control treatment fruit during cold storage (Table 16) and after shelf life (Table 17). Decay was rather high after 27 days cold storage, but no differences owing to the treatments were discernible. Incidence of woolliness was significantly lowered by the treatment with higher CO_2 and lower O_2 (LP2 + 60% CO_2), but its severity was decreased by both MAP treatments (Table 17).

Discussion

Woolliness represents a major limitation to fruit quality of the cultivars studied. The use of MAP is a potentially useful tool to control woolliness to levels already reported with CA in nectarines (Retamales et al., 1992), but it could not prevent it in Calred peaches. Activity of MAP treatments in preventing woolliness was apparently related to high CO_2 and low O_2 levels attained with low permeability films. This agrees with previous work with MAP (Lurie, 1993), but the concentrations shown as beneficial in our work were higher than previously reported by Lurie and no visible CO_2 damage was observed. Notwithstanding the high potential of the method, high respiration rates in the 1996/97 season often led to excessive CO_2 accumulation together with very low O_2 levels, which could result in development of off flavor. Therefore, studies are needed in order to relate respiration rate with fruit maturity for each cultivar and to define film material in terms of permeability to respiration gases. Further work is also needed to determine if initial injections of gases in given combinations are necessary. Despite absence of visible CO_2 damage, tolerance of different cultivars to high CO_2 and/or low O_2 levels should be defined together with potential of the benefit obtained, before precise recommendations can be given.

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Table 1. Gas concentrations (%) during cold storage in Fantasia nectarines (95/96).

Treatment	Jan. 31 0 d.		Feb. 3 2 d.		Feb. 6 5 d.	
	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP1 + air	21.0	0.0	16.3 b	3.2 a	5.2 a	9.5 b
LP1 + 40% CO_2	14.8	3.0	9.3 a	6.8 b	5.3 a	8.2 b
LP1 + 60% CO_2	11.0	4.2	8.5 a	7.7 b	11.3 b	6.6 b
HP. + air	21.0	0.0	17.5 b	1.3 a	18.5 c	0.5 a
Control	21.0	0.0				

Treatment	Feb. 10 10 d.		Feb. 20 20 d.		Mar. 2 30 d	
	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP1 + air	2.5 a	8.0 b	5.0 a	8.0 b	4.2 a	9.8 b
LP1 + 40% CO_2	5.2 a	8.6 b	5.0 a	12.8 c	4.5 a	11.8 b
LP1 + 60% CO_2	5.8 a	6.3 b	4.2 a	12.2 c	4.3 a	10.2 b
HP. + air	11.0 b	0.0 a	16.0 b	1.0 a	19.0 b	1.5 a
Control						

Table 2. Firmness (lb-force) of Fantasia nectarines at harvest and after cold storage (95/96).

Treatment	Jan. 31	Feb. 20	Mar. 2
LP1 + air	11.6	11.7 a	12.1 a
LP1 + 40% CO_2	11.6	10.9 a	12.2 a
LP1 + 60% CO_2	11.6	12.4 a	12.1 a
HP + air	11.6	12.4 a	11.1 a
Control	11.6	11.8 a	11.3 a

Table 3. Quality measurements in shelf life of Fantasia nectarines (95/96).

Treatment	Firmness (lbf)	Woolliness Degree 1 (%)	Woolliness Degree 2 (%)	Woolliness Total (%)
LP1 + air	4.5 c	0.0 a	0.0 a	0.0 a
LP1 + 40% CO_2	4.7 c	0.0 a	0.0 a	0.0 a
LP1 + 60% CO_2	4.4 c	0.0 a	0.0 a	0.0 a
HP + air	2.1 a	20.8 b	25.0 b	45.8 b
Control	3.1 b	27.0 b	37.5 b	64.5 c

Table 4. Gas concentrations (%) during cold storage in Flamekist nectarines (95/96).

Treatment	Feb. 22		Feb. 24		Feb. 27	
	0 d.		2 d.		5 d.	
	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP1 + air	21.0	0.0	5.0 a	4.0 a	3.0 a	7.3 a
LP1+ 100% CO_2	16.0	9.0	4.8 a	13.5 b	3.2 a	13.2 b
Control	21.0	0.0				

Treatment	Mar. 2		Mar. 13		Mar. 23	
	10 d.		20 d.		30 d.	
	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP1 + air	4.3 a	9.0 a	8.8 a	8.2 a	5.0 a	12.2 a
LP1+ 100% CO_2	4.3 a	11.8 a	6.5 a	10.3 a	3.5 a	9.6 a
Control						

Table 5. Firmness (lbf) of Flamekist nectarines at harvest and after cold storage (95/96).

Treatment	Feb. 22	Mar. 13	Mar. 23
LP1 + air	12.0	13.4 a	12.5 a
LP1 + 100% CO_2	12.0	13.3 a	10.6 a
Control	12.0		12.5 a

Table 6. Quality measurements in shelf life of Flamekist nectarines (95/96).

Treatment	Firmness (lb)	Woolliness total (%)	Decay (%)	Browning (%)	Reddish color (%)
LP1 + air	6.2 a	0.0 a	0.0 a	0.0 a	6.3 a
LP1 + 100% CO_2	6.6 a	4.2 a	0.0 a	0.0 a	0.0 a
Control	5.9 a	54.2 c	4.2 a	2.1 a	18.8 a

Table 7. Gas concentrations (%) during cold storage in July Red nectarines (96/97).

Treatment	Feb. 22		Feb. 25		Mar. 4		Mar. 12		Mar. 22	
	2 d.		5 d.		12 d.		19 d.		29 d	
	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP1 + 60% CO_2	9.9 a	8.8 a	4.9 b	18.4 a	3.8 a	19.8 a	6.3 b	17.1 a	6.7 a	19.5 a
LP2 + 60% CO_2	7.4 a	11.9 a	1.0 a	23.2 a	1.7 a	24.7 a	2.6 a	24.0 a	8.1 a	16.4 a
Control										

Table 8. Firmness (lbf) of July Red nectarines at harvest and after cold storage (96/97).

Treatment	Feb. 20	Mar. 12 (20d)	Mar. 22 (30d)
LP1 + 60% CO_2	11.9	9.8 a	9.1 a
LP2 + 60% CO_2	11.9	11.0 a	11.2 b
Control	11.9		9.2 a

Table 9. Quality measurements in shelf life of July Red nectarines (96/97).

Treatment	Firmness (lbf)	Decay (%)	Int. Browning (%)	Woolliness total (%)
LP1 + 40% CO_2	2.4 a	10.0 b	8.8 b	15.7 a
LP2 + 60% CO_2	2.3 a	0.0 a	0.0 a	31.8 a
Control	2.3 a	6.2 b	11.8 b	85.8 b

Table 10. Gas concentrations (%) during cold storage in Flamekist nectarines (96/97).

Treatment	Feb. 21 0 d.		Feb. 22 1 d.		Feb. 25 4 d.	
	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP1 + 60% CO_2	41.7	23.4	1.0 a	20.9 c	1.8 a	26.4 b
LP1 + air	21.0	0.0	3.7 a	12.5 a	1.9 a	27.8 b
LP2 + 60% CO_2	41.7	23.4	1.3 a	17.0 bc	1.3 a	27.8 b
LP2 + air	21.0	0.0	0.5 a	14.0 ab	1.3 a	22.1 a
Control	21.0	0.0				

Treatment	Mar. 4 11 d.		Mar. 12 20 d.		Mar. 22 30 d.	
	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP1 + 60% CO_2	1.3 a	27.1 a	2.9 b	27.0 a	2.1 a	27.5 a
LP1 + air	2.4 a	26.8 a	1.7 ab	29.7 a	5.5 a	21.0 a
LP2 + 60% CO_2	1.7 a	27.9 a	2.1 b	30.1 a	1.9 a	28.0 a
LP2 + air	1.0 a	27.2 a	0.7 a	32.3 a	1.0 a	30.4 a
Control						

Table 11. Firmness (lbf) of Flamekist nectarines at harvest and after cold storage (96/97).

Treatment	Feb. 21	Mar. 12 (20d.)	Mar. 22 (30d.)
LP1 + 60% CO_2	8.4	6.8 a	5.4 a
LP1 + air	8.4	6.9 a	5.9 a
LP2 + 60% CO_2	8.4	7.3 a	5.1 a
LP2 + air	8.4	7.9 a	6.0 a
Control	8.4		

Table 12. Quality measurements in shelf life of Flamekist nectarines (96/97).

Treatment	Firmness (lbf)	Decay (%)	Woolliness total (%)
LP1 + 60% CO_2	3.0 ab	0.8 a	18.1 a
LP1 + air	4.4 c	2.2 a	23.9 a
LP2 + 60% CO_2	3.5 bc	0.7 a	22.6 a
LP2 + air	3.5 bc	0.0 a	8.3 a
Control	2.2 a	5.1 a	99.0 b

Table 13. Firmness (lbf) of Calred peaches at harvest and after cold storage (96/97).

Treatment	Feb. 21	Mar. 12	Mar. 22
LP1 + 60% CO_2	12.8	10.7 a	10.5 a
LP2 + 60% CO_2	12.8	9.7 a	11.0 a
Control	12.8		5.3 a

Table 14. Quality measurements in shelf life of Calred peaches (96/97).

Treatment	Firmness (lb)	Decay (%)	Woolliness total (%)
LP1 + 60% CO_2	4.6 b	0.0 a	100.0 a
LP2 + 60% CO_2	4.4 b	0.0 a	100.0 a
Control	1.7 a	5.0 b	100.0 a

Table 15. Gas concentrations (%) during cold storage in August Red nectarines (96/97).

Treatment	Mar. 1 4 d.		Mar. 4 7 d.		Mar. 19 22 d.		Mar. 24 27 d.	
	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2
LP2 + 40% CO_2	7.1 b	15.3 a	6.0 b	18.1 a	5.4 b	17.4 a	6.8 b	18.8 a
LP2 + 60% CO_2	2.2 a	20.4 a	0.7 a	25.0 b	0.7 a	23.3 b	0.9 a	23.4 a
Control								

Table 16. Firmness (lbf) of August Red nectarines at harvest and after cold storage (96/97).

Treatment	Feb. 26	Mar. 24
LP2 + 40% CO_2	11.9	10.8 c
LP2 + 60% CO_2	11.9	9.2 b
Control	11.9	7.3 a

Table 17. Quality measurements in shelf life. August Red (96/97).

Treatment	Firmness (lbf)	Decay (%)	Woolliness Degree1 (%)	Woolliness Degree 2 (%)	Woolliness total (%)
LP2 + 40% CO_2	4.1 b	11.0 a	48.4 b	29.2 a	67.6 b
LP2 + 60% CO_2	3.9 b	10.2 a	26.2 ab	18.0 a	44.2 a
Control	2.6 a	12.2 a	13.9 a	68.9 b	82.8 b

Controlled Atmosphere Storage of South African Plums

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Additional index words. Gel breakdown, eating quality, firmness

Abstract. **Three plum cultivars were stored for different periods under 4 storage conditions. Shelf life simulation of 7 days was done at 10°C. Promising results were obtained. 'Laetitia' plums could be stored for 8 weeks, followed by 7 days at 10°C. Pre-storage conditioning, controlled atmosphere (CA) storage at 3% O_2 + 5% CO_2 and partial CA storage were the best treatments for this cultivar. 'Casselman' could also be stored for 8 weeks plus a further 7 days at 10°C. The best treatments for this cultivar were CA storage at 3% O_2 + 5% CO_2 and partial CA storage. For 'Songold' plums the best treatment was CA storage at 3% O_2 + 5% CO_2 and the maximum storage time was 7 weeks, followed by 7 days at 10°C. The incidence of decay was low throughout in all cultivars and treatments, but wilting, although of a light intensity, was too high agter 8 weeks. Shorter storage periods resulted in less wilting.**

As the production of stone fruit in South Africa increases, the need for longer storage periods than the traditional 4 weeks is also increasing. Periods of 6 weeks or even longer are needed for orderly overseas marketing. Longer storage periods can also be of benefit for the local domestic market.

Controlled atmosphere (CA) storage is known for its ability to reduce the respiration rate of fruit and thus extends the life time of the product (Wankier et al., 1970). In the case of pome fruit like apples, it is possible to double the storage life through application of CA, compared with regular atmosphere (RA) storage, but the same is not necessarily possible for stone fruit (Truter and Combrink, 1992). In a few isolated instances, plums have been stored under CA for up to 12 weeks, but this could not afterwards be repeated on a regular basis (A Sive, Israel Fruit Growers' Association, personal communication). In Italy, a large stone fruit producing country, plums are seldom stored under CA for more than 4 weeks, and it has been established that a period of 6 weeks is already too long. CA storage is only used to extend the storage life of popular cultivars for domestic marketing (G Tonini, CRIOF, University of Bologna, Italy, personal communication).

An extension of the storage period is normally associated with an increase in the incidence of physiological disorders in fruit (Nanos and Mitchell, 1991; Tonini et al., 1989). Internal physiological disorders of plums are also influenced by production, cold storage and handling practices (Taylor, 1996).

Another disorder that can cause major problems during storage is decay (Fourie and Holz, 1985). Decay control will have to receive serious attention if the long term storage of stone fruit is to be realised.

The object of this study was to extend the storage life of plums with the use of CA storage or modifications thereof, while still maintaining an acceptable eating quality.

Materials and Methods

The storage potensial of 'Laetitia', 'Casselman' and 'Songold' plums was examined. The following treatments were applied:

Control. The plums were stored under RA conditions in cycles of 10 days at -0.5°C and 18 days at 7.2 °C.

CA Storage at 3% O_2 + 5% CO_2. The same temperature regime was followed as in the control and CA storage was applied for the full storage periods.

Partial CA Storage. The plums were stored under CA at 2% O_2 + 5% CO_2 at -0.5°C for 10 days, after which they were stored in cycles of 18 days at 7.2°C and 10 days at -0.5°C under RA conditions.

Pre-Storage Conditioning (Nanos and Mitchell, 1991). The plums were kept for 2 days at 20°C in an atmosphere containing 21% O_2 + 5% CO_2 and were thereafter kept in cycles of 10 days at -0.5°C and 18 days at 7.2°C under RA conditions.

Storage Period and Evaluation. The fruit were stored for periods of 4,5,6,7 and 8 weeks and thereafter kept at 10°C for 7 days before evaluation. The sample size was 5 standard export cartons (5 kg each) of fruit per treatment and storage period. During evaluation the firmness of the plums was measured, using an Effegi penetrometer with a 11mm plunger. The incidence of wilting, decay and gel breakdown (Taylor, 1996) was noted. Taste was determined organoleptically.

Results

Only the results of the 8 weeks storage period are presented.

'Laetitia'. Three of the treatments, i.e. pre-storage conditioning, CA at 3% O_2 + 5% CO_2 and partial CA achieved good results (Table 1). The incidence of wilting was too high in all treatments, but of a very light intensity. CA storage resulted in the lowest incidence of wilting and the highest firmness. Gel breakdown (Taylor, 1996) was low in fruit of all treatments and no decay developed in any of the fruit. Although the results indicate that the control treatment also performed well, the taste of these fruit was totally unacceptable after 8 weeks storage and 7 days at 10°C.

'Casselman'. The best treatment for this cultivar was CA storage at 3% O_2 + 5% CO_2. Under these conditions only 3.4% gel breakdown developed and the fruit still had a firmness of 50N (Table 2) which is an indication that the plums had not yet reached the eating ripe stage. There was no difference in the incidence of gel breakdown between plums stored under CA and partial CA conditions. However, fruit of the latter treatment were significantly softer than those of the CA treatment. The fruit of these 2 treatments also developed less decay than those of the other 2

treatments. Wilting was highest in fruit of the pre-storage conditioning treatment and lowest in the CA and partial CA treatments.

'Songold'. Fruit of this cultivar stored best under CA conditions of 3% O_2 + 5% CO_2. These fruit were the firmest and developed 10.9% gel breakdown, compared with 100% in the control treatment (Table 3). After 7 weeks storage, fruit of this treatment only showed 4.5% gel breakdown. Fruit from the control and pre-storage conditioning treatments already showed gel breakdown after 5 weeks (results of 5 and 7 weeks storage not shown).

Discussion

According to the results of this trial it seems as if plums can be stored for longer periods than other kinds of stone fruit. Couey (1960) stored 'Nubiana' plums for 10 weeks and concluded that softening, decay and loss of total soluble solids (TSS) were delayed. Sive and Resnizky (1991) stored 'Red Rosa' and 'Golden King' plums for "relatively long periods". According to a personal communication the period under discussion was 12 weeks, but this performance could not be repeated every season. It is important to pick the plums at the start of the harvesting period, rapidly cool the fruit to O°C and also to reduce the oxygen concentration without delay. The use of polyethylene sheets in the storage bins to limit moisture loss is essential (Sive and Resnizky, 1991).

In California, success has also been achieved with the long term storage of plums. A temperature of 0.6°C and an atmosphere of 2% O_2 + 5% CO_2 was used. 'Friar' plums could te stored for 2 months, 'Casselman' for 3 months and 'Angeleno' for 4 months (G. Mitchell, University of California, Davis, personal communication). In Italy, 'Angeleno' plums are stored for 3 months every year. As in Israel, early picking is emphasized. The best atmosphere was 1.5% O_2 + 2.5% CO_2 at a temperature of -0.5°C to O°C (D Betta, Bomporto, Italy, personal communication).

Although it is theoretically possible to store South African plums for periods of approximately 8 weeks, there are logistical problems that would first need attention. To utilise CA storage to its full potential, the fruit will not only have to be shipped under CA conditions, but also be stored further under CA upon arrival in the overseas country. This will cause a drastic increase in costs. The aim should be to make the process as cost effective as possible, while still complying with the strict requirements with regard to atmosphere control, which forms the basis of successful CA storage.

Another technique that is being investigated is short term or partial CA storage. This means that fruit are kept under CA conditions locally for approximately 2 weeks after which it is shipped under RA conditions and further stored overseas under the same conditions. However, a promising new development is the establishment of a CA shipping industry in South Africa. Fruit can now be shipped under CA conditions and the average shipping period of 18 days can be regarded as partial CA storage if the fruit must for some reason be stored further prior to distribution and marketing. A reasonable measure of success has already been achieved with this technique under experimental and semi-commercial conditions. However, strict selection requirements will have to be applied to identify fruit of the best quality. Initial findings also indicate that different cultivars have different requirements with regard to storage atmosphere.

'Laetitia' and 'Casselman', for example, achieved good results with partial CA, while 'Songold' performed better under conventional CA conditions, i.e. CA for the full storage period.

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Table 1. Condition of 'Laetitia' plums after 8 weeks storage under different regimes and 7 days at 10°C.

Treatment[z]	Firmness (Newton)	Wilting (%)	Decay (%)	Gel breakdown (%)
Control	30.4	46.8	0	2.8
Pre-storage conditioning	26.5	48.6	0	2.3
Controlled atmosphere	37.3	35.6	0	3.2
Partial CA	33.3	45.0	0	2.0
LSD ($P \leq 0.05$)	4.9	12.8	-	2.6

z - see text for details

Table 2. Condition of 'Casselman' plums after 8 weeks storage under different regimes and 7 days at 10°C.

Treatment[z]	Firmness (Newton)	Wilting (%)	Decay (%)	Gel breakdown (%)
Control	46.1	30.6	5.9	10.8
Pre-storage conditioning	28.4	44.8	3.8	7.4
Controlled atmosphere	50.0	16.0	0.6	3.4
Partial CA	36.3	28.8	0	3.5
LSD ($P \leq 0.5$)	7.2	13.3	1.6	3.0

z - see text for details

Table 3. Conditions of 'Songold' plums after 8 weeks storage under different regimes and 7 days at 10°C.

Treatment[z]	Firmness (Newton)	Wilting (%)	Decay (%)	Gel breakdown (%)
Control	18.6	55.9	0	100.0
Pre-storage conditioning	16.7	64.3	0	21.2
Controlled atmosphere	29.4	26.3	0	10.9
Partial CA	16.7	76.6	0	14.2
LSD (P 0.05)	4.3	18.7	-	16.4

z - see text for details

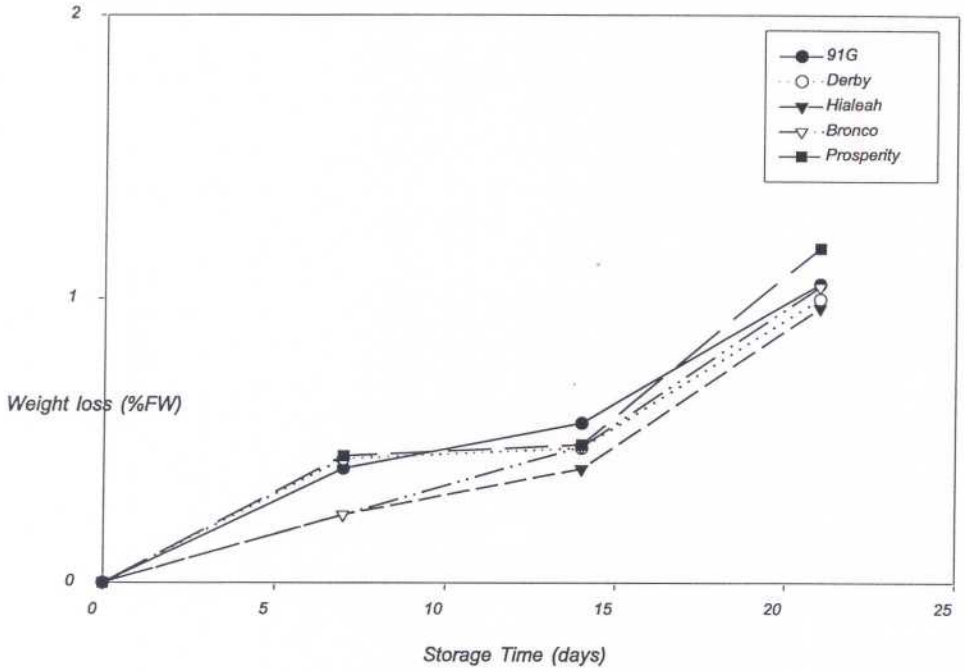
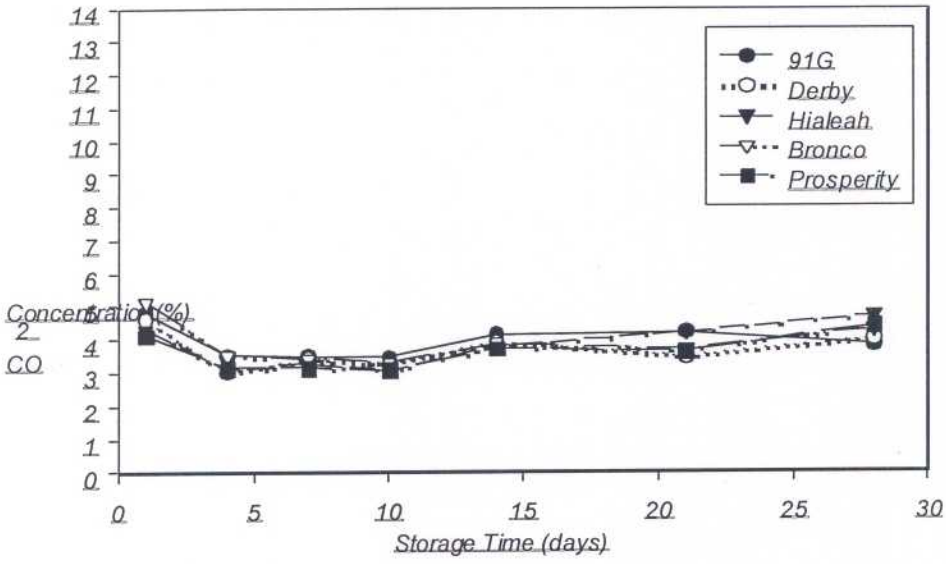


Figure 1. Weight loss of five snap bean varieties packaged in Cryovac PD 941 after storage at 5 C



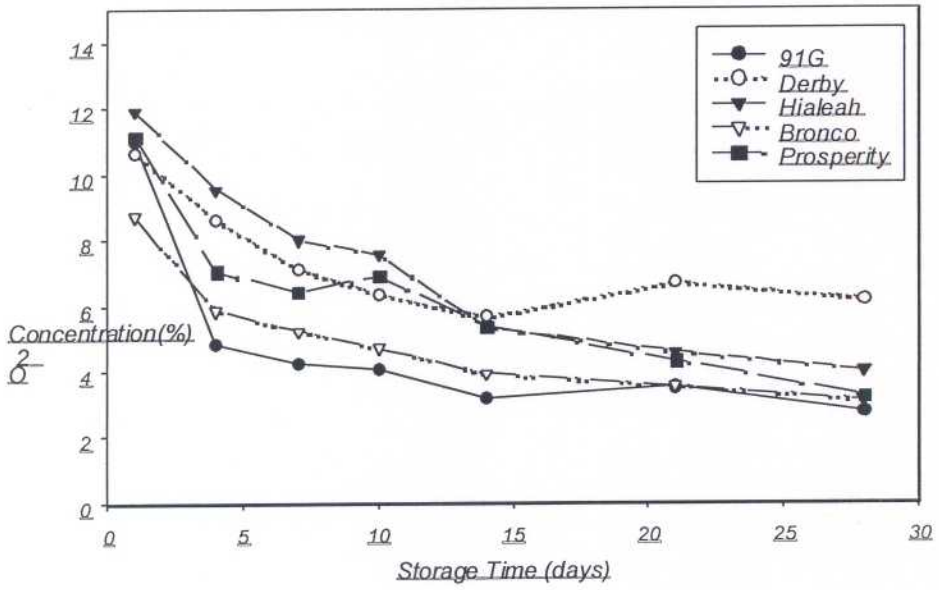


Figure 2. CO_2 and O_2 concentration (%) of five snap bean varieties packaged in Cryovac PD 941film during 5 C storage. Each point is mean of 8 observations.

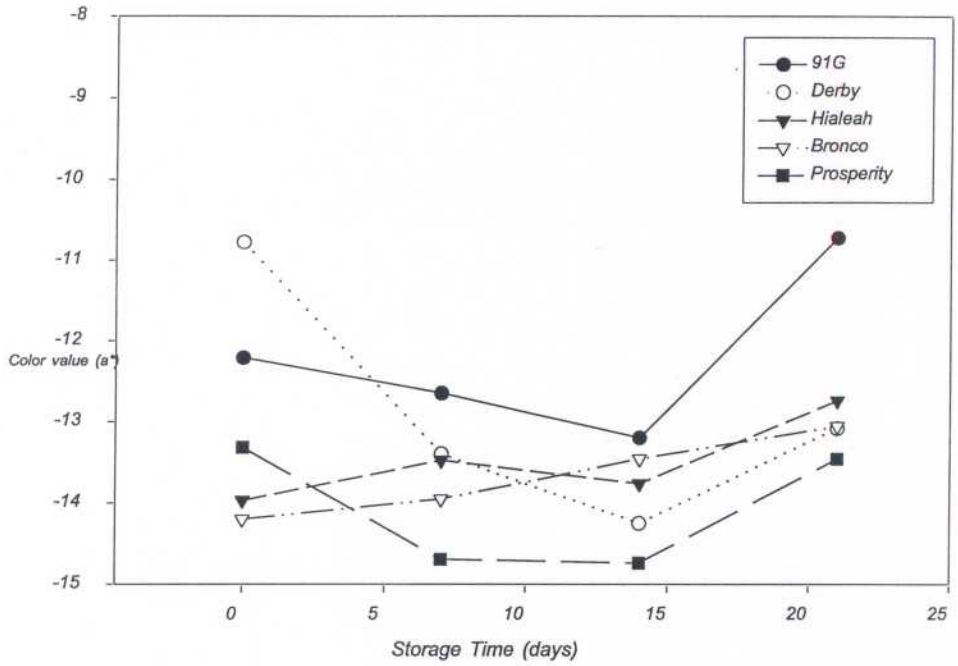


Figure 3. Minolta CR-200 chromameter color value (a) of five snap bean varieties packaged in Cryovac PD 941 film during 5 C storage.*

Condition of Kiwifruit on the European Market After Storage Under CA in New Zealand

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Additional index words. Ethylene production, firmness, soluble solids content

Abstract. New Zealand kiwifruit was stored for three months under CA (2% O_2 and 5% CO_2) or air in open bins. Before being transported to the European market, a 1 month marine shipment in air, fruit was repacked. Upon arrival, fruit was placed at room temperature and tested for flesh firmness, soluble solids content (SSC), ACC content, ACC oxidase (ACO) activity and ethylene production during shelf life. CA stored fruit was significantly firmer at repack in New Zealand. On arrival in Europe, no significantly differences were found between both storage types. Only the ACC content of CA stored fruit was significantly lower than the air stored fruit, but this did not result in a change in ethylene production. So far the CA storage gives no advantage or disadvantage in shelf life behavior of kiwifruit on the European market. The only advantage of CA storage is that it gives more flexibility at the time of industrial grading and packing in New Zealand.

Kiwifruit (Actinidaia deliciosa (A. Chev.) C.F. Liang et A.R. Ferguson var deliciosa) intended for export is harvested firm and unripe, but mature, packed into export packaging soon after harvest irrespective of the storage period, stored in New Zealand at 0°C and subsequently shipped under refrigeration to the European market as required. Depending on the storage time and the incidence of disorders, it may be necessary to repack the fruit before fruit is shipped to the European market. An alternative is to store the fruit in bins until required for export, than pack it out. This may be anytime in the six months following harvest, although it is not possible to mechanically handle fruit if fruit is too soft (McDonald, 1990).

Fruit firmness of kiwifruit can be maintained by controlled atmosphere (CA) storage as shown by studies in New Zealand (McDonald and Harman, 1982; Harman and McDonald, 1983, 1989), USA (Arpaia et al., 1984, 1985, 1986), Italy (Brigati et al., 1989) and France (Nicolas et al., 1988). Advantages of the use of CA storage for kiwifruit could be achieved if fruit could be stored in bins directly after harvest and packed into export packaging at some later stage during the season. This provides flexibility in delaying the time and choice of packaging.

In most previous experimental CA trials, the quality of kiwifruit was assessed immediately after CA storage. According to Arpaia et al. (1984, 1994), the benefits of CA storage will be reduced if fruit is subsequently stored in air. It is stated that CA conditions should be maintained until just prior to marketing to optimize the fruit market life.

The purpose of our work was to investigate the influence of commercial CA storage in New Zealand followed by a commercial marine shipment to Europe in conventional atmosphere.

Materials and Methods

Kiwifruit 'Hayward' were harvested during 1995 season from 3 selected growerlines in the Bay of Plenty, New Zealand, called A, B and C.

The fruit of growerline A, respectively B and C, was harvested on 13 June 1995, respectively 9 and 5 June 1995. Soluble solid content (SSC) and flesh firmness was determined at harvest (Table 1). Growerline B was the most mature growerline with the highest SSC and the softest fruit. Growerline C had the lowest percentage SSC and had the firmest fruit at harvest. Growerline A can be situated between B and C. The fruit was cured for 72 hours in block stacked bins, under cover with natural ventilation. Cured bins were loaded into the stores. The stores were precooled for 7 days after sealing the room to draw the temperature down to 0°C. Half of the fruit was stored in air, the other half under CA (2% O_2 and 5% CO_2). After three months storage in New Zealand, evaluation was performed on 10 randomly chosen fruit for flesh firmness and SSC. The rest of the fruit was packed and shipped by sea to Zeebrugge (Belgium) on a 1 month marine shipment. At arrival the fruit was transported to the lab (Leuven, Belgium) where it was placed in a conditioned room at 22°C ± 2°C, RH was 60%, for 18 days. Flesh firmness, soluble solids content, 1-aminocyclopropane-1-carboxylic acid (ACC) content, ACC oxydase (ACO) and ethylene production were evaluated during shelf life.

Table 1. Stage of maturity of kiwifruit used in the experiments on the day of harvest for the three growerlines A, B and C.

Growerline	Harvest date	Soluble solids content (%)	Flesh firmness (kgf)
A	13/06/95	9.5	7.3
B	09/06/95	11.0	6.8
C	05/06/95	7.5	8.8

Flesh firmness was determined every 3 or 4 days on 10 randomly chosen fruit using a R. Bryce type handpenetrometer FT011, 7 mm head. Soluble solids content was determined on the same 10 fruit using an Aus Jena Refractometer. ACC content was determined every 3 or 4 days on 3 randomly chosen fruit according to the method of Lizada and Yang (1979). ACO activity was determined on the same 3 fruit as ACC determination. Two equatorial slices were taken of each fruit. One slice was put in a sealed reaction vessel with phosphate buffer 0.1 M, pH 5.6, with ACC 10^{-3} M, the other slice in a similar reaction vessel, but without ACC. Both vessels were placed at 30°C. The ethylene production rate was measured over a period of 3 hours. Every 3 or 4 days the ethylene production of 10 randomly chosen fruit was determined. The produced concentration was measured with a Delsi 200 GC equipped with a Poropack R, 50/80 mesh column and a flame ionization detector.

Statistical analysis was performed using the SAS analysis of variance statistical program with means separated by Tukey's test at $P \leq 0.05$.

Results and Discussion

At repack (i.e. after 3 months of storage, before marine transportation to Europe), the CA stored kiwifruit was significantly firmer than the air stored fruit for the 3 evaluated growerlines (Table 2). Growerline A had the softest fruit (2.8 kgf after CA-storage - 2.1 kgf in air) compared to the 2 other growerlines (both 3.9 kgf after CA storage and 2.3 kgf in air), although at harvest the average flesh firmness of this growerline was between B and C.

Table 2. Flesh firmness (kgf) of kiwifruit at repack in New Zealand and during shelf life after transport to Europe for the three growerlines A, B and C.

Growerline	repack in NZ		0 days		9 days		18 days	
	CA	Air	CA	air	CA	air	CA	air
A	2.8[az]	2.1[b]	0.91	0.86	0.56	0.52	0.06	0.01
B	3.9[a]	2.3[b]	1.17	1.02	0.68[a]	0.47[b]	0.04	-
C	3.9[a]	2.3[b]	0.91	0.85	0.38	0.26	-	-

z: Mean separation within rows for each time of assessment by Tukey's test at $P \leq 0.05$. Each value is the mean of ten observations.

There was no significant difference in SSC between both storage types for the tested kiwifruit at repack (Table 3). Harman and McDonald (1989) found a significantly higher SSC for air stored fruit than the CA stored (2% O_2 + 5 % CO_2), evaluated directly after storage. Arpaia et al. (1984) did not find differences in SSC between both treatments.

Table 3. SSC (%) of kiwifruit at repack in New Zealand and during shelf life after transport to Europe for the three growerlines A, B and C.

Growerline	Repack in NZ		0 days		9 days		18 days	
	CA	air	CA	air	CA	air	CA	air
A	14.4	14.3	13.5	13.8	14.9	14.6	14.5	13.3
B	12.9	13.0	12.9	13.0	13.1	14.0	14.4	-
C	12.2	12.2	12.2	12.1	12.8	12.9	-	-

After transport to Europe and during the succeeding shelf life, there was no significant difference found between CA and air stored fruit for firmness and SSC (Table 2 and 3). Similar results were found by Arpaia et al. (1984). Although growerline B had the ripest fruit at harvest, at repack and during shelf life in Belgium, growerline B and C have the same fruit firmness for both storage types, growerline A has the softest fruit.

The ACC content of the fruit was the same for both treatments after storage and transportation at 0°C (Fig. 1). During shelf life, the ACC content accumulated in both treatments, but CA stored fruit have significantly less ACC accumulation than the controls. For example, 40 nmol ACC/g after storage in CA compared to 90 nmol ACC/g in air controls.

The ACO activity of air stored fruit from growerlines A and C is after 4 and 7 days of shelf life significantly higher than the CA stored fruit after transportation to Europe (Fig. 2). There was no significant difference between both storage types during shelf life for growerline B. Gorny et al. (1996) found a significant increase of ACO activity during storage of 'Golden Delicious' Apples. Reduced O_2 and/or elevated CO_2 atmospheres inhibit the conversion of ACC to C_2H_4 (Chaves and Tomas, 1984 and Gorny et al., 1996). However, apple tissues' reduced ability to convert ACC to C_2H_4, under commercially applied controlled atmosphere regimes, may have only small a impact on reducing C_2H_4 biosynthesis, and extending the storage life of apples (Gorny et al., 1996).

No difference was found in ethylene production of the evaluated kiwifruit during shelf life, except for growerline C (Fig. 3). The CA stored kiwifruit of the latter growerline has a significantly higher ethylene production compared to the air control. From this we can conclude that a lower ACC content is no guarantee for a lower ethylene production. The ACC content of growerline C starts to increase after 7 days of shelf life, which is the moment when its ACO activity and ethylene are decreasing. ACO activity is a membrane bound enzyme. After 7 days of shelf life, membranes are probably degrading which can be the cause of the bad functioning of ACO activity from then on.

Conclusion

This study indicates that immediately after breaking the controlled atmosphere, CA stored fruit will be firmer and less ripe than the conventionally stored fruit in air. After transportation to Europe for one month by sea, there was not much difference found between both storage types. Only the ACC content of CA stored fruit was significantly lower than the controls, but this did not result in a lower or later ethylene production of the CA stored fruit. More differences were found between growerlines than between treatments. The only advantage of CA storage is that it can give more flexibility at the time of industrial grading in New Zealand. Packing decisions can be made later in the season. These extra months of flexibility CA storage can give, should be compared with the extra costs of equipment and energy for CA storage.

Acknowledgment

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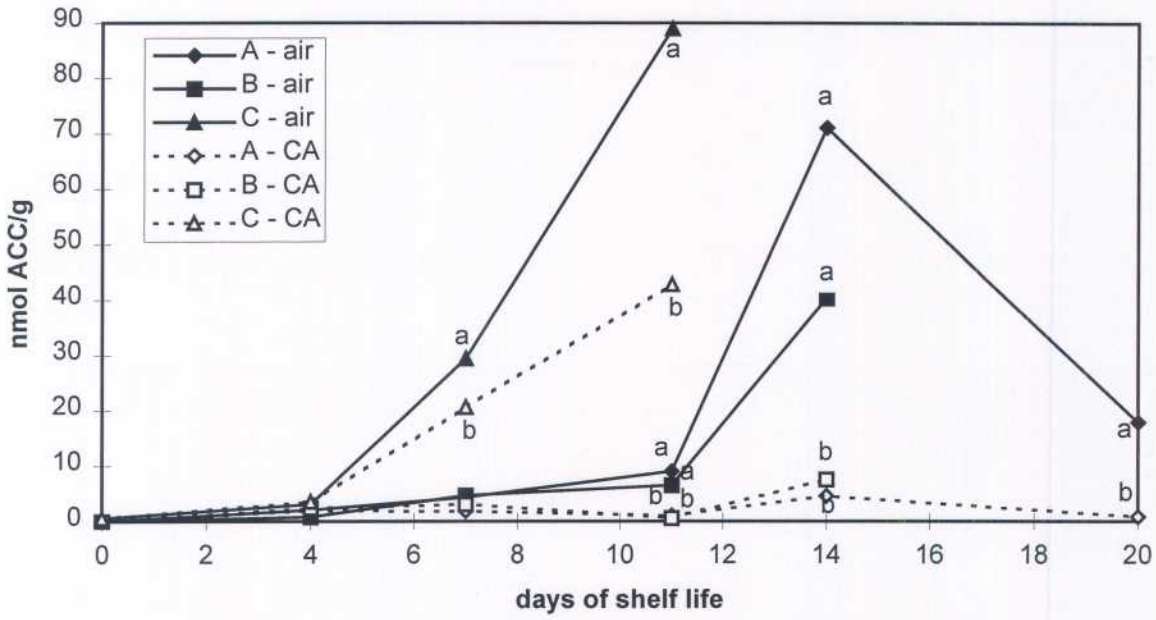

Figure 1: ACC content of kiwifruit during shelf life stored under CA and air in New Zealand, for 3 months and then transported by sea for 1 moor three growerlines A, B and C. Each value is the mean of three replicates. Mean separation within growerlines for each day of shelf life by Tukey's test at P≤0.05.

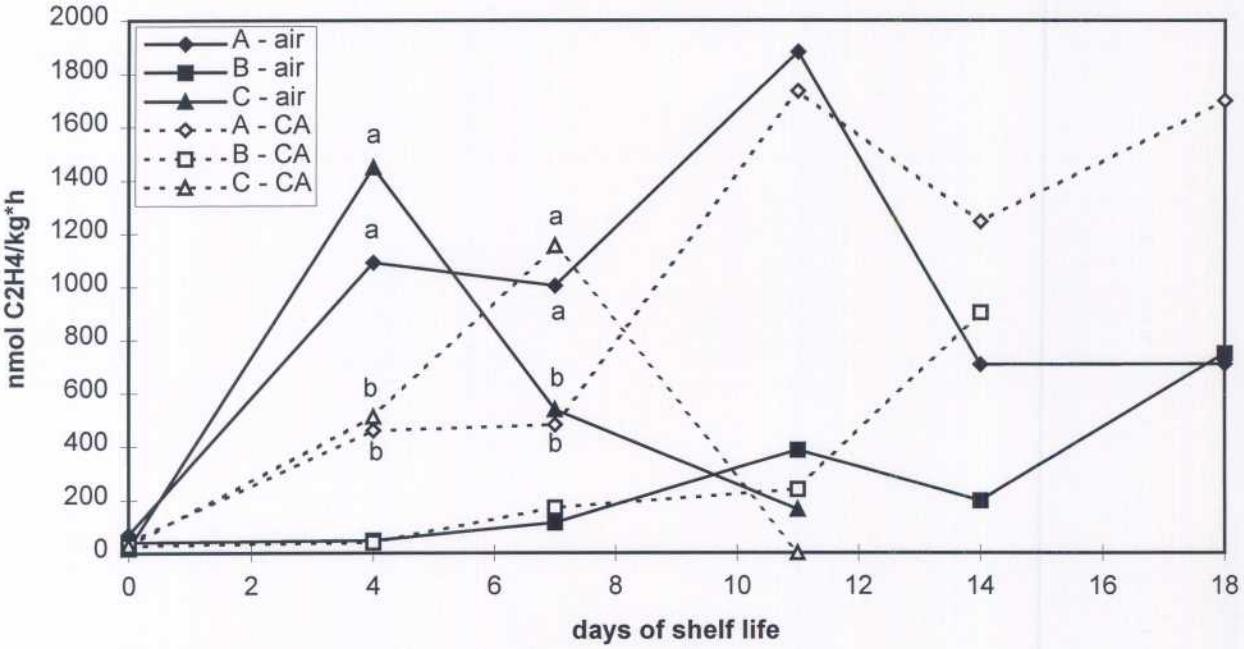

Figure 2: ACO activity of kiwifruit during shelf life stored under CA and air in New Zealand, for 3 months and then transported by sea for 1 month for the three growerlines A, B and C. Each value is the mean of three replicates. Mean separation within growerlines for each day of shelf life by Tukey's test at P≤0.05.

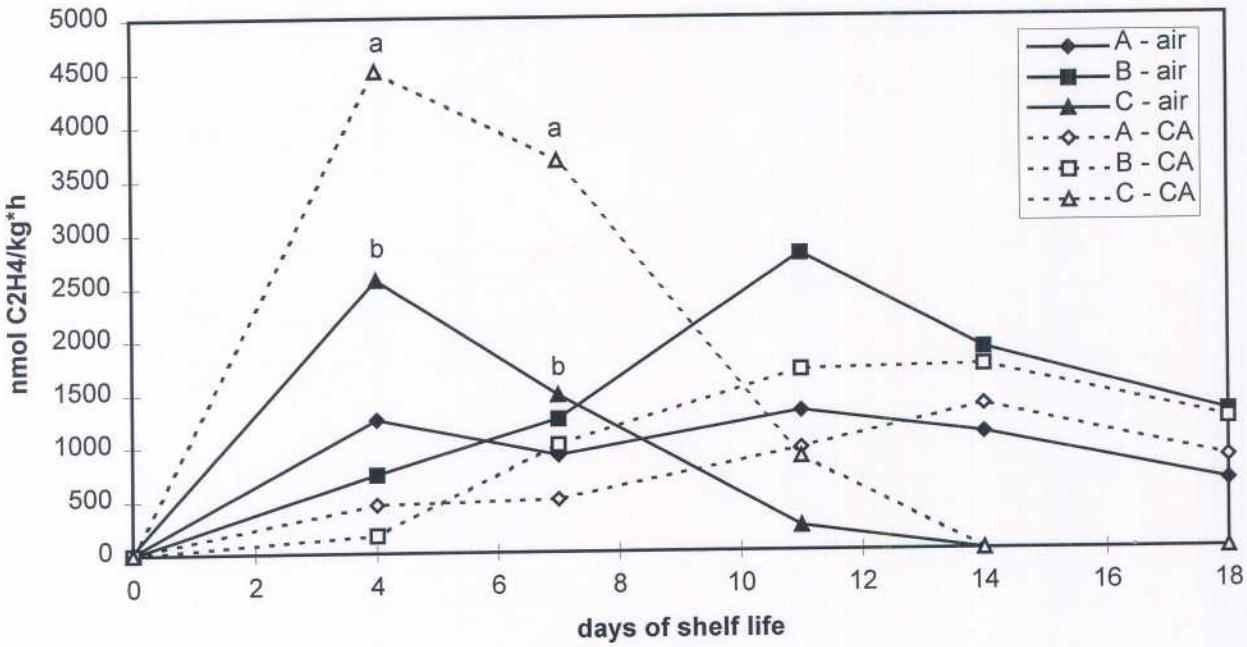

Figure 3: ethylene production of kiwifruit during shelf life stored under CA and air in New Zealand, for 3 months and then transported by sea for 1 month for the three growerlines A, B and C. Each value is the mean of ten replicates. Mean separation within growerlines for each day of shelf life by Tukey's test at $P \leq 0.05$.

Physiological and Biochemical Responses of "Hass" Avocado Fruits to Cold-Storage in Controlled Atmospheres

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Additional index words. Chilling injury, *Persea americana*, ethanol, acetaldehyde, respiration

Abstract. **Late-season avocado fruits (Persea americana Mill., cv Hass) were kept at 2° or 5°C for 30 days in air or in controlled atmospheres (CA) containing 5% O_2 + 5% CO_2 (5+5) or 2% O_2 + 15% CO_2 (2+15), the balance being N_2 in both CA. The fruits were evaluated immediately upon removal from cold-storage (unripe), and during ripening in air at 20°C. Acetaldehyde and ethanol contents in pulp, external fruit color, and flesh firmness were tested at once, and again after 4 days in air at 20°C. Respiratory rate patterns of the fruits were determined during ripening process. Softening, external color change, and respiratory climacteric of the fruits was delayed by cold-storage, especially in CA. Fruits showed atypical respiratory rate patterns in general. Fruits held in air showed notably higher respiratory rates than those kept in both CA. The climacteric peak occurred after 1 day at 20° in fruits kept in air or in (5+5) ; fruits kept in (2+15) peaked after 2 days. In general, acetaldehyde contents were significantly higher in unripe fruits than in ripe fruits, whereas ethanol contents were significantly higher in ripe fruits than in unripe fruits (acetaldehyde probably became ethanol during ripening). Cold storage in air caused significantly higher contents of ethanol than cold-storage in CA. Fruits held in (2+15) showed levels of acetaldehyde and ethanol significantly lower than the fruits kept in air or in (5+5), indicating that the most extreme CA reduced this adverse effect caused by cold-storage (chilling injury).**

According to Pesis et al. (1994) the avocado is a subtropical fruit sensitive to chilling injury (CI) when exposed to low but nonfreezing temperatures. This physiological disorder has been described by several workers (Eaks, 1976 ; Chaplin et al., 1982 ; Couey, 1982 ; Van Lelyveld and Bower, 1984 ; Zauberman et al., 1985). According to them, the main symptoms of CI are black spots on the peel and a gray or dark-brown discoloration of the mesocarp. However these symptoms are evident only when the fruit reaches the ripe stage. Zauberman et al.(1973) found that in "Ettinger", "Fuerte" and "Nabal" avocados, low temperature injury was not apparent in the fruit during the cold storage period; injury became apparent only after the fruit was transferred to shelf conditions.

Spalding and Reeder (1975) reported that in cold sensitive 'Fuchs' and 'Walding' avocados stored during 3 or 4 weeks at 7.2°C, the development of both anthracnose (Colletotrichum gloeosporioides) and CI was prevented with CA (2% O_2 + 10% CO_2). Exposing "Hass" avocado to 20% CO_2 three times during 21 days at 4 °C reduced CI (Marcellin and Chaves, 1983). Storing avocado in polyethylene bags (MA) also reduced CI symptoms (Scott and Chaplin, 1978).

Treating "Fuerte" avocado with 25 % CO_2 for 3 days before 28 days of storage at 5°C reduced incidence of disorders and lowered the total phenols level (Bower et al., 1989). Other authors have also reported that CA can reduce CI in avocado fruits (Vakis et al., 1970 ; Reeder and Hatton, 1971 ; Spalding and Reeder, 1972 ; Eksteen and Truter, 1983). In all these studies, the CI incidence was determined in different ways, but not as an increment of anaerobic metabolites.

Under certain conditions, MA or CA can induce a shift from aerobic to anaerobic respiration leading to fermentation with the accumulation of ethanol and acetaldehyde. Ethanol is the temporary end metabolite produced under anaerobic respiration in many higher plants (Chang et al. 1982). However, ethanol has been detected as a normal constituent of apples and many other fruits held under aerobic conditions (Nursten, 1970). According to Kimmerer and Koslowsky (1982) a number of woody and herbaceous plant species produced acetaldehyde and ethanol in response to freezing stress, while others did not. Besides they showed that ethanol production by plants under stress does not require restricted O_2 availability.

In the present study, acetaldehyde and ethanol contents (as CI incidence) and other physiological responses of "Hass" avocado fruits after 30 days of cold-storage in CA were determined.

Materials and Methods

Mature late-season "Hass" avocado fruit were obtained from a packinghouse in Uruapan, Mich., Mexico in April of 1995. After transport by land to the laboratory (arrived 2 days after harvest) the fruits were immediately precooled by immersion in ice water and TBZ (1500 ppm) during 40 min. They were then dried and selected for uniformity of size and freedom from defects. The selected fruits were distributed randomly. Four fruit were placed in a 2-liter plastic jar connected to flow boards and capillary tubing for the flow control and ventilated with a humidified and specified gas mixture at a continuous 25 $mL \cdot min.^{-1}$ flow rate. The gas mixtures included 5% O_2 + 5% CO_2 + 90% N_2 (5+5) and 2% O_2 + 15% CO_2 + 83% N_2 (2+15). Another four fruit unit (in non-covered jar) was exposed to air. Four replicates (plastic jars) were used for each treatment. All of the fruit samples were kept at 2° or 5°C for 30 days. The gas mixtures were tested periodically to determine the compositional accuracy by taking a 100 mL gas sample and analyzing the O_2 and CO_2 concentrations using an ORSATgas analyzer.

Determination of anaerobic volatiles in pulp. For non-ripe fruits (just upon removal from treatments) samples of pulp were taken with an appropiate punch along the mesocarp. Plugs were extracted to obtain thin disks. Fruit disks (5 g) were placed into a 15 mL flasks. The flasks were sealed and frozen in liquid nitrogen immediately and kept at -18°C until analysis (8 days). For ripe fruits, the flesh sample was taken by cutting pieces with a knife and placed into a plastic syringe without needle in order to introduce the sample (5 g) into the flask quickly and easily. The flasks were sealed and frozen in the same way. Similar flasks were used for standard solutions (5 mL), which were prepared with distilled, deionized water and a mixture of ethanol (17.4 $mg \cdot L^{-1}$) and acetaldehyde (3.14 $mg \cdot L^{-1}$). For the analysis, the flasks were put in a constant temperature (60°C) water bath. Head space samples (Davis and Chase, 1969) of 1 mL were taken with a syringe flushing at least 3 times. The gas chromatograph used was a Hewlett Packard 5890 Series II equiped with a flame ionization detector (200°C) and a 27.5 m chrompack capillary column (130°C) with poraplot Q as stationary phase.

External fruit color was tested upon removal from treatments and again after 4 days of ripening in air at 20°C using a Hunter Lab Colorimeter ; the color index (Mateos et al., 1988) was calculated by the formula : $C_I = (-10\ a\ b) \cdot (L^{-1})$.

Flesh firmness was tested with an Universal Texturometer (Sommer & Runge KG) with a conical tip (200g). The distance (10^{-1} mm) the tip could penetrate into the pulp (without peel) was recorded after 5 sec. of free vertical penetration. This evaluation was made at the beginning (when fruits arrived), upon removal from treatments, and again after 4 days of ripening in air at 20°C.

The respiratory rate of individual fruits was taken daily (11 AM) using the method of Claypool and Keefer (1942) starting when fruits were removed from tratments or immediately after harvest (a group of 6 fruits ripened in air at room temperature was used as control)

All data, except those of the respiratory rates were subjected to analysis of variance and comparison of means.

Results and Discussion

After 30 days of cold-storage in different atmospheres, the results (Fig.1) indicate that (a) in general terms, acetaldehyde decreased while ethanol increased during ripening in air, probably because ethanol is an end product metabolite while acetaldehyde is an intermediate (Pesis et al., 1994). (b) The lower the temperature, the higher the levels of anaerobic metabolites. This confirms that ethanol can be produced in response to low temperature stress as a symptom of CI and is not produced only in response to restricted O_2 availability (Kimmerer and Koslowsky, 1982). In addition, (c) cold-storage in CA caused lower contents of ethanol than in air ; besides, avocados held in (2 + 15) showed acetaldehyde and ethanol levels significantly lower than those kept in air or in (5 + 5) indicating that the more extreme CA reduced this CI symptom, confirming what some of the workers cited above have suggested, in the sense that CA can reduce CI in avocados.

Softening, external color change, and respiratory climacteric of the fruits were delayed by cold-storage, specially in CA. In general, fruits showed atypical respiratory rate patterns, indicating possible stress caused by low temperature (Figs. 2 and 3). Those avocados refrigerated in air showed notably higher respiratory rates than control fruits and those kept in any of the CA. The climacteric peak of all treated fruits did not occur until treatment ended, after 1 day of ripening in air at 20°C for those kept in air or in (5+5). Avocados kept in (2+15) peaked after 2 days, indicating that this CI symptom was reduced by CA, especially the most extreme atmosphere (2+15).

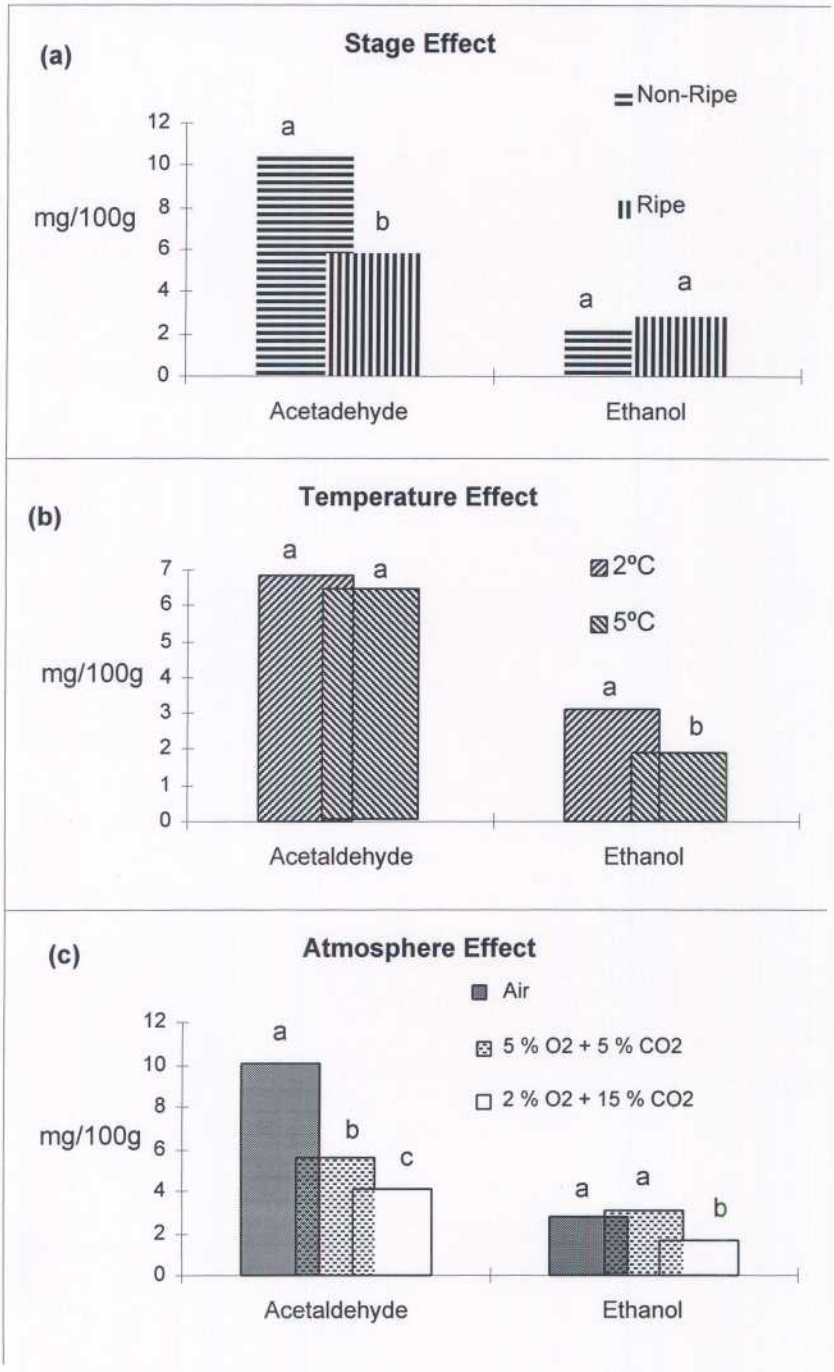

Fig. 1 Global effects of different factors (stage, temperature and atmosphere) on anaerobic volatile contents in avocado pulp, after 30 days of cold-storage.
Bars with same letters within each volatile are not statistically different (Tukey, α=0.05)

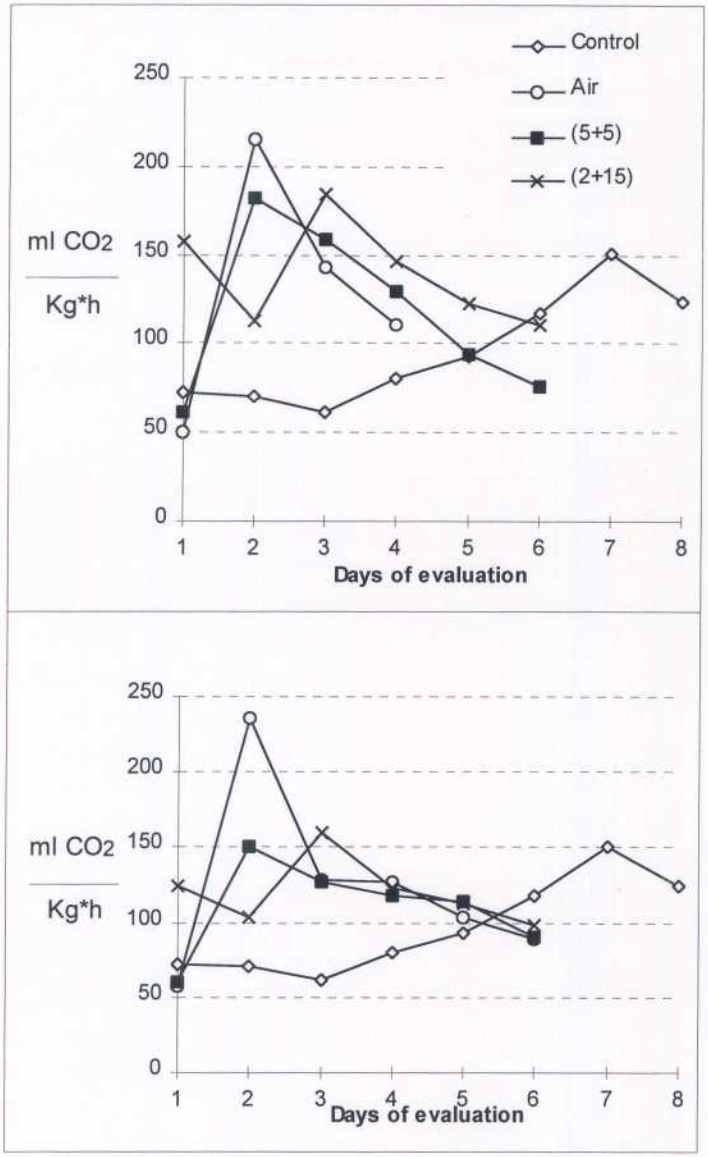

Fig. 2. Respiratory pattern of "Hass" avocados at 20°C after 30 days of cold storage at 5°C (upper section) or 2°C (lower section) in different atmospheres.
(5+5) = 5 % O2 + 5 % CO2; (2+15) = 2 % O2 + 15 % CO2

Acknowledgement

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Respiratory Metabolism and Changes in Chemical Compositions of Banana Fruit After Storage in Low Oxygen Atmosphere

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Additional index words. Respiration, ripening, starch, sugars

Abstract. **Storage of fruits in low oxygen atmosphere has been shown to reduce the respiration rates and other associated metabolic processes, hence, extend storage life. Mature green banana (Musa acuminata cv. 'Berangan') fruit were stored in an atmosphere consisting of 0.5%, 2%, 5%, 10% O_2 in N_2 or in air (21% O_2) for 8 weeks at 14°C. Following storage in low-O_2 atmosphere, the fruit were transferred to ambient at 25°C and allowed to ripen naturally or induced with 250 ppm ethylene for 24 hours. 'Berangan' banana can be stored for 8 weeks in 2% O_2 and 5 weeks in 5% O_2 atmospheres at 14°C. Fruit stored in 2% and 5% O_2 for 4 weeks exhibited a reduction in CO_2 production rates after transfer to ambient air for 1 day compared to higher O_2 levels. Following transfer to air, the preclimacteric period of fruit previously stored in 2% and 5% O_2 for 4 weeks was extended to 5 days and skin color changes were slow. However, exogenous ethylene treatment at 250 ppm drastically shortened the preclimacteric period by 1 day and skin color development was rapid and uniform. The respiratory quotient (RQ) value of fruit after storage in 0.5% O_2 for 4 weeks was higher than 1, while those in 2% O_2 or higher were closed to unity. This indicates the occurrence of a slight incident of anaerobic metabolism in fruit stored in 0.5% O_2 atmosphere. Total sugar and starch contents of ripe fruit after storage in low-O_2 atmosphere were also discussed.**

Banana (Musa acuminata) is one of the important fruit crop grown in Malaysia. The fruit are readily available in the domestic markets and some of the cultivars especially 'Mas' and 'Berangan' are gaining popularity in the export markets. For instance the 'Mas' cultivar has been successfully shipped to Japan and Europe by sea using the technique of modified atmosphere packaging (MAP). The technique of extending the storage life of both banana cultivars by MAP has been developed by Abdullah et al. (1993 a,b). 'Berangan' has been identified as another potential cultivar for export.

The technique of MAP has been shown to be effective in extending the storage life of 'Berangan' banana for 5 weeks at 14°C (Abdullah et al. 1993). However, banana fruit stored in MA condition are often subjected to physiological disorders due to exposure to high levels of CO_2 (Abdullah et al. 1987). This is highly apparent during prolonged storage in MA packages where CO_2 liberated from the fruit increased to injurious level. Controlled atmosphere (CA) storage allows precise regulation of the desired amount of CO_2 and O_2 throughout the storage

period. This method is useful for long distance shipment of banana fruit using CA marine container.

Controlled atmosphere or MA storage involves storing fruits or vegetables in an atmosphere containing a low level of O_2 and/or elevated CO_2 (Zagory and Kader 1988). It is well documented that reduced O_2 and/or elevated CO_2 in CA environment cause significant reductions in respiration and ethylene production rates, reduce tissue sensitivity to ethylene, delay ripening and softening and decelerate biochemical changes associated with ripening and senescence (Kader 1986).

The present study attempts to elucidate the respiratory characteristic and quality changes in 'Berangan' banana fruit exposed to low levels of O_2.

Materials and Methods

Fruit material. Banana cv. 'Berangan' were harvested at approximately 12-13 weeks from flower emergence and transported to the Horticulture Research Centre, MARDI in Serdang, Selangor. Upon arrival the fruit were dehanded, washed, treated with fungicide (300 ppm Benomyl), air-dried and placed in a 47-litre plastic container. Each container consisted of 10 fruit hands.

Low-O_2 treatment. The fruit were exposed to 2%, 5%, 10% O_2 in N_2 and air (21% O_2) for 8 weeks at 14°C. The air treatment served as a control. Humidified O_2 mixture and air were introduced by means of a continuous flow-through system and the flow rates were adjusted to keep CO_2 levels below 0.3% (Abd Shukor et al. 1993). Five hands from each gas treatment were removed on a weekly interval and transferred to air, and ventilated with humidified air at 25°C. Another 5 hands were removed from each gas treatment and exposed to 250 ppm ethylene for 24 hours followed by natural ripening to color score 6 (full yellow).

Gas measurements. Carbon dioxide production rates from the headspace gas were determined at daily intervals during exposure to air until the fruit attained color score 6. Measurements of CO_2 were done by injecting 0.5 ml of the headspace gas into a Varian 1420 gas chromatography equipped with a thermal conductivity detector.

Chemical compositions. The total soluble solids (TSS), total sugar and total starch contents were analysed from fruit which had attained colour score 6. The analysis of total sugar and starch were done following the methods of AOAC (1975). Each analysis was replicated four times. The TSS (%) determined with a refractometer using the supernatant of the blended sample.

Skin colour. Skin colour development was monitored at daily interval after transfer of the fruit from the low-O_2 atmosphere to air based on a hedonic score rating from 1 (green) to 6 (full yellow).

Results and Discussion

The magnitude of reduction in CO_2 production of 'Berangan' banana fruit after 1 day in air following storage in low-O_2 atmosphere for 2 weeks was greater in 0.5% and 2% O_2 compared to the higher O_2 levels (Figure 1). Thereafter, the CO_2 production rate of fruit stored in low-O_2 increased gradually and attained the climacteric peak of respiration after 3 days in air. Fruit stored in low-O_2 for 4 weeks showed a similar trend in CO_2 production as fruit stored for 2 weeks (Figure 2).A slight suppression in CO_2 production after 1 day in air following storage for 4 weeks

in 2% and 5% O_2 indicated the presence of a slight residual effect as a consequence of prior exposure to low O_2. The poststorage respiratory suppression (PRS) was however, temporary since CO_2 production rate recovered and attained the climacteric peak of respiration after 5 days in air. This study demonstrated that an extension of the storage period in 0.5%, 2% and 5% O_2 from 2 to 4 weeks resulted in an extension of the preclimacteric period for 2 days. A residual effect of low-O_2 on the respiration and ethylene production rates has been demonstrated in 'Selva' strawberries by Li and Kader (1989) and in bell pepper by Abd Shukor et al. (1993) and Rahman et al. (1995).

In contrast to the other O_2 levels, fruit stored in 0.5% O_2 for 4 weeks showed a 3 fold increase in CO_2 production after 1 day in air. The respiratory quotient (RQ) value greater than 1 indicated the occurrence of a slight incident of anaerobic metabolism. Fruit stored in 2% O_2 for up to 8 weeks exhibited RQ value closed to unity. It has been shown by Hole et al. (1992) that anaerobiosis can induce an appreciable increase in the RQ, indicating an increase in CO_2 production relative to O_2 consumption.

Fruit stored for 8 weeks in 2% O_2 and then induced to ripen with 250 ppm ethylene resulted in a shortening of the preclimacteric period for 1 day compared to non-induced fruit. Hence, ethylene treatment to low-O_2 stored fruit is effective in shortening the preclimacteric period and enhanced an early onset of respiratory climacteric and ripening.

Skin color development of fruit in air following storage in 0.5% and 2% O_2 for 1 week was slower compared to fruit stored in 5% and 10% O_2 (Figure 4). Extending the storage period in 2% O_2 to 8 weeks further suppressed the skin color development.

Fruit stored continuously in air at 14°C started to ripen after storage for 1 week, while fruit stored in 5% O_2 was acceptable for up to 5 weeks. Fruit stored in 2% O_2 remained green for 8 weeks and able to ripen with good quality after removal to ambient air.

Fruit stored in 0.5% O_2 had lower levels of total sugar compared to fruit stored in higer O_2 atmospheres (Table 1). The low level of sugar in 0.5% O_2 stored fruit can be attributed to non-uniform ripening and incomplete conversion of starch to sugar. This is demonstrated by the higher starch content in fruit stored in 0.5% O_2 compared to the higher O_2 levels (Table 2). Although a decrease in total sugar was observed in fruit stored in 2% and 5% O_2 atmospheres, the values remained fairly similar through the storage period. This indicates that the sugar content is maintained at an optimum level during storage under reduced O_2 levels. Studies conducted by Ke et al. (1990) indicated that low O_2 or high CO_2 treatment did not significantly affect the soluble solids content in 'Bartlett' pears.

In conclusion, banana fruit cv. 'Berangan' can be stored for 8 weeks in 2% O_2 and 5 weeks in 5% O_2 atmospheres at 14°C. The preclimacteric period of fruit stored for more than 4 weeks in 2% and 5% O_2 was extended to 5 days after removal to ambient air. However, exposure of fruit to ethylene gas shortened the preclimacteric period for 1 day. Fruit stored in 0.5% O_2 and transferred to air to ripen had lower sugar and higher starch contents compared to fruit stored in higher O_2 atmospheres.

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Table 1. Total sugar content of ripe banana fruit (full yellow) after storage in atmosphere consisting of different levels of oxygen.

Oxygen level (%)	Storage period (weeks)							
	1	2	3	4	5	6	7	8
0.5	14.8	14.1	14.6	14.8	-	-	-	-
2	18.2	16.4	16.6	16.8	17.1	17.6	17.8	17.5
5	17.3	17.1	17.0	17.6	16.9	-	-	-
10	18.4	18.0	-	-	-	-	-	-
21	19.5	-	-	-	-	-	-	-

Table 2. Total starch content of ripe banana fruit (full yellow) after storage in atmosphere consisting of different levels of oxygen.

Oxygen level (%)	Storage period (weeks)							
	1	2	3	4	5	6	7	8
0.5	4.7	6.8	8.4	7.1	-	-	-	-
2	4.4	4.4	4.6	5.0	4.2	3.7	4.6	3.7
5	4.3	4.7	4.7	4.9	4.3	-	-	-
10	4.9	4.7	-	-	-	-	-	-
21	4.5	-	-	-	-	-	-	-

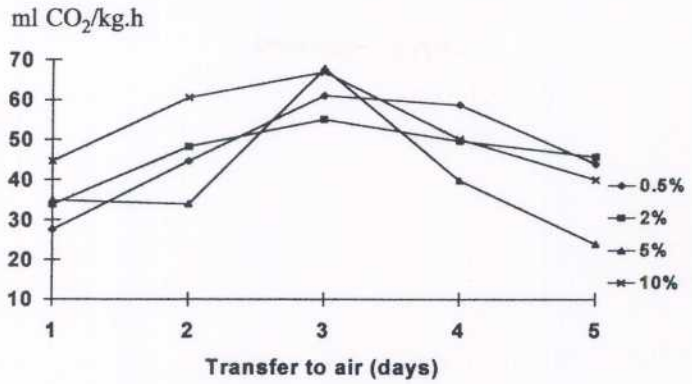

Fig. 1: Carbon dioxide production rates of 'Berangan' banana in air at 25°C following storage in 0.5%, 2%, 5% and 10% O_2 for 2 weeks at 14°C.

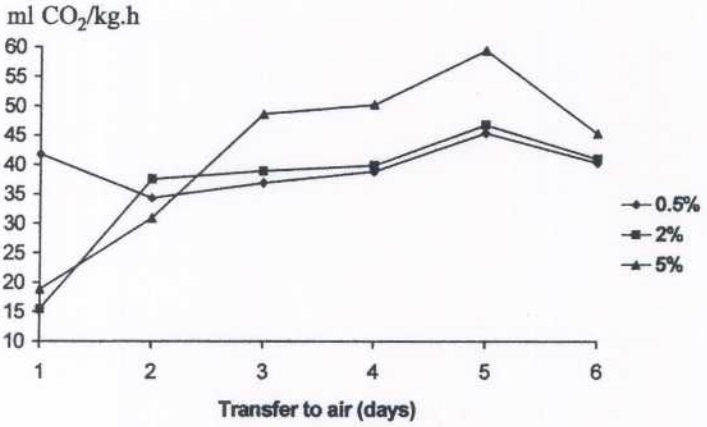

Fig.2: Carbon dioxide production rates of 'Berangan' banana in air at 25°C following storage in 0.5%, 2% and 5% O_2 for 4weeks at 14°C.

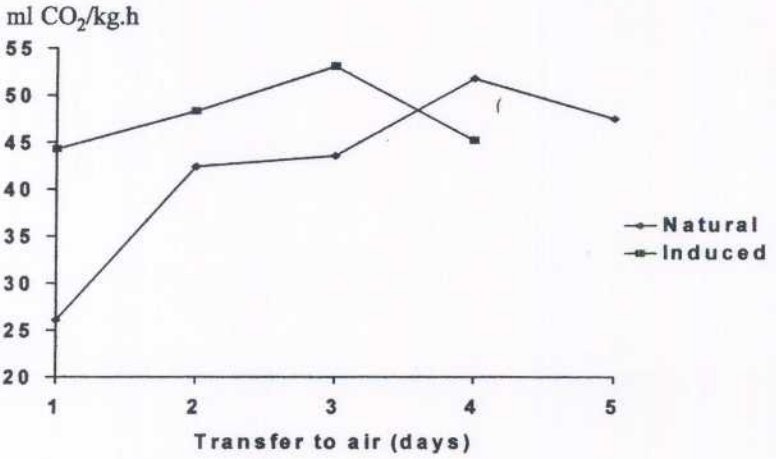

Fig. 3: Carbon dioxide production rates of 'Berangan' banana in air ripened naturally or induced with 100 ppm ethylene for 24 hours at 25°C following storage in 2% O_2 for 8 weeks at 14°C.

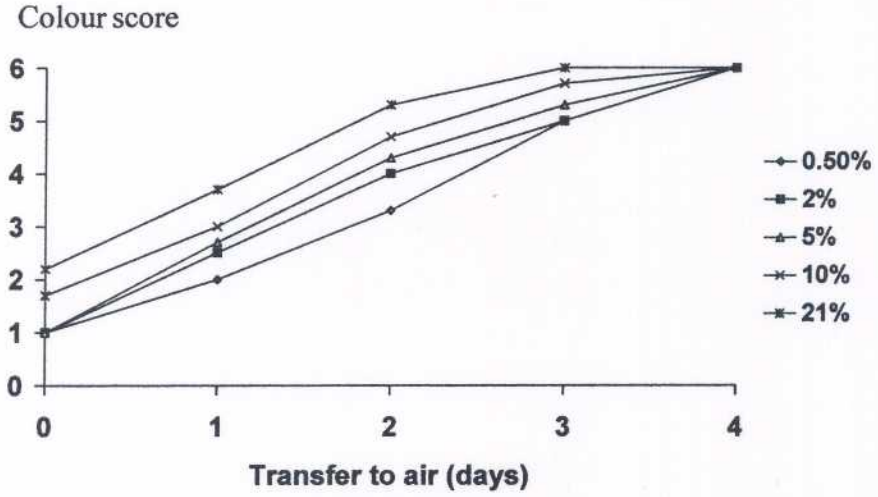

Fig. 4: Colour score of 'Berangan' banana in air at 25°C following storage in 0.5%, 2%, 5%, 10% and 21% O_2 for 1 week at 14°C.

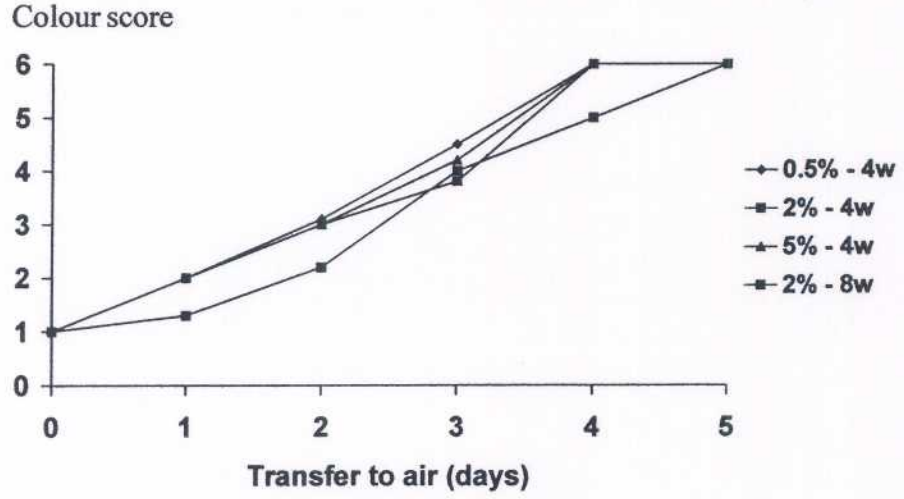

Fig. 5: Colour score of 'Berangan' banana in air at 25°C following storage in 0.5% and 2% O_2 for 4 and 8 weeks at 14°C.

Effects of Controlled Atmosphere Storage on Aroma Volatiles of Tommy Atkins Mangoes

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The objective of the present work was to determine the effects of controlled atmosphere (CA) storage on aroma volatiles of 'Tommy Atkins' mangoes. Volatiles were determined from mature green and tree ripe mangoes that had been stored for three weeks in air or CA of either 10 or 25% CO_2 plus 5% O_2 at both 8 or 12°C. Mesocarp tissue was homogenized from samples that had ripened for 2 days in air at 20°C after the 21-day storage period. Mangoes from both ripeness stages stored under the 25% CO_2 atmosphere at either temperature showed a tendency to lower terpene concentration, while, on the other hand, acetaldehyde levels in the tree ripe mangoes of the same treatment were significantly higher. The concentrations of the terpenes, alfa-pinene, 3-carene and limonene, in mango tissue of all the treatments stored at 12°C were significantly higher in the tree ripe compared to mature green fruit.

Controlled Atmosphere Storage Shows Potential for Maintaining Postharvest Quality of Fresh Lychee Fruits

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Additional index words. Browning, soluble solids content, titratable acidity

Abstract. **A study was conducted to assess the effects of controlled atmosphere (CA) on the postharvest quality of lychee fruits (cv. Mauritius). Defect-free, detached fruits (25± 0.3g) were placed into 1.765 L glass jars (n=17± 1 fruits/jar) where CA was applied utilizing a flow-through, humidified system at 5°C. The CA treatments consisted of combinations of 3% or 4% O_2 with 5%, 10%, or 15% CO_2 atmospheres. Fruits stored in air were used as control. Fruit quality was assessed at regular intervals during 22 days of CA storage plus 1 day storage in air to simulate retail conditions. Weight loss was lowest (1.27%) for fruits stored at 3(% O_2)/5(% CO_2). Fruits held in 3/5, 4/5, and 4/10 were darker in color than those in the other treatments (lower L* value); there were no effects of treatments on hue angle and chroma values. Significant reductions in soluble solids content (SSC) were found in all treatments when compared with initial SSC, except for 3/10 and 3/15. Control fruits had the lowest titratable acidity, whereas 4/15 had the highest (0.40% and 0.62%, respectively). Total sugars (TS) were also significantly lower for all treatments when compared to initial values. CA treatments showed negligible incidence of black spot and lesser incidence of stem-end decay when compared with control fruits. The sensory quality tests showed that 3/5 and 4/5 treatments were rated higher in flavor and texture than the other treatments; treatments involving 3/15 and 4/15 were rated lowest due to off-flavors.**

Lychee (*Litchi chinensis* Sonn.) is a member of the Sapindaceae family native to Southern China, Northern Vietnam and Malaysia. Lychee fruits are grown in South Florida for local and distant ethnic markets. Because of their semi-tropical climate, Dade and Collier Counties have traditionally constituted the two main lychee production areas in the continental United States. With approximately 430 hectares in commercial production during 1996, lychees are considered an important tropical fruit crop for South Florida (Florida Agricultural Statistics Service, 1996).

The short harvest season for South Florida lychees lasts about six to eight weeks from the end of May to beginning of July. This narrow market window allows for the early and late season fruits to soar in price. Two main lychee varieties comprise the majority of acreage planted in South Florida. 'Mauritius' produces regular sized fruits lacking uniform red pericarp coloration but extremely desired because of the earliness of its crop. 'Brewster' on the other hand, produces fruits of uniform red coloration and great appeal later in the season. Through improved postharvest handling practices, such as rapid hydrocooling and better temperature management during cold storage, Florida lychee growers have been able to reach markets where prices are favorable.

The greatest worldwide postharvest problem for litchi marketing is the browning of the pericarp, which often occurs within 48 hours if cold storage is not properly maintained (Underhill and Critchley, 1993; Campbell, 1959; Akamine, 1960). Extensive research aimed at retaining pericarp coloration has been conducted (Fuchs et al., 1993) with relative success. The use of sulfur dioxide treatments combined with acid dips is effective and common in Thailand and Malaysia (Fuchs et al, 1993). Nevertheless, U.S. Food & Drug Administration (FDA) regulations ban the use of sulfur dioxide and hot benomyl dips (Huang and Scott, 1984) for U.S. producers. The use of CA storage may prove effective in retaining postharvest quality of lychee fruits by avoiding the depletion of sugars and organic acids used in respiration. In addition, CA storage may also reduce the activity of oxidative enzymes such as polyphenol oxidase and peroxidase allegedly involved in pericarp browning (Underhill and Critchley, 1995).

The objective of this study was to explore the feasibility of using CA storage for maintaining postharvest quality of litchi fruits. The use of CA storage and modified atmosphere packaging may enable litchi fruits to be marketed for longer periods of time.

Materials and Methods

Lychee fruits from the early fruiting cultivar 'Mauritius' were harvested from a commercial orchard located in Homestead, Florida, on June 7th, 1996. 'Mauritius' lychees were harvested without detachment from panicles, hydrocooled with chilled water, and packed into polyethylene bags before land shipment the same day to Gainesville (~400 miles). Once in Gainesville, fruits were clipped from the panicles and stored overnight at 5°C. Only defect-free fruits were selected as experimental material.

Controlled Atmosphere Treatments. 'Mauritius' lychees were stored for up to 22 days at 5°C using six different O_2/CO_2 humidified atmospheres and a humidified air atmosphere (21% O_2) as control (Table 1). Immediately after initial weight and surface color readings were measured, approximately 16-17 clipped fruits were randomly placed inside each CA jar. The CA set-up was achieved by placing the litchi fruits inside 1.765-liter glass jars fitted with gas-tight lids and connected to a flow-through system, which delivered the desired humidified gas atmospheres into the jars. The atmospheres inside the CA storage jars were monitored daily with a Servomex O_2/CO_2 analyzer (Food package analyzer 1400, Servomex Company, Sussex, UK).

Table 1. Controlled Atmosphere Treatments for 'Mauritius' Lychee fruits.

Treatment Number	Oxygen Concentration (%)	Carbon Dioxide Concentration (%)	Number of Fruits per CA jar	Combined weight of fruits (g)
1	3	5	16	399.5
2	3	10	16	399.5
3	3	15	16	401.7
4	4	5	16	400.1
5	4	10	17	400.7
6	4	15	18	402.6
7	21	0.03	17	400.2

Color measurements. Fruit surface color was measured with a tristimulus colorimeter (Minolta CR-200, Ramsey, NJ) using the L*, a*, b* color coordinates. The a* and b* values

were then computed into hue angle and chroma. Color measurements were obtained from marked sections on each fruit after 0 (initial), 7, 15, and 22 days of CA storage at 5°C. Final color readings were collected after 22 days storage at 5°C + 1 day storage at 20°C to document color changes induced by a simulated retail condition.

Chemical Composition Analyses. Lychee fruit samples were peeled and pitted, and the aril (pulp) homogenized using a Waring blender at high speed for 2 minutes. The homogenate was centrifuged for 20 minutes at 15,000 rpm and the resulting supernatant filtered through cheesecloth to remove additional debris. The supernatant was then frozen and stored at –20°C for later analyses. Soluble solids content (SSC) was measured using a Reichert-Jung digital refractometer (Abbe Mark II, Cambridge Instruments Inc., Buffalo, NY). The aril pH was measured using a digital pH meter (Corning Medical and Scientific Instruments, model 140, Halsted Essex, UK). Titratable acidity, expressed as percentage of malic acid, was measured by titration with a 0.1N NaOH solution up to a 8.2 pH endpoint using an automatic titrimeter (Fisher Scientific Co., Pittsburg, PA). The total sugar content of the aril was measured using a colorimetric phenol method with a Beckman DU-20 spectrophotometer at 490-nm absorbance. Weight-loss was determined during storage on a fresh-weight basis.

Sensory Evaluation. A group of five panelists evaluated the effects of CA storage on the flavor and texture of lychee fruits. After 22 days storage at 5°C + 1 day storage, pulp samples were rated using a 7 point rating scale where 1 = extremely poor quality, while 7 = harvest-fresh quality. Panelists were asked to judge the aril samples for characteristic lychee flavor, texture, color, and juiciness.

Fruit Marketability and Pathological Disorders. Fruits were subjectively rated to assess the external appearance of the fruits after 22 days CA storage at 5°C + 1 day at 20°C. The visual rating included pericarp color, pericarp shriveling due to weight-loss, and incidence of postharvest decay. Infected fruit tissues were isolated, cultured, and causal organisms identified.

Results

The surface color readings taken on fruits throughout the storage period indicated no significant differences in a*, b*, hue angle, or chroma values due to CA treatments. The only significant change in surface color observed was a reduction in lightness coefficient (L*), where fruits from 3/5, 4/5, and 4/10 became darker with storage time (Table 2).

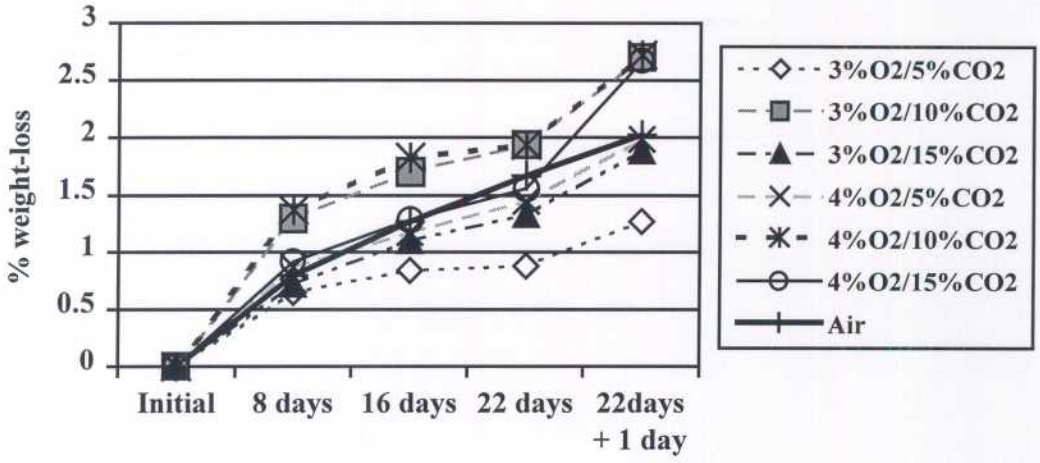
Table 2. Effect of CA storage on pericarp lightness coefficient (L*) of 'Mauritius' Lychee fruits during 22 days storage at 5°C + 1 day at 20°C.

Days in Storage	Storage Atmosphere (% O_2 / % CO_2)						
	3/5	3/10	3/15	4/5	4/10	4/15	Air
Initial	35.75a	36.25a	39.25a	36.96a	45.74a	39.79a	40.72a
7	35.66a	35.29a	38.96a	35.98a	45.10a	38.05a	38.92a
15	33.25b	34.41a	36.67a	32.66bc	42.9ab	34.47a	36.45a
22	34.24ab	33.42a	37.1a	33.84abc	41.31ab	33.98a	38.32a
23	32.77b	31.82a	35.87a	31.47c	39.59b	35.47a	35.54a

Fruit weight-loss after 8 days storage at 5°C was lower for fruits stored in 3/5 and Air (0.65% and 0.80%, respectively) (Figure 1). By the 22nd day of storage, weight-loss was greatest for 3/10 and 4/10, while 3/5 remained lowest (1.93%, 1.93%, and 0.88%, respectively). After 22

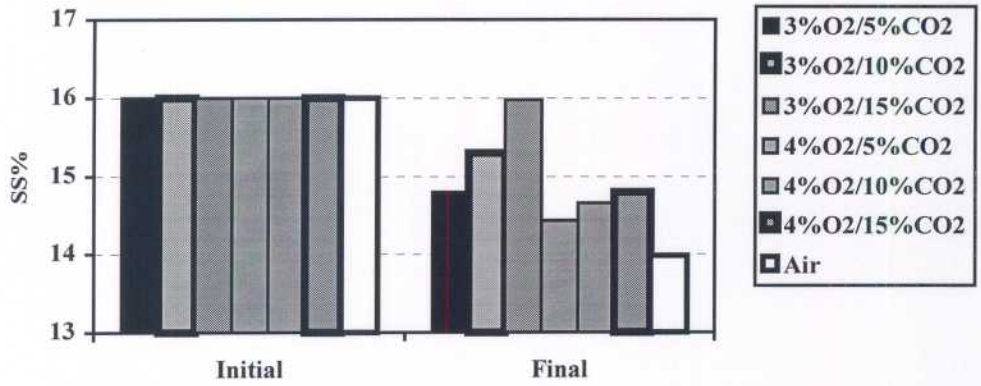
days at 5°C + 1 day at 20°C lychees stored in 3/5 had significantly lower weight-loss (1.27%) when compared to the rest of the treatments.

Figure 1. Weight-loss from 'Mauritius' lychee fruits during 22 days storage at 5°C + 1 day at 20°C.



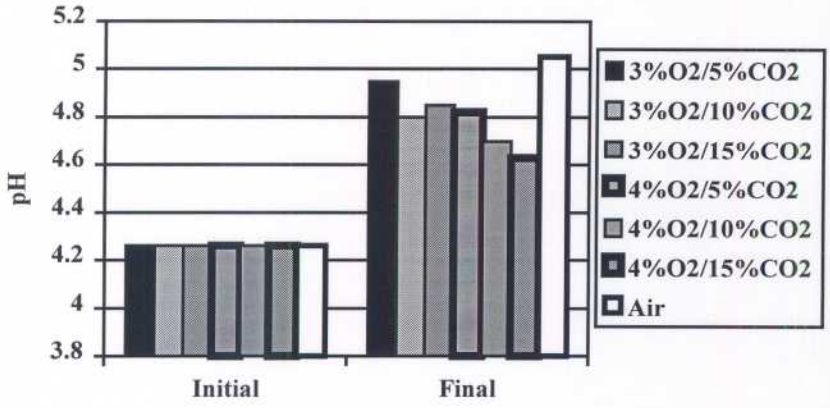
Lychee chemical composition experienced changes as a result of the different CA treatments. Fruit soluble solids content after 22 days storage under 3/10 and 3/15 atmospheres remained unchanged when compared to initial values (15.3%, 16.0%, and 16.0%, respectively) (Figure 2). Meanwhile, Air samples showed significant SSC reduction during the same storage period (14.0%).

Figure 2. Soluble Solids Content from 'Mauritius' fruits after 22 days of storage at 5°C + 1 day storage at 20°C.



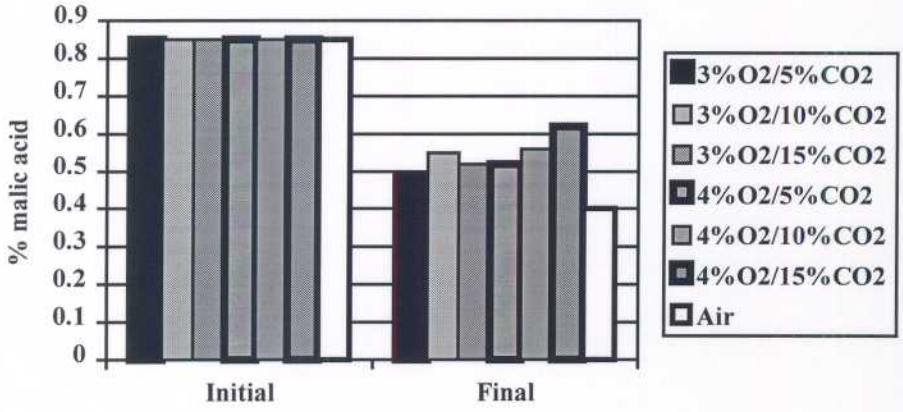
The pH values increased significantly from 4.26 (initial) to a maximum value of 5.07 for air control fruits after 22 days of storage. All other CA treatments had significantly lower pH values compared to the air control (Figure 3).

Figure 3. Changes in pH values from 'Mauritius' lychee fruits after 22 days storage at 5°C + 1 day storage at 20°C.



Titratable acidity was highest for the initial samples (0.85%); meanwhile, at the end of storage TA remained highest for 4/15 (0.62%) (Figure 4). The lowest TA values were observed for lychees stored in Air (0.40%). Total sugar contents in the fruit samples decreased by about 30% during storage (from an initial 11.7% to a low 8.3% for 3/15) (data not shown). All treatments were significantly lower than the initial values in total sugars.

Figure 4. Changes in titratable acidity (expressed as % malic acid) after 22 days storage at 5°C + 1 day storage at 20°C.



The sensory panelists gave higher overall acceptability ratings in flavor, texture, and juiciness to fruits stored in either 3% O_2 or 4% O_2 and 5% CO_2. Meanwhile, lychees stored in air were rated significantly higher in flavor and texture than those stored in 4/10 and 3/10. The lowest sensory ratings were given to treatments involving 15% CO_2 due to the presence of off-flavors and poor pulp coloration (a dull, gray appearance).

Pathological disorders at the end of storage consisted of black spots caused by *Colletotrichium spp.* and fruit surface discoloration caused by *Cladosporium spp.* All CA

treatments were effective in reducing the symptoms of black spot when compared to the Air controls. The 4/15 atmosphere had only a slightly lower black spot incidence than the air controls. The highest proportion of decay-free, marketable fruits was found in 4/5 (62.5%) followed by 3/5 and 3/10 (56.3% and 56%, respectively) (data not shown). Meanwhile, the lowest number of marketable fruits was for those stored in air (23.5%).

Discussion

The use of CA storage was comparable to Air in its ability to retain pericarp red coloration. The lack of uniform red coloration characteristic of 'Mauritius' fruits complicated the color measurements and increased variability from fruit to fruit. Significant reductions in L* throughout the storage period agree with reports by Huang et al., 1990. The effects of pericarp desiccation on the development of browning could not be contrasted between different treatments due to the nearly saturated relative humidity inside of the CA jars. It would seem, from the color data collected during this experiment, that CA treatments had very little beneficial effect on the retention of pericarp color when compared to air controls. Future work must address the effects of CA atmospheres on the retention of anthocyanin pigments, synthesis of phenolic compounds, pH of the pericarp, and the activity of enzymes such as polyphenol oxidase and peroxidase.

After 22 days of storage at 5ºC + 1 day storage at 20ºC, 3/15 still maintained its initial soluble solids content (SSC) as could be expected because it represented the lowest O_2 concentration combined with the highest CO_2 concentration. The air control, on the other hand, had the lowest SSC, probably due to the higher demand for sugars and organic acids to be used as substrates sustaining higher respiratory rates.

The initial pH of the lychee fruits (4.26) increased dramatically in the Air samples (5.07), representing a 19% increase after the 23-day storage period. pH values were lowest for 4/15 followed by 4/10 (4.63 and 4.70, respectively), thus reiterating the effect of high CO_2 atmospheres on the chemical composition of lychee fruits. Titratable acidity (TA) was a good indicator of the metabolism demand on organic acids as a result of different CA atmospheres. Congruent with the results obtained in the pH analysis, fruits stored in 4/15 showed higher TA values, although the differences were not significant when compared to the other CA treatments. Air controls were lowest in TA; a drastic reduction of 52.9% of the malic acid content illustrates the high demand of lychees on organic acids for metabolism.

When compared with the initial values, total sugars content of the fruits following storage was significantly lower in all treatments, including Air. It seems that the reduction in SSC observed in lychee fruits after CA storage was a result of a higher demand on organic acids and sugars as substrates for metabolism. The authors feel that the loss in acidity is one of the key causes for poor flavor in fruits which have been stored in Air for longer than 14 days.

Togdee et al. (1982) observed brown patches, which were attributed to chilling injury following storage at 5ºC. The reduced incidence of black spot observed in this study in lychee fruits stored under CA atmospheres showed a beneficial effect in reducing fruit susceptibility to chilling injury. The presence of *Colletotrichum spp.* might have been due to a secondary infection of pericarp suffering chilling injury. Information on promising CA atmospheres will be used in future experiments with 'Brewster' lychee fruits.

Acknowledgements

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Preliminary Study on Effects of Modified Atmosphere Packaging on Postharvest Storage of Longan Fruit

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Additional index words. Longan (*Dimocarpus longana* Lour.cv.Shixia) fruit, modified atmosphere packaging (MAP), browning, total soluble solids, ascorbic acid, polyphenol oxidase(PPO)

Abstract. **Longan (*Dimocarpus longana* Lour.cv.Shixia) fruit were stored in modified atmosphere packaging consisting of 1% O_2, 3% O_2, 10% O_2 and air (21% O_2) for 7 days at room temperature and 35 days at 4°C respectively to investigate the effects of modified atmosphere packaging on some storage behaviour of Longan fruit; 0.03 mm thick polyethylene film was used in modified atmosphere packaging of the fruit. Results indicate that MAP consisting of 1% O_2 + 5% CO_2 or 3% O_2 + 5% CO_2 was effective in delaying browning of the peel for 2 days or 1 day at room temperature and for 7 days or 5 days at 4°C, respectively, in inhibiting the respiration of the fruit, in maintaining total soluble solids and ascorbic acid level of the fruit, and in partially inhibiting the activity of polyphenol oxidases. MAP consisting of 10% O_2 + 5% CO_2 was not effective as MAP consisting of 1% O_2 + 5% CO_2 and 3% O_2 + 5% CO_2. Taste panel results indicated that the MAP treatment consisting of 1% O_2 + 5%CO_2 produced slight off-flavours. Although there is a need to further understand the tolerance of Longan fruit to low O_2 concentrations, this preliminary study indicates that establishing an atmosphere that is close to the desired atmosphere actively and quickly for the stored fruit is able to improve its storage behaviour.**

The longan fruit (*Dimocarpus longana* Lour.) is a subtropical fruit with a distinct flavour, being a native of subtropical China and grown as a commercial crop in subtropical Asia. The aril is the edible fleshy part with a white to creamy coloured translucent pulp surrounding a brown-black seed. After harvest, fruits are very perishable and quickly turn brown within a few days at ambient temperature since the fruit has active physiological characteristics when fully mature (Paull and Chen, 1987; Pan, 1994). Cold storage is necessary to preserve the quality of longan and it may be held under refrigeration for longer periods (Shi, 1990; Lu, 1992; Saranant, 1992). Therefore, reducing the physiological metabolism of the fruit quickly after harvest may be an important way to extend storage life and preserve the quality of the fruit.

MAP facilitates maintenance of the desired atmosphere during the entire postharvest handling time between harvest and use (Kader et al. 1989). A number of fruits such as apple, peach, banana, mango, avocado, strawberry, cherry, persimmons, broccoli heads, peppers, and some cut vegetables have been wrapped in films with some success (Kader et al. 1989). For preservation, longan fruit is generally packed in bamboo bins or wrapped in films within which the modification of the atmosphere is obtained through respiration of the commodity (Lu,1992). Establishing MA through active initial modification in longan fruit could be beneficial in reducing the physiological activity

of the fruit. This preliminary study investigates how establishing an atmosphere that is close to the desired atmosphere actively and quickly influences storage behaviour of the longan fruit.

Longan fruit (*Dimocarpus longana* Lour.cv.Shixia) was obtained from Guangdong, South China. 60 kg Longan fruit (cv.Shixia) at 80 - 90% maturation, free of physical damage, injury caused by insects, and fungal infection was picked in August, and three independent experiments were set up. The fruit were dipped in 0.1% TBZ (Thiabendazole, a fungicide), air-dried for about one hour, packed in units of 20 fruit into initial atmospheres consisting of 1% O_2 + 5% CO_2, 3% O_2 + 5% CO_2, and 10% O_2 + 5% CO_2 within polyethylene bags (0.03 mm thick) using a gas-flushing technique. The fruit packed into an initial atmosphere consisting of air were regarded as the control. Then they were stored at ambient temperature(about 25°C) or 4°C cold storage respectively with 95% RH for regular analyses.

Determination of gas composition in the package headspace. Gas composition of the package headspace was analysed using a Gow-Mac spectra gas chromatograph with a thermal conductivity detector.

Browning assessment. Browning of longan fruit was assessed by measuring the extent of the browned area on the inner pericarp of each fruit on the following scale: 0 = no browning; 1 = slight browning or a few browning spots; 2 = < 1/4 browning; 3 = 1/4 - 1/2 browning; 4 = > 1/2 browning. The browning grade was calculated using the following formula: Browning grade = $\sum$ (browning scale × proportion of corresponding fruit within each class).

Polyphenol oxidase assays. Fruit peel (2g) were homogenized in 5 ml of 0.05M phosphate buffer pH6.8 at 4°C. The homogenate was centrifuged at 19000g for 20 min and polyphenol oxidase (PPO) activity in the supernatant was determined according to the method of Tan and Li (1984), by measuring the oxidation of 4 - methylcatechol. PPO activity was calculated as the increase of 0.001 unit of absorbance per min at 398nm per mg protein.

Quality assessment. Fruits were randomly removed from each treatment and analysed for total soluble solids, ascorbic acid, and taste panel. Soluble solids content of the fruit was determined by refractometer on expressed juice. Ascorbic acid content was determined by the AOAC indophenol method (Horwitz, 1980). All measurements were done in triplicate except the taste panel.

Package atmosphere changes during storage. Package atmosphere changes in different initial atmospheres are given in Tables 1 and 2. In the controls and treatments, O_2 level decreased, while CO_2 level increased. However, there were significant differences among the controls and treatments. In the control, the equilibrated atmosphere of 3.4-3.5% O_2 and 5.2-6.0% CO_2 was created in 2 days at ambient storage and 7 days at cold storage respectively through respiration of the fruit. Similarly, in the initial atmosphere 10%O_2+5%CO_2 treatment, establishing the equilibrium of 3.2-3.5% O_2 and 5.3-5.8% CO_2 took 2 days in ambient storage and 7 days in cold storage respectively. In initial atmosphere 1% O_2 + 5% CO_2 and 3% O_2 + 5% CO_2 treatments, establishing the equilibrium only took 1 day in ambient storage and 3 days in cold storage. No symptoms of visual injury were found in any treatment after 7 days of ambient storage and 35 days of cold storage. Atmospheres can be developed within the package using modified atmosphere package technology (Zagory and Kader, 1988). This relies on the balance between the produce respiration and the gas permeability of the packaging film to establish an optimum atmosphere. However, establishing an optimum atmosphere through produce respiration within the package can take some time during which physiological changes of the fruit still progress at a higher level. Our study indicates that active modification can shorten the time needed to obtain optimum atmospheres.

Quality changes in soluble solids (SS) and ascorbic acid during storage. Changes in SS and ascorbic acid during storage are given in Table 3 and 4. In all controls and treatments, sugar and ascorbic acid contents decreased. There was no significant difference between the controls and the initial atmosphere 10% O_2 + 5% CO_2 treatment. Also there was no significant difference between the initial atmosphere 1% O_2 + 5% CO_2 treatment and the initial atmosphere 3% O_2 + 5% CO_2 treatment. SS and ascorbic acid in initial atmosphere 1% O_2 + 5% CO_2 and 3% O_2 + 5% CO_2 treatments decreased significantly slower than the controls and initial atmosphere 10%O_2+5%CO_2 treatment ($P<0.05$).

Changes in browning grade and PPO activity during storage. Changes in browning grade and PPO activity during storage are given in Table 5 and 6. In all controls and treatments, PPO activity of the pericarp increased significantly with the development of storage, which corresponded to browning of the pericarp. Where browning has been studied in other fruit (Coseteng, 1987; Martinez-Cayuela et al., 1988), discoloration correlates well with PPO activity and phenolic concentration. The results indicate that there were no significant differences between the controls and the initial atmosphere 10% O_2 + 5% CO_2 treatment, while changes in browning and PPO activity of initial atmosphere 1% O_2 + 5% CO_2 and 3% O_2 + 5% CO_2 treatments were slowed down (Tables 5 and 6), compared to controls and initial atmosphere 10% O_2 + 5% CO_2 ($P<0.05$).

The taste panels at day 7 of ambient storage and day 35 of cold storage indicated that there were slight off-flavours in initial atmosphere 1% O_2 + 5% CO_2 treatment in ambient storage and very slight off-flavours in initial atmosphere 1% O_2 + 5% CO_2 treatment in cold storage. There were no off-flavours in the others. Even though modified atmosphere of low O_2 concentration is reported to suppress enzymatic browning in minimally processed vegetables (O'Beirne, 1990; Ballantyne,1987), the benefit could be valid as long as tolerance limits of produce are not violated in the modification of these package. In addition, a better effect can be obtained in combination with using an optimum cold storage temperature.

Although there is a need to further understand the tolerance of Longan fruit to low O_2 concentrations and CO_2 concentrations, this preliminary study indicates that establishing an atmosphere that is close to the desired atmosphere actively and quickly for longan fruit is able to improve its storage behaviour.

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Table 1. Package atmosphere changes during ambient storage of longan fruit*

Measurement	Days of Storage	Air	$1\%O_2+5\%CO_2$	$3\%O_2+5\%CO_2$	$10\%O_2+5\%CO_2$
O_2 %	0	21.0	1.0	3.0	10.0
	1	7.5	0.7	2.0	5.2
	2	3.5	0.7	2.0	3.3
	3	3.5	0.8	2.1	3.4
	5	3.4	0.8	2.0	3.3
	7	3.4	0.7	2.0	3.2
CO_2 %	0	0.0	5.0	5.0	5.0
	1	5.5	5.1	5.2	5.5
	2	6.0	5.2	5.3	5.8
	3	5.2	5.3	5.3	5.3
	5	5.5	5.2	5.2	5.4
	7	5.5	5.3	5.2	5.5

* All data are means of triplicate experiments.

Table 2. Package atmosphere changes during cold storage of longan fruit (4°C)*

Measurement	Days of Storage	Air	$1\%O_2+5\%CO_2$	$3\%O_2+5\%CO_2$	$10\%O_2+5\%CO_2$
O_2 %	0	21.0	1.0	3.0	10.0
	3	11.6	0.9	2.1	7.5
	7	3.5	0.8	2.1	3.5
	14	3.5	0.7	2.0	3.3
	21	3.4	0.8	2.1	3.4
	28	3.5	0.8	2.1	3.3
	35	3.4	0.7	2.0	3.2
CO_2 %	0	0.0	5.0	5.0	5.0
	3	5.8	5.1	5.2	5.8
	7	6.0	5.2	5.2	5.6
	14	6.0	5.2	5.1	5.6
	21	5.8	5.3	5.2	5.7
	28	5.6	5.3	5.2	5.6
	35	5.5	5.3	5.2	5.5

* All data are means of triplicate experiments

Table 3. Quality changes in soluble solids and ascorbic acid contents during ambient storage of longan fruit*

Measurement	Days of Storage	Air	$1\%O_2+5\%CO_2$	$3\%O_2+5\%CO_2$	$10\%O_2+5\%CO_2$
Soluble solids %	0	22.8	22.8	22.8	22.8
	2	20.5b	21.5a	21.4a	20.6b
	3	18.8b	20.3a	20.3a	18.9b
	5	18.0b	19.7a	19.6a	18.15b
	7	17.4b	19.3a	19.2a	17.5b
Ascorbic acid (mg/100g)	0	86.1	86.1	86.1	86.1
	2	79.0b	81.2a	81.1a	79.1b
	3	76.8b	79.1a	78.9a	77.0b
	5	75.3b	77.9a	77.8a	75.5b
	7	74.2b	76.6a	76.4a	74.3b

* All data are means of triplicate experiments.
a-b Means with the same letters within a row is not significantly different ($P<0.05$).

Table 4. Quality changes in soluble solids and ascorbic acid contents during cold storage of longan fruit (4°C)*

Measurement	Days of Storage	Air	$1\%O_2+5\%CO_2$	$3\%O_2+5\%CO_2$	$10\%O_2+5\%CO_2$
Soluble solids %	0	22.8	22.8	22.8	22.8
	3	21.8	22.2a	22.1a	21.9a
	7	20.7b	21.7	21.5a	20.8b
	14	19.7	21.0a	20.9a	19.7b
	21	19.0	20.6	20.5a	19.0b
	28	18.3b	20.0a	19.9a	18.5b
	35	18.0	19.6a	19.5a	18.1b
Ascorbic acid (mg/100g)	0	86.1	86.1	86.1	86.1
	3	83.5b	85.0	84.7a	83.6b
	7	81.6b	83.2a	83.1	81.7b
	14	80.3b	82.1a	81.9a	80.4
	21	79.4b	81.0a	80.8a	79.5b
	28	78.3a	79.7a	79.6a	78.4b
	35	76.3b	78.3a	78.1a	76.4b

* All data are means of triplicate experiments
a-b Means with the same letters within a row are not significantly different ($P<0.05$,n=9).

Table 5. Changes in browning grade and PPO activity during ambient storage of longan fruit*

Measurement	Days of Storage	Air	$1\%O_2+5\%CO_2$	$3\%O_2+5\%CO_2$	$10\%O_2+5\%CO_2$
Browning grade	0	0	0	0	0
	1	0	0	0	0
	2	0.4a	0.2b	0.2b	0.31a
	3	1.2a	0.6b	0.7b	1.01a
	5	1.9a	1.3b	1.5b	1.80a
	7	2.6a	1.9c	2.2b	2.48ab
PPO activity*	0	135.0	135.0	135.0	135.0
	1	137.0a	135.5b	136.0b	136.7a
	2	141.2a	137.3c	138.8b	139.0ab
	3	238.1a	185.1b	190.9b	221.0a
	5	300.2a	250.5b	270.0b	290.5a
	7	365.7a	304.2c	327.6b	341.2b

* All data are means of triplicate experiments

** PPO activity: unit/mg protein/min.

a-c Means with the same letters within a row is not significantly different ($P<0.05$,n=9).

Table 6. Changes in browning grade and PPO activity during cold storage of longan fruit (4◦C)*

Measurement	Days of Storage	Air	$1\%O_2+5\%CO_2$	$3\%O_2+5\%CO_2$	$10\%O_2+5\%CO_2$
Browning grade	0	0	0	0	0
	3	0	0	0	0
	7	0.3a	0.2b	0.2b	0.30a
	14	0.7a	0.4b	0.45b	0.60a
	21	1.3a	0.7b	0.8b	1.08a
	28	1.8a	1.2b	1.3b	1.70a
	35	2.6a	1.8b	2.0b	2.46a
PPO activity**	0	135.0	135.0	135.0	135.0
	3	138.2a	135.1b	135.9b	136.3b
	7	140.1a	136.5b	137.1b	139.1a
	14	191.2a	145.6b	154.1b	186.8a
	21	245.3a	195.3b	207.4b	228.9a
	28	290.7a	241.0b	250.6b	278.3a
	35	335.4a	290.2c	305.0bc	320.5ab

* All data are means of triplicate experiments

** PPO activity: unit/mg protein/min.

a-c Means with the same letters within a row is not significantly different ($P<0.05$,n=9).

Modified/Controlled Atmospheres for Avocado (*Persea americana* Mill)

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Extensive work has been done on M/CA of avocado, both to extend the storage/shelf life of the fruit, and to characterize its responses to M/CA (Yahia, 1997; Yahia and Paull, 1997). Very early research by Overholser (1928) reported that the storage life of 'Fuerte' avocados was prolonged one month when fruit was held in an atmosphere of 4 to 5% O_2 and 4 to 5% CO_2 at 7.5°C compared to air storage. Brooks et al. (1936) reported that fruit could be held in atmospheres containing 20 to 50% CO_2 at 5 to 7.5°C for 2 days without causing any injury. Atmospheres with CO_2 levels below 3% prolonged the storage life of Florida avocados at all temperatures, and reduced the development of brown discoloration of the skin (Stahl and Cain, 1940). Extensive work was later done also with 'Fuerte' avocado at the University of California at Los Angeles, and concluded that the time for the fruit to reach the climacteric is extended in proportion to the decrease in O_2 concentration from 21 to 2.5% (Biale, 1946). In later years Young et al. (1962) demonstrated that the delay of the climacteric could also be achieved by 10% CO_2 in air, and the combination of low O_2 and high CO_2 suppresses further the intensity of fruit respiration. Hatton and Reeder (1965) and Spalding and Reeder (1972, 1974) found that a CA of 2% O_2 and 10% CO_2 at 7.5°C doubled the storage life of the cultivars 'Lula', 'Fuch', and 'Booth 8'. Jordan and Smith (1993) reported that 'Hass' avocados remained firm and unripe for 7 to 9 wks in CA of 2-10% O_2 and 4-10% CO_2 at 7°C. Truter and Eksteen (1982) reported that a mixture of 2% O_2 and 10% CO_2 extended the shelf life and reduced grey pulp and virtually eliminated pulp spot of 'Fuerte', 'Edranol', and 'Hass', but an increase in anthracnose was observed. Truter and Eksteen (1987) found that a 25% CO_2 shock treatment applied one day after harvest reduced physiological disorders without any increase in anthracnose. Marcellin and Chavez (1983) reported that intermittent exposure to 20% CO_2 of `Hass` avocados stored in air delayed senescence at 12°C, reduced chilling injury (CI) at 4°C, and controlled decay at both temperatures. CA delays the softening process, and thus maintains the resistance of the fruit to fungal development (Spalding and Reeder, 1975). Prusky et al. (1993) reported that 30% CO_2 (with 15% O_2) for 24 hours increased the levels of the antifungal compound: 1-acetoxy-2-hydroxy-4-oxo-heneicosa-12,15-diene in the peel and flesh of unripe avocado fruits, and delayed decay development. This diene has been suggested as the basis for decay resistance in unripe avocados (Prusky et al., 1991). The high concentration of CO_2 increased the activity of the enzyme phenylalanine ammonia lyase (PAL) in fruit peel, enhanced the messenger RNA expression of the gene encoding PAL activity, and increased the concentration of the soluble phenolic epicatechin (Prusky et al. 1993). The 20% CO_2 can be tolerated by thick-skinned avocados such as `Hass` and `Lula`, but causes browning of the skin in thin-skinned cultivars such as `Ettinger' (Collin, 1984). Moderately high concentrations of CO_2 (up to 10%) were shown to ameliorate CI in avocados

(Vakis, et al., 1970). Spalding and Reeder (1973) found less internal and external CI in CA than in air storage of 'Booth 8' and 'Lula' avocados. Intermittent high CO_2 treatment (3 treatments during 21 days) reduced CI symptoms (Marcellin and Chaves, 1983). 'Fuerte' avocados had less pulp spot and blackening of cut vascular bundles after storage in 2% O_2 and 10% O_2 at 5.5°C for 28 days, or after a "shock" treatment of 25% at 5.5C for 3 days and an additional 28 days at normal atmosphere at 5.5°C (Bower et al., 1990). Spalding (1976) concluded that the CO_2 must be kept below 15% to prevent other fruit injury. Prestorage of 'Fuerte' avocados in N_2 atmosphere for 24 hours at 17°C significantly reduced CI symptoms after storage at 2°C (Pesis et al. 1993). Fruit prestored in 97% N_2 had lower respiration and ethylene production, lower ion leakage, higher reducing power (expressed as SH groups, mainly cysteine and glutathione), and longer shelf life than the untreated fruit. 'Booth 8' and 'Lula' avocados were reported to be held successfully for up to 8 weeks in a CA of 2% O_2 with 10% CO_2 at 4-7°C and 98-100 RH, and removal of ethylene further improved the keeping quality of the 'Lula' fruits (Spalding and Reeder, 1972). `Fuerte' and `Anaheim' fruits were stored in Brazil for up to 38 days in 6% O_2 and 10% CO_2 at 7°C, but only for 12 days in air (Bleinroth et al., 1977). Storage of 'Waldin' and `Fuchs' avocados in 2% O_2 and 10% CO_2 for up to 4 weeks at 7°C was also reported to prevent development of anthracnose and CI (Spalding and Reeder, 1974; 1975). 'Hass' avocado was reported to be stored for up to 60 days in atmospheres of 2% O_2 and 5% CO_2 (Faubian et al. 1992). Four commercial CA rooms were constructed in Florida in the season of 1972/73 for storage of 'Lula' avocados in bulk bins (Spalding and Reeder, 1974). The rooms were run at 2% O_2 and 10% CO_2 at 7.2°C and 95% RH, and fruits were reported to be marketed in excellent conditions after 5 weeks storage, except for some fruits with rind discoloration (CI) where temperature dropped below 4.4°C (Spalding and Reeder, 1974). In South Africa, Bowers et al. (1992) suggested that eventhough fruit stored in CA (2% O_2 and 10% CO_2) were superior than in other forms of storage, the economic and logistical realities were not significant. No current commercial CA storage is reported any where.

'Hass' avocados sealed in non-characterized polyethylene bags and stored at 20 or 30°C for 4 to 11 days were reported to stay firm and apparently non-ripening while were wrapped (Chaplin and Hawson, 1981). Atmospheres developed in the bags were from 2.4 to 6.2% O_2, 6.5 to 8.9% CO_2, and 0.1 to 12.7 ppm of ethylene. The presence or absence of $KMnO_4$ in the bags had no effect on O_2 and C_2H_4 levels, but significantly decreased the CO_2 levels. Fruits of the cultivars 'Hass' and 'Fuerte' individually sealed in polyethylene bags (0.05 mm thickness) and stored at 4 and 7.5°C showed little or no CI symptoms compared to control fruits (Scott and Chaplin, 1978). The composition of the gas inside these bags varied from 3 to 7% CO_2, 2 to 6% O_2, and up to 2.5 ppm of C_2H_4. Oudit and Scott (1973) reported a considerable extension in the storage life of 'Hass' avocados sealed in polyethylene bags. 'Hass' avocados sealed in polyethylene bags (0.015 to 0.66 mm) ranging in permeability from 111 to 605 cc O_2/m^2.hr.atm., and from 0.167 to 0.246 g H_2O/m^2.hr.atm. and stored at 5°C for up to 4 weeks lost less weight and firmness compared with unsealed fruits (Gonzalez et al. 1990). Bags with the least permeability maintained the lowest O_2 and highest CO_2 atmosphere, and resulted in the least losses in firmness. Initial modification of the atmosphere by introducing CO_2 and N_2 to the packages reduced the accumulation of C_2H_4, but had no significant additional benefits due to the short period in which the initially modified atmosphere was maintained. Decay development in avocados sealed in polyethylene bags was considered to be a problem by some researchers (Aharoni et al., 1968), but not by others (Thompson et al. 1971). Fruits of 'Booth 7' coated with NatureSeal, a polysaccharide-based edible film, and stored at 20°C

delayed ripening by 2 days, even when treated with 100 ppm ethylene for up to 3 days (Bender et al., 1993). Treatment with ethylene for 4 days overcame the ripening delay. Coated avocados had an internal atmosphere of 15.2% O_2 and 3.7% CO_2, while it was 10.2% O_2 and 10.1% CO_2 in uncoated fruits. Coating with Natureseal was found to be ineffective once the onset of ethylene production occurs. 'Fuerte' avocados coated with 12% water emulsion of polyethylene-baesd wax and stored for 14 days at 5°C did not modify significantly the internal O_2, CO_2, and C_2H_4 concentration, and had little effect on fruit softening (Durand et al., 1984).

The storage life of fruits held in low pressure storage was reported to depend on their susceptibility to decay and to CI. LP, especially below 100 mm Hg, markedly delayed the storage life of 'Hass' avocados (Apelbaum et al., 1977b). For example fruit stored in 60 mm Hg at 6°C remained unripe for 70 days, had no adverse effects, and ripened normally after transfer to normal atmsopheric pressure at 14°C. However, storage of fruit in 50 mm Hg caused substantial fruit descication. Optimum conditions for low pressure storage of Florida avocados were suggested to be 20 mm Hg at 4.5°C (Spalding, 1976; Spalding and Reeder, 1976). Fruits held in these conditions for up to 3 weeks were firmer, and had less decay and CI than fruits held in 76 or 760 mm Hg. However, CO_2 is considered to be essential for control of decay and to ameliorate CI in avocados. Gases, such as CO_2 and CO, can not be added when LP system is used. Spalding (1977) concluded that LP system is not recommended for avocado, but his results are in the contrary to those of Burg (1975) and Apelbaum et al. (1977).

Storage of `Hass` avocados in 2.5% O_2 suppressed the celulase activity, and produced an alternation in the profile of fruit total protein, causing no effect, suppression, enhancement and induction of new polypeptides (Kanellis et al. 1989). Storage of `Hass` avocados in 2.5-5.0% O_2 which suppressed the activity of ripening enzymes such as celulase and polygalacturonase at the protein level as well as at the mRNA level, induced the synthesis of new isoenzymes of ADH (Kanellis et al., 1991). Low O_2 levels induced the appearance of new as well as the increase in staining intensity of pre-existing polypeptides in both preclimacteric and propylene initiated `Hass` avocados, but suppressed polypeptides in ripening fruits (Kanellis et al., 1993). Low O_2 (0-5%) did cause detectable suppressive effect on pre-existing mRNA in preclimacteric or initiated fruit, but caused evident repressive effect on newly synthesing ripening mRNA (Kanellis et al., 1993). Induction of specific protein synthesis and gene expression were reported to take place in `Hass` avocados stored in 0 to 5% O_2 (Kanellis et al., 1993). These authors reported that ADH, LDH, and glucose phosphate isomerase (GPI) isoenzymes were expressed in low O_2 in both pre-climacteric and initiated avocado fruit, and the increase in ADH protein corresponded to its elevated mRNA levels.

'Hass' avocados maintained in MA (0.1-0.44% O_2, 50-75% CO_2, balance N_2) at 20°C had higher CO_2 production compared to air (control) fruit, most likely reflecting anaerobiosis (Yahia, 1993b; Carrillo-Lopez and Yahia, 1990; Yahia and Carrillo-Lopez, 1993). Fruits stored in MA and then ripened in air had mesocarp and exocarp injury after 2 days. Storage for 2 days in MA decreased the concentration of glucose 3-phosphate, fructose 3-phosphate, and 2-phosphoglycerate, while the concentration of glyceraldehyde 3-phosphate, 1,3-bisphosphoglycerate decreased after storage for 5 days. Cross-over plots for changes in the concentration of the glycolytic intermediates between air and MA did not show significant effects of MA on control sites (Carrillo-Lopez and Yahia, 1990). On the basis of these results Yahia (1993b) and Yahia and Carrillo-Lopez (1993) concluded that 'Hass' avocado fruit is very sensitive to insecticidal atmospheres, tolerating only one day at 20C.

These findings were confirmed later by Yahia and Kader (1991) and Ke et al. (1995). Biale and Young (1981) stated that avocado is very sensitive to anaerobic conditions, unlike other fruits which can swich to fermentative metabolism when deprived of O_2. CA injury in avocado seem to be aggravated as the result of the combining effect of low O_2/high CO_2. For example, rind injury in `Lula` avocado appeared in fruits held for 3 days in 0.5% O_2 and 25% CO_2, was very slight in 0.5% O_2 and 0% CO_2, and absent in 21% O_2 and 25% CO_2 (Spalding and Marousky, 1981).

`Hass` avocados kept in 0.25% O_2 alone or in combination with 80% CO_2 for 3 days at 20°C, had higher concentrations of acetaldehyde and ethanol, increased NADH, and decreased NAD levels (Ke et al., 1995). `Hass`avocado was reported to have a cytoplasmic pH of 6.9, and storage at 0.25% O_2, 80% CO_2, or the combination of both decreased the pH value to 6.7, 6.3, and 6.3 respectively (Hess et al., 1993). Optimum pH for PDC was about 6-6.5 (Ke et al., 1995), and thus the decrease in cytoplasmic pH reported by Hess et al. (1993) would activate this enzyme. The reported decrease in pH would also inhibit pyruvate dehydrogenase (PDH), and affect the activity of lactate dehydrogenase (LDH) and ADH (Ke et al, 1995). Exposure of the fruit to 0.25% O_2, 80% CO_2, or combination of both reduced ATP level by 20%, 22%, and 63%, respectively (Hess et al., 1993).

Ke et al. (1995) proposed a mode of action of very low O_2 stress on fermentative metabolism in avocado. Low O_2 substantially reduces NADH flux through the electron transport system (ETS), and as a result NAD and ATP levels decrease and NADH level increases. Cytoplasmic pH is decreased to the level where PDH activity is decreased or inhibited, and pyruvate flux through the TCA cycle is decreased. PDC activity is increased due to changes in cytoplasmic pH and to an increase in pyruvate concentration. A new ADH isoenzyme is induced, and thus acetaldehyde and ethanol are produced from pyruvate. LDH activity is increased due to the increase in pyruvate and NADH concentrations, and the decrease in NAD and ATP levels, and thus lactate is acumulated. The accumulation of fermentative products (ethanol, acetaldehyde, and lactate), the energy shortage, and the modification of the normal metabolism may be the cause of injury in avocado fruits exposed to low O_2 stress.

There is no current use of CA storage for avocados. MA has been used for several years during marine shipment of avocados from several countries such as USA, Mexico, Chile, and Israel (Yahia, 1995; Spalding and Marousky, 1981). Some shipments have failed. Recently the improved MA and CA in transport has solved some problems and fruit shipped in these systems is increasing. Optimum atmosphere composition for long-term storage of avocados is about 2-5% O_2 and 3-10% CO_2. These atmospheres delay ripening and reduce CI. Avocados are not stored in MA or CA, but their use during long-term marine transport is increasing. Avocados are very sensitive to insecticidal atmospheres (Yahia, 1997; Yahia and Paull, 1997).

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Modified/Controlled Atmospheres for Bananas and Plantains (*Musa* spp)

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MA/CA extends the storage life of green bananas (Mapson and Robinson 1966; Scott and Robert 1966; Smock 1967; Barden and Lima 1969; Woodruff 1969b; Liu 1970; Quazi and Freebairn 1970; Scott et al. 1970; Fuchs and Temkin-Forodeiski 1971; Scott 1971; Duan et al. 1973; Scott and Gandanegara 1974; Burg 1975; Scott 1975; Liu 1976a; Liu 1976b; Scott and Chaplin 1978; Brown 1981; Satyan et al. 1992a; Satyan et al. 1992b; Banks 1984a; Hesselman and Freebairn 1986; Kanellis et al. 1989a; Yahia, 1997; Yahia and Paull, 1997). Bananas are very responsive to MA/CA when the fruit is at the preclimacteric stage (Smock 1979). Optimum atmospheres differ for different cultivars but are about 2 to 5% O_2 and 2 to 5% CO_2, and optimum temperature for MA/CA storage is 13°C (Woodruff 1969b). Cooking bananas have similar CA requirements (Satyan et al. 1992b). Atmospheres containing 5% O_2 and 5% CO_2 were found to be suitable for 'Gros Michel' bananas held for 20 days at 12C (Wardlaw 1940). 'Lacatan' and 'Dwarf Cavendish' bananas were kept for 3 weeks in atmospheres containing 6 to 8% CO_2 and 2% O_2 at 15°C (Smock 1967). The recommended atmosphere for 2 Malaysian cultivars of bananas at 20°C and 80% RH was 5 to 10% CO_2 and a continuous removal of ethylene (Broughton and Wu 1979). Atmosphere of 1% O_2 inhibited ripening in green bananas and was considered as the lower limit at 15.5°C (Parsons et al. 1964). O_2 concentrations less than 1% cause fruit injury which include dull yellow to brown skin discoloration, failure to ripen, flaky gray flesh, and off-flavors (Parsons et al. 1964). However, 1% O_2 was reported by other researchers (Mapson and Robinson 1966; Chiang 1970) to result in poor quality and more stalk rot. Furthermore, research by Hesselman and Freebairn (1986) have indicated that O_2 levels less than 2.5% affect the taste of 'Valery' bananas. CO_2 concentration higher than 5% are reported to result in undesirable flavor and texture after fruit ripening (Woodruff 1969b). CO_2 level of 10% was considered to be the upper limit for 'Gros Michel' bananas (Gane 1936).

Experiments were conducted with storage of bananas in CA sealed rooms (Woodruff 1969b). Rooms were flushed with N_2 to reduce the O_2 level and supplemental CO_2 was added. Water scrubber was used to control the CO_2 concentration. Purifiers containing brominated, activated carbon were used to absorb volatiles (including ethylene). CA markedly reduced the crown rot. Woodruff (1969b) listed 4 advantages of CA storage of bananas including 1) fruit can be held for long periods without significant ripening or turning. 2) decreases incidence of rots and molds. 3) maintains a fresher appearance fruit, and 4) more flexibility in coping with glutted markets. However, there has been no commercial CA storage for bananas. Bananas are available all year around, and therefore there is no need for long-term storage. Gas tight CA chambers would have to be built aboard ships, since most of the postharvest life of bananas is maintained during transit. In the past this was not technologically feasible, however, the recent advances in CA technology and

marine containers facilitates the application of CA aboard marine ships, which can provide a postharvest life of up to 2 months.

MA has been used commercially for the last 3 decades during marine shipments of banana (Woodruff 1969a; b). In this system green fruits are usually packed in polyethylene bags of about 0.04 mm (1.5 mil) thickness, which are then evacuated (usually using a vacuum cleaner) and sealed (Woodruff 1969a). High temperatures at the time of evacuation accelerate the establishment of the desirable atmosphere (Woodruff 1969b). The atmosphere in these bags usually averages about 2.5% O_2 (1 to 4.5%) and 5.2% CO_2 (4 to 6%) after 3 to 4 weeks. This system has been called "Banavac" by United Fruit Company (Smock 1979; Woodruff 1969b). Bananas can be held for 30 days by this method, and can be maintained green for up to 60 days but rots increase and quality declines after 30 days (Woodruff 1969b). Fermentation problems have occurred in up to 1% of fruits shipped in this system (Woodruff 1969a). Only green fruits should be used, and care should be taken not to use punctured bags. Punctured bags will not allow the development of an appropriate atmosphere. Ripe fruits would increase the accumulation of ethylene inside the bags, and would further stimulates fruit ripening. Ethylene concentration of 10 ppm accelerated the ripening of 'Valery' bananas (Woodruff 1969b). A concentration of 10 ppm or more of ethylene can also stimulate the softening of green fruit (Chiang 1968; Chiang 1970), a condition known as "soft-green" (Woodruff 1969b) or "green ripeness" (Scott 1975). High temperature, high CO_2, and low O_2 in the storage atmosphere were suggested to be the main factors causing this disorder, however, the exact mechanism is not fully understood (Zhang et al. 1993). The use of ethylene absorbent agents such as potassium permanganate absorbed on aluminum silicate or vermiculite inside the bags can prevent this disorder and prolong the postharvest life of the fruit (Scott et al. 1968; Liu 1970; Scott 1975). Ethylene removal with brominated carbon was found to extend the storage life of 'Lacatan' and 'Cavendish' bananas held in 2-3% O_2 and 8% CO_2 (Smock 1967), and was found to be more effective than using molecular sieve 5A in a continuous air and C_2H_4 stream (Chiang 1968). The use of MA for bananas was found to prolong their storage life even at ambient temperatures (Scott and Gandanegara 1974).

The use of sealed polyethylene (0.1 mm thickness) containing 100 g vermiculite impregnated with a saturated solution of $KMnO_4$ allowed a storage life of 'Williams' bananas for up to 6 weeks at 20 to 28°C and 16 weeks at 13°C (Satyan et al. 1992a; b). 'Latundan' banana was stored in 0.08 mm thick polyethylene bags for up to 13 days at 26-30°C (Agillon et al. 1987). Storage of green mature `Cavendish' bananas in low density polyethylene bags (0.05 mm thickness) for up to 30 days at 8, 11 and 14°C developed an in-package atmosphere of 3 to 11% O_2 and 3 to 5% CO_2 (Hewage et al. 1995). However, these authors reported that these storage conditions did not affect ripening and sensory quality, nor did they alleviate CI symptoms developed at 8 and 11°C. `Emas' bananas stored in polyethylene bags (0.04 mm thickness) for 6 days at 24°C generated an atmosphere of up to 3% C_2H_4, up to 14.6% CO_2, and as low as 2.9% O_2 (Tan et al. 1986). Accumulation of 10% CO_2 or more, especially from day 3 to day 6, and an O_2 concentration below 2% in the bags caused abnormal ripening when fruit was ripened later in air. Fruit had skin and pulp darkening, and softening of the inner portion of the pulp, eventhough the outer portion remained hard. Water insoluble protopectins decreased, and water soluble pectins and pectates increased in wrapped fruits. The authors suggested that a minimum of 10% CO_2 for few days is required to cause injury in `Emas' bananas. $CO_2$ (10%) injury was also reported for `Mas' bananas (Abdullah et al. 1987). Several cultivars of cooking banana ('Bluggoe', `Pacific plantain', `Blue Lubin', and `Pisang Awak') behaved similarly to the dessert cultivar `Cavendish' when stored in

polyethylene bags (0.1 mm) with or without an ethylene absorbent (potassium permanganate on aluminum oxide) at 7, 13, 20, and 28°C (Satyan at al. 1992b). The storage life increased by a factor of two in the absence of an ethylene absorbent and a factor of three in the presence of the ethylene absorbent. CO_2 concentration inside the packages increased up to 15%, and concentrations as high as 32% were reported at the end of storage. Packaging with or without ethylene absorbent had no effect on the incidence of chilling injury (CI) neither in the cooking banana cultivars nor in `Cavendish'. The authors suggested that this method of sealing in polyethylene bags "appears to be an alternative method to refrigeration" (!).

Liu (1976a) suggested pretreatment of the fruit with ethylene at the production or packing site before storage or shipping, to avoid post shipping treatment due to high costs, and to provide even ripening. `Dwarf Cavendish' pretreated with ethylene and stored for 28 days in 1% O_2 or in 0.1 atmospheric pressure at 14°C remained green and firm until the end of the storage period, and started to ripen almost immediately after being placed in air at 21C without additional ethylene treatment. However, the period of ethylene pretreatment is critical and should not exceed a "threshold length of time (TLT)". The TLT is defined by Liu (1976b) as the minimum time required for a fixed concentration of ethylene treatment to induce banana ripening response. Only bananas which had been pretreated with ethylene for a period equal to TLT were successfully stored in CA (Liu 1976a). Neither CA nor LP could prevent the ripening of bananas pretreated with ethylene for a period longer than TLT. Fruits are not uniform in their TLT. Commercially mature bananas may have TLT between 4 and 20 hours, and a test for TLT requires 1 to 2 days (Liu 1976b). Therefore, from a practical point of view the author concluded that it would be extremely difficult to select large lots of fruit with uniform TLT, and thus the potential hazard of fruit ripening during storage or shipping after excessive ethylene pretreatment jeopardize the commercial applicability of this method.

Treatment with "Prolong" (a mixture of sucrose esters of fatty acids and sodium salt of carboxymethylcellulose) extended the shelf-life of bananas (Lowings and Cuts 1982; Banks, 1984a; 1984b). The commercial wax "Decco Luster 202" at a 1:2 (wax:water, v/v) delayed ripening of 'Saba' bananas (Pastor and Pantastico 1984), but other formulations ("Carbowax" and "Prima Fresh") had no effect. The action of "Pro-long" has been attributed to increased resistance to CO_2 diffusion and to O_2 creating an internal atmosphere with a reduced O_2 and elevated CO_2 (Lizada and Novenario 1983).

'Gros Michel' bananas held in a low pressure (LP) of 150 mm Hg at 15°C were maintained longer in a better quality than those held in normal pressure (Burg and Burg 1966). Fruits held in LP of 760, 250, and 80 mm Hg at 14°C were reported to be maintained for 30, 60, and at least 120 days, respectively. The authors reported that fruits had an acceptable texture, taste, and aroma, and no injury.

The quality of green bananas was not affected when fruits were held for up to 7 days in 100% N_2 at 15.5°C, but had dark-brown to black skin blemishes when held for 10 days (Parsons et al. 1964). After 4 days in 100% N_2 at 15.5°C, fruits ripened to a normal color and flavor in 13 days at 20C. However, fruit failed to ripen in air, and developed decay, brown skin discoloration, and off-flavor after storage in 100% N_2 for 7 days. Fruits were ripened normally in air at 20°C after being held in 99% N_2 and 1% O_2 at 15.5°C for 10 days.

Low O_2 (2.5%) suppressed the activity of acid phosphatase, and the addition of 500 ml of ethylene to the low O_2 atmosphere did not reverse this suppression (Kanellis and Solomos 1985; Kanellis et al. 1989a). However this atmosphere either alone or in combination with 500 ml

ethylene prevented the decline in the activity of pectin methyl esterase. Kanellis et al. (1989a) suggested that there was differential effects of low O_2 on metabolic processes since that the accumulation of sugars increased gradually for 4 days in low O_2, but no increase in acid phosphatase was observed throughout the duration of the low O_2 treatment. Low O_2 (3%) limited the operation of the Krebs cycle in fruits of Musa paradisiaca L., but high CO_2 showed no rate limiting steps in this cycle (McGlasson and Wills 1972). Ali Azizan (1988) reported that high CO_2 suppressed the activities of ADH, LDH, PDC, and phosphofructokinase (PFK), but not malic enzyme and phosphoenol pyruvate carboxylase in 'Pisang Mas' bananas.

Optimum atmosphere composition for bananas is 2 to 5% O_2 and 2 to 5% CO_2. These atmospheres delay fruit ripening without causing any deleterious effects. CA can maintain the fruit for a longer period in good quality. Although a recent a report (Blankenship 1996) indicated that bananas that have ripened under CA conditions are not as high quality as those ripened in air in terms of visual appearance. MA, sometimes in combination with ethylene-absorbent agents, are commonly used during long-distance marine transport. LP also can maintain the fruit for a longer period in a very acceptable quality. However, due to availability of the fruit almost all year around and because of costs considerations, CA is not commonly used and LP is not commercially used. There is potential for the use of CA on marine ships. Research needs for this fruit include investigation on the cost and technological feasibility of the establishment and use of CA (Yahia, 1997; Yahia and Paull, 1997).

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Modified/Controlled Atmospheres for Mango (*Mangifera indica* L.)

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A very early study by Singh et al. (1937) suggested that mangos could be kept in an atmosphere with 9.2% O_2 to prolong the ripening period. Kapur et al. (1962) reported that 'Alfonso' mango was kept satisfactorily in 7.5% CO_2 at 8.3-10.0°C for 35 days, and 'Raspuri' mango in 7.5% CO_2 at 5.5-7.2°C for 49 dyas. 'Haden' mangos were stored in CA (2% O_2 + 1 or 5% CO_2) for 6 weeks. Maekawa (1990) concluded that it is possible to maintain 'Irwin' mangos for up to 4 weeks in 5% O_2 and 5% CO_2 at 12°C and the use of an ethylene absorbent (activated charcoal/vanadium oxide catalyst). In addition, the author reported that temperature can be safely reduced to 8°C. 'Rad' mangos was reported to be successfully kept for up to 25 days in 6% O_2 and 4% CO_2 at 13°C and 94% RH (Noomhorm and Tiasuwan, 1995). In Brasil, 'Haden' mangos was held for 30 days and 'Carlota', 'Jasmin', and 'Sao Quirino' were held for 35 days in 6% O_2 and 10% CO_2 at 8°C and 90% RH (Bleinroth et al., 1977). In France, 'Amelie' mangos stored for 4 weeks in 5% O_2 and 5% CO_2 at 10 to 12oC had less decay, and fruits were reported to be more acceptable after CA than after air storage (Kane and Marcellin, 1979). The Philippines Council for Agriculture and Resource Research (1978) reported that 'Caraboa' mangos can be kept for 28 days in 5% O_2 and 5% CO_2 at 10°C, however, this cultivar was reported by other researchers in the Philippines (Gautam and Lizada, 1984; Nuevo et al. 1984) to be very susceptible to MA injury. Gautam and Lizada (1984) reported that storage in MA using polyethylene bags for more than one day causes ripening abnormalities. It has been suggested that CA is not, or only slightly beneficial for mango (Hatton and Reeder, 1966; Spalding and Reeder, 1974). The best atmosphere for 'Keitt' mango was reported to be 5% O_2 and 5% CO_2 at 13°C, however, quality was not better than in air storage (Spalding and Reeder, 1977). A 10% CO_2 atmosphere alleviated chilling symptoms in fruit of the cultivar 'Kensington', but higher concentrations were injurious, while low O_2 (5%) had no significant effect (O'Hare and Prasad, 1993). Higher concentrations of CO_2 (more than 10%) were found by these authors to be ineffective in alleviating chilling injury (CI) at 7°C, and tended to cause tissue injury and high levels of ethanol in the pulp. 'Rad' Mangos had internal browning and off-flavor in atmospheres containing 6 and 8% CO_2 (Noomhorm and Tiasuwan, 1995). The presence of starchy mesocarp in 'Carabao' mango, which is characteristic of internal breakdown, increases in the this cultivar during storage in MA (Gautam and Lizada, 1984). Fruits stored for 4-5 days exhibited severe symptoms which included air pockets in the mesocarp resulting in spongy tissue (Nuevo et al., 1984a, 1984b). Parenchyma cells of affected tissues had an average of 18 starch granules per cell, compared to an average of 2 starch granules in healthy adjecent cells. However, no difference in starch granule shape was detected between the 2 tissues. The spongy

tissue, which usually occurs in the inner mesocarp near the seed and becomes evident during ripening, had almost 10 times of starch content compared to the healthy tissue in the same fruit. External symptoms of the internal browning due to MA was reported to consist in the failure of the peel to develop color beyond the half-yellow stage. 'Carabao' mango stored in polyethylene bags (0.04 mm) had faint fermented odor that disappeared during ripening when fruit was kept for one day (Gautam and Lizada, 1984). The fermented odor was stronger the longer the storage duration, and persisted throughout ripening when fruit were kept for 2 to 5 days in polyethylene bags. The respiratory quotient of this cultivar ranged from 0.59 at 21% O_2 and 6.03 at 2.4% O_2, which indicates a progressively anaerobic metabolism (Sy and Mendoza, 1984). The same authors reported that CO_2 production decreased from 21 to 3% O_2, but increased at concentrations below 3%. Fermented odor was explained as a possible indication of fermentative decarboxylation as was reported in 'Alfonso' mango subjected to elevated concentrations (more than 15%) of CO_2 (Lakshminarayana and Subramanyam, 1970). Injury in 'Kensington' mango caused by higher levels of CO_2 appeared to be more severe at lower temperatures (Ohare and Prasad, 1993), which could be due either to compounding injury (chilling + CO_2) or to reduced sensitivity of ripe mango to CO_2.

Diseases, especially anthracnose and stem-end rot, are the principal limiting factors for mango storage. Moderate O_2 ($\geq$5%) and CO_2 atmospheres ($\leq$ 5%) are not sufficient for control of diseases. Pronounced decay incidence appeared after storage of 'Rad' mangos for 20 days in atmospheres containing 4-6% O_2 and 4-8% CO_2 at 13°C and 94% RH, and severe incidence appeared after 25 days (Noomhorm and Tiasuwan, 1995). Greater incidence of decay (stem-end rot and anthracnose) was observed in 'Carabao' mango stored in MA for 2 to 5 days at 25 to 31°C (Gautam and Lizada, 1984). The enrichment of CA with 5 to 10% CO was suggested during shipment of mango for better disease control (Woodruff, 1977). However, CO is potentially toxic and explosive, and should not be used unless safe measures for application are developed.

Mango fruit wrapped in 0.08 mm thick polyethylene bags, with and without perlite-$KMnO_4$, and stored for 3 weeks at 10°C before treatment with ethylene, were ripened to normal color, texture, and flavor (Esguerra et al., 1978). Individually sealing of 'Keitt' mangos in low density (LDPE) and high density (HDPE) polyethylene films for 4 weeks at 20°C delayed ripening, reduced weight loss, and did not result in any off-flavors (Gonzalez et al., 1990). LDPE had a thickness of 0.010 mm and permeabilities of 700 cc O_2/cc.m^2.hr.atm, and 0.257 g H_2O/m^2.hr.atm. HDPE film had a thickness of 0.020 mm and permeabilities of 800 cc O_2/m^2.hr.atm., and 0.166 g H_2O/m^2.hr.atm. Combined effect of hot 1000 ppm benomyl solution at 55°C for 5 min, and seal packaging in 0.01 mm PVC extended the storage life of mature-green 'Nam Dok Mai' mango stored at 13°C (Sornsrivichai et al., 1992). The authors found that fruit quality was not affected by film packaging after 4 weeks, but fruit showed inferior quality after 6 weeks. The inhibition of carotene pigmentation in the peel of this variety was suggested by Yantarasri et al. (1994) to be related to O_2 concentration inside the package and not to CO_2 concentration. The authors suggested that a concentration of 16% O_2 is essential to develop peel color to the marketable stage (greenish). 'Tommy Atkins' mangos individually sealed in heat shrinkable films and stored for 2 wks at 12.8°C and then ripened at 21°C did not show differences in firmness, skin color development, decay development, or time to fruit ripening, but had more off-flavors than unwrapped fruits (Miller et al. 1983). However, these fruits had less weight loss. Polyethylene films used were: Clysar EH-60

film of 0.01 nominal thickness, Clysar EHC-50 copolymer film of 0.013 mm nominal thickness, and Clysar EHC-100 copolymer film of 0.025 mm nominal thickness. Individual mature fruits of the same variety were later sealed in Clysar EHC-50 copolymer film with 0.013 mm thickness, and Cryovac D955 with 0.015 thickness, and stored at 21°C and 85-90% RH (Miller et al., 1986). O_2 permeabilties of the films were 620 cm^3/24 hr.m^2.atm and 9833 cm^3/24hr.m^2.atm, respectively. Water permeability was 1.5 g/24 hr.m^2, and 2.0 g/hr.m^2 at 23°C, respectively. Fruit had less weight loss, but higher incidence of decay and off-flavor at soft-ripeness than unsealed fruit. The authors concluded that there was no practical benefits by wrapping this cultivars in these films and storing them at 21°C or even at lower temperatures. They have even suggested that "film wrapping mangos at various stages of ripeness after harvest is not a technique which will improve the maintenance of mango quality during storage for ripening". `Kensington' mango treated with heated benomyl (0.5 g/l at 51.5 for 5 min) and sealed in polyethylene bags (0.04 mm thickness) for various durations at 20°C, had off-flavor and lacked normal skin color when ripened, but ripened satisfactorily when held in perforated bags (Chaplin et al., 1982). The postharvest life of these fruits was not consistently longer than the control. CO_2 in the bags exceeded 20% and that of O_2 was lower than 5%. The incidence of off-flavors was reduced by the inclusion in the bags of C_2H_4 absorbent blocks ($KMnO_4$ on vermiculite/cement block). The authors concluded that "mangos can not be stored satisfactory at ambient temperature by such technique". However, Stead and Chithambo (1980) reported that mango ripening at 20 to 30°C was delayed 5 days by sealing in polyethylene bags (0.02 mm thickness) containing potassium permanganate, without any abnormal flavor. Gas composition in the bags was not reported by these authors. 'Langra' and 'Dusehri' fruit stored in perforated polyethylene bags for 12 days at ambient temperature (26-34°C) ripened normally (Bhullar et al., 1984). 'Tommy Atkins' and 'Keitt' mangos were individually sealed in shrinkable Cryovac polyolefin films (15 or 19 um thickness), either non-perforated (MD film) or perforated with 8 holes of 1.7 mm diam./sq.inch (MPY) or 8 holes of 0.4 mm diam./sq.inch (SM60M) (Rodov et al. 1994). After 2-3 weeks storage at 14°C and additional week at 17°C mango packaged in perforated polyelefin films ripened normally, and best results were achieved when film with 0.4 mm perforations was combined with increased free volume inside the package by sealing the fruit within polystyrene trays. After 3 weeks of storage and one week of shelf life sealed 'Keitt' mango had inferior quality than the control because it was less ripe, but beyond 4 weeks (up to 6 weeks) sealed fruits had better quality scores because it was less overripe. Sealing did not reduce decay of fruit stored for long periods. Chaplin et al. (1986) reported that symptoms of CI were reduced in 4 cultivars of mango stored in sealed polyethylene bags for up to 15 days at 1°C (!!!).

'Julie' mangos treated with 0.75% w/v aqueous soln of Pro-long (a mixture of sucrose esters of fatty acids and sodium salt of caboxymethylcellulose) and stored at 25°C and 85-95% RH reduced weight loss, retarded ripening, and increased storage life (6 days longer) without causing any adverse effects on quality (Dhalla and Hanson, 1988). A treatment with 1.0% increased ethanol concentration in the pulp of some fruits.

Mango fruits were artificially infested with larvae of *Drosophila melanogaster*, and individually wrapped with a Cryovac D-955 cross-linked, 60-gauge polyofin shrink film (Shetty et al. 1989). None of the insects survived in fruits wrapped for 72 hours or more. Gould and Sharp (1990) reported a 99.95% mortality of the Caribbean fruit fly in film wrapped mangos for 15 days. However, the fruit deteriorated after only 6 days.

Storage of 'Keitt' mangos in an insecticidal MA (0.03-0.26% O_2, 72-79% CO_2, and balance is N_2), and CA (0.2% O_2, balance N_2 or 2% O_2 + 50% CO_2, balance N_2) for up to 5 days at 20°C delayed fruit ripening as indicated by respiration, flesh firmness and color development (Yahia, 1993; Yahia et al. 1989; Yahia and Hernandez, 1993; Yahia and Vazquez, 1993). These atmospheres increased the activity of posphofructokinase, alcohol dehydrogenase, and pyruvate decarboxylase, and did not affect the activity of pyruvate kinase, succinate dehydrogenase, and a-keto-glutarate dehydrogenase. Although these atmospheres caused changes in glycolysis and tricarboxylic acid cycle, there was no indication of injury and fruit ripened normally after exposure to air. Sensory evaluation conducted after fruit ripening showed no presence of off-flavors, and there was no differences between fruits maintained in M/CA and those maintained continually in air. On the basis of these results the authors concluded that 'Keitt' mango is very tolerant to insecticidal atmospheres. There is still not enough studies to determine the mortality of different insects in these atmospheres. However, it is assumed that the 5 days tolerated by mango are sufficient to control many insects. The tolerance of other mango cultivars to these atmospheres is still needed.

Burg (1975) reported that 'Haeden' mangos ripened 4 times slower at a low pressure (LP) of 150 mm Hg. Several cultivars of mango including 'Irwin', 'Keitt', 'Kent', and 'Tommy Atkins' were found to be firmer after storage for 3 weeks in 76 y 152 mm Hg at 13°C and 98-100% RH (Spalding and Reeder, 1977). These fruits ripened normally after storage, had less decay, and higher percentage of acceptable fruits. A pressure of 76 mm Hg resulted in the most greener fruit, however, caused splitting. Therefore, a pressure of 152 mm Hg is considered as the optimum LP. Mango was shipped experimentally in LP (80 mm Hg at 10°C) from Mexico to Japan and arrived in satisfactory condition after 28 days from picking (Spalding, 1977b). LP (152 mm Hg) was reported to be suitable for shipping or maintaining of mango, together with bananas and limes (Spalding, 1977a). 'O Krong' mangos precooled at 15°C and waxed were maintained in 60-100 mm Hg at 13°C for up to 4 weeks, and then ripened normally (Ilangantileke and Salokhe, 1989). 'Rad' mangos were kept in 100 mm Hg and 15°C for 30 days (Chen, 1987). However, due to cost considerations no commercial use of LP is reported at the present.

There is no current use of CA storage, however, long-distance marine shipping in MA is commercially used on a very limited basis from Mexico (Yahia, 1993a) and some other countries. The recent use of CA during shipping will most probably improve the quality of shipped fruit (Yahia, 1997).

Optimum atmosphere composition for mango are reported to range between 3-5% O_2 and 5-10% CO_2. These atmospheres can delay ripening, but benefits are not very significant. CA and MA would most probably be beneficial in delaying fruit ripening during long-distance marine transport for 2 weeks or more. Mangos (cv Keitt) are very tolerant to insecticidal atmospheres, and thus a potential commercial application is feasible. Research on insect mortality by M/CA is needed. Studies are needed for the development of M/CA, most probably in combination with other treatments such as heat (Yahia, 1997; Yahia and Paull, 1997).

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Modified/Controlled Atmospheres for Papaya (*Carica papaya* L.)

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'Solo' papaya in Hawaii held for 6 days in 10% CO_2 at 18°C developed less decay than fruit stored in air or in higher concentrations of CO_2 (Akamine 1959; 1969). In 1986, Chen and Paull reported that ripening of 'Kapaho Solo' papaya was delayed by storage in 1.5 to 5% O_2 with or without 2 or 10% CO_2, but chilling injury (CI) symptoms were not reduced. In Florida, papaya held in 1% O_2 and 3% CO_2 at 13°C for 3 weeks and then ripened at 21°C was 90% acceptable, with fair appearance, slight or no decay, and good flavor (Hatton and Reeder 1969c). Storage life of 'Bentong' and `Taiping' papaya in Malaysia was extended by maintaining the fruit in 5% CO_2 at 15°C and removal of ethylene (Nazeeb and Broughton 1978). CA storage of papaya was reported to be beneficial only when the O_2 concentration is kept under 1%, and when it is used along with low temperature, hot water treatment, and ethylene dibromide (EDB) (Akamine and Goo 1969). EDB was banned in 1984 (Federal Register 1984). Arriola et al. (1980) concluded that MA raised the cost but did not maintain better quality fruit. Spalding and Reeder (1974) concluded that CA is not beneficial to prolong the storage life of papaya. Akamine and Goo (1969) reported that the shelf life of papaya held in 1% O_2 and at 13°C for 6 days was only one day longer than fruit held in air. However, Hatton and Reeder (1969c) reported that they held papayas for 21 days with an acceptable quality in an atmosphere containing 1% O_2 and 5% CO_2. Optimum maturity for CA stored fruit is mature green or 10% yellow (Akamine and Goo 1969). CA was suggested to supplement the hot water treatment for a potential storage or shipping period of up to 12 days (Akamine and Goo 1969). Sankat and Maharaj (1989) and Maharaj and Sankat (1990) reported that 'Known You No.1' and 'Tainung No.1' papayas at the color break stage treated with hot water (48°C for 20 min) and dipped in heated (1.23-1.50 g/l) Benlate (52°C for 2 min) were maintained for up to 29 days in 1.5-2.0% O_2 and 5% CO_2 at 16°C, compared to 17 days in air. Akamine and Goo (1968) suggested that it is feasible to use CA during the shipment of hot-water treated or irradiated papayas when shipping period is from 6 to 12 days.

'Kapoho' and 'Sunrise' papayas individually sealed in HDPE (0.18 mm thickness) had less CI symptoms than unsealed fruits, but developed off-flavor (Chen and Paull 1986). Seal packaging of 'Backcross Solo' papayas in 3 layers of low density polyethylene (0.0125 mm thickness) and storage at 24-28°C for 18 days retarded development of peel color and fruit softening, and reduced the increase in titratable acidity (Lasan et al. 1990). In addition, seal packaging alleviated water stress and modified internal and external atmospheres. Internal CO_2 increased to 2.2%, and O_2 decreased and was maintained at 1.2%. The retardation in fruit softening was attributed partly to a decrease in polygalacturonase activity, and to polyuronide solubilization. MAP (using 0.05 mm shrinkable polyethylene films) at 15°C retarded the firmness loss in 'Exotica' papaya fruit (Lazan et al. 1993). 'Sunset', 'Sunrise', and 'Kapoho Solo' papayas had a double hot water treatment, dipped

in 0.65 g/l thiabendazole, and either dipped in various wax solutions or shrink wrapped with various films (Paull and Chen 1989). Films used were Cryovac MPD-2055, Cryovac D-955, Dupont 75EHC, Dupont 60EHC, and Dupont 50EHC. Type of wax solutions used were Brogdex 505-20 (1:11), FMC-7051 (1:9), FMC 560 (1:4), FMC-219B (1:4), Decco-261 (1:4), Agric Chem 93-8510078 (1:0), Prima Fresh-30 (1:3), Wax-On shellac (1:4), and Wax-On polyethylene (1:4). After holding of fruit for up to 2 weeks at 10°C weight loss was reduced by 14 to 40% by waxing, and 90% by shrink wrapping. Some treatments delayed ripening by 1 to 2 days after fruit was ripened in air, however, some off-flavor was also developed. CO_2 concentration that caused off-flavor was found to be 7 to 8%; no off-flavor was developed at 6% CO_2.

Applying a cellulose-based film to papaya altered the internal gas concentration, retarded ripening, and extended the shelf life of the fruit (Baldwin et al. 1992). 'Kapoho' and 'Sunrise' papayas treated with Sta-Fresh 7051 wax solution (1:10 v/v) and stored at 2°C for 14 days or 10°C for 24 days had less CI symptoms (Chen and Paull 1986).

Fruit infested with eggs or first instar larvae of the Oriental fruit fly (*Dacus dorsalis* Hendel), wrapped in a Cryovac D-955 cross-linked, 60-gauge polyolefin shrink film, and stored at 24 to 25°C showed a reduction in the number of insects survived after 96 hours (Shetty et al. 1989). Eggs and first instar larvae survived when the wrap was present for less than 48 hours. The authors suggested that shrink wrap may affect the survival of eggs and larvae by creating a modified environment due to the depletion or accumulation of certain gases. However, they did not report any gas analysis in the packages. Jang (1990) infested 'Solo' papayas with eggs or one of 3 larval stages of *Ceratitis capitata* or *Dacus cucurbitae*, and individually wrapped the fruit in the same film (Cryovac, D-955) used by Shetty et al. (1989). Fruits were held at 22 to 24°C for 72 to 144 hours. Fruit infestation significantly decreased as the storage period increased, especially after 96 hrs. Infestation with eggs of *Ceratitis* decreased about 80% between 72 and 120 hrs, and larval infestation was also reduced but some infestation remained even after 6 days of wrapping. Dacus larvae were found to be more resistant than *Ceratitis* eggs and larvae. The author reported that more than 90% of the infestation found after 120-144 hrs were due to loosely wrapped fruits or holes in the wrap. Larvae were observed to exit the fruit onto the fruit surface within 30 to 60 min, and often die between the fruit surface and the wrap. The author suggested that this might be due to modification of gases or altered metabolism inside the fruit. No gas monitoring was reported.

Fruits shipped in hypobaric containers from Hawaii to Los Angeles and New York (20 mm Hg, 10°C, and 90-98% RH) for 18 to 21 days had longer postharvest life, developed less diseases, and mostly were ripened normally after removal from hypobaric containers (Alvarez 1980). Fruit held in hypobaric storage had 63% less peduncle infection, 55% less stem end rot, and 45% less fruit surface lesions than those held in normal atmospheric pressure. Fruit stored for 21 days at 10 mm Hg and 10°C immediately after being inoculated with *Colletotrichum gloesporioides* and then ripened for 5 days at room temperature had less anthracnose than the control fruit (Chau and Alvarez, 1983). However, the authors indicated that LP only retard pathogen and disease development and thus will only be effective if disease control programs are used to reduce fruit infection.

'Sunrise' papayas stored in an insecticidal atmosphere (0.17 to 0.35% O_2, balance is N_2) for up to 5 days at 20°C had less firmness loss than the control, and no apparent external or internal injury (Yahia et al. 1989; Yahia 1991; Yahia et al. 1992; Yahia 1993). However, about 30% of the fruits had very weak fermentative odor after 3 days, and increased in intensity as the exposure period to low O_2 was prolonged. Activity of LDH and PDC increased after 3 and 5 days, respectively, while

concentration of pyruvate and lactate did not change. On the basis of off-flavor development, papaya was suggested to tolerate these insecticidal atmospheres for less than 3 days. Decay was evident after one day storage in low O_2, indicating that low O_2 alone is not sufficient, and there is a necessity for an antifungal treatment (Yahia et al. 1989).

Powrie et al. (1990) patented a preservation procedure for cut and segmented fruit pieces where they claimed to store papaya pieces in MAP for up to 16 weeks at 1°C with little loss in taste and texture. This was supposedly done in a high gas barrier package (DuPont LP 920™) consisting of polyethylene/tie/ethylene vinyl alcohol/tie/polyethylene plastic laminated pouches. Papaya was cut into pieces of 10-25 g, dipped in 5% citric acid, and the package was flushed with 15-20% O_2 and 3% helium before sealing. The ratio of gas to fruit volume was 1:4.

No commercial use for MA/CA storage is reported at present. Ideal atmospheres are not yet fully defined, but range between 2-5% O_2 and 5-8% CO_2. It is not known yet if MA/CA have potential application for papaya. Further controlled studies are still needed to establish the beneficial applications and adequate atmospheres (Yahia, 1997; Yahia and Paull, 1997).

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Predicting Market Life for 'O'Henry' and 'Elegant Lady' Peaches Under Controlled Atmosphere Conditions

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Additional index words. Chilling injury, internal breakdown, quality

Abstract. **During the 1995 season, large (~275g), medium (~175g), and small (~125g) 'O'Henry' peaches were stored in either air, 5% CO_2 + 2% O_2, or 17% CO_2 + 6% O_2 at 3.3°C. The onset of internal breakdown (I.B.) symptoms was related to both fruit size and storage atmosphere. Large size fruit developed mealiness and flesh browning symptoms earlier than medium and small size fruit. Large size fruit benefited most from the 17% CO_2 + 6% O_2 treatment which increased their market life 10 days beyond that of the 5% CO_2 + 2% O_2, or air storage atmosphere treatments. In all of the cases, mealiness was observed before the development of flesh browning. Thus, market life was dependent on the incidence of mealiness rather than flesh browning.**

During the 1996 season, large, medium and small 'Elegant Lady' and 'O'Henry' peaches were stored in air or 17% CO_2 + 6% O_2 at either 0°C or 3.3°C. Fruit size, storage atmosphere, and temperature all had significant effects on market life. Small 'Elegant Lady' peaches stored in air at 0°C had 14 days longer market life than large fruit. At 0°C, large size 'Elegant Lady' fruit had a market life of 19 days under CA and 9 days in air storage. At 3.3°C, market life for all treatments was reduced. At this temperature, large size 'Elegant Lady' fruit had 7 more days of market life under CA than in air storage. However, at 3.3°C small size 'Elegant Lady' fruit in CA had a shorter market life than air stored fruit. This suggests that 17% CO_2 + 6% O_2 may be inducing problems in small size fruit. A computer program was developed to predict the performance of these two peach cultivars under air or CA (17% CO_2 + 6% O_2) storage conditions.

One of the most frequent complaints by consumers and wholesalers is flesh browning, flesh mealiness, black pit cavity, flesh translucency, red pigment accumulation (bleeding), and loss of flavor in apricots, peaches, nectarines, and plums. These symptoms are caused by internal breakdown (IB), also called chilling injury, dry fruit, mealiness, or woolliness. The onset and intensity of internal breakdown symptoms during postharvest handling varies according to cultivar, preharvest cultural practices, growing season environmental conditions, and postharvest handling. IB normally appears during prolonged cold storage and/or after ripening at room temperature following cold storage. Because of this, mostly retailers and consumers encounter the problem, which then affects the reputation of the California stone fruit industry. This physiological disorder is the main limitation to long-term storage and shipment to distant markets for IB-sensitive peach and nectarine cultivars. In stone fruit, the greatest development of IB symptoms is in storage at temperatures between 2.2°C and 7.8°C, which are normal during transit and warehouse handling

operations. Shipments under controlled atmosphere (CA) conditions are being commercially used to delay IB symptoms and extend postharvest life. Benefits, however, have been erratic and unreliable for use by the stone fruit industry. We believe that CA storage performance can be improved once we understand the relationships between cultivar susceptibility and "orchard factors". This research was focused on understanding the possible role of orchard factors on internal browning, mealiness and bleeding. As our previous work on the role of "orchard" factors indicated that fruit size is the most important factor on IB, we investigated the role of fruit size on peach IB susceptibility under air or CA shipment conditions.

Materials and Methods

1995 Season Trial. Large (~275 g), medium (~175 g), and small (~125 g) 'O'Henry' peaches, harvested at commercial maturity, were collected from the packinghouse immediately after packaging. During packaging, iprodione (Rovral) fungicide and wax were applied to the fruit. Fruit were immediately transported to the F. Gordon Mitchell Postharvest Laboratory at the Kearney Agricultural Center and forced air cooled overnight to a pulp temperature of approximately 0°C. After cooling, the fruit were stored at 0°C for four days then subdivided into four replications of 80 fruit for each size/atmosphere condition. The fruit were stored in 338-liter, sealed aluminum tanks under a continuous flow of either ethylene-free air, 5% CO_2 + 2% O_2, or 17% CO_2 + 6% O_2 at 3.3°C. Flow rates and gas mixtures were established using a mixing board with micro-metering valves. Supply and exhaust gas composition was monitored using a Carle gas chromatograph model AGC-111 equipped with a thermal conductivity detector for O_2 and CO_2 or a Horiba model PIR-2000R Infrared CO_2 analyzer, and a Carle gas chromatograph model AGC-211 equipped with a flame ionization detector for C_2H_4.

Four replications of 20 fruit each for each size/treatment were withdrawn after 0, 10, 20, and 30 days storage. The fruit were ripened at 20°C until flesh firmness reached 9 - 18 N, then evaluated for incidence of IB. For all of the following experiments, determination of IB symptoms were evaluated as flesh browning (score 1-6), texture (juicy, mealy, leathery), and bleeding (light, moderate, severe). At the same time, an informal taste panel evaluated the presence of "off flavors". The end of market life was determined when more than 25% of the fruit were mealy or 15% of the fruit had a score of 3 (25% flesh browning) or higher for internal browning.

1996 Season Trial. Because the fruit under the 17% CO_2 + 6% O_2 had superior storage performance than the fruit under the 5% CO_2 + 2% O_2, only this CA shipment treatment was used. Large, medium, and small size fruit were collected from the packinghouse, cooled, and stored at 0°C for four days as described above. Stone fruit were stored in 338-liter, sealed aluminum tanks under a continuous flow of ethylene-free air, or 17% CO_2 + 6% O_2 at either 0°C or 3.3°C. Four replications of 20 fruit each for each size/treatment/temperature were withdrawn after 0, 7, 14, and 21 days storage. Firmness, soluble solids concentration (SSC), and acidity were measured on 10 fruit per replication the day of removal after the fruit were warmed to ambient temperature (20°C). The skin from opposite cheeks of each fruit was removed and the firmness measured using a U.C. Firmness tester with an 8 mm tip. Then, a longitudinal wedge (from stem end to calyx end) was removed from each fruit, pressed through cheesecloth, and the SSC of the juice was measured with a temperature compensated refractometer (Atago model ATC-1). Juice from each replication was pooled to form a composite sample, and acidity was measured with an automatic titrator (Radiometer, Copenhagen, Denmark). IB symptoms were evaluated in the remaining 10 fruit per replication after the fruit was

ripe as described previously.

Results and Discussion

1995 Season Trial. The effect of fruit size and controlled atmosphere conditions during shipment on IB was assessed on commercially grown 'Elegant Lady' peaches. Fruit size played an important role in reducing IB during CA shipping. Fruit size significantly influenced the onset and intensity of IB symptoms in peaches stored at 3.3°C under air and CA (Fig. 1). Large size peaches (275 g) had 50% mealiness and 36% internal browning while medium size fruit (175 g) had only 10% mealiness and no flesh internal browning. Small size fruit (125 g) did not have any significant internal breakdown symptoms, but IB symptoms appeared by 10 days (Fig. 1).

Flesh browning became visible approximately 10 days later than mealiness. Flesh browning developed earlier and more intensely than in medium and small size fruit (Fig. 1) than in large size fruit. By 30 days, large fruit had flesh browning levels of approximately 80% while smaller sizes only had approximately 30%. Large size fruit under the 5% CO_2 + 3% O_2 CA treatment had 30% mealiness and 16% internal browning. In the medium fruit size, the 5% CO_2 + 3% O_2 treatment did not affect mealiness but reduced internal browning. The small size fruit had the lowest IB problems under any storage conditions. The least mealiness and internal browning symptoms were observed on all fruit sizes under the 17% CO_2 + 6% O_2. Bleeding was not observed.

After 20 days of air storage at 3.3°C, large size fruit had approximately 92% mealiness and 90% internal browning while medium size fruit had only 50% mealiness and 30% internal browning. Small size fruit had 20% mealiness and 15% internal browning. The 5% CO_2 + 3% O_2 treatment did not affect any IB symptoms of any fruit size. The large and medium fruit sizes had approximately 50% mealiness and 23% internal browning on fruit subjected to the 17% CO_2 + 6% O_2 treatment. The small size fruit had 20% mealiness and only 7% internal browning under the 17% CO_2 + 6% O_2 treatment (Fig. 1). Of the three fruit sizes, bleeding was higher in the 17% CO_2 + 6% O_2 treated fruit. The bleeding did not affect fruit taste.

After 30 days of air storage at 3.3°C, large size fruit had approximately 96% mealiness while medium size fruit had 77% mealiness and small size fruit had only 62% mealiness. Both CA treatments did not affect mealiness in any fruit size (Fig. 1). The 17% CO_2 + 6% O_2 treatment induced bleeding in the three fruit sizes.

1996 Season Trial. In 'Elegant Lady' and 'O'Henry' peaches, fruit size also played an important role in reducing IB during CA (17% CO_2 + 6% O_2) storage (Fig. 2). Fruit size significantly influenced the onset and intensity of flesh mealiness (Fig. 2) and flesh browning (Fig. 3) symptoms in peaches stored at 0°C or 3.3°C under air or CA. For 'Elegant Lady' small and medium fruit sizes, flesh mealiness did not develop under CA at 0°C, even after 3 weeks storage (Fig. 3). With size 42 fruit, CA storage at 0°C was necessary to maintain a high percentage of fruit that were juicy after 3 weeks. After 2 to 3 weeks storage in air at 0°C approximately 21% of the large size fruit remained juicy. After 2 weeks under these conditions, CA (17% CO_2 + 6% O_2) stored fruit had a higher percentage remaining juicy (87%) than air stored fruit (21%). The results were similar after 3 weeks at 0°C with 67% of CA stored fruit remaining juicy as compared to 21% for air (Fig. 2).

At 3.3° C, 'Elegant Lady' fruit developed mealy flesh in all three sizes tested (Fig. 2). The first symptoms became visible on the large size fruit after the first week and in medium and small sizes after 2 weeks (Fig.2). In the large fruit size, CA provided significant protection against the development of flesh mealiness. After the first two weeks, CA reduced mealiness by approximately

39%. After 3 weeks, there was no difference between the CA and air stored fruit with respect to mealiness. CA stored large size fruit had approximately 50% less mealiness than air stored fruit of the same size after weeks two and three. CA storage did not show any significant benefit for small size fruit.

In 'Elegant Lady' stored at 0°C, flesh browning became visible after 3 weeks only on the large fruit size. CA treatment limited the development of flesh browning on large fruit size. Small and medium size fruit did not develop any flesh browning when stored at 0°C (Fig. 3). On fruit stored at 3.3°C, flesh browning appeared after two weeks on large size fruit and after 3 weeks on medium and small size fruit. CA (17% CO_2 + 6% O_2) reduced flesh browning development on medium and large size fruit. However, a flesh color problem was observed in the small size fruit when stored under CA at 3.3°C for longer than two weeks. Further studies need to be carried out to determine if these symptoms are a consequence of high CO_2 and/or low oxygen injury.

Controlled A at 3.3°C storage treatment reduced the rate of softening for 'Elegant Lady' and 'O'Henry' peaches. However, on fruit stored under the 0°C temperature regime, the rate of fruit softening did not differ between fruit under CA or air storage (Fig. 4).

For small size 'O'Henry' fruit stored under CA at 0°C, flesh mealiness did not develop even after 3 weeks (data not shown). After 3 weeks at 0°C, medium size fruit started to become mealy. CA storage was necessary to maintain the juiciness of large size fruit after 2 weeks storage. Fruit stored under CA at 0°C for 2 weeks had a higher percentage that remained juicy (100%) than the air stored fruit (63%). After 3 weeks at 0°F, CA stored fruit still had a higher percentage of juicy fruit (83%) than the air treatment (4%). All three sizes of 'O'Henry' fruit became mealy at 3.3°C. Mealiness first became visible in the large size fruit after the first week and in the medium size after 2 weeks storage. With large size fruit, CA provided significant protection against development of flesh mealiness. By week 2, CA reduced mealiness by approximately 60% in large size fruit. After 3 weeks, it did not make any difference with respect to mealiness whether the fruit were stored in CA or air. With the medium size fruit, CA storage reduced mealiness by approximately 75% after two and three weeks. CA storage did not show any significant benefit for small size fruit.

In all of these tests, mealiness developed at least one week earlier than flesh browning. This agrees with our observations of the last 5 years on fruit grown under San Joaquin Valley conditions. For this reason, we consider loss of fruit texture to be a more accurate indicator of IB than flesh browning.

In informal taste tests, many panelists could detect differences between storage conditions with respect to mealy texture and off flavors on 'Elegant Lady' or 'O'Henry' fruit. Storage temperature had a significant effect on the perception of fruit juiciness. All of the fruit stored at 0°C were judged acceptably juicy, whereas ~25% of the fruit stored at 3.3°C were rated as having poor texture. Some panelists also noted off-flavors in fruit stored for one week at 3.3° C (data not shown).

A computer model to predict market life based on mealiness incidence of fruit shipped at 0°C or 3.3°C in air or CA was developed for 'Elegant Lady' and 'O'Henry' peaches. Maximum market life (0°C) of large, medium and small size 'Elegant Lady' fruit in CA storage was 19, 21+ and 21+ days, respectively, while all three sizes of 'O'Henry' fruit lasted 21+ days. Minimum market life (3.3°C) of 'Elegant Lady' fruit in CA was 9, 15, and 16 days for sizes large, medium, and small, respectively. While sizes large, medium and small 'O'Henry' fruit in CA had a minimum market life of 14, 18, and 18 days, respectively. In both cultivars, the one week cold storage (0°C) period prior to the CA treatment did not affect CA performance (Table 1).

Conclusions

1. Fruit size influenced the onset and intensity of mealiness and flesh browning, and thus market life potential. Large size fruit developed IB symptoms earlier and with greater intensity than medium and small size fruit under the different storage conditions.

2. A four day cold storage (0°C) period prior to the CA storage did not affect CA performance.

3. 17% CO_2 + 6% O_2 CA was more effective than 5% CO_2 + 2% O_2 at delaying the mealiness and flesh browning.

4. IB developed more rapidly and with greater intensity at 3.3°C than 0°C. In all of the cases, fruit mealiness developed earlier than flesh browning.

5. At 3.3°C, the firmness of fruit stored in 17% CO_2 + 6% O_2 was higher than that of fruit stored in air. At 0°C there was no difference in firmness between CA and air stored fruit.

6. A computer model to predict mealiness incidence of fruit shipped at 0°C or 3.3°C in air or CA was developed for 'Elegant Lady' and 'O'Henry' peaches.

7. Small size 'Elegant Lady' peach fruit stored in 17% CO_2 + 6% O_2 at 3.3°C developed internal browning earlier and with greater intensity than air stored fruit. Further studies to be carried out to determine if these symptoms are a consequence of IB or high CO_2 and/or low oxygen injury when fruit are exposed to higher temperatures.

Table 1. Prediction of market life for 'Elegant Lady' and 'O'Henry' peaches for different temperature shipments and fruit sizes.

Storage Temperature & Fruit Size	Market Life[z] (days)			
	'Elegant Lady'		'O'Henry'	
	CA[y]	Air	CA	Air
0°C				
Large	19	7	21+	13
Medium	21+	19	21+	16
Small	21+	21+	21+	21+
3.3°C				
Large	9	1	14	5
Medium	15	6	18	6
Small	16	21+	18	12

[z] The end of market life was determined when more than 25% of the fruit were mealy.
[y] CA = 17% CO_2 + 6% O_2.

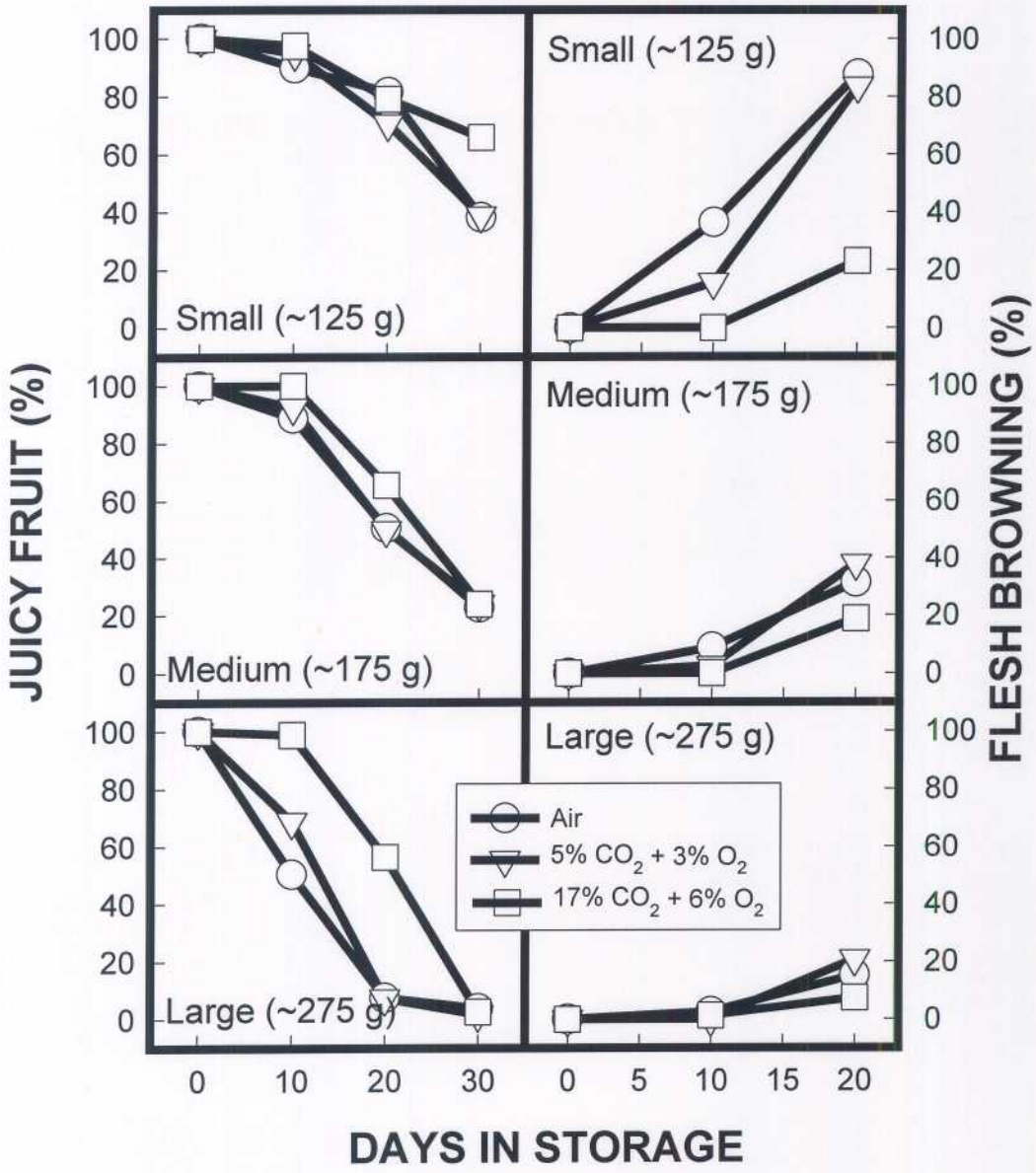

Fig 1. Influence of storage atmosphere and fruit size on 'O'Henry' peach juiciness and flesh browning after simulated shipment at 3.3°C, 1995.

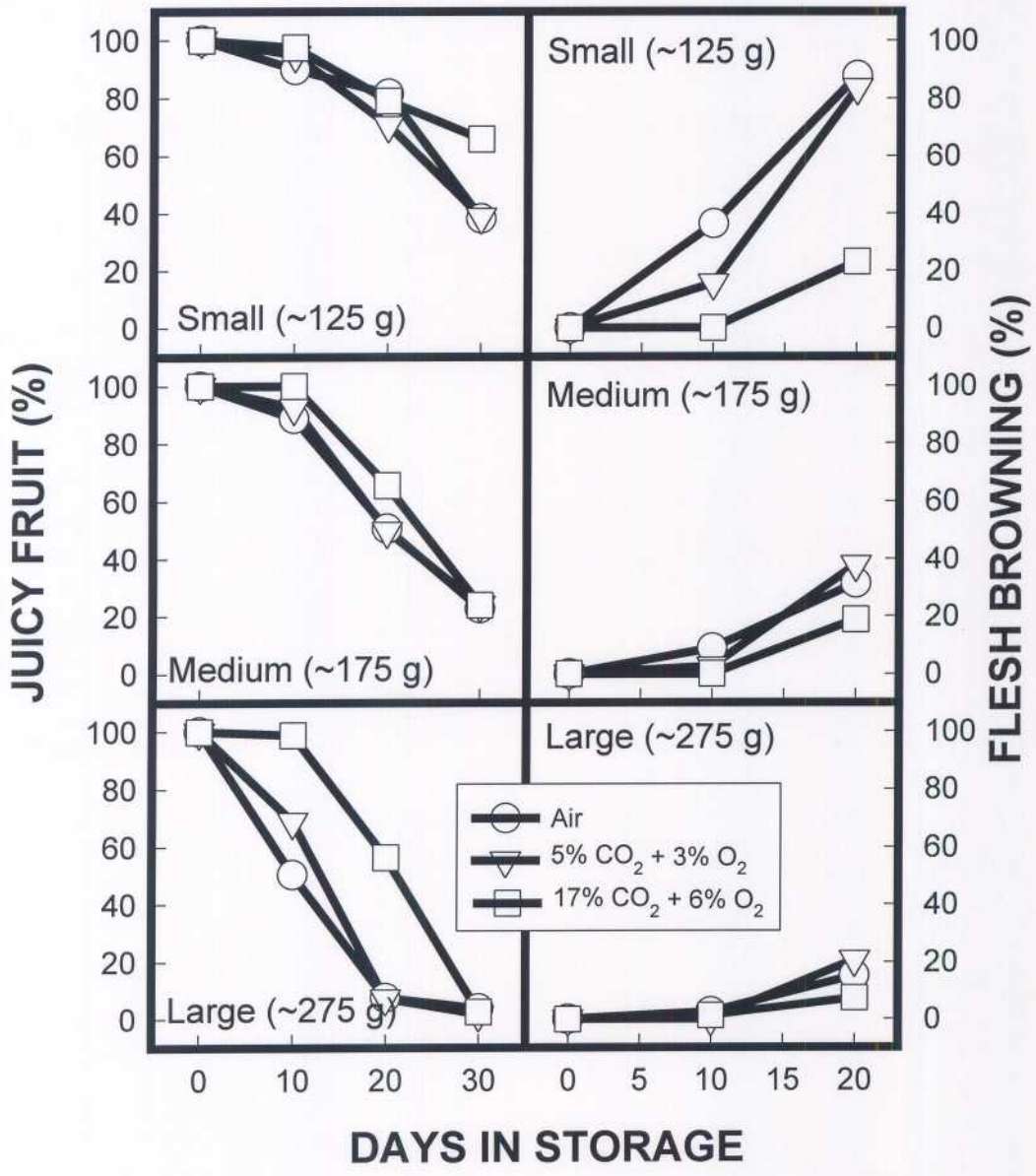

Fig 1. Influence of storage atmosphere and fruit size on 'O'Henry' peach juiciness and flesh browning after simulated shipment at 3.3°C, 1995.

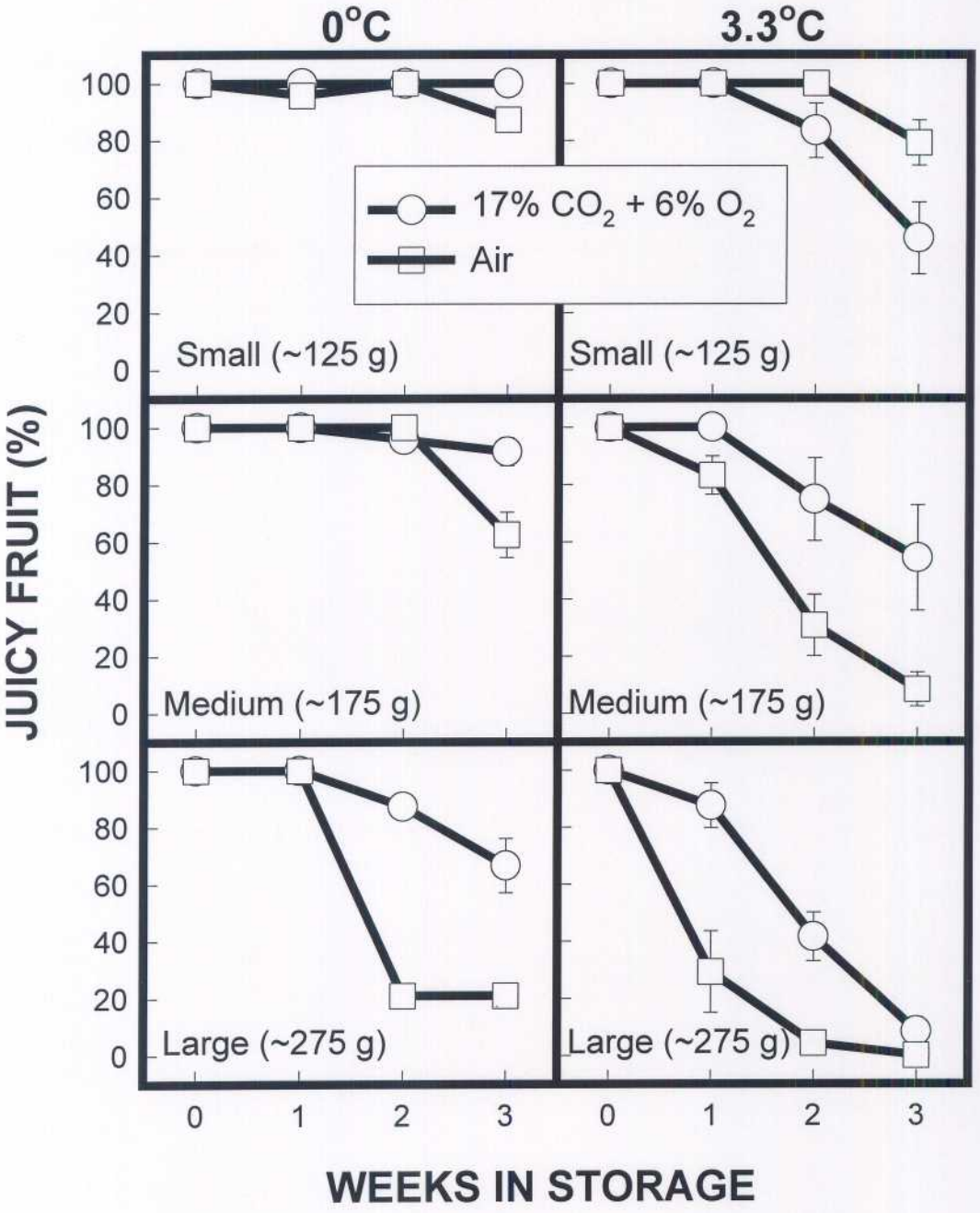

Fig 2. Influence of storage atmosphere and fruit size on 'Elegant Lady' peach juiciness under two simulated shipment temperatures, 1996.

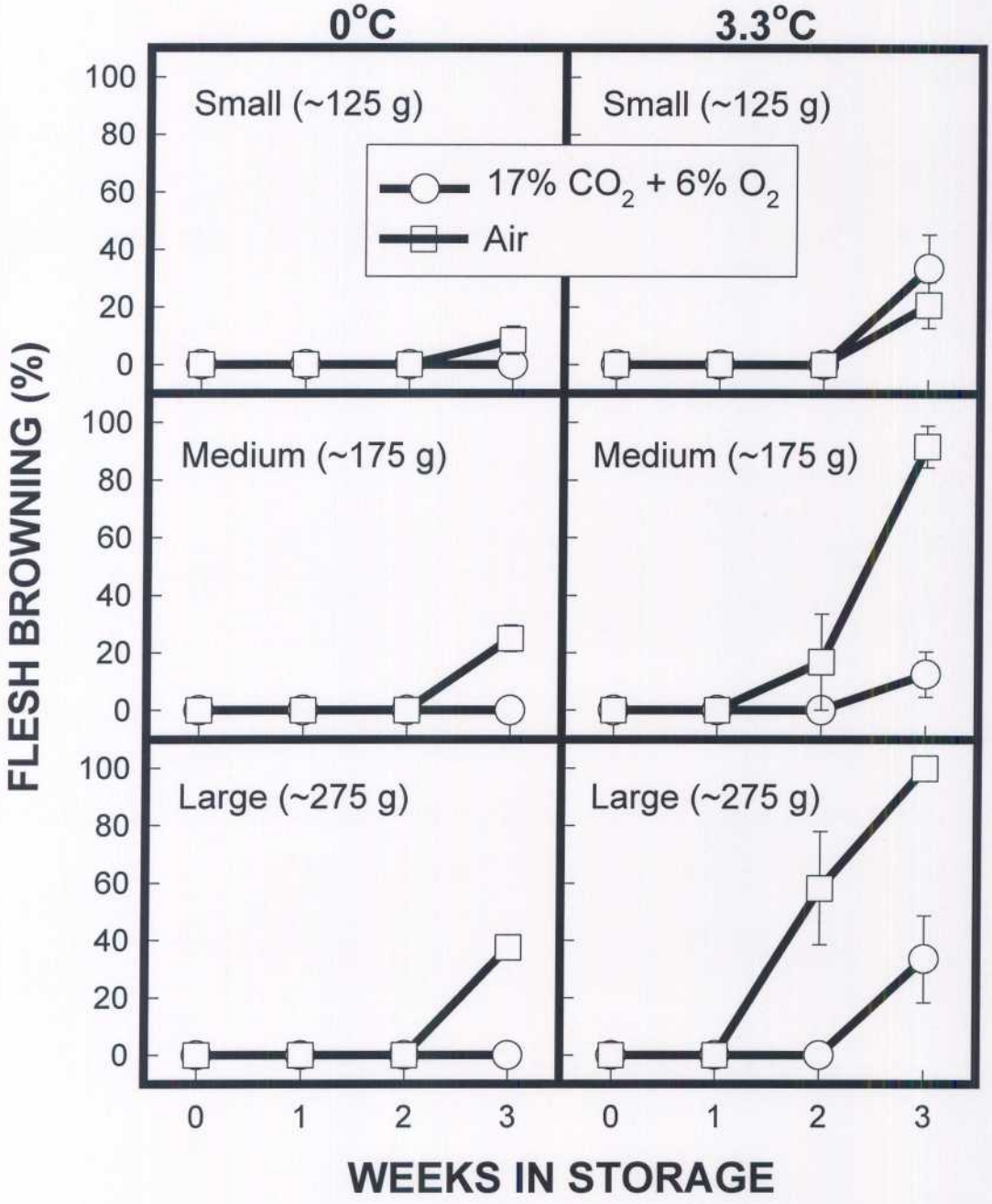

Fig. 3. Influence of storage atmosphere and fruit size on 'Elegant Lady' peach flesh browning under two simulated shipment temperatures, 1996.

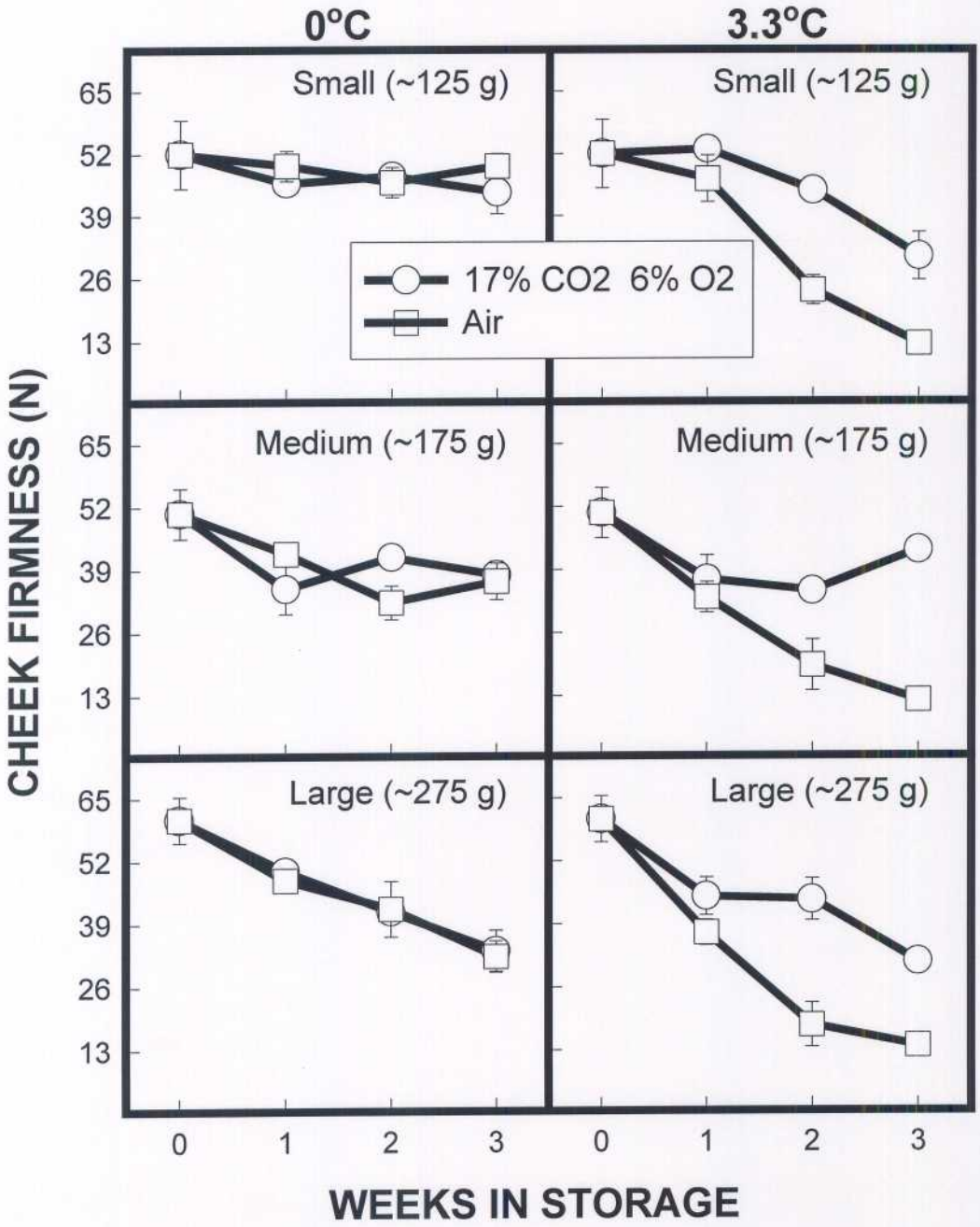

Fig. 4. Influence of storage atmosphere and fruit size on 'Elegant Lady' peach cheek firmness under two simulated shipment temperatures, 1996.

Effect of MA Storage on Woolliness of 'Yumyeong' Peaches

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Additional index words. Chilling injury, internal breakdown, textural quality

Abstract. **'Yumyeong' peach fruit was stored at 0°C with or without MA using PE film, 0.03mm thickness, for 4 weeks, after which the fruits were examined during ripening at 20°C. Woolliness developed both in cold and MA storage; however, less woolliness was found in MA storage. Electrolyte leakage of stored fruit increased rapidly during the first 3 days of ripening and then decreased, and was higher in MA-stored fruit than cold-stored fruit. In non-stored fruit, water soluble pectin content increased, EDTA soluble pectin content remained constant, and sodium carbonate soluble pectin content decreased during ripening. In contrast, stored-fruit showed lower polygalacturonase (PG) activity, lower water soluble pectin content, and higher sodium carbonate soluble pectin, which is likely to be a cause of woolliness. In fruit of MA storage, PG activity, water soluble pectin content, and EDTA soluble pectin content were higher and sodium carbonate soluble content was lower than those of cold storage. Pectinmethylesterase (PME) activity and EDTA soluble pectin content did not correlate with the woolliness. Reduction in woolliness of 'Yumyeong' peaches in MA condition seemed to be based on increase in water soluble pectin and decrease in sodium carbonate soluble pectin by increased PG activity.**

When stored at low temperature, peaches develop poor texture as the result of abnormal ripening (Lill et al., 1989). These fruits taste dry and unpalatable, and these poor textural characteristics have been described as 'woolliness' and are thought to be associated with chilling injury. As a fruit ripens, substantial portion of its cell wall pectin is converted to a water-soluble form, and these changes are of considerable importance in fruit texture (Ben-Arie et al., 1979; Labavitch, 1981). Undesirable textural changes of the flesh due to woolliness have been associated with impaired solublization of pectin, with reduced concomitant removal of galactan side chains and accumulation of insoluble high molecular weight pectins in the cell wall (Dawson et al., 1992), due presumably part to impaired polygalacturonase (PG) activity and increased pectinmethylesterase (PME) activity (Ben-Arie and Lavee, 1971; Ben-Arie and Sonego, 1980; Buescher and Furmanski, 1978). According to Ben-Arie and Sonego (1980), the pectates form a gel in the presence of water, resulting in a loss of expressible juice and the development of woolliness.

Various treatments have been demonstrated to be helpful in maintaining the quality of fruits and vegetables at low temperatures (Lill et al., 1989). An increased CO_2 concentration and a decrease in O_2 concentration in the storage atmosphere has been reported to inhibit the development of chilling injury symptoms in pineapple (Paull and Rohrbach, 1985) and zucchini squash (Mencarelli, 1987). Apparently, peach cultivars differ markedly in their response to CA conditions. Carbon dioxide concentration above 10% is harmful for some peaches (Kajiura, 1975). Conversely, Wade (1981) and Retamales et al. (1992) was able to store fruit at 20% CO_2 without apparent injury and obtained

good control of low temperature storage disorders.

The objective of this research was to investigate if modified atmosphere could alleviate the woolliness of 'Yumyeong' peach fruit and how pectolytic enzyme activity associated with woolliness would be changed by modified atmosphere.

Materials and Methods

Uniform size peach fruits ('Yumyeong') were obtained at harvest. One group of fruits was allowed to ripen at 20°C (non-stored) while the other fruits were placed in storage at 0°C with or without MA using PE film (0.03 mm thickness). After 4 weeks, samples were allowed to ripen at 20°C. Electrolyte leakage, woolliness, pectic substances, and pectolyte enzyme activities were determined during ripening.

Degree of woolliness of the fruit was assessed by eye into four classes. Fruit in class 0 was juicy without any sign of woolliness. If squeezed, the juice of fruit in class 1 appeared thick and did not flow freely from the fruit tissue. No juice flowed from fruit in class 2 when squeezed, while the fruit tissue appeared relatively wet. The fruit in class 3 was extremely dry with a whitish sheen.

Mesocarp tissue was prepared for electrolyte leakage by slicing cylinders extracted with a cork borer into discs (2 mm thickness and 8 mm diameter), washing 3 times with distilled water, and incubating in 200 ml of 0.4 M mannitol for 3 hrs at 35°C. Electrolyte leakage was determined with conductivity bridge both after incubating and after homogenizing for 3 min. Electrolyte leakage was calculated as percentage of total electrolytes.

Fifty grams of pericarp tissue was homogenized for 3 min in 95% methanol (250 ml). After filtration, the retained material was washed three times with 95% methanol (250 ml), rinsed with acetone (250 ml), and then dried for 24 hrs in a drying oven at 45°C. Dried materials were designated as alcohol-insoluble solids (AIS). Water soluble pectin was determined by extracting 0.1 g of AIS with 50 ml of water at room temperature for 2 hrs. The residue materials were filtered after extraction with 1 M EDTA for 8 hrs at room temperature, and the filtrates represented EDTA soluble pectin. And then, the residue materials were dissolved with 0.05 M sodium carbonate for 18 hrs at 1°C, and filtered. The filtrates represented residue pectin. The amount of each pectin fraction was assessed by the arsenomolybdate-copper method with spectrophotometer at 520 nm (Ashwell, 1957). One hundred grams of tissue was added to 100 ml of cold aqueous solution containing 12% Carbowax 4000 and 0.2% sodium bisulfite. After blending for 2 min, the sample was centrifuged at 8000 X g for 20min and the supernatant discarded. The residue was suspended in 200 ml of cold water, homogenized for 2 min and recovered by centrifugation. It was washed twice with 200 ml of cold water and then suspended in 100 ml of water.

Polygalacturonase (PG) was assayed by measuring the liberation of reducing groups from polygalacturonic acid. The reaction mixture containing 0.2 ml of 0.1 M sodium acetate, 0.25 ml 0.15 M NaCl, 0.5 ml of 1% polygalacturonic acid, and 0.05 ml of enzyme solution. After 15 min at 37°C, the solution was analyzed for reducing groups by Nelson method. A unit PG is defined as that amount which liberates 1mmol of galacturonic acid in 1min at the condition.

Pectinmethylesterase (PME) was assayed spectrophotometrically according to Hagerman and Austin (1986). Two milliliters of pectin substrate (pH 6.5) containing 0.5% (w/v) pectin, 0.02 M sodium phosphate, 0.3 M KCl, 3 mM NaN_3, and 0.03 mM bromothymol blue were incubated with 0.5 ml of enzyme solution at 35°C for 1 hr, and the absorbance at 600 nm was determined after 5 min using distilled H_2O as a blank. A unit PME is defined as the amount which produces 1 mmol

of acid.

Results and Discussion

Symptom of woolliness developed rapidly upon transfer to 20°C only in fruit previously stored at 0°C for 4 weeks, and woolliness score rapidly increased with futher ripening (Fig. 1). This result differed from von Mollendoff et al. (1992) reporting that incidence of woolliness increased to high levels during ripening and decreased thereafter to no woolly fruit. In the fruit placed in MA storage, woolliness was retarded, and the severity was less than that of cold-stored fruit. MA storage was found to be effective in alleviating the woolliness of 'Yumyeong' peach. Retamales et al. (1992) reported that high CO_2 delayed fruit ripening in CA storage, keeping the fuit firmer and preventing the development of woolliness, but low O_2 concentration did not show clear effects.

In non-stored fruit, electrolyte leakage increased continuously during ripening. In contrast, electrolyte leakage of stored fruit increased rapidly during the first 3 days of ripening and then decreased, and was higher in MA-stored fruit than cold-stored fruit (Fig. 2). This result agreed with von Mollendorff reporting that internal conductivity of fruit stored more than 3 weeks at low temperature increased rapidly and then decreased during futher ripening. Dawson et al. (1993) reported that mealy fruit tissue had higher rates of calcium uptake and efflux, internal air space and cation exchange capacity than that from normal ripened fruit. Buescher and Furmanski (1978) reported decreased electrolyte leakage in mealy peaches, which they interpreted as reflecting increased binding of ions into cell wall rather than changes in membrane permeability. Therefore, in this examination, the reduction in electrolyte leakage of cold-stored fruit during later ripening period, although severity of woolliness increased (Fig. 1), seemed to be associated with more ion binding sites.

Undesirable textural changes of the flesh due to woolliness have been associated with impaired solubilization of pectin, with reduced removal of galactan side chains and accumulation of insoluble high molecular weight pectins in the cell wall (Dawson et al., 1992), due presumably to impaired polygalacturonase (PG) activity and increased pectinmethylesterase (PME) activity (Ben-Arie and Lavee, 1971; Ben-Arie and Sonego, 1980; Buescher and Furmanski, 1978). Ben-Arie and Lavee (1971) postulated that pectic substances can form gels with water. We investigated changes in pectic substances and pectolytic enzyme activity to confirm their relationship to woolliness. In non-stored fruit, water soluble pectin content increased (Fig. 3), EDTA soluble pectin content remained constant (Fig. 4), and sodium carbonate soluble pectin content decreased (Fig. 5) during ripening. In cold-stored fruit, water soluble pectin content was lower, and sodium carbonate soluble pectin contentwas higher than non-stored fruit during ripening. These changes of pectic substances in cold-stored fruit were diminished by MA storage. In MA-stored fruit, water soluble pectin contnent was higher and sodium carbonate soluble pectin content was lower than in cold-stored fruit. We could not find correlation of EDTA soluble pectin content with the woolliness.

PG activity of fruit was found to decline after 4 weeks at 0°C, and the increase of PG activity during ripening was slight in cold-stored fruit (Fig. 6). This result agrees with earlier researchers explaining lower PG activity in cold-stored fruit as a cause of woolliness (Ben-Arie and Lavee, 1971; von mollendorff and Villiers, 1988). MA-stored fruit, in which incidence of woolliness was reduced, showed higher PG activity than cold-stored fruit. Pectinmethylesterase (PME) activity was higher in MA-stored fruit than cold-stored fruit which was lower than non-stored fruit (Fig. 7). In contrast

to other researchers (Ben-Arie and Sonego, 1980) showing that woolliness in peach was accompanied by increased activity of PME and inhibition of PG activity, we could not find the direct relationship between PME activity and the incidence of woolliness. Reduction in woolliness of 'Yumyeong' peaches in MA storage seemed to be based on increased PG activity causing increment in water soluble content and decrease in sodium carbonate soluble pectin content.

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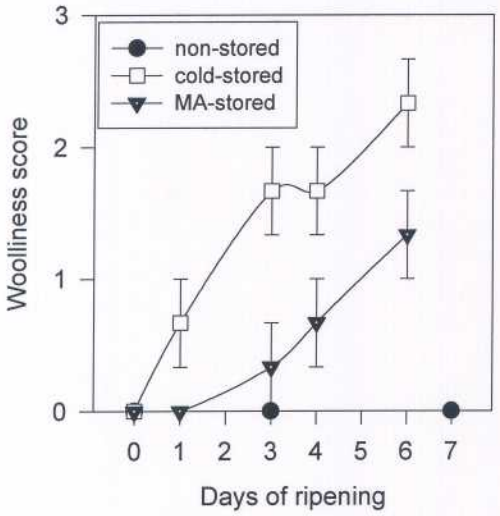

Fig. 1. Degree of woolliness of 'Yumyeong' peach fruits during ripening.

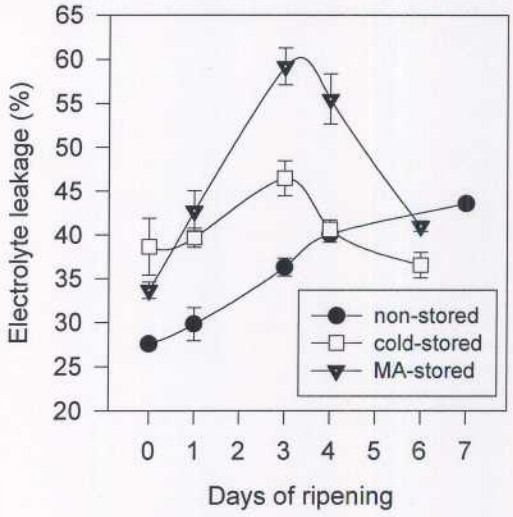

Fig. 2. Changes in electrolyte leakage of 'Yumyeong' peach fruits during ripening.

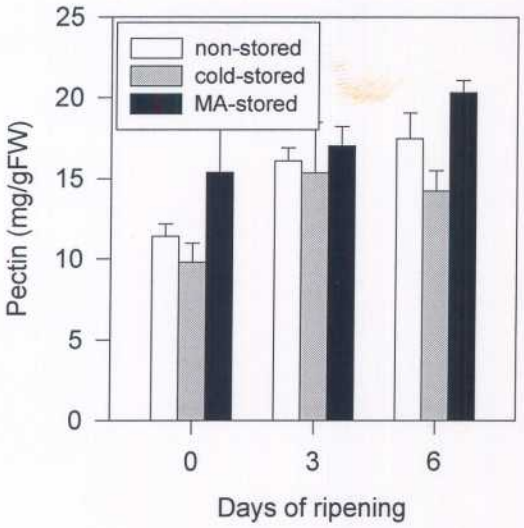

Fig. 3. Changes in water soluble pectin of 'Yumyeong' peach fruits during ripening.

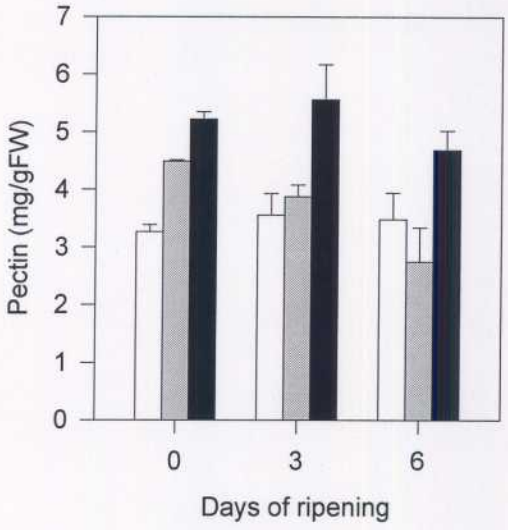

Fig. 4. Changes in EDTA soluble pectin of 'Yumyeong' peach fruits during ripening.

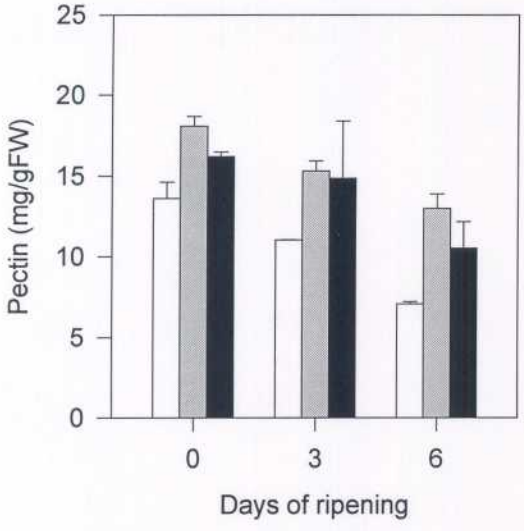

Fig. 5. Changes in sodium carbonate soluble pectin of 'Yumyeong' peach fruits during ripening.

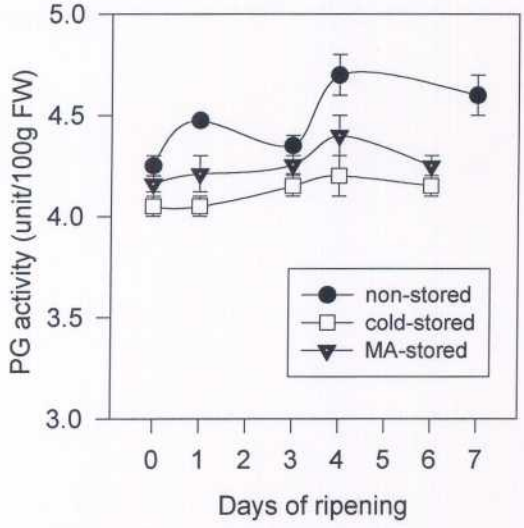

Fig. 6. Changes in PG activity of 'Yumyeong' peach fruits during ripening.

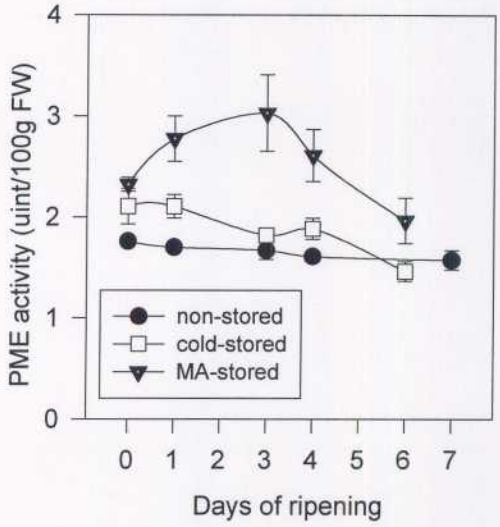

Fig. 7. Changes in PME activity of 'Yumyeong' peach fruits during ripening.

Influence of Extreme Atmospheres-Short Term (EAST) Treatments at Room Temperature on Apricot Quality

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Additional index words. Ethylene, respiration, firmness, color

Abstract. **Results from EAST treatments on two apricot cultivars (*Prunus armeniaca* L. cv Tyrintos and Boccuccia Spinosa) are reported. We have been testing EAST treatments: pure nitrogen or 100% CO_2 for 24 or 48 h and 7 and 4 days of shelf life, respectively for Tyrintos and Boccuccia Spinosa. In Tyrintos, ethylene production of control fruits at 18°C showed a climacteric pattern; following treatment, ethylene increased in the other samples only after 5 days and the highest increase was for N_2 treated fruits due to decay. In Boccuccia Spinosa, ethylene production rate was lower and at 18°C the increase was slight. CO_2 treated fruits for 48 h and 5°C treated ones at the end of experiment showed the lowest rate of ethylene production. Respiration pattern in gas-treated Tyrintos fruits was stable without significant difference at the end of test. 18°C-treated fruits had the highest respiration rate. In Boccuccia Spinosa 5°C-treated fruits had sgnificantly lower respiration rate than the other samples but at the end of test there was not significant difference between gas-treated samples (48 h) and 5°C-treated ones. Tyrintos cultivar showed a very low level of SSC (soluble solid content) at the beginning of experiment even though the firmness was right for the harvest. SSC decreased during all treatments but less for 5°C fruits. L* parameter of colorimeter decreased significantly less in 5°C treated fruits whereas CO_2-treated ones for 48h decreased greatly in parallel with the loss of chroma which was the highest. Development of decay was more in EAST-treated fruits than at 5°C. In Boccuccia Spinosa, L* of 48 h treated fruits decreased less than in the other samples and chroma, which in contrast with Tyrintos, increased to indicate more saturated color. Even the loss of firmness in those fruits was less and the SSC increased at the same rate in all samples but more in 5°C-treated ones. Ethanol odor developed in CO_2-treated fruits for 48 h after 4 days but the odor was lost at the end of test. EAST treatments for 48 h in Boccuccia Spinosa could be used as alternative to low temperature to improve the aromatic quality apricots.**

The interest for short term exposure to low oxygen (LO) or high carbon dioxide has been increasing as a potentially alternative quarantine treatment to chemical fumigation for insect control (Ke and Kader, 1992). Several studies have been published on this subject (Gaunce et

al., 1982; Brandle et al., 1983; Ripp et al., 1984). Short-term exposure to LO or high CO_2 might be an economic benefit for short-term preservation (oversea transport) or shelf -life storage of some crops where there is limited potential for use of refrigeration such as for tropical fruits or mature green tomato. Unfortunately, most of fruits do not tolerate low oxygen or high carbon dioxide for prolonged periods because anomalies in the metabolism occur such as the increased activity of anaerobic metabolism enzymes such as pyruvate decarboxylase, lactate dehydrogenase, and alcohol dehydro-genase which provoke the accumulation of acetaldehyde and ethanol (Ke et al., 1991; Ke and Kader, 1992; Ke et al., 1995). Cold storage and early picking reduce the flavor quality of peaches and nectarines (Rizzolo et al., 1995) and consumer is complaining about the flavour of stone fruits, even apricots. The use of room temperatures in combination with LO or high CO_2 for short time periods, for example 20°C for 1-4 days, has been used in different fruits not only with the aim of disinfestation but even for improving the quality (Wills et al., 1979; Lurie and Pesis, 1992; Ke et al., 1991; Klieber et al., 1996).

In a previous paper (Anelli et al., 1996), we have studied the behaviour of apricots at different LO or ULO atmospheres. In this paper we present some of physiological and quality data of EAST treatments on two varieties of apricots with the purpose to define an easy-to use, cheap treatment to maintain high quality apricots in terms of aroma, during short term distribution.

Materials and Methods

Apricots, cultivars Tyrintos (Tyr) and Boccuccia Spinosa (BS) were picked in June-1997 close to the edible ripening stage (7.6 and 13.6 % SSC). Tyrintos fruits are characterized by low sugar and juice content and flat taste which is enhanced at low emperature. We wanted to see if it was possible to improve the aroma. Boccuccia Spinosa fruits has more pleasant aroma. Fruits of uniform size, shape and color were cleaned, dipped in 100 ppm of hypochlorite solution for 1 min, rinsed with distilled water and dried in still air. Thirty selected fruits were placed in a 3.5 L glass jar as one replicate and three replicates were used per treatment. The jars were placed in a 18°C (EAST) and 5°C (control) room and ventilated with humidified air. We tested 100% N_2 and 100% CO_2 for 24 and 48 hours and then the fruits were kept at 18°C in air for 7 and 4 days, respectively for Tyr and BS. Gas mixtures were drawn from cylinders (Rivoira, Union Carbide, Turin, Italy) . Ethylene evolution from apricots was measured by removing 1 mL of the head space atmosphere and injecting the sample into a gas chromatograph (GC) Fractovap (mod. 4200; Carlo Erba SpA, Milan, Italy) with a 1-m long alumina column (80/100 mesh) and a flame ionization detector (FID), oven temperature 100°C; CO_2 was read by removing ½ mL of the head space atmosphere and injecting the sample in the GC with a Chromosorb 102 column at 70°C and adapted with a methane converter to read CO_2 by FID. Three initial samples of 10 fruits each were evaluated for skin color, firmness, and SSC. Similar evaluations were made under the treatment condition and in shelf life. Color was measured by a Hunterlab mod. 25A-PC2 colorimeter (Hunterlab Inc., Reston, VA, USA), using L*, and the "a* and b* values transformed in hue angle ($\tan^{-1}$ b/a) and chroma $(a^2 + b^2)^{\frac{1}{2}}$ .Firmness was measured by an EFFEGI penetrometer (Facchini s.r.l., Alfonsine, RA, Italy) using 8 mm round-headed flat probe and pushing the probe in the equatorial area of the fruit after removing the peel. The same fruits were used for SSC analysis with a hand refractometer (Model N1;Atago, Japan).

Data were subjected to ANOVA and mean separation accomplished with the LSD procedure at 5% probability level.

Results

Ethylene production of 18°C Tyr fruits showed a climacteric pattern (Fig. 1). Ethylene did not rise in the other samples after the removal of the atmosphere but only at the end of test where N_2-treated samples produced much more ethylene than the other samples due to development of decay. In BS, the lowest production of ethylene was from 5°C-treated fruits and during the treatment, as expected, in N_2-treated ones (Fig. 2). Even in this cultivar, at the end of experiment the rise of ethylene was higher in fruits treated for 24 h with nitrogen. No decay was observed. CO_2 controlled ethylene rise at the same extent of 5°C. Respiration rate of Tyr fruits did not differentiate significantly during all the treatments and did not rise except for 18°C samples (Fig. 3). Unusual peak on the 2nd day for 24 h N_2-treated fruits was observed. Respiration of BS fruits kept at 5°C was significantly lower than those from the other samples but after the transfer to higher temperature the rate of CO_2 production reached the same level of the other samples (Fig. 4). 24 h N_2-treated fruits showed the highest respiration at the end of test.

In parallel with the increase of ethylene, 18°C Tyr fruits became redder with higher loss of lightness and lower reduction in color saturation (chroma) (Table 1). These fruits were discarded on the 6th day because of decay. CO_2-treated fruits for 48 h maintained the color better than the other samples: lower ΔL and higher Δchroma. SSC decreased in all samples but more in these last samples. Firmness decreased in all samples but without significant differences among samples. In BS, fruits treated for 48 h, regardless the gas, showed higher increase of chroma, in contrast with Tyr fruits, and less decline of L (Table 2). SSC increased by 0.6-0.9% in all samples whereas the firmness at the same extent of Tyr fruits but 5°C fruits were firmer than the other fruits (they lost only 29 N vs 36-41 N of the other samples). No decay was observed inBS fruits. Slight fermented odor was detected subjectively soon after the removal of gas treatments, odor which disappeared at the end of test. Odor of Tyr was completely flat at the end of test and there was not recovered in any treatment. BS fruits were more odorous and at the end of test N_2-treated ones presented a more pleasant ripe apricot-like odor.

Discussion

Tyrintos cultivar has poor commercial quality. The low SSC at the beginning of the experiment diminished during the test with loss of firmness. Fruits are sensitive to decay development over the shoulders. Gas treated fruits showed higher percentage of decayed fruits than 5°C-treated ones. CO_2 showed a stronger control of ethylene production even after the removal of the atmosphere (residual control) above all after the 48 h treatment in both varieties. This effect of CO_2 on ethylene has been well reviewed by Mathooko (1996) and seems due to control of ACC (1-aminocyclopropane-1-carboxilic acid) synthase and to a certain extent of ACC oxidase. The residual effect is probably due to the slow depletion of the high concentration of CO_2 during the shelf life period and it would explain the lower effect of 24 h treatment, confirming the hypothesis of a competition for the binding site (Burg and Burg, 1967). ACC oxidase in vivo soon after the gas treatment in our apricots revealed a marked

effect of CO_2 to inhibit the enzyme (data not shown). We have not yet data on ACC but this response could be due to less activity of ACC synthase. 48 h -treated fruits both in nitrogen or carbon dioxide showed half of ACC oxidase activity of 24 h treated ones at the end of experiment in BS fruits. Nitrogen was not effective as residual control of ethylene but it was effective during the treatment in controlling ethylene. This is a normal response since the O_2 dependent ACC oxidase; when the oxygen becomes available the upsurge of ethylene is immediate (Gorny and Kader, 1997). Even respiration was controlled by gas treatments above all CO_2 treatments after the transfer to air. This effect was observed in both cultivars. It's not clear which is the reason of this effect but as reported by Mathooko (1996) could be a response to ethylene inhibition, to pH drop, to regulation of TCA cycle. As a consequence of these main physiological effects, qualitative parameters were affected and CO_2-treated fruits were firmer such as 5°C-treated ones above all in BS fruits confirming what reported in other fruits (Kader, 1986). 48 h treatments with N_2 or CO_2 were effective to control the changes in color above all in term of L* and chroma.

Conclusion

High carbon dioxide (100%) for 48 h on apricots is more effective to control loss of firmness during the following shelf life and it is comparable with low temperature treated fruits. Nitrogen atmosphere controls the color changes but slightly the loss of firmness even though the odor is more pleasant than for carbon dioxide treated fruits and 5°C-treated ones. 24 h treatment is not enough to give good results. Boccuccia Spinosa behaves better than Tyrintos which loses sugars and firmness quickly.

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Table 1. Color parameters, SSC and firmness of Tyrintos apricots treated with the indicated atmospheres for 24 and 48 h at 18°C and then kept in air at 18°C for 7 days. Control fruits were kept at 5°C for 7 days + 2 days at 18°C. Initial values were 55, 70, 30, 7.6 %, and 52 N, respectively for L, hue angle, chroma, SSC, and penetrometer firmness. Data are the means of 12 apricots readings.

		Difference between beginning and end of treatments				
Atmosphere	Temperature °C	L	Hue angle	Chroma	SSC %	Firmness N
N_2 24 h	18	-2.3	-6.0	-0.4	-1.3	-40
N_2 48 h	18	-3.9	-4.1	-0.5	-1.6	-35
CO_2 24 h	18	-3.7	-9.6	-0.3	-0.6	-35
CO_2 48 h	18	-4.8	-7.7	-1.6	-1.7	-36
Air	18	-5.1	-7.4	-0.2	-1.4	-41
Air	5	-1.3	-8.1	-0.4	-1.0	-33
LSD (5%)		1.2	1.5	0.3	0.4	4

Table 2. Color parameters, SSC and firmness of Boccuccia Spinosa apricots treated with the indicated atmospheres for 24 and 48 h at 18°C and then kept in air at 18°C for 7 days. Control fruits were kept at 5°C for 7 days + 2 days at 18°C. Initial values were 54, 70, 29, 13.6%, and 52 N respectively for L, hue angle, chroma, SSC, and penetrometer firmness. Data are the mean of 12 apricots readings.

		Difference between beginning and end of treatments				
Atmosphere	Temperature °C	L	Hue angle	Chroma	SSC %	Firmness N
N_2 24 h	18	-3.7	-13.5	0.6	0.6	-42
N_2 48 h	18	-2.0	-9.4	1.5	0.8	-41
CO_2 24 h	18	-4.6	-12.5	0.6	0.6	-38
CO_2 48 h	18	-2.1	-11.6	1.4	0.6	-36
Air	18	-6.3	-17.9	-0.2	0.4	-41
Air	5	-2.5	-9.2	0.1	0.9	-29
LSD (5%)		1.0	4.6	0.6	0.4	7

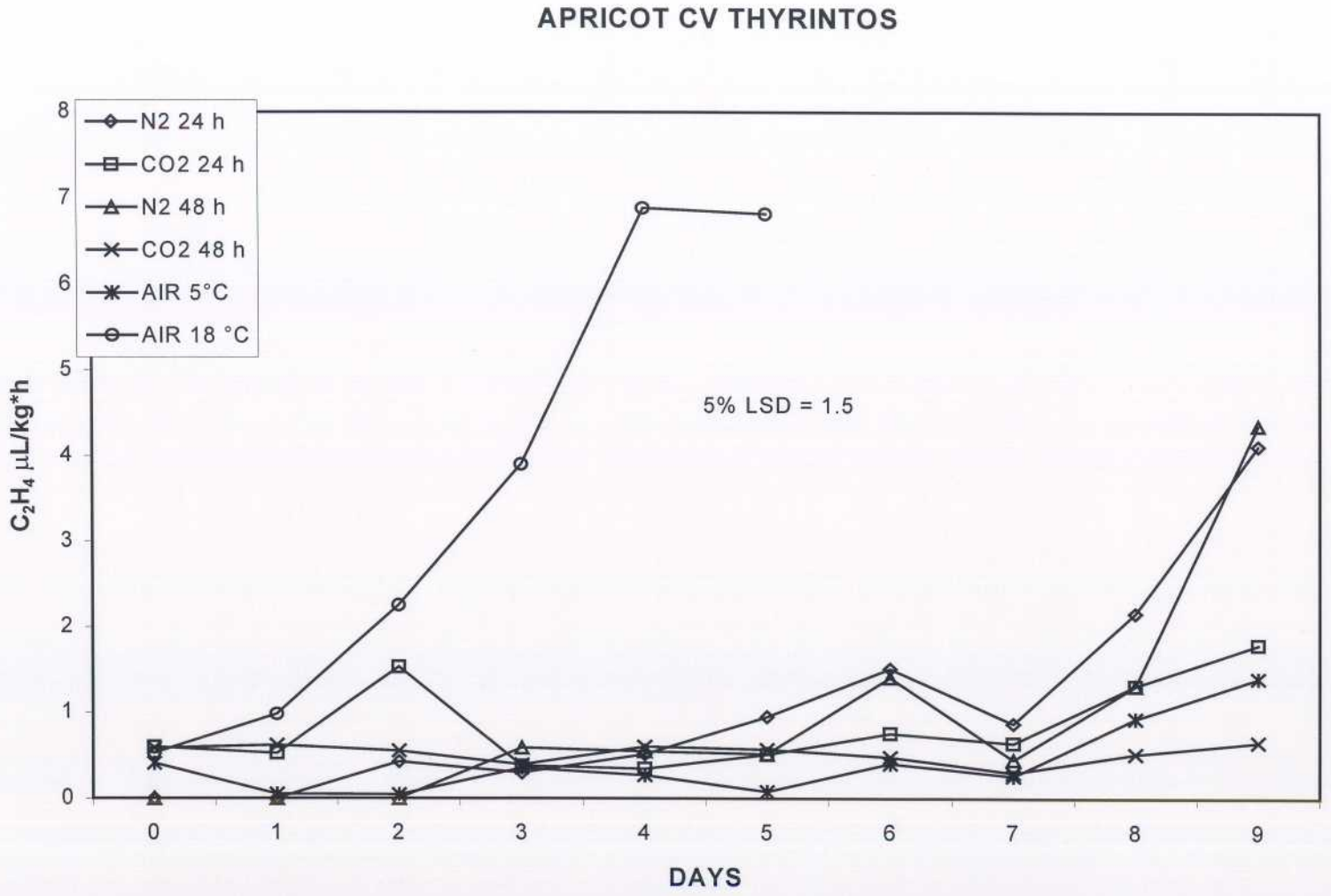

Fig. 1. Ethylene production of Tyrintos apricots during the EAST treatments at 18°C and the shelf life (air at 18°C). Data are the mean of 3 jars readings. Shelf life on day 1, 2 and 7, respectively for 24h, 48h and 5C samples .

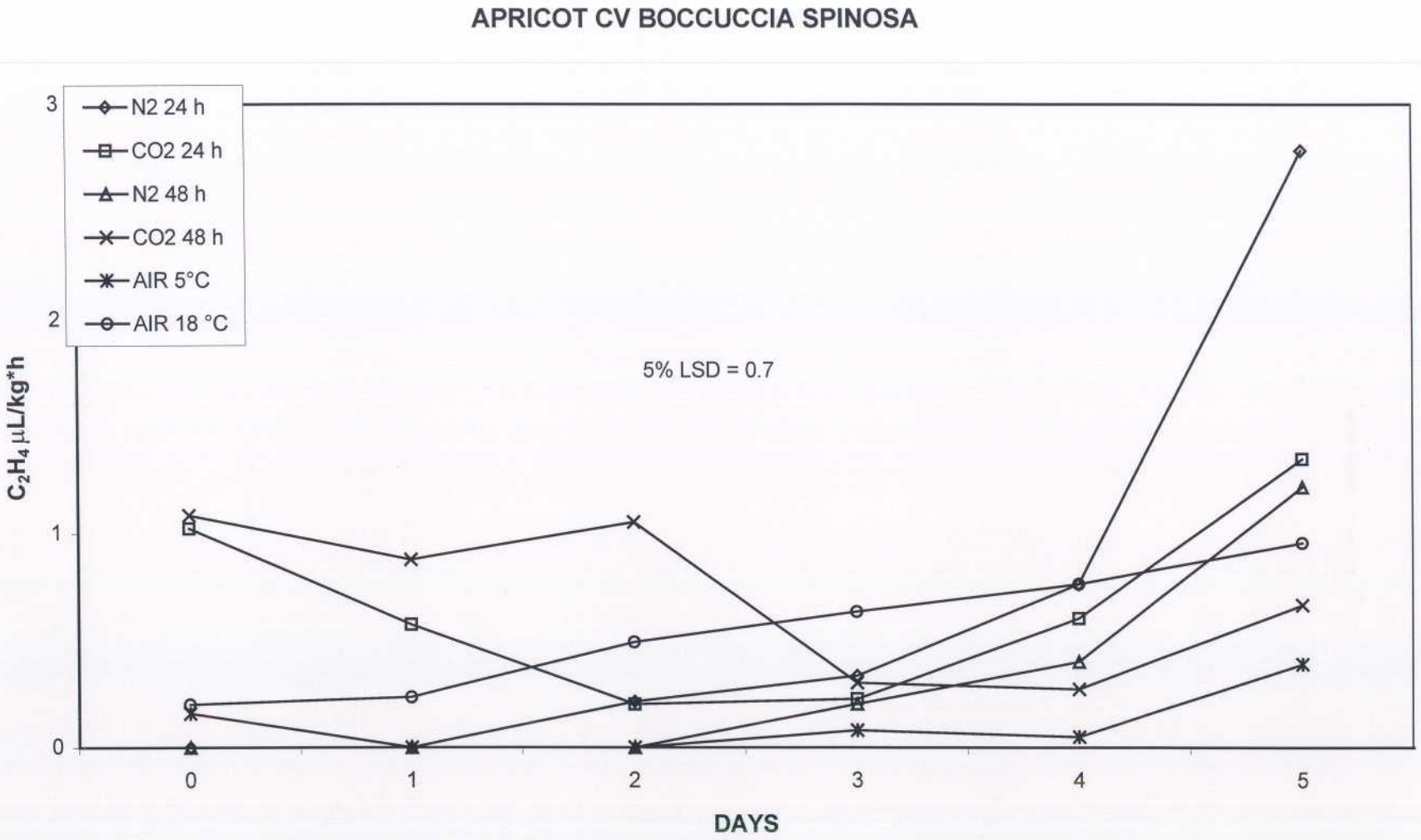

Fig. 2. Ethylene production of Boccuccia Spinosa apricots during the EAST treatments at 18°C and the shelf life (air at 18°C). Data are the mean of 3 jars readings. Shelf life on day 1, 2 and 7, respectively for 24h, 48h and 5C samples .

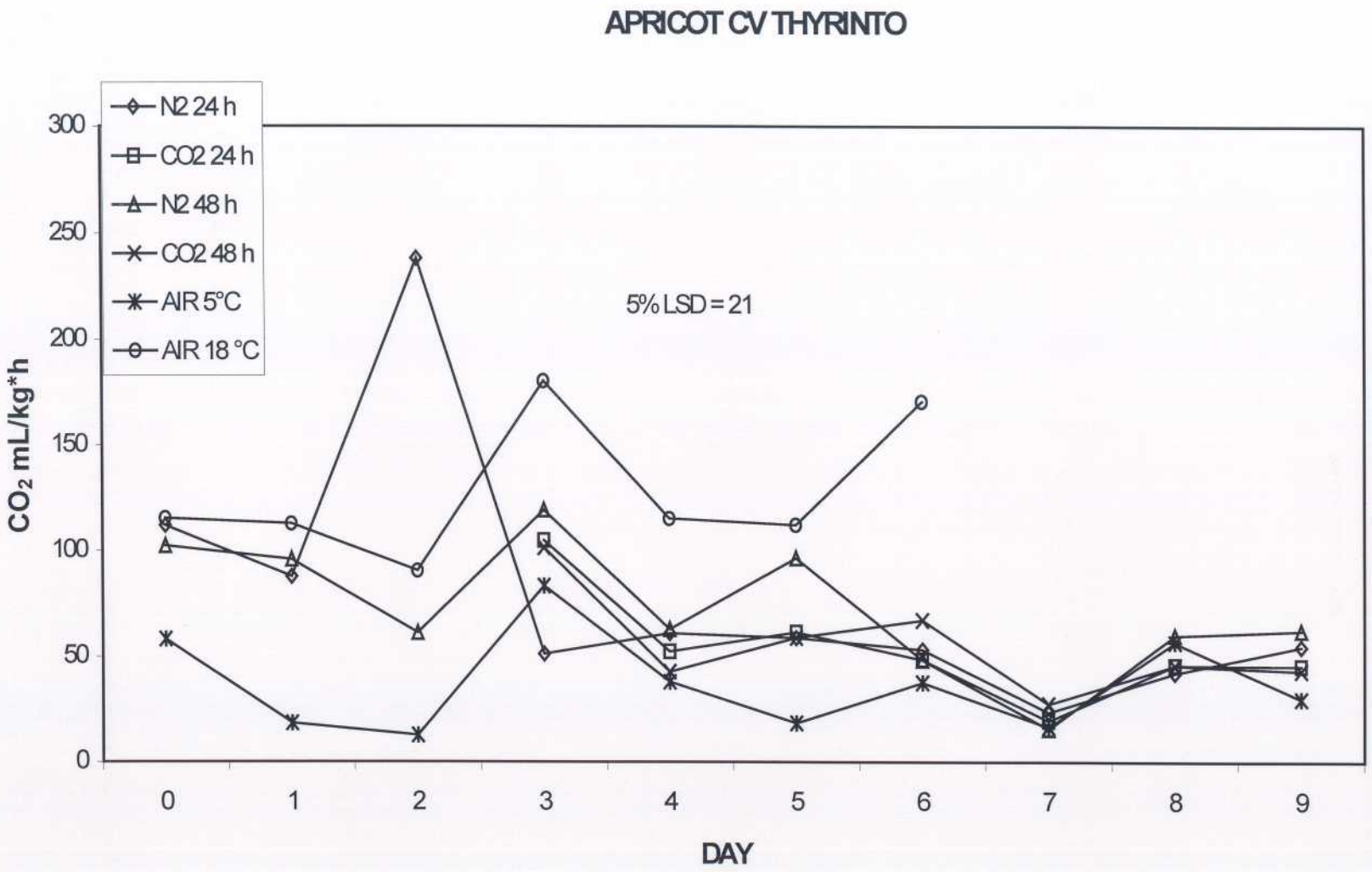

Fig. 3. CO_2 production of Tyrintos apricots during the EAST treatments at 18°C and the shelf life (air at 18°C). Data are the mean of 3 jars readings. Shelf life on day 1, 2 and 7, respectively for 24h, 48h and 5C samples .

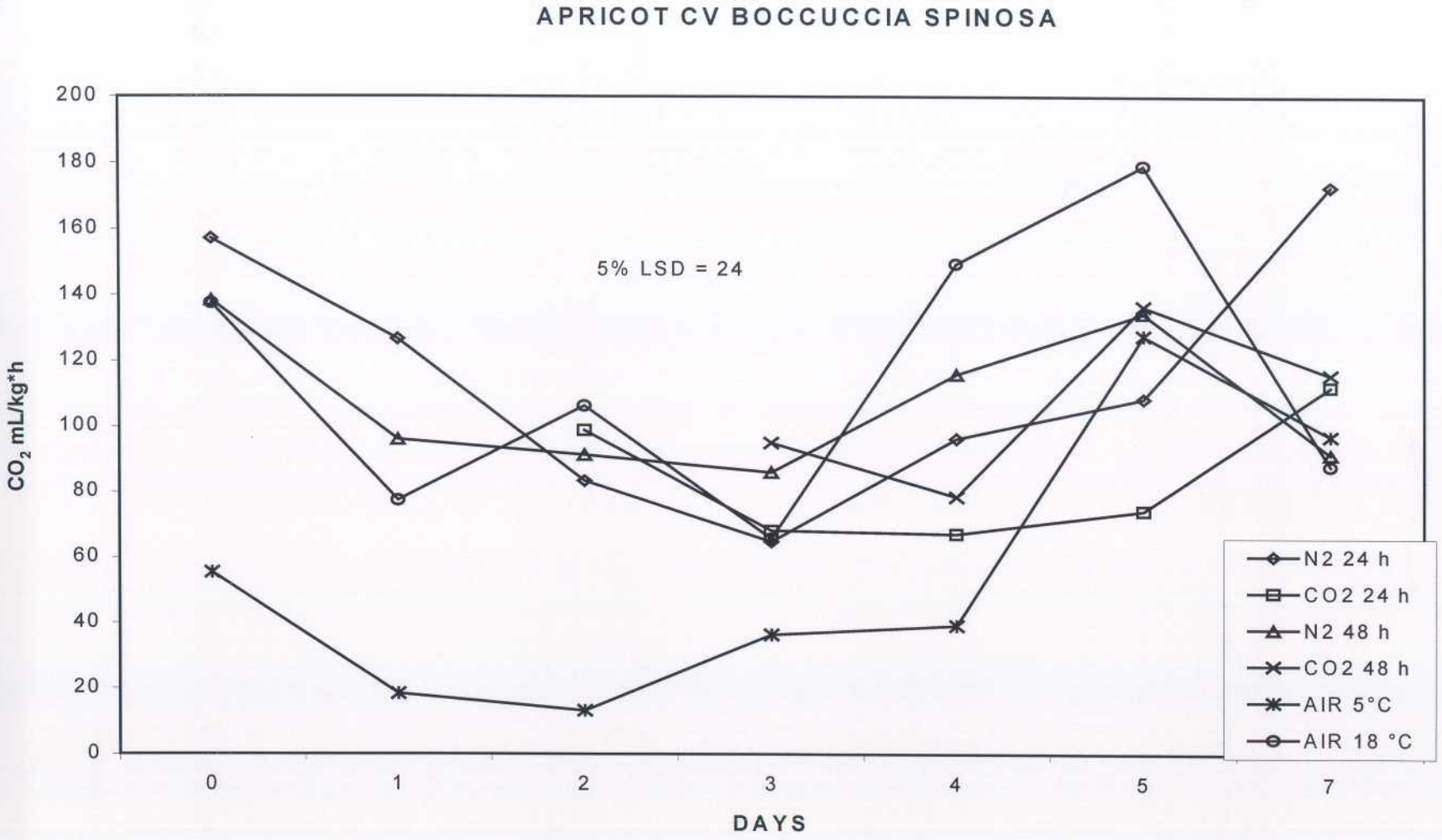

Fig. 4. CO_2 production of Boccuccia Spinosa apricots during the EAST treatments at 18°C and the shelf life (air at 18°C). Data are the mean of 3 jars readings. Shelf life on day 1, 2 and 7, respectively, for 24h, 48h and 5°C samples.

Modified Atmosphere Storage of Cherries

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Additional index words. Packaging, quality, decay control

Abstract. **Two cherry cultivars were tested during the 1996 season for their response to MAP (modified atmosphere packaging). Chinook was stored for two weeks and Bing was stored for up to three months. The plastic film used was Xtend™ (StePak, Tefen, Israel) film with microperferation. The gas concentrations of fruit packaged and held at 0°C stabilized after 2 days whether the Xtend™ film had microperferations or not. However, when transferred to 20°C sealed fruit became anaerobic while fruit in microperforated packages did not. When compared to 40μ polyethylene film (PE) CO_2 concentrations were higher and relative humidity lower in Xtend™ film than in PE film. Xtend™ film also maintained green stem color while PE packaging did not. Bing cherries stored well for up to two months at 0°C in MAP using Xtend™ film, but their quality deteriorated rapidly during the third month of storage. Xtend™ MAP decreased weight loss, decreased decay and maintained green stem color compared to unsealed control fruit. MAP did not affect fruit firmness, soluble solids content, titratable acidity or the amount of surface pitting, compared to control fruits. MAP packaging of cherries using Xtend™ film is beneficial for extending storage and shelf life of cherries.**

Stone fruits are among the commodities which respond well to elevated CO_2. Cherries, nectarines and peaches can store better in 10% CO_2 than in air (Lurie, 1992; Patterson, 1982; Retemalas et al., 1992). Elevated CO_2 is generally applied by controlled atmosphere storage, but it is also possible to generate elevated CO_2 by closing the fruit in a plastic bag and allowing respiration to raise the CO_2. A problem with this method of storage, called modified atmosphere, is precise control of the gas composition in the bag compared to controlled atmosphere where the atmosphere around the product is continually monitored and adjusted.

A new film, Xtend™, is impermeable to CO_2 and O_2, but partially permeable to water vapor. By using microperforations the level of CO_2 and O_2 created by commodity respiration can be adjusted, and with microperforations there is less chance of temperature fluctuations leading to anaerobic conditions. The permeability to water vapor means that humidity conditions inside the bag are closer to those in a storage room (95%) RH) and not 100% RH which encourages fungal development. In the present study, Xtend™ film was used to store cherries, and compared to modified atmosphere storage in polyethylene bags.

Methods and Materials

Fruits were taken directly from the orchard or from the packinghouse after sorting and placed in bags, Xtend™ or 40μ polyethylene, inside cardboard cartons. Cherries were packed 4 kg to a bag. The bags were then sealed and a rubber septum attached to the surface to allow for gas sampling. Control fruits were placed in a cardboard box with a unclosed plastic liner. Each treatment had 4 replicates (one box per replicate) for each removal. The fruits were then placed into 0°C storage and the gas composition measured periodically. The CO_2 and O_2 composition was measured in a GC with a TCD detector and a poropak column, while ethylene and ethanol were monitored on a GC with a FID detector and an alumina column for ethylene and a 20% CW20 on Supelcoport column for ethanol.

At the end of the storage period the fruits were removed to 20°C and the bags opened. The fruits were examined for quality both at removal and after varying times at 20°C. For shelf life the cherries were put into perforated plastic boxes holding about 0.5 kilo a box. Cherry firmness was determined using a Duometer and measuring the force needed to depress a plunger 2 mm into the fruit surface. Twenty fruits were measured in each replicate. Soluble solids (SSC) and titratable acidity (TA) were measured on combined juice samples from the 20 fruit used for firmness in each replicate. SSC was determined with a refractometer, and TA by titrating 2 ml of juice against 0.1N NaOH to pH 8.3 and expressing the result as percent malic acid. Physiological disorders and decay were measured visually either by examining the fruit surface or by halving the fruit and examining the flesh. All fruits in each replicate were examined.

Results

Two cherry cultivars were tested, Chinook and Bing. Chinook was stored for 12 days while Bing was stored for one and two months. The storage of Chinook cherries compared completely sealed or microperforated Xtend™ and polyethylene bags. The Xtend™ film was more successful in maintaining a high level of CO_2 than the polyethylene film (Table 1). The sealed polyethylene bags began with a 6.3% CO_2 level which declined to 4% after 12 days and microperforation decreased the concentration further. The CO_2 levels in the Xtend™ bags were higher than in polyethylene film. While the O_2 levels in the sealed bags were close to 2% at the beginning, they rose as storage continued, and there was no measurable ethanol found in the bags (data not shown).

Table 1. Gas composition inside bags with Chinook cherries during 0°C storage.

Treatment	CO_2% Day					O_2% Day				
	1	2	5	9	12	1	2	5	9	12
PE*	6.5	5.4	4.0	4.1	4.0	2.6	3.1	6.8	6.5	8.0
PE MP	5.4	4.2	3.1	3.4	3.1	10.8	13.9	16.4	16.3	15.9
Xtend	10.6	12.0	14.8	16.2	16.4	1.6	1.4	2.4	3.0	3.3
Xtend MP	9.9	9.7	9.1	7.2	7.2	3.1	5.7	14.1	14.8	14.2

* PE = polyethylene; MP = microperforation

The fruit at the end of storage showed minor differences in firmness, SSC and TA (Table 2). The major differences were the weight loss, the color of the fruit and the appearance of the stems. The control fruit lost almost 4% of their weight during 12 days at 0°C. The stems were brown and dry looking and 70% of the fruit were dark red. The polyethylene stored fruit lost the least weight, but all the sealed fruit retained green stems and fruit of a lighter red color. Following two days of 20°C shelf life there were no differences in the percentage of healthy fruits among the different treatments which ranged from 81 to 87%. The causes of non healthy fruit were decay (2 to 10%), cracking (7 to 12%) and pitting (8 to 12%).

Table 2. Ripeness and quality attributes of Chinook cherries after 12 days at 0°C.

Treatment	Firmness (A.U.)	SSC (%)	TA (%)	Red Color (%)			Wt Loss (%)
				Light	Medium	Dark	
Control	13.5	12.8	0.40	1	29	70	3.90
PE	14.1	13.6	0.38	5	49	47	0.04
PE MP	11.2	11.5	0.46	23	48	21	0.60
Xtend	12.1	10.5	0.45	12	58	30	0.51
Xtend MP	12.3	11.2	0.44	6	44	50	0.56

A.U. Arbitrary durometer units; PE polyethylene; MP microperforation

Bing cherries were stored in microperforated Xtend™ packages for one or two months, and compared to fruits held in boxes with a plastic liner. The sealed packages established stable gas concentrations by day 4 with values of 7.5 and 16% for CO_2 and O_2, respectively. These remained constant for the two months of storage.

Firmness of the control fruits increased as storage progressed, probably because of weight loss which was 10% after two months (Table 3). However, in the second month, firmness in the packaged fruit also increased, although the weight loss was less than 2%. This is an indication that other factors contribute to the fruit texture.

Table 3. Ripeness characteristics, weight loss, and quality attributes of Bing cherries after 1 and 2 months at 0°C and 2 days at 20°C.

A. Removal

	Months in Storage									
	1	2	1	2	1	2	1	2	1	2
Treatment	Firm. (A. U.)		SSC (%)		TA (%)		Wt. loss %)			
Control	15.7	18.5	16.4	18.5	0.52	0.43	3.1	10.3		
Xtend MP	15.3	17.1	14.8	17.6	0.47	0.41	0.9	1.4		

B. Shelf life

Treatment	Stem Color		Stemless (%)		Pitting (%)		Decay (%)		Healthy (%)	
Control	brown	brown	4	10	0	11	26	45	64	43
Xtend MP	green	green	4	23	0	16	6	7	92	76

The SSC increased between the first and second month of storage, while acidity gradually decreased throughout storage in all treatments. In informal taste tests after two months the fruits from both treatments were judged tasty, but the Xtend™ fruits were more attractive in appearance. The control fruits had dry, brown stems and decay was 45%, while the sealed fruits still had green stems and decay was about 7%.

Conclusions

Cherries benefited from Xtend™ packaging. Xtend™ was found to be more effective in maintaining cherry quality than polyethylene bags. Xtend™ was found to be beneficial for maintaining cherry quality both in short (12 days) and long (60 days) storage. The major benefits were in decreasing rots and preventing senescence of the stems and thus improving appearance. Xtend™ packaging did not affect the taste of the cherries or the organoleptic components of firmness, SSC and TA, nor did it decrease physiological problems of splitting or pitting. But in lowering decay incidence Xtend™ packaging greatly increased the percentage of marketable fruit.

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Effect of Modified Atmosphere Packaging on Strawberry Quality During Shelf-Life

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Abstract. **Strawberry fruits were placed in 250 g polyethylene(terphthalate) baskets and wrapped with polyvinylchloride (PVC) and polypropylene (PP) films, control was storage without film. Baskets were stored at 2°C for 3 days to simulate refrigerated transport and then kept at 16°C for 4 days to simulate the shelf-life period. Gas composition inside each basket was analyzed during storage. CO_2 levels increased up to 16% on day 7. Fruits firmness losses from 40 to 53% were observed. Similar sucrose losses were detected. Minor changes in citric acid and vitamin C contents were observed and a slight decrease in malic acid content was found during the experiment. Color expressed as L, Hue angle and Chroma showed significant differences. Flavor development, evaluated as total furanones production, was quite similar in all samples. Off-flavor development was evaluated during storage; ethanol was found to be the main volatile compound in relation of off-flavor, reaching 100 ppm on day 7.**

Spanish strawberries are produced mainly in Huelva province, South-Western Spain, but the primary market for fresh fruits extends across central Europe. Therefore surface transport strawberries need 3 or 4 days for arriving to the markets. Strawberry is one of the most delicate and perishable fruit, being susceptible to mechanical injury, physiological deterioration, water loss and decay, at room temperature the post-harvest life is about a week. To decrease the fruit respiration rate and the fungal spoilage, forced air precooling at 1-2°C is being increasingly used (Olías et al., 1995). To reduce weight loss and to maintain fruit quality Modified Atmosphere Packaging (MAP) is an useful technique to extend strawberry shelf-life, although changes in respiration rate, due to exposure to different temperature during distribution and shelf-life, and film permeability can greatly affect initial gas composition leading to detrimental high CO_2 and low O_2.

In this study our objective was to evaluate the effect of two plastic films commonly used for MAP, polyvinylchloride (PVC) and polypropylene (PP), on quality parameters of Spanish strawberries subjected to the habitual post-harvest process for fruits exported to Central Europe.

Materials and Methods

Plant material. Camarosa strawberries were harvested by experimented pickers, selecting for uniformity of size and color, packed in 250 g polyethylene(terphthalate) punnets, transported to the packinghouse facility, refrigerated to 6°C. One group was manually wrapped with a PVC film, a second one was automatically wrapped with PP film, and the third group was not wrapped,

constituting a control. The fruits were subsequently cooled to 2°C, and stored during three days, for simulating the refrigerated transport to the markets, and then kept for 4 days at 16°C to simulate the shelf-life period. The physical and chemical properties of strawberries after cooling to 2°C are designated as day 0. Samples day 3 correponding to fruits stored at 2°C for 3 days; samples day 5 are the strawberries kept three days at 2°C plus two days at 16°C, and finally samples day 7 are the fruits stored at 2°C for three days plus four days at 16°C.

Atmosphere composition. CO_2 and O_2 contents inside each basket were analyzed by a gas chromatograph, Hewlett-Packard 5890, equipped with a thermal conductivity detector, on a stainless steel Carbosieve S-II (3 m x 3 mm i.d.) column and helium as carrier gas.

Color. Strawberry skin color was evaluated with a Minolta CR-200 portable tristimulus colorimeter using color space L^*, a^*, b^*. Numerical values were converted into Hue angle [$h=\arctan(b^*/a^*)$] and chroma [$C^*=(a^{*2} + b^{*2})^{1/2}$]. For this purpose two determinations at the strawberry equatorial zone were made on 15 fruits.

Firmness. Firmness was measured as penetration force required to depress 2.4 mm into the fruit with a Zwick 3303 densimeter, using a 5 mm plunger tip, and it is expressed as newtons (N). For this purpose two determinations at the strawberry equatorial zone were made on 15 fruits.

Sugars and organic acids determination. Fifteen strawberries were cut symmetrically in eight pieces. Fifteen portions were blended in the dark with 95% ethanol for 3 min at maximum speed with an Omnimixer. The homogenate was vacuum filtered through Whatman No. 1 filter paper and the residue washed twice with ethanol 80%. The filtrates were combined and adjusted to 5 mL/g FW with ethanol 80%. Ten mL of this ethanolic extract were evaporated in the dark to dryness at 50°C. The dry residue was redissolved in 1 mL of 0.2N H_2SO_4 containing 0.05% EDTA, loaded onto a C_{18} Sep-Pak cartridge (Lida, Kenosha, USA), and eluted with up to 4 mL of the same solution. These extracts containing sugars and organic acids, including vitamin C, were filtered through 0.45 μm Nylon filters before HPLC analysis. A Hewlett-Packard 1090 liquid chromatograph equipped with a photodiode array detector and a Waters 410 differential refractometer connected in series was used for HPLC analysis. Isocratic separation of the compounds were made on a stainless-steel Ion-300 (300 mm x 7.8 mm, 10 μm) column, containing a cation-exchange polymer in the ionic hydrogen form, with an IonGuard GC-801 guard column, and thermostatized at 23°C. The mobile phase used for the elution consisted of a filtered (0.22 μm nylon) and degassed solution of 0,0085N H_2SO_4 and a flow rate of 0.4 mL/min. UV detector was selected at 195 nm and 245 nm, refractive index detector was used at sensitivity 16x and the injection volume was 20 μL.

Furanones analysis. Fifteen portions of strawberries (ca 20 g), obtained as above, were ground with 5 mL of distilled water in a Waring blender at 0-4ºC. Celite 545 (10 g) was added and after mixing allowed to settle for 5 min. The mixture was filtered, washed three times with 10 mL distilled water, and again filtered first through a 0.45 μm and then through a 0.2 μm nylon membrane before analysis. A liquid chromatograph, Beckman Golden System, equipped with an ODS (4.6 mm x 250 mm) 5 μm column was used. UV detector was selected at 280 nm and the injection volume was 20 μL. The mobile phase consisted of two eluents: 0.2 M sodium acetate/acetic acid, pH 4 (solvent A), and methanol (solvent B). Chromatographic conditions were 0-11 min, isocratic 13% B; 11-26 min, gradient 13-23% B; 26-30 min, isocratic 23% B; 30-33 min, gradient 23-80% B.

Determination of volatile compounds. Fifteen portions of strawberries were used to extract juice in order to analyze volatiles. A 3 mL sample was put in a 11 ml sealed vial. The vial was then transferred into an automatic headspace sampler (Hewlett-Packard 19395 A) where a 15 min

equilibrium time at 60°C was set to allow the volatiles to enter the gas phase. The volatiles were determined by GLC in a gas chromatograph equipped with FID and a glass column (2 mm x 1.0m) containing 5% Carbowax on a 60/80 Carbopack as the stationary phase.

Results and Discussion

Strawberries are highly perishable, and effective handling procedures are required to prevent excessive deterioration. Low temperature and a suitable atmosphere are often recommended for optimum storage. To mimic the strawberry market life we kept the fruit at 16°C in order to study the effect of the plastic film. Although MAP can potentially extend shelf-life, they cannot be expected to overcome the negative effects of enhanced temperature. Atmosphere composition in the baskets is presented in Table 1. After three days at 2ºC, few changes are noticed in the atmosphere. When strawberries were stored at 16ºC the atmosphere in the PP wrapped baskets change from 1.34% CO_2 on day 3 to 14.66% on day 7. In similar conditions, the atmosphere of PVC wrapped baskets reached 4.92% CO_2. To study the effect of this atmosphere physical and chemical quality characteristics of strawberries were evaluated.

For consumers the color is the basis of their first purchase, specially if commodity is wrapped in a basket and cannot be touched or smelt. Color indicators of the fruit during the 7 days of storage are listed in Table 2. In the last day of storage all strawberries were darker (lower L^* value), less red (lower a value), and less bright (lower chroma); nevertheless, both films exhibited significantly higher values than control. From these results we could say the color of wrapped strawberries was better.

After the first purchase the consumer decides a new one according to the flavor of the product. Firmness, sugars, organic acids and furanone contents were used to estimate the evolution of quality. The benefit of high CO_2 in the atmosphere was only observed in strawberries wrapped with PP. These fruits, in the last day of the study, were significantly firmer (Table 3). The evolution of sucrose content was similar in all samples with a reduction of around 50%. Concomitant with the decrease in sucrose content, an increase in glucose and fructose was observed, but no clear differences were found between samples (Table 4). During the storage, the content of citric and ascorbic acids remained practically unchanged. On the other hand, malic acid content after 4 days at 16°C decreased almost 50%. Furaneol and derivatives are considered among of the most important strawberry aroma contributors (Pyysalo et al. 1979; Larsen and Poll, 1992). The development of furanone compounds in all cases appears to be quite similar (Table 4). Total furanone content increased during storage. These results agree with those reported on the evolution of these compounds during ripening in different strawberry varieties (Pérez et al., 1996). This increase in furaneol derivatives could indicate that the enzymatic system responsible for these processes is still active.

Changes in concentrations of volatiles may influence flavor. Off-flavor may be induced by anaerobic respiration with accumulation of certain volatile compounds such as acetaldehyde and ethanol. During the storage only ethanol was detected (Table 5). After the second days of storage at 16°C, the strawberries wrapped with PP showeed significant higher concentrations. In this case the effect of CO_2 level (ca 15%) begins to be significant.

Conclusion

Results obtained in this study, globally analyzed, allow to give an affirmative answer to the implicit question about the convenience of wrapping strawberries. In the studied conditions, 3 days at 2°C plus 4 days at 16°C, wrapped fruits showed, in general, better physical and chemical characteristics, and there was no indication that the level of CO_2 reached caused any undesirable changes in fruit quality.

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Table 1. Evolution of Atmosphere Composition inside of basket during storage studied

	O_2 (%)		CO_2 (%)	
Days	PVC	PP	PVC	PP
0	21	21	0.032	0.032
3	20.23±0.09*	19.46±0.59	0.88±0.08	1.34±0.30
5	16.46±0.59	16.28±0.18	3.07±1.1	6.40±1.10
7	17.85±1.19	15.01±1.59	4.92±0.62	14.66±0.50

*mean and standard deviation of three replicates

Table 2. Evolution of strawberry color during storage.

	*L**			*a**		
Days	CONTROL	PVC	PP	CONTROL	PVC	PP
0	37.03± 5.04*	37.03± 5.04	37.03± 5.04	30.00±2.30	30.00±2.30	30.00±2.30
3	31.37± 3.60^{b}	32.13± 4.00^{b}	34.87± 5.23^{a}	28.83± 2.94^{a}	29.93±2.64^{a}	29.67±4.10^{a}
5	37.03± 5.18^{a}	34.4 ±2.71^{b}	33.93± 3.33^{b}	29.43±3.66^{a}	28.93±2.76^{a}	29.46±3.54^{a}
7	33.33± 2.86^{a}	32.5±2.40^{a}	32.53± 2.40^{a}	27.53±3.74^{b}	28.60±4.08^{ab}	30.10±2.88^{a}
	Hue			*Chroma*		
Days	CONTROL	PVC	PP	CONTROL	PVC	PP
0	37.05±8.35	37.05±8.35	37.05±8.35	37.83±4.85	37.83±4.85	37.83±4.85
3	34.61±6.39^{ab}	32.64±6.20^{b}	36.17±6.22^{a}	35.51±4.95^{a}	35.99±4.48^{a}	37.17±5.46^{a}
5	33.91±9.10^{a}	32.56±4.54^{a}	31.16±4.98^{a}	36.14±4.33^{a}	34.56±4.15^{a}	34.74±5.18^{a}
7	29.47±4.37^{b}	31.88±3.55^{a}	32.31±4.78^{a}	31.77±4.61^{b}	33.78±5.06^{ab}	35.84±4.04^{a}

*mean and standard deviation of 30 determinations. Significant differences between baskets determined by ANOVA, p=0.05.

Table 3. Evolution of strawberry firmness (N) during storage.

Days	CONTROL	PVC	PP
0	59.15±4.88*	59.15± 4.88	59.15±4.88
3	60.60±10.40^{ab}	62.03±7.69^{a}	55.73±10.67^{b}
5	50.13±6.60^{a}	48.36±7.20^{a}	44.43±7.63^{b}
7	28.83±7.86^{b}	28.33±10.06^{b}	36.06±8.60^{0a}

*mean and standard deviation of 30 determinations. Significant differences between baskets determined by ANOVA, p=0.05.

Table 4. Evolution of strawberry sugars, organic acids and furanones content in strawberry during storage.

	Sucrose (mg/g FW)			*Glucose (mg/g FW)*			*Fructose(mg/g FW)*		
Days	CONTROL	PVC	PP	CONTROL	PVC	PP	CONTROL	PVC	PP
0	17.05±0.86*	17.05±0.86	17.05±0.86	11.91± 0.44	11.91± 0.44	11.91± 0.44	13.16± 0.33	13.16± 0.33.	13.16± 0.33
3	15.47±0.80 ^{a}	15.74± 0.39^{a}	12.51± 0.39^{b}	10.55±0.47^{a}	10.25±0.20^{a}	8.78±0.31 ^{b}	11.99±0.51^{a}	11.83±0.15^{a}	10.45±0.37^{b}
5	9.92 ±2.63^{a}	15.87± 0.68^{b}	12.97± 0.15^{c}	10.35±0.86^{b}	11.85± 0.29^{a}	11.80± 0.12^{a}	11.77± 1.28^{b}	13.65± 0.11^{a}	13.68± 0.35^{a}
7	7.93 ±0.07^{c}	8.62± 0.06^{b}	9.73± 0.11^{a}	12.09± 0.07^{c}	12.90±0.06^{b}	13.73±0.13^{a}	14.09±0.01^{b}	14.33±0.20^{b}	15.15±0.09^{a}
Days	*Citric* (mg/g FW)			*Malic (mg/g FW)*			*Ascorbic (mg/g FW)*		
	CONTROL	PVC	PP	CONTROL	PVC	PP	CONTROL	PVC	PP
0	7.06±0.34	7.06±0.34	7.06±0.034	1.76±0.06	1.76±0.06	1.76±0.06	0.35± 0.02	0.35±0.02	0.35±0.02
3	6.53±0.22^{b}	7.59±0.04^{a}	6.00±0.21^{c}	1.17±0.14^{c}	1.58±0.02^{a}	1.35±0.03^{b}	0.30± 0.02^{b}	0.32±0.01^{a}	0.25±0.01^{c}
5	7.65± 0.61^{a}	6.56± 0.18^{b}	6.97 ±0.04^{ab}	1.76± 0.42^{a}	1.49± 0.04^{a}	1.33±0.01^{a}	0.35± 0.03^{a}	0.39± 0.03^{a}	0.37± 0.01^{a}
7	7.31± 0.06^{a}	7.19 ±0.06^{a}	6.91± 0.16^{b}	1.06 ±0.01^{a}	0.89± 0.01^{b}	0.87± 0.02^{a}	0.37± 0.01^{a}	0.33 ±0.01^{b}	0.38±0.01^{a}
	Furaneol (μg/g FW)			*Mesifurane* (μg/g FW)			*Furaneol- Glucoside* (μg/g FW)		
Days	CONTROL	PVC	PP	CONTROL	PVC	PP	CONTROL	PVC	PP
0	0.33 ±0.01	0.33± 0.01	0.33± 0.01	0	0	0	0.14 ±0.02	0.14±0.02	0.14± 0.02
3	3.31 ±0.51^{a}	3.24± 0.45^{a}	1.33± 0.06^{b}	0	0	0	0.21± 0.01^{a}	0.23 ±0.03^{a}	0.06± 0.01^{b}
5	3.67± 0.09^{b}	3.65± 0.05^{b}	4.69± 0.17^{a}	0.05±0.01^{c}	0.67± 0.02^{a}	0.39 ±0.09^{b}	0.49± 0.01^{c}	0.93± 0.04^{b}	1.15± 0.03^{a}
7	7.92± 0.40^{a}	6.75± 0.01^{b}	6.72± 0.50^{b}	2.10± 0.04^{b}	2.32± 0.05^{a}	2.20± 0.16^{ab}	1.48± 0.23^{b}	2.08± 0.02^{a}	1.95± 0.10^{a}

*mean and standard deviation of three replicates. Signinificant differences between baskets determined by ANOVA, p=0.05.

Table 5. Evolution of ethanol content in strawberry during storage.

	Ethanol(μL/L)		
Days	CONTROL	PVC	PP
0	0	0	0
3	30.64±8.70[a]*	26.67±3.51[a]	36.31±3.55[a]
5	37.10±3.44[b]	38.73±1.04[b]	66.33±0.58[a]
7	75.54±2.10[b]	56.88±1.57[c]	107.48±5.72[a]

*mean and standard deviation of three replicates. Significant differences between baskets determined by ANOVA, p= 0.05.

Controlled Atmosphere Alternatives to the Post-Harvest Use of Sulphur Dioxide to Inhibit the Development of *Botrytis Cinerea* in Table Grapes

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Additional index words. Decay control, flavor quality

Abstract. **The effects of controlled atmosphere storage treatments on inhibiting Botrytis cinerea development and maintaining the quality of table grapes (*Vitis vinifera* L. cv. Thompson Seedless) were compared to identify a treatment that could replace the use of sulphur dioxide during post-harvest handling. Two experiments were conducted at 0-1°C over 7 and 12 week periods respectively. The treatments that incorporated a carbon dioxide concentration of 15-25% were most effective and suppressed infection by between 95 - 100%. At higher concentrations, however, berry discolouration occurred. There was no significant difference between treatments for taste but the treatment 5% O_2 - 15% CO_2 was liked most by panelists and matched the fresh control treatments most closely.**

Botrytis cinerea (*B. cinerea*) causes pre- and post-harvest decay of table grapes. Spores from the pathogen can affect the flowering parts and fruits of grapevines and lie dormant within fruit until conditions become favourable for growth. (Snowdon, 1990). Infected fruit that look healthy at harvest are packed for distribution. *B. cinerea* is able to develop at temperatures as low as -0.5°C. If it develops after packing 'nesting' (berry to berry contamination) can cause consignments to be lost and lead to severe losses in the market. (Smilanick, 1992). Sulphur dioxide (SO_2) is used as the main post-harvest control of pathogen infection in table grapes. The gas prevents fruit to fruit transmission of the pathogen by killing its spores and inhibiting mould growth on the grape surface. It is mainly applied in one of two ways. Grapes can be fumigated with the gas at regular intervals during cold storage, or SO_2-generating pads containing sodium or potassium metabisulphite can be placed within grape packaging and release the gas steadily over time. Rapid cooling and a temperature control of 0-1°C help to control the rate of release of SO_2 from the pads. SO_2 can cause chemical injury to grapes if it gets under the skin of the fruit berries, through wounds or through the capstem (the area of berry attachment to the bunch stem). It causes the flesh under the berry to break down, bleaches the skin and produces off-flavours when eaten. (Snowdon, 1990). The optimum SO_2 concentration is usually a compromise between achieving the best possible pathogen control and not causing excessive injury to the fruit. (Yahia et al., 1983.) It is possible that sulphur dioxide may soon be removed from the Generally Regarded As Safe (GRAS) chemicals in the Food and Drug Administration's register in the USA. It is suspected that people can have allergic reactions to residues and there are concerns about the carcinogenic effect of long-term ingestion of the residues left on the fruit on consumption.

Controlled atmospheres have been increasingly used in fresh fruit and vegetable storage during the last 20 years. Continued respiration by the commodity after harvest leads to a

depletion of the commodity's resources. Its tissues begin to weaken, break down and eventually die. As the tissue weakens so the quality of the fruit is affected and it becomes more susceptible to attack by pathogens. Altering the atmospheric composition around fruit and vegetables in conjunction with temperature and humidity control can slow the process of respiration and hence maintain the quality of the commodity and its resistance to pathogens for longer periods. (Sommer, 1992). Studies by Lazlo (1985) suggest that CA storage treatment alone of the Waltham Cross grape variety, at 5% O_2 and 10% CO_2, is not sufficient to suppress pathogen development. It was suggested that other CA combinations might be found which had a desired effect. The results presented are from a further investigation of the potential of CA storage to control *B. cinerea* on Thompson Seedless grapes.

Materials and Methods

Greek Thompson Seedless grapes were obtained from a fruit importer / supplier company. Each batch was less than 1 week old having been picked fresh from the vine and transported directly to the U.K. by truck; 500g $\pm$ 3g bunches were placed separately in 3.3-litre plastic ontainers. Three berries from 3 separate areas on each bunch were injected with 0.2 ml $\pm$ 0.1 ml of conidial suspension of *B. cinerea* and tagged for identification. Each bunch was treated under controlled atmosphere storage (CAS) conditions at 0 - 1°C for 7 weeks. CAS treatment combinations of 1% oxygen (O_2) + 25% carbon dioxide (CO_2), 5% O_2 + 2% CO_2, 50% O_2 + 30% CO_2, and 50% O_2 + 1% CO_2 were used. The results of these treatments (see Table 1 and 2,) were used to select further CAS treatment combinations which were treated for 12 weeks. For this combinations of 5% O_2 + 20% CO_2, 5% O_2 + 15% CO_2, 30% O_2 + 20% CO_2, and 5% O_2 + 10% CO_2 were used. (See Tables 3 and 4.) In total, investigations were conducted using 8 CAS combinations. Two control treatments were set up in containers attached to an outside airflow, which were inoculated and not inoculated, respectively. Three replicates were used for each treatment. Quality assessments were carried out at the end of treatment. Destructive testing was carried out to assess the level of mould growth on each bunch. Thirty unaffected berries were used to conduct 10 replicate assessments of berry skin colour, titratable acidity and total soluble solids content. The remaining unaffected berries were assessed by a taste panel of 20 panelists. The panellists were untrained and were instructed to mark each category according to the degree to which it would affect their purchasing choice in a supermarket situation. Texture, sweetness, sharpness, the presence of off-flavours and liked preferences were tested on a 3-point scale. Freshly purchased grapes were used as a control during the taste panel. The results obtained for the controls were used as an indication of treatment acceptability.

Results

Table 1 shows the results of initial testing of grapes under CA storage for 7 weeks. There were significant differences between CA treatments in reducing the occurrence of B. cinerea ($p = 0.01$). No rot was found when the treatments 25% CO_2 + 1% O_2 and 30% CO_2 + 50% O_2 were used. There was no significant difference between the treatments for T.S.S levels. There were significant differences in berry colour assessments ($p = 0.05$) for the colour Minolta a* (green / red colour dimension) and b* (yellow / blue dimension) readings. Although there were variations in L* (brightness / darkness) dimensions this was not to a significant level. The treatment CA

combination 50% O_2 + 30% CO_2 had a lower saturation of greenness than the other treatments and had a deep brown appearance. In general, berries treated with higher levels of CO_2 became discoloured and were more brown in appearance. Table 2 shows the results of taste tests conducted on the 2 combinations. There was no significant difference between the treatments. The combinations matched the freshly bought control in almost all categories. Table 3 shows the results of follow up testing of grapes held under CA storage for 12 weeks. There were no significant differences in testing between the CA treatments for titratable acids, T.S.S., and berry colour measurements although there were variations. Generally, treated berries had a darker colouring than the control berries and, as in Table 1 the treatments with the highest CO_2 tended to be more brown. All of the bunches contained some discoloured berries. Each of the treatments showed some rot development although there was a highly significant difference between the CA treated bunches and the controls ($p = 0.01$). The treatments 20% CO_2 5% O_2 and 20% CO_2 $\pm$ 30% O_2 inhibited rot development most effectively but each of these were liked the least during taste testing as is shown in Table 4. As in Table 2, there was no significant difference between treatments for taste, however, the CA treatment 5% O_2 $\pm$ 15% CO_2 was liked most by panelist and matched the fresh control most closely.

Table 1. The results of objective quality assessment tests for each CA treatment over a 7-week period. Each result is the mean value of 3 replicate 500g $\pm$ 3g bunches. Standard deviation values are shown in brackets.

Treatment			Minolta Assessment		
% O_2 + % CO_2	% Rot	% T.S.S.	L*	a*	b*
1 + 25	0.0 ($\pm$0.00)	15.4 ($\pm$2.00)	42.06 ($\pm$1.27)	-3.76 ($\pm$1.16)	9.84 ($\pm$1.50)
5 + 2	22.7 ($\pm$9.50)	15.3 ($\pm$1.40)	43.65 ($\pm$0.65)	-6.06 ($\pm$0.27)	12.39 ($\pm$0.12)
50 + 30	0.0 ($\pm$0.00)	15.6 ($\pm$1.60)	40.81 ($\pm$0.54)	-1.82 ($\pm$0.34)	9.41 ($\pm$0.49)
50 + 1	24.1 ($\pm$1.60)	14.6 ($\pm$0.90)	42.23 ($\pm$1.12)	-5.70 ($\pm$0.76)	11.52 ($\pm$1.29)
Not inco. Air	100.0 ($\pm$0.00)	15.9 ($\pm$1.02)	41.21 ($\pm$1.10)	-4.41 ($\pm$0.68)	8.67 ($\pm$0.26)
Anova significance:					
Fpr	0.0000	0.3923	0.0957	0.0014	0.0122

Table 2. The results of taste tests conducted on berries from each of the bunches held under the treatments shown in Table 1; 20 panelists took part in the test. Only those combinations which were free from rot were treated.

Treatment	Texture	Sweetness	Sharpness	Off-flavours	Liked
1% O_2 + 25% CO_2	2.05	1.85	1.46	1.49	1.82
50% O_2 + 30% CO_2	1.73	2.05	1.39	1.85	1.53
Fresh bought	1.80	1.68	1.68	1.24	1.85
Freidman test of significance: 0.8187					

Table 3. The results of objective quality assessment tests for each CA treatment over a 12 week period. Each result is the mean value of 3 replicate 500g ± 3g bunches. Standard deviation values are shown in brackets.

Treatment		% Titratable		Minolta Colour Assessment		
% O_2 + % CO_2	% Rot	Acids	% T.S.S.	L*	a*	b*
5 + 20	0.97 (±0.96)	4.00 (±0.00)	22.73 (±0.58)	38.80 (±0.94)	-2.79 (±0.98)	7.98 (±0.67)
5 + 15	3.58 (±2.74)	4.30 (±0.60)	21.83 (2.05)	40.31 (±2.38)	-4.02 (±0.95)	9.72 (±1.43)
30 + 20	0.29 (±0.33)	4.30 (±0.30)	21.40 (±1.47)	39.47 (±2.62)	-1.74 (±2.47)	7.44 (±1.75)
5 + 10	4.10 (±0.77)	4.00 (±0.40)	24.20 (±1.54)	38.75 (±1.87)	-3.53 (±0.59)	9.27 (±1.95)
Innoc – air (±0.00)	100.00	–	–	–	–	–
Not inoc - air	47.70 ±(7.64)	3.50 (±0.10)	20.30 (±1.50)	41.21 (±1.10)	-4.41 (±0.68)	8.67 (±0.26)
Anova significance:						
Fpr.	0.00	0.1159	0.1834	0.5301	0.2905	

Table 4. The results of taste tests conducted on berries from each of the bunches held under the treatments shown in Table 1; 20 panelists took part in the test. Only those combinations which were free from rot were tested.

Treatment	Texture	Sweetness	Sharpness	Off-flavors	Liked
5% O_2 + 20% CO_2	1.65	2.15	1.50	1.88	1.63
5% O_2 + 15% CO_2	1.58	2.08	1.45	1.30	1.90
30% O_2 + 20% CO_2	1.53	2.00	1.33	1.65	1.68
5% O_2 + 10% CO_2	1.98	2.00	1.40	1.20	1.85
Freshly bought	2.63	1.83	2.03	1.13	2.15

Freidman test of significance: 0.5713

Discussion and Conclusion

The results above suggest that CA storage can be effective in inhibiting the development of *B. cinerea*. Combinations that incorporate CO_2 concentration of 15% or more are most effective; however, at this concentration visual quality becomes compromised. This finding is in keeping with studies carried out previously on table grapes (Yahia *et al.*, 1983). The duration of each test may play a part in this deterioration. It should be noted that there was no discernible difference in quality detected between CA treatment 1% O_2 + 25% C O_2 used for 7 weeks and the CA treatments used for 12 weeks. This suggested that the use of sulphur dioxide, a treatment which itself can easily produce off-flavours and discolouring in grapes (Pentzer *et al.*, 1933), might be replaced by CA storage at carbon dioxide concentrations above 15% and below 25%. Future experiments will look at the possibility of using these treatments combinations to develop an effective modified atmosphere pack for grapes along the lines of those already in existance (Day, 1993).

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Relationship Between Kiwifruit Size and the Rate of Softening Under Controlled Atmosphere Conditions

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Abstract. **The rate of fruit softening under controlled atmosphere (CA) and air storage conditions was related to fruit size and storage conditions. However, soluble solids concentration (SSC) increase was independent of the fruit size and the storage conditions. Large (~101 g), medium (~93 g), and small (~81 g) size 'Hayward' kiwifruit were stored in either ethylene-free air or 5% CO_2 + 2% O_2 at 0°C during a 16 week cold storage period. Under both storage conditions, large size fruit had a slower rate of softening than medium and small size kiwifruit. The rate of fruit softening was always slower under CA than air conditions. Air stored kiwifruit softened approximately 2.5 times faster than CA stored fruit. Because kiwifruit are more susceptible to physical damage during the packaging operation and shipment when they soften below 17.8 N (penetration force with an 8-mm tip), we determined the number of weeks to reach this firmness under each of the different size-storage conditions. Under air conditions large, medium, and small size kiwifruit reached 17.8 N fruit firmness by 13, 12, and 11 weeks, respectively. Large, medium, and small size kiwifruit under CA conditions (5% CO_2 + 2% O_2) were estimated to reach 17.8 N fruit firmness by 57, 35, and 25 weeks, respectively. Thus, the duration of cold storage of kiwifruits in bins prior to packaging will depend on fruit size and storage conditions.**

Any technology to reduce the cost of kiwifruit repackaging will increase profit to the grower and packer. Traditionally, kiwifruit are picked, sorted, sized, and packed immediately into various size containers. Generally, after 2-3 months storage, the kiwifruit is repackaged to remove fruit infected with Botrytis. In most cases, kiwifruit are packed into other size boxes to satisfy market conditions at that time. It is very difficult for the packers to predict the container/size combination that will be required by buyers 2-3 months after harvest. One approach to eliminate this repackaging cost is to store kiwifruit in bins for up to three months before packaging in the final container. Short-term bin storage of up to 3 months will reduce packaging pressure, cooling time, ethylene contamination and repackaging costs. For these reasons, we investigated the relationship between fruit size and storage conditions on the rate of softening.

Materials and Methods

The rate of fruit softening under ethylene-free controlled atmosphere and air storage conditions was investigated for different sizes of kiwifruit. During the 1996 season, large (~101 g), medium (~93 g), and small (~81 g) 'Hayward' kiwifruit were collected directly from a commercial packing line after sorting and packaging. The kiwifruit were grown in the Visalia, California area and picked at late maturity (51.2 $\pm$ 1.8 N flesh firmness and 11.0 $\pm$ 0.3 % SSC). The fruit were transported to the F. Gordon Mitchell Laboratory at the Kearney Agricultural Center in Parlier, California and forced air cooled to 0°C within 6 hours. Then, the kiwifruit were stored in 9.5-liter jars under a continuous flow of either ethylene-free air or 5% CO_2 + 2% O_2 at 0°C. Flow rates and gas mixtures were established using a mixing board with micrometering valves. Supply and exhaust gas composition was monitored using a Carle gas chromatograph model AGC-111 equipped with a thermal conductivity detector for O_2 and CO_2 or a Horiba model PIR-2000R Infrared CO_2 analyzer, and a Carle gas chromatograph model AGC-211 equipped with a flame ionization detector for C_2H_4.

Three replications of 10 fruit each for each size/treatment were withdrawn after 0, 2, 4, 6, 8, 10, 12, 14, and 16 weeks storage. The fruit were warmed to ambient temperature (20°C) for evaluation of firmness and soluble solids concentration (SSC). The skin from opposite cheeks of each fruit was removed and the firmness was measured using a U.C. Firmness tester with an 8 mm tip. Then, a longitudinal wedge (from stem end to calyx end) was removed from each fruit, pressed through cheesecloth, and the SSC of the juice measured with a temperature compensated refractometer (Atago model ATC-1).

Results and Discussion

The rate of fruit softening during the 16 week cold storage period was related to fruit size and storage atmosphere (Fig.1). SSC increase during storage, however, was independent of the fruit size and the storage atmosphere (Fig. 2). Under both storage conditions, large size fruit had a slower rate of softening than medium and small size kiwifruit. The rate of fruit softening was always slower under CA than air conditions. Air stored kiwifruit softened approximately 2.5 times faster than CA-stored fruit. After 16 weeks of CA storage, large, medium, and small kiwifruit had firmnesses of 53.4, 40.0, and 40.0N, respectively. Large, medium, and small air stored fruit all had firmnesses of approximately 13.3 N after this same period of time (Fig. 1).

Because kiwifruit are more susceptible to physical damage during packaging when they soften below 17.8 N (8 mm tip), we predicted the number of weeks to reach this firmness under each of the different size/storage conditions. Under air storage conditions large, medium, and small size kiwifruit reached 17.8 N fruit firmness by 13, 12, and 11 weeks, respectively. Large, medium, and small size kiwifruit under CA storage conditions were estimated to reached 17.8 N fruit firmness by 57, 35, and 25 weeks, respectively. Thus, the length of the bin cold storage period prior to packaging will be influenced by fruit size and storage conditions.

Conclusions

1. The rate of kiwifruit softening is related to kiwifruit size and storage conditions. Under both storage conditions, large size fruit had a slower rate of softening than medium and small size kiwifruit.

2. Based upon rates of kiwifruit softening during bin storage, large kiwifruit have a longer prepackaging storage potential than medium and small size kiwifruit.

3. In packaging kiwifruit ethylene-free air cold storage in bins is a promising technique for short delays (approx. 2.5 months). However, it is dependent on fruit softening.

4. Controlled atmosphere cold storage (5% CO_2 + 2% O_2) is a possibility for long term bin storage of kiwifruit prior to packaging. Cold storage potential in bins under ethylene-free CA conditions may be double that of storage in air.

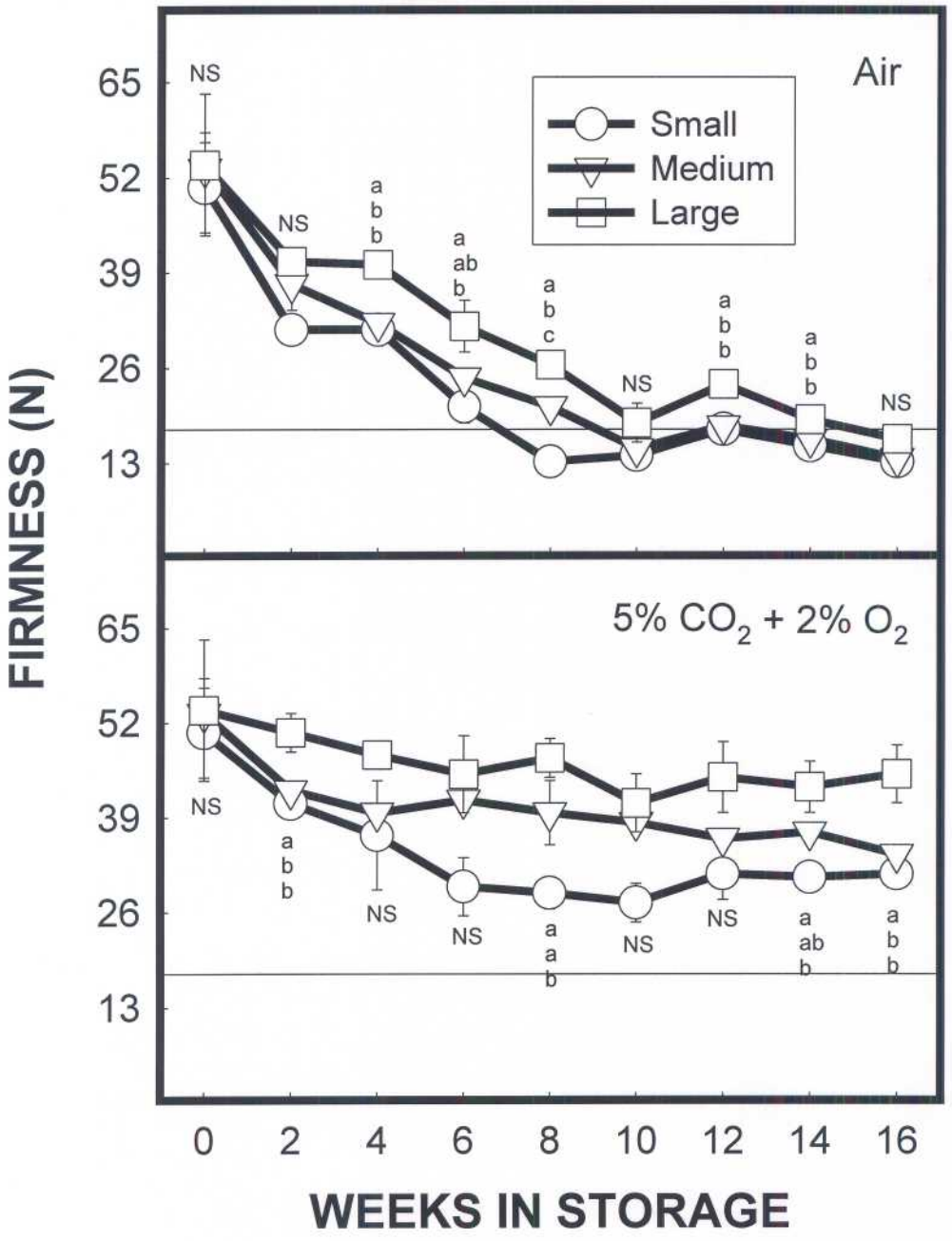

Fig. 1. Cheek firmness of small (size 45, ~81 g), medium (size 39, ~93 g), and large (size 36, ~101 g) kiwifruit stored in air or 5% CO_2 + 2% O_2. Different letters indicate a significant difference in firmness on that date by $LSD_{0.05}$.

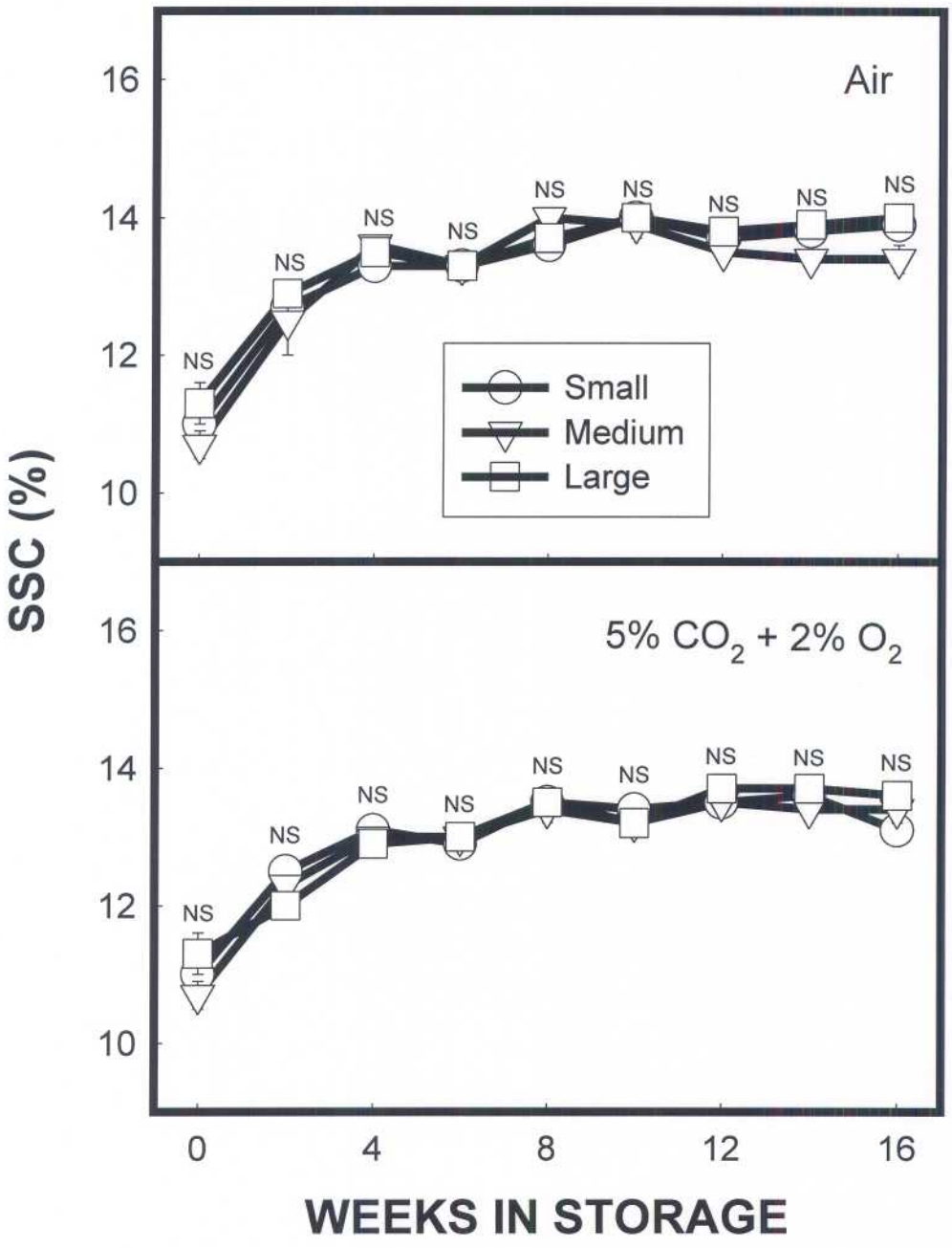

Fig. 2. SSC of small (size 45, ~81 g), medium (size 39, ~93 g), and large (size 36, ~101 g) kiwifruit stored in air or 5% CO_2 + 2% O_2. Different letters indicate a significant difference in SSC on that date by $LSD_{0.05}$.

Changes in Fruit Skin Blackening, Phenolic Acids and Ethanol Production of Non-astringent 'Fuyu' Persimmon Fruits During CA Storage

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Additional index words. **Acetaldehyde, polyphenol oxidase**

Abstract. **Non-astringent 'Fuyu' persimmon fruits (Diospyros kaki L.) were stored in a CA (4% O_2 + 10% CO_2, or 6% O_2 + 10% CO_2), MAP (packaged in 0.06mm polyethylene film) or air for 28 weeks at 0°C. Flesh firmness was consistently highest in persimmon stored in either of the CA treatments. The occurrence and severity of the fruit skin blackening dramatically increased after 12 weeks of storage and was most severe in the MAP and air treatments. Polyphenol oxidase activity in the tissue and skin significantly increased after 10 weeks of storage and was highest in the MAP and air treatments. Among all treatments the chlorogenic acid, p-coumaric acid and caffeic acid content of persimmon fruit declined significantly with storage time, while p-hydrobenzonic acid, gallic acid and catechin only slightly decreased during storage. Ethanol production increased considerably after 10 weeks of storage and the air stored persimmon had the highest levels among all treatments. Acetaldehyde concentration in fruit tissue decreased slightly over time in all treatments tested.**

'Fuyu' persimmon fruits are grown commercially in southern region of Korean peninsula. Persimmon are very popular as a fresh fruit, due to their high content of ascorbic acid, carotenoids and good taste. In republic of Korea, 15,000ha are currently cultivated and production was about 200,000 tons in 1996. Increasing fruit production, has caused the need to store fruit long-term in order to effectively market sweet persimmon.

Maintenance of fruit quality during storage depends on the rate of flesh softening, changes in fruit composition and occurrence and severity rate of physiological disorders (Ben-Arie and Or, 1986; Ben-Arie and Zutkhi, 1992; Chen et al., 1981; Ke et al., 1991; Kader, 1986; Min and Oh, 1975; Park et al., 1997; Zagory and Kader, 1988).

One of the most prevalent disorders during storage in sweet persimmon is skin blackening, superficial discoloration of the fruit skin, somewhat similar to the superficial scald of apple. This symptom is caused mainly by the polyphenol oxidase (PPO) activity (Ben-Arie and Or, 1986; Coseteng and Lee, 1987). Other researchers (Kahn, 1976; Maestro, 1993; Paulson, 1980) have demonstrated that browning is correlated to phenol substrate concentration. Harel et al. (1966) and Louis et al. (1984) have shown that both PPO activity and substrate concentration determine the degree of flesh browning.

Zagory and Kader (1988) reported that reduced O_2 or elevated CO_2 treatment during storage

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reduced tissue browning by the reduction of PPO activity in lettuce. In sweet persimmon, the rate of skin blackening reduced when the fruit stored elevated CO_2 or 2-3% O_2 condition (Kitagawa and Glucia, 1984). While, fruit quality significantly declined at the end of storage due to skin blackening in MAP storage (Min and Oh, 1975; Park et al., 1997).

In the present work I have measured the firmness, PPO activity, phenolic acids, ethanol content and the degree of skin blackening of sweet persimmon during air and CA storage in order to determine the factors which are responsible for the skin blackening.

Materials and Methods

'Fuyu' persimmon fruits were harvested at the commercial maturity stage from trees grown in Mokpo County, Chonnam, and transported to our laboratory at the University of Mokpo. Fruits with defects were discarded and 40 good fruits were put into 8 liter plastic jar as one replicate, with three replicate used per treatment.

After cooling in overnight in cold storage, fruits were placed at O°C in a continuous (200 ml $\cdot min^{-1}$) flow of humidified air, 4% O_2 + 10% CO_2 and 6% O_2 + 10% CO_2 or, fruits were sealed in .06 mm polyethylene film and stored at O°C (MAP).

At the start of experiment, and after 4, 8, 12, 16, 20 and 24 weeks of storage, fruit firmness as well as occurrence and severity rate of blackening was evaluated by the method of Park, et al. (1997), immediately upon removal from storage.

Polyphenol oxidase activity. Acetone powder was prepared from flesh fruit and skin by the method of Kahn (1975), with yields ranging 10-15% of fresh weight. PPO was extracted from the acetone powder by suspending it in 0.1M sodium phosphate buffer, pH 6.8, and stirring continuously at 2°C. Following extraction, the suspension was centrifuged at 15,000 X g for 20 min and the supernatant was used as the enzyme source. The standard reaction mixture consisted of 5ml of 0.1M sodium phosphate buffer, at pH 6.5 and 5ml of 0.02M 4-methyl catechol. Absorbance at 420nm was measured using a spectrophotometer (Hewlett Packard, USA). Reaction velocity was computed from the initial linear slopes of the curves obtained by plotting the optical density against time.

Free phenolic acids contents. Phenolic acid were extracted by homogenizing fruit tissue and skin in 80% ethanol solution. The homogenate was centrifuged at 10,000 X g for 10 min at 2°C in centrifuge (Beckman, Germany) and filtered through Whatman No. 1. Each extract was mixed with chloroform and shaking until two phases separated. The upper layer was discarded and the lower layer removed and evaporated in rotary evaporator. The residue was extracted with petroleum ether and stirring until two phases separated. The upper layer was discarded and the lower layer extracted 4 times with ethyl acetate. After drying with Na_2So_4, the solution was concentrated by rotary evaporator to 2-4ml. The residue was dried with N_2 gas and then stored at 4°C until analysis. After dissolving with methyl alcohol, the sample was filtered using ultra-sepak C_{18} extraction cartrige (Waters, USA) and then filtered through a nylon microfilter (0.45μm pore size).Reversed phase HPLC (Waters, USA) was performed with model 6000 pump, UV detector, analytical u-18 column and guard column. The mobile phase consisted of gradient system containing 2% acetic acid in methanol and a flow rate is 1.0ml $\cdot min^{-1}$. A methanol-water gradient as established was running from 10% to 30% methanol in water for 30 min. The detector was adjusted to measure a absorbance at 254, 276 and 280 nm.

Ethanol and acetaldehyde content: the amount of ethanol and acetaldehyde that accumulated in the fruit was estimated by collecting 10 ml of juice from 3 fruits per replicate in a 50ml flask. The

flask was sealed immediately with a rubber septum and placed in a shaking bath at 30°C for 60 min. A 1ml sample from the headspace was then withdrawn and injected into a gas chromatography (HP 5890A, Hewlett Packard) equipped with a 5% carbowax on a 60/80 Carbopak and flame ionization detector. The carrier gas was N_2 and the temperature of injection, oven and detector was 110 °C, 100°C and 180°C, respectively.

Results and Discussion

Flesh firmness of 'Fuyu' persimmon fruit decreased significantly after 4 weeks of storage and slightly decreased with storage time, regardless of treatments (Fig. 1). Fruit firmness was such higher in CA treated fruit than in air or MAP treatment. There was no difference in firmness between air and MAP treatments.

The occurrence and severity of skin blackening differed considerably among treatments (Fig. 2). Skin blackening of fruit beginning after 8 weeks of storage and increased significantly with storage time and reached 18.3% and 17.5% after 24 weeks in air and MAP, respectively. However, skin blackening in fruit begin after 16 weeks of storage and reached 5.1% and 5.0% in 4% O_2+10% CO_2 and 6% O_2+10% CO_2. Therefore, CA treated fruit consistently had the lower incidence of flesh blackening than air or MAP treated fruit.

Kader (1986) observed that reduced O_2 or elevated CO_2 maintain flesh firmness by reducing respiration and ethylene production. Park et al. (1977) reported that CO_2 enriched treatments within PE film bags reduced fruit decay and skin blackening in sweet persimmon. Kitagawa and Glucia (1984) have also stated that the rate of skin blackening reduced in CA storage and good quality retained in 2- 3% O_2 and 5-8% CO_2.

The occurrence and severity rate of skin blackening was significantly decreased by controlled atmospheres of 4% or 6% O_2 compared to air or MAP. The 2% O_2+10% CO_2 treatment induced fruit softening and severe skin blackening at the end of storage (data not shown). Reduced skin blackening in CA treated persimmon may be due to reducing O_2 from 21% to 4 - 6% and hence to reducing the affinity of PPO for its substrates.

Figure 3 showed the changes of PPO activity in different storage conditions during storage. PPO activity in fruit skin remained constant during the first 8 weeks, then sharply increased between 8 and 20 weeks of storage and decreased at the end of storage. In fruit tissue, PPO activity increased after 12 weeks of storage and peaked at 20 weeks and then decreased. The rate of PPO activity was much higher in air and MAP than in CA treated fruit. The pattern of PPO activity similar between fruit tissue and skin, but its activity was much lower in fruit tissue than in the skin.

Burton (1974), Coseteng and Lee (1987) and Kahn (1976) reported that degree of flesh browning closely related to PPO activity in fruits. Min and Oh (1975) and Park et al (1997) also reported that the occurrence of skin blackening beginning with increasing PPO activity.
Results of the present study indicated the degree of blackening of fruit tissue and skin closely correlated with PPO activity.

Phenolic acids extracted from fruit tissue and skin during storage are shown in figure 4. The main phenolic compounds detected by HPLC were catechin, gallic acid, $_p$-hydrobenzonic acid, caffeic cid, $_p$-coumaric acid and chlorogenic acid. All phenolic acids gradually decreased with storage time in fruit tissue and skin. Caffeic acid, $_p$-coumaric acid and chlorogenic acid decreased considerably in fruit skin over time. There were no differences in penolic acids content in fruit tissue and skin among treatments.

Coseting and Lee (1987) have suggested that the browning in apples appears to be a complex

process involving substrate levels and enzyme activity. Khan (1977) showed that the degree of rowning was positively correlated with the level and the kind of substrate in avocado. Other investigators showed that high rate of browning was correlated with a high phenol content or henol type in fruits (Burton, 1974; Kahn, 1976; Ke, et al., 1990; Mondy et al., 1966; Thomas and Nair, 1971).

In this experiment, the individual phenolic acids in 'Fuyu' persimmon were analyzed in an attempt to determine whether compositional variations in phenolics acid were related to the degree of browning at different storage condition. Results of the present study indicated that the kinds and contents of phenolic acids were almost the same in all treatments. I found no correlation between phenolic types or concentrations and degree of browning.

Ethanol content decreased rapidly at the beginning of storage and then sharply increased after 12 weeks of storage (Fig. 5). The concentration of ethanol was slightly higher in air and MAP than in CA treated fruit. Acetaldehyde concentration in fruit decreased at initially and then did not change after 12 weeks of storage. Ke et al. (1991) reported that changes in concentration of volatiles during storage might influence the flavor. Low concentration of ethanol may not affect fruit flavor, however high concentration of ethanol may cause off-flavor (Ben-Arie and Zutkhi, 1992; Ke et al., 1990). Results of this study demonstrated that 300-450ul @1^{-1} of ethanol did not affect flavor, but further study is needed to know the relationship between ethanol content and flavor.

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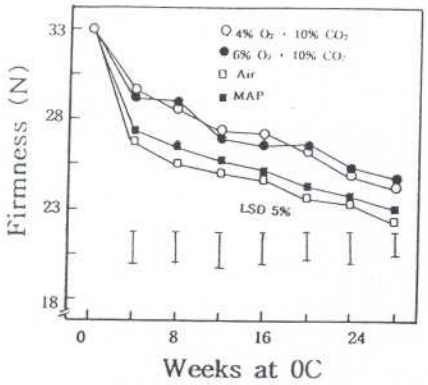

Fig. 1. Changes in flesh firmness of non-astringent 'Fuyu' persimmon fruits in controlled atmosphere storage and modified atmosphere packaging.

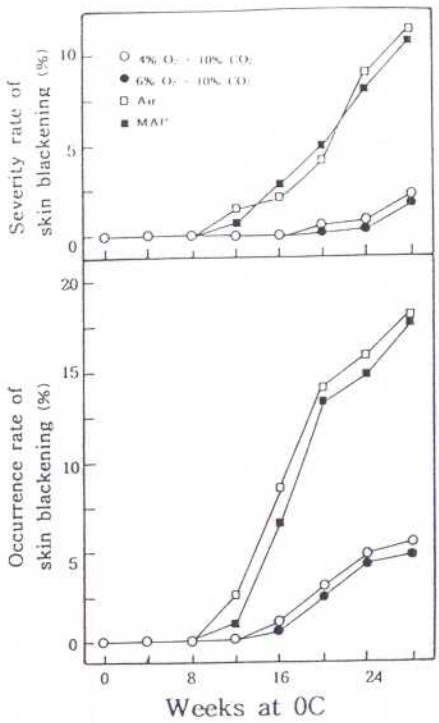

Fig. 2. Changes in occurrence and severity rate of skin blackening in non-astringent 'Fuyu' persimmon fruits by controlled atmosphere storage and modified atmosphere packaging.

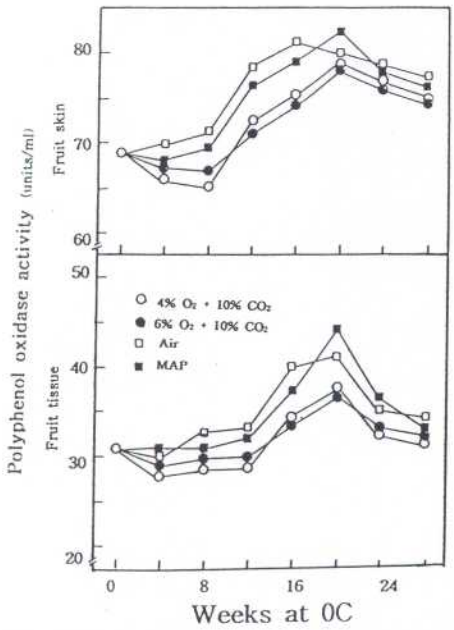

Fig. 3. Changes in polyphenol oxidase activity of non-astringent 'Fuyu' persimmon fruits in controlled atmosphere storage and modified atmosphere packaging.

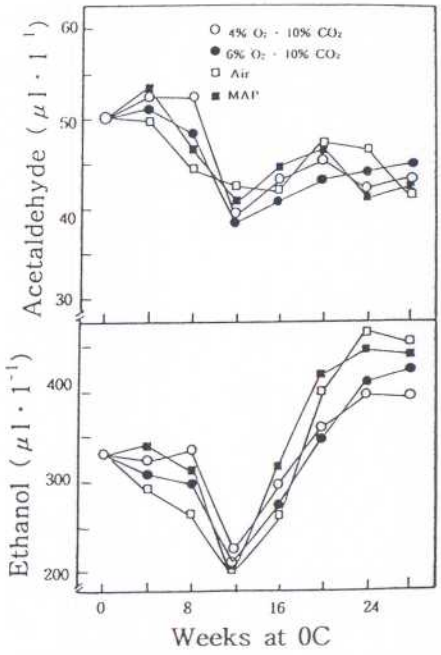

Fig. 5. Changes in ethanol and acetaldehyde concentration of non-astringent 'Fuyu' persimmon fruits in controlled atmosphere storage and modified atmosphere packaging.

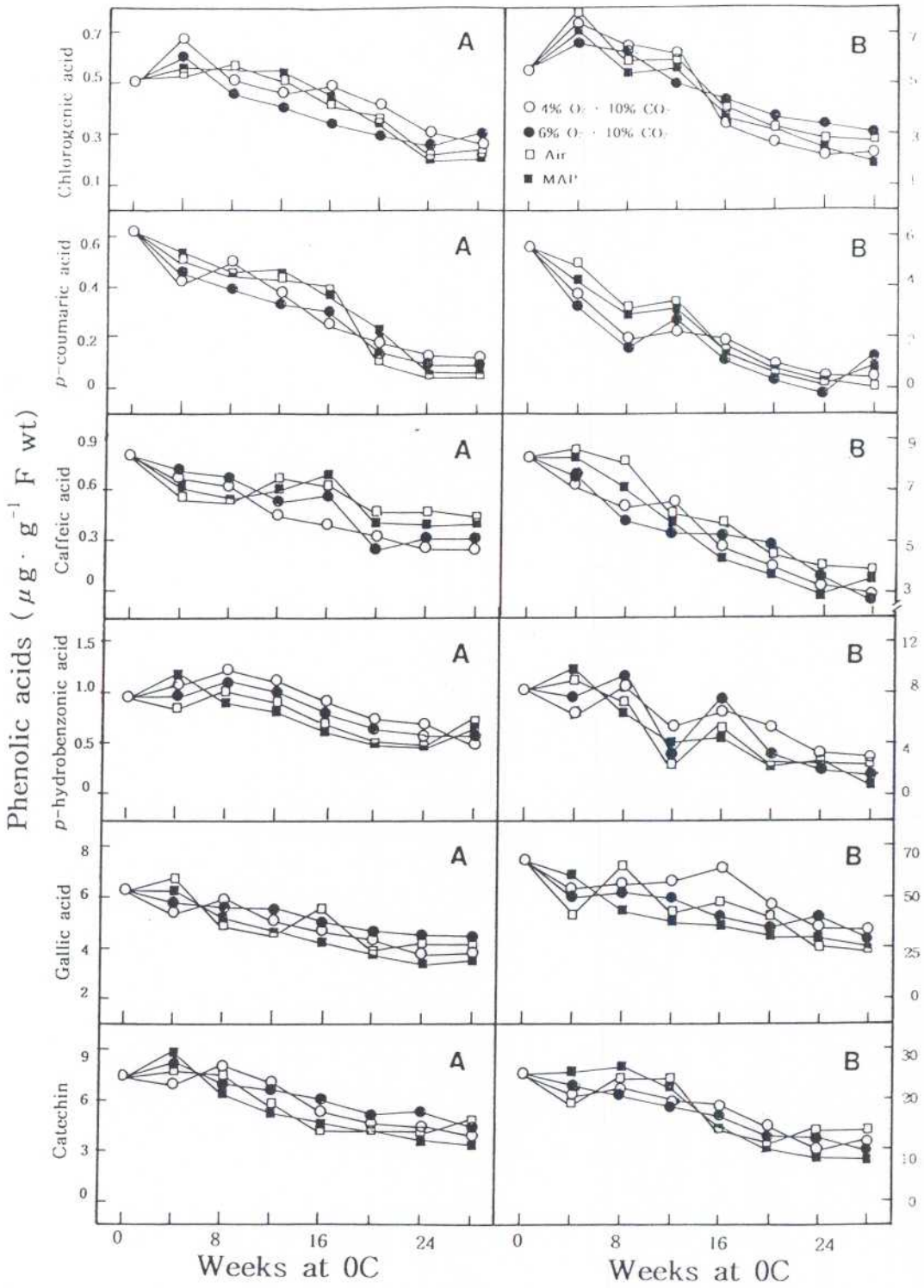

Fig. 4. Changes in phenolic acids content in fruit tissue (A) and fruit skin (B) of non-astringent 'Fuyu' persimmon fruits by controlled atmosphere storage and modified atmosphere packaging.

Effects of Polyethylene Bag Packaging and Low-temperature Storage on the Physical and Chemical Characteristics of Loquat Fruits

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Additional index words. Physiological disorders, phenolic compounds, organic acids, sugars, carotenoids

Abstract. **Loquat fruits were packaged with different thickness of PE (20, 30 and 50 micrometer; PE-20, PE-30 and PE-50) and perforated PE (PE-pf) bags (as control) stored at 5°C. Loquats seal-packaged with PE bags had minimal water losses (0.9-1.5%) while the fruits packaged with perforated PE shriveled (8.9% water loss) after storage for 60 days. Malic acid, a predominant acid, was retained at a higher level in fruits packaged in tight PE bags than in fruits packaged in perforated PE bags. Citric, fumaric and succinic acids were minor in loquats and the content of succinic acid increased 1.9 and 2.9 folds in fruits stored for 60 days in PE-30 and PE-50 bags, respectively. Packaging did not significantly increase the decay of fruits stored at 5°C. Total sugars did not vary remarkably regardless of the treatments, though sucrose decreased and sorbitol increased steadily during storage. Developments of cryptoxanthin and beta-carotene occurred progressively during storage except for those in PE-50 bags. Fruits stored at 5°C with PE packaging for 2 months developed some physiological disorders, including internal browning, stuck peel and corky pulp. The incidence of these disorders increased with the thicker PE bags. The changes of phenolic compounds and relevant enzymes during the occurrence of postharvest disorders were also investigated. This study indicated that loquat fruits could be stored at 5°C for 2 months when packaged in 20 micrometer PE bag with higher level quality and a minimum risk of disorder development.**

Loquat (*Eriobotrya japonica* Lindl.) is widely cultivated in subtropical regions of Asia and other continents. The harvest season of loquat in China and Japan is rather short, lasting only from middle May to middle June in open fields cultivation. Being juicy, loquat fruits are susceptible to decay, mechanical damages, moisture and nutritional losses during their postharvest life. Various researches have been conducted to seek treatments and techniques that can maintain the quality of the fruits and extend their postharvest life (Shaw,1980). Lower temperatures can extend their storage period. However, these lower temperatures did not completely inhibit the decreases of organic acid and water loss during prolonged storage (Ding et al., 1997b). The effects could be also influenced by the variety and the stage of ripeness (Ogata, 1950; Mukerjee, 1958). Simple modified atmosphere (MA) storage packaged with polyethylene (PE) film bags could prevent the decrease of fresh fruit quality, though the gas concentration in PE bag during storage cannot be controlled accurately. The atmosphere can be regulated partially by the selection of films of different gas permeabilities. Therefore, this method provide a relatively low-cost alternative to the controlled atmosphere storage. Guelfat-Reich (1970) indicated that polyethylene wraps increased internal browning and postharvest rotting of loquat

fruit. Singh (1959) implied that polyethylene bags appeared to cause adverse chemical changes in loquat fruit. Since then, little research has been reported. The objective of the present study was to evaluate the use of polyethylene bags for storage of loquat fruit. The changes of chemical compositions and polyphenol oxidase activity in loquat packaged with PE bags during storage at low-temperature was also investigated.

Materials and Methods

Plant materials. The loquat (E. japonica Lindl. cv. Mogi) fruits were obtained from the farm of Osaka Prefecture University, Osaka, Japan. The fruits were hand-picked and were packaged with different thickness of polyethylene bags (20, 30 and 50 micrometer; PE-20, PE-30 and PE-50) or perforated polyethylene (PE-pf) bag (0.15% perforation). During the storage period, samples were collected at 15-day intervals and 30~40 loquats were analyzed each time.

Extraction and determination of carotenoids. The extraction and saponification of carotenoids were carried out according to the method of Kon and Shimba (1988). The extracts were run through an HPLC under the conditions introduced by Hamauzu et al. (1997). Chromatographic peaks were identified by comparing both the retention time and absorbance spectra obtained at each peak maximum with those found in the literature, and the concentration was determined from published 1% absorptivity coefficients (Davis, 1976).

Extraction and determination of phenolics. Phenolic compounds were extracted with methanol, separated with a C_{18} Sep-Pak (Waters, Milford, MA) according to the method of Jaworski and Lee (1987). Total phenolic content was determined with Folin-Ciocalteu phenol reagent (Julkunen-Tiitto,1985). Chlorogenic acid content was identified and quantified by HPLC as described previously (Ding et al., 1997c).

Determination of sugars and organic acids. Sugars were analyzed by an HPLC system consisted of a Shim-park SCR-101P column and acids were analyzed by an HPLC Organic Acid Analysis System as described previously (Ding et al., 1997b).

Determination of PPO activity and protein. Extraction and determination of enzyme activity were conducted as described previously (Ding et al., 1997a). Protein was assayed according to Bradford method with bovine serum albumin as a standard.

Results and Discussion

Incidences of loquat decay packaged in PE-20, PE-30 and PE-50 bags reached to 40%, 50% and 100%, respectively, at the end of 21-day storage at 20°C. But the incidences of rotten fruits packaged with PE-20, PE-30 and PE-50 bags were 10%, 15% and 20%, respectively, even after 60 days of storage at 5°C. The decay of loquat fruits was caused predominantly by an internal physiological disorder. The disorder started with internal flesh browning and then whole fruits became rotten during storage. We suspect that the high CO_2 concentrations (data not shown) inside the fruits stored in thicker PE bags or high temperature may be the cause of the higher incidence of decay that occurred in fruits packaged in thicker PE bag or stored at higher temperatures. This result indicated that PE bag packaging is not fit for loquat stored at ambient temperature. In view of this, all the storage experiments at 20°C were discontinued.

The weight loss of loquats packaged in perforated and tight PE bags, in general, progressively increased with storage time and was linear for all treatments. The total weight loss of fruits packaged in PE-pf was 8.9%, while the fruits packaged in tight PE bags lost only 0.9 to

1.5% in weight after 60 days storage. The loss of water from the PE-pf packaged fruit was associated with shrinkage of fruit skin. The weight losses showed no significant difference among tight PE bag packagings. The seal-packaging with PE bag was fairly effective in preventing weight loss.

Table 1. Changes of organic acids (mg/100g FW) in loquat fruits (cv.Mogi) packaged with PE bags during storage at 5°C.

Storage period	Bag type[a]	Malic acid	Citric acid	Succinic acid	Fumaric acid	Total
Initial		390.0	35.0	5.2	3.2	433.4
15 days	PE-pf	291.0	32.0	5.4	2.7	331.1
	PE-20	346.0	33.0	5.4	2.8	387.2
	PE-30	363.0	32.0	5.6	2.9	403.5
	PE-50	371.0	34.0	7.9	3.6	416.5
30 days	PE-pf	259.0	29.0	5.3	2.6	295.9
	PE-20	315.0	31.0	5.4	2.7	354.1
	PE-30	323.0	32.0	6.2	2.6	363.8
	PE-50	352.0	32.0	10.8	3.2	398.0
45 days	PE-pf	193.0	27.0	5.1	2.3	227.4
	PE-20	284.0	30.0	5.8	2.5	322.3
	PE-30	292.0	28.0	8.1	2.6	338.7
	PE-50	314.0	29.0	13.2	2.9	359.1
60 days	PE-pf	158.0	24.0	5.4	2.5	189.9
	PE-20	234.0	26.0	6.2	2.4	268.6
	PE-30	253.0	24.0	10.3	2.3	289.6
	PE-50	284.0	27.0	15.4	2.6	329.0

[a]PE-pf: perforated polyethylene bag; PE-20, PE-30 and PE-50: 20, 30 and 50 micrometer thickness of polyethylene film of bags.

The changes in organic acid contents during storage are shown in Table 1. Malic acid was the principal nonvolatile organic acid and represented about 90% at harvest. During storage at 5°C, the malic acid concentration of loquat packaged in PE-pf bag rapidly declined; while succinic acid and fumaric acids remained relatively constant. Likewise, the concentration of both malic and citric acids in fruits packaged in tight PE bags declined linearly during storage, but the rate of decrease was slowed down. Succinic acid in fruits packaged in PE-30 and PE-50 bags, on the contrary, was increased by 1.9 and 2.9 times, respectively, at the end of storage. Ke et al. (1993) indicated that high CO_2 concentration reduced succinate dehydro-genase activity and resulted in succinate accumulation. The result indicated that fruits packaged in tight PE bags retained higher amounts of malic acid than those packaged in PE-pf bags. High acidity in fruit has been suggested to contribute in part to the flavor retention of ripened fruit (Ulrich, 1970).

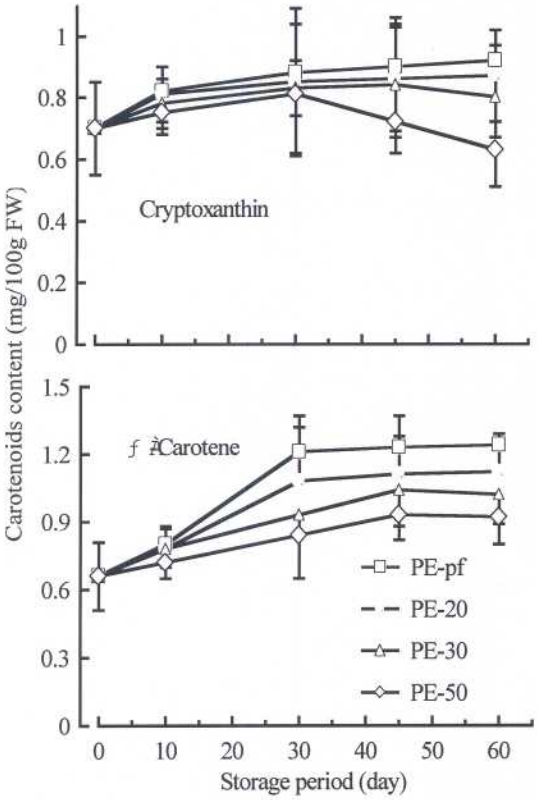

Fig. 1. Changes of carotenoids in loquats (cv.Mogi) packaged with PE bags stored at 5°C. PE-pf: perforated polyethylene bag; PE-20, PE-30 and PE-50: 20, 30 and 50m thickness of polyethylene bags, respectively. Data are the means and SD of 3 replications. Bars not shown when smaller than point markers.

Table 2. Changes of sugars (g/100g FW) in loquat fruits (cv.Mogi) packaged in PE bags during storage at 5°C.

Storage period	PE-bags [a]	Sucrose	Glucose	Fructose	Sorbitol	Galactose	Other [b]	Total
Initial		2.41	2.53	3.89	0.82	0.10	0.16	9.91
15 days	PE-pf	2.02	2.81	4.02	0.72	0.10	0.15	9.92
	PE-20	2.25	2.67	3.89	0.76	0.08	0.17	9.82
	PE-30	2.28	2.64	3.83	0.84	0.09	0.21	9.89
	PE-50	2.34	2.59	3.78	1.02	0.07	0.25	10.05
30 days	PE-pf	1.05	2.92	4.35	0.91	0.08	0.17	9.48
	PE-20	1.75	2.73	3.92	0.94	0.04	0.21	9.58
	PE-30	1.82	2.64	3.83	1.08	0.05	0.26	9.68
	PE-50	2.12	2.72	3.81	1.45	0.06	0.32	10.48
45 days	PE-pf	0.62	2.53	3.98	1.12	0.05	0.18	8.68
	PE-20	1.05	2.63	3.80	1.25	0.04	0.22	8.99
	PE-30	1.36	2.60	3.81	1.36	0.03	0.25	9.40
	PE-50	1.55	2.72	3.82	1.63	trace	0.29	10.02
60 days	PE-pf	0.43	2.36	3.87	1.28	trace	0.22	8.35
	PE-20	0.75	2.56	3.83	1.27	trace	0.24	8.65
	PE-30	0.98	2.54	3.84	1.42	trace	0.24	9.02
	PE-50	1.04	2.42	3.61	1.65	trace	0.25	8.96

[a]Legends are the same as those in Table 1. [b]Other: showed one peak on an HPLC chromatograms, but unidentified.

The changes in sugars of loquats are shown in Table 2. Total sugars (TS) did not change significantly during first 15-day storage and then decreased steadily. After 60 days storage, the decrease of TS was about 9 to 16%. The contents of fructose and glucose changed little during the storage except for that packaging in PE-pf bags. On the other hand, the sucrose content declined rapidly to a low constant level during the storage. Sorbitol content is relatively low and showed a steadily increasing trend during storage and was enhanced with increasing thickness of PE film. The steady increase of sorbitol observed during storage can be attributed to the anaerobic conversion of fructose (Ackermann et al. 1992). Galactose does not normally occur in its free state (Gross, 1983); however, soluble, monomeric galactose has been detected in the pulp of loquats and increased with ripening (Ding et al., 1997b). During storage at 5°C, the concentration of galactose decreased and reached a trace level regardless of the bag conditions. Those results showed that total sugars content of loquats were not significantly effected by PE bag packaging.

Table 3. Effects of PE bags packaging on incidences of internal browning (IB), stuck peel (SP) and corky pulp (CP) of loquats stored at 5°C.

Storage days	15			30			45			60		
Disorders	IB*	SP*	CP*	IB	SP	CP	IB	SP	CP	IB	SP	CP
PE-pf	0	0	0	0	0	0	0	0	0	1	1	0
PE-20	0	0	0	0	0	0	0	1	0	1	1	0
PE-30	0	0	0	1	1	0	2	1	1	3	3	2
PE-50	1	1	0	2	1	1	3	2	2	4	3	3

*Rated on 0 to 4 scale: where 0 = none; 1 = slight; 2 = moderate; 3 = moderately severe; 4 = severe.

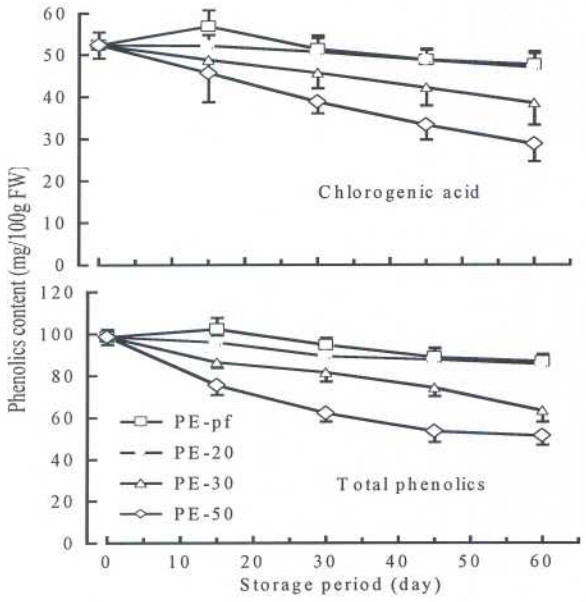

Fig. 2. Changes in polyphenolic content of loquats (cv.Mogi) packaged with PE bags during storage at 5°C. Symbols and vertical lines are the same as in Fig.1.

The effects of packaging with PE bags on carotenoids are shown in Fig. 1. The content of beta-carotene of all categories increased significantly during the first 30 days and then showed a slight increase. The concentration of cryptoxanthin increased gradually during storage with the exception of those packaged in PE-50 bag, this packaging resulted in a significant decrease of cryptoxanthin when storage is over 30 days. At the end of storage, perforated or thinner PE bag packaged fruits had higher beta-carotene and cryptoxanthin contents in comparison with thicker PE film packaged fruits. This result indicated that loquats after harvest would develop more yellow and orange color and increase carotenoids even in low temperature storage (5°C). But the biosynthesis of carotenoids was inhibited by tight PE bag packaging.

With seal-polyethylene packaging, the main cause of the loss of loquat fruit quality was internal browning. Its incidence was very high in fruits packaged in PE-30 and PE-50 bags (Table 3). Other disorders included corky pulp and stuck peel. As storage time was prolonged, these disorders occurred at higher rates, particularly in fruits packaged in PE-30 and PE-50 bags. Those results confirmed that polyethylene packaging will increase internal browning and other disorders (Shaw, 1980).

Loquat fruits packaged in 20 micrometer polyethylene film bag had better quality and a minimal risk of disorder development.

During storage at 5°C, no significant variation occurred in the total phenolic and chlorogenic acid contents in loquats packaged in PE-pf and PE-20 bags, but there appeared to have a significant decreasing trend in fruits packaged in PE-30 and PE-50 bags (date not shown). The result indicated that some browning may occur in fruits packaged in PE-30 and PE-50 bags during storage. During storage, PPO activity in loquats packaged in PE-30 and PE-50 was lower than the loquats packaged in PE-pf and PE-20. High CO_2 atmosphere inhibits PPO activity (Siriphanich and Kader, 1985), which was confirmed by our results. We found the highest CO_2 accumulation and the lowest PPO activity in loquats packaged in PE-50 bags. No correlation between fruit browning (data not shown) and PPO activity was found. Those results implied that brown discoloration of internal or intact fruit enhanced by thicker PE film resulted from high CO_2 in seal-bags. It disrupted normal metabolic balance of fruit cells, and consequently led to cell discompartmentation that allows the phenolic substrates to be accessible to PPOs which catalyze the phenolic oxidation.

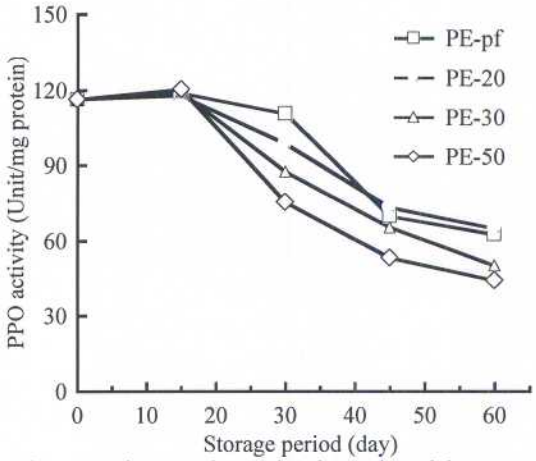

Fig. 3. Change in polyphenol oxidase activity of loquat fruits (cv.Mogi) packaged with PE bags during storage at 5°C. Symbols are the same as those in Fig.1.

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Postharvest Storage of "*Piñones*" from *Araucaria araucana* ((Mol.) C. Koch) Under Controlled Atmosphere Conditions

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Additional index words. Pine nuts, sugars, starch

Abstract. **"Piñones" are pine nuts from Araucaria araucana ((Mol..) C.Koch) tree, which grows in the Andes area of the southern region of Chile. At harvest, piñones have a high amount of moisture (48%) and starch (55% on dry basis). The high moisture content makes them very susceptible to dehydration and fungal attack durig storage under normal refrigerated conditions. Research was conducted in order to evaluate the effect of modifying the atmosphere composition, upon some chemical characteristics of *piñones*. *Piñones* collected in April were stored during 6 months under five different conditions: conventional refrigerated storage (control), controlled atmosphere control (CA), polyethylene bags lined with volcanic dust (Modified Atmosphere-MA), 10-5 (CO_2/O_2%) CA and 20-5 (CO_2/O_2%) CA. Every two months analysis were performed for: moisture, starch, total sugars, reducing sugars and tannins content. Moisture of control piñones showed a decrease, up ot 42%, at the end of the storage period; nuts stored under CA and MA conditions kept almost the same moisture content during the whole storage period. Starch showed a similar evolution in the MA and 20-5 CA conditions, maintaining the same content as the initial evaluation. Control and CA control treatments showed a decrease in starch (from 57 to 51 and 54% respectively) and an increasing in total sugars (from 3.2 to 6.0 and 8.1 respectively) at the end of storage; they also showed fungi development. MA and 20-5 CA storage were the best treatments in keeping a good nut quality up to 7 months.**

Araucaria araucana ((Mol.) C. Koch) is a tree which grows in the Andes areas of the southern region of Chile between the parallels 37 and 39 (Schmidt,1980). This species has been declared under protection since 1976 (Donoso et al.,1986). The fruit of the araucaria tree is a cone of about 20 cm in diameter with 150 to 120 piñones inside. The *piñon* has an external brown husk and a reddish membrane involving a white endosperm. Each *piñón* has an average weight of 3.8 g and it is 4.0 cm long and 1.5 cm width (Fichet et al.,1995). *Piñones* have been for many years part of the staple food for the mapuche people; they also are appreciated as snack food. Recently, some research has been conducted to study their possible use as raw material for sweet snack production and starch source The chemical proximate composition of *piñones* is characterized by a low content of protein (4.5 g/100g), and lipids (1.1 g/100g) and a high amount of starch (40.0g/100g) (Estévez, 1991).

At "harvest" time (collection) *piñones* have a high moisture content (about 50%), which makes them very susceptible to dehydration and fungi development during storage under normal refrigerated conditions. Some foregoing research done in *piñones* have shown that dehydration could be avoided by using modified atmosphere conditions during storage (polyethylene bags with or without lining of volcanic dust), but not the starch degradation. Similar results has been obtained in chestnut fruit stored in bags semipermeable to O_2 and CO_2.

This reseach was conducted in order to evaluate the effect of modifiyng the atmophere composition during storage, upon some chemical characteristics of *piñones*.

Material and Methods

Piñones were collected on late March and stored during 6 months under five different conditions:

- Conventional refrigerated storage (net bags) at 0°C and 65-85 % R.H. (CRS)
- Controlled atmosphere control at 0°C and 90 % R.H. (CAC)
- Modified atmosphere with polyethylene bags of 0.038 mm thickness lined with volcanic dust (Oya stone powder) at 0°C and 65-85 %R.H. (MA)
- Controlled atmosphere with 10% CO_2 and 5% O_2 at 0°C and 90 % R.H. (10-5 CA)
- Controlled atmosphere with 20% CO_2 and 5% O_2 at 0°C and 90 % R:H. (20-5 CA)

Every two months analysis were performed for moisture, starch, total sugars, reducing sugars (AOAC,1984) and condensed tannins content (Price et al.,1978). External fungi development was also evaluated.

Results

Starch degradation was higher during conventional storage of *piñones* as expected in material of high starch content (Chuch and Parsons,1995).The best conditions in preserving the starch content were both controlled atmospheres. Losses of starch in MA storage were small, probably due to the effect of the volcanic dust used as ethylene absorber (Figure 1)

As shown in Figure 2, *piñones* kept in conventional conditions, had the largest loss of moisture during storage (40%) as a response to a lower relative humidity in the enviroment. The other treatments had not differences in preventing dehydration of pine nuts. Similar results were obtained in storage of chestnut under M.A. conditions (Estévez et al.,1997).

Piñones stored in all conditions showed an increase of total sugars (Figure 3); the highest amount of total sugars was obtained in conventional storage(CRS).At the end of the storage period, M.A. and 20-5 C.A. were very similar and quite low (5.0 and5.2 g/100g).This increase is due probably to an enzymatic hydrolysis of starch into more simple sugars. Ogushi and Harada (1993) got similar results in stored ginkgo seed.

Reducing sugars also increased in all treatment, especially in those stored in enviroment with high O_2 concentration (CRS. and CAC) (Figure 4).Parkin and Schwobe (1991) found a higher transformation into reducing sugars in potatoes kept in O_2 rich atmospheres.

A small migration of tannins from the testa into the endosperm was found in all condition studied, except for the 20-5 CA treatment. Tannins could be related with loss of organoleptic characteristisc of cooked *piñones*.

Some fungi development was found at the end of the storage time in CA conditions; however, the higher amounts of CO_2 seem to reduce the intensity of fungal growth.

Conclusions

* *Piñones* storage under standard refrigeration causes a significant moisture loss and a high large increase in total sugars.

* Keeping *piñones* in polyethylene bags lined with volcanic dust (ethylene absorber) decreases the conversion of starch into total and reducing sugars and the accumulation of tannins in the kernel.

* Using controlled atmosphere (10-5 or 20-5 $\%CO_2/O_2$) allows the maintenance of "*piñones*" quality up to for six months.

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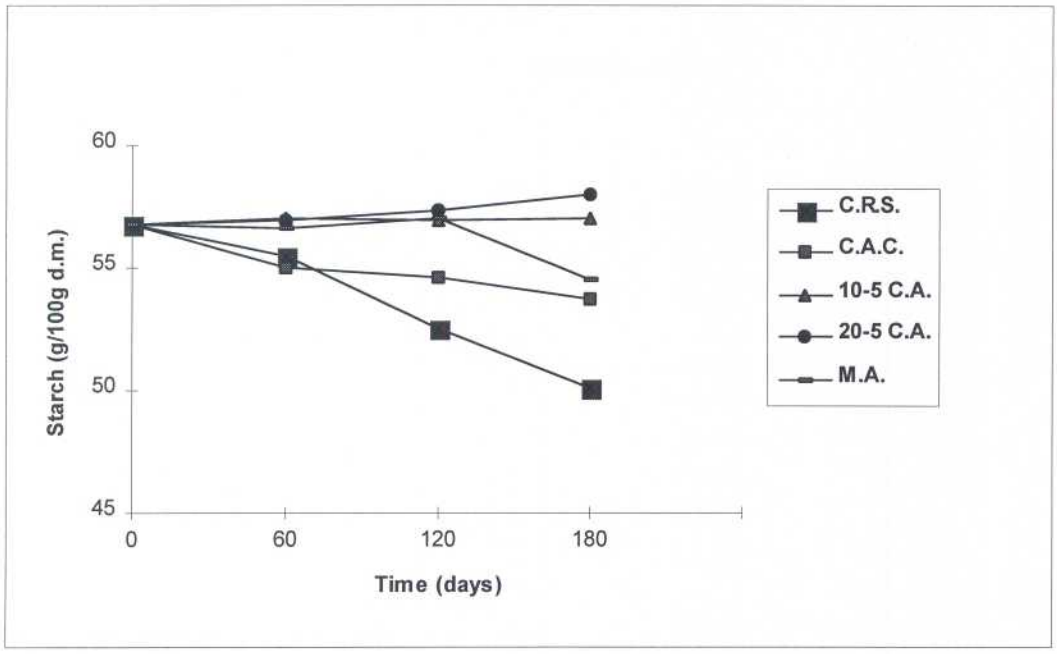

Figure 1. Starch changes during storage of *piñones*

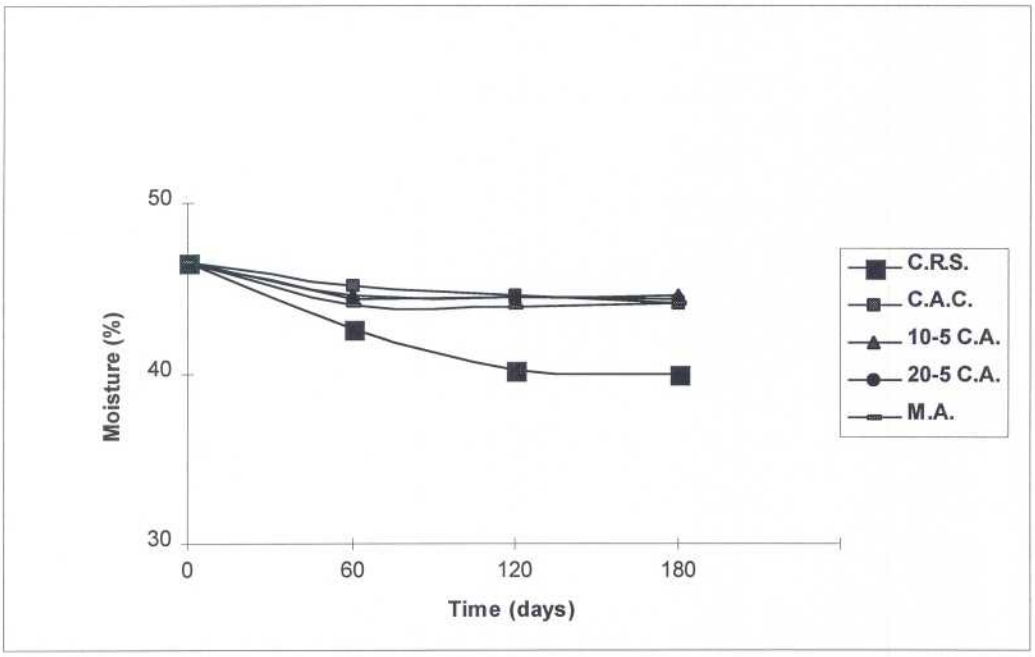

Figure 2. Moisture content of *piñones* during storage

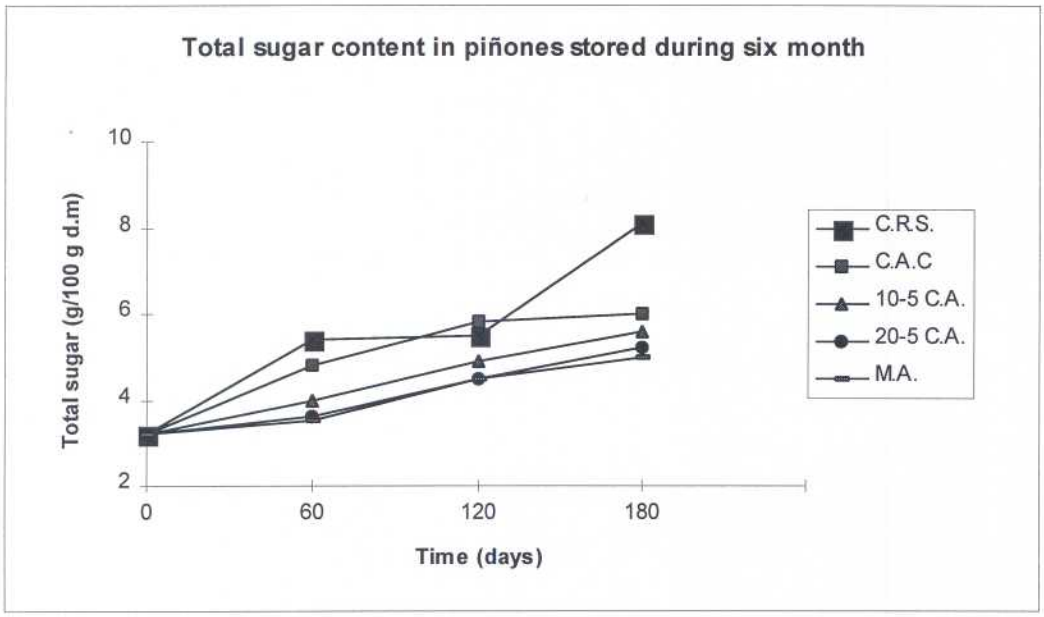

Figure 3. Total sugars content in *piñones* stored for six months

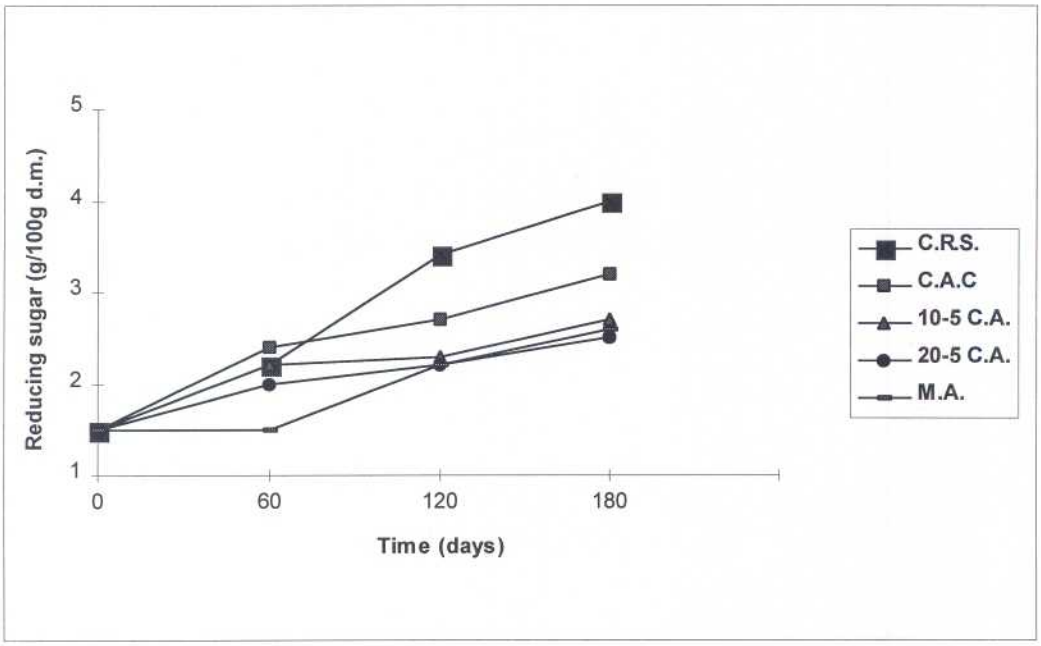

Figure 4. Reducing sugars in stored *piñones*

The Influence of Light on Atmosphere Modification by Banana Fruits

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Modified and controlled atmospheres have been shown to extend the shelf life of green bananas and are of commercial use for the long-distance maritime transportation of this fruit. To our knowledge, the potential use of MA for extension of the shelf life of postclimacteric bananas at the retailer level (i.e. after treatment with ethylene in ripening chambers) has not been investigated. On the other hand, we have observed that exposure to light considerably shortens the storage potential of green bananas.

In our experiments we stored either green (pre-climacteric) or turning (ethylene-treated) fruits (cv. Dwarf Cavendish) under three different atmosphere modification conditions and three different light regimes (fluorescent light, darkness, red-filtered light). We monitored evolution of O_2, CO_2 and ethylene as well as quality parameters of the fruits (color, TSS, pH, firmness). Experiments were repeated at transit (14°C) and retail (20°C) temperatures.

The results obtained are discussed in terms of their potential application to the commercial handling of the fruit.

A Transient Model to Predict O_2 and CO_2 Concentrations in Modified-atmosphere Packaging of Banana at Various Temperatures

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Additional index words. Dynamic model, enzyme kinetic model, film permeability

Abstract. **Respiration rate of bananas was determined as a function of O_2, CO_2, and temperature using a closed system. Temperature dependence of the respiration rate constants followed the Arrhenius-type relationship. Polyethylene film permeabilities were measured at various temperatures. The Arrhenius equation was used to describe the permeation of O_2 and CO_2 through polymer films. A mathematical model which could be used to describe the dynamic changes of O_2 and CO_2 gas compositions inside modified-atmosphere packages of fresh bananas at different temperatures was proposed and its solution was obtained numerically.**

The optimum conditions for the storage of bananas are suggested to be 2-5% O_2 and 2-5% CO_2 at 12-15°C. Below the minimum O_2 tolerance, the bananas respire anaerobically and fail to ripen. Above the maximum CO_2 tolerance level, the CO_2 injury occurs. The level of O_2 less than 1% and CO_2 greater than 7% are the injurious level for bananas (Kader, 1994). For a modified-atmosphere packaging (MAP) designed to achieve and maintain the O_2 and CO_2 concentrations in the desired range, it is necessary to select the appropriate film permeability, film thickness, film surface area, and fruit weight. There is a need to design the suitable packaging film for different temperatures. Ideally, a package should maintain the appropriate atmospheric composition over the range of temperatures between harvest and consumption, but fruits held in a MAP may go anaerobic if temperature increases (Kader et al.,1989). In this work, we set out to study the respiration rate of bananas as a function of O_2 and CO_2 concentrations and temperature, to study the influence of temperature on package O_2 and CO_2 concentrations, and to develop a mathematical model for predicting the O_2 and CO_2 concentrations inside MAP of fresh bananas at different temperatures.

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Mathematical Model

Respiration is an enzymatic reaction. The dependence of the respiration rate of fresh produce with O_2 can be expressed by a Michaelis-Menten enzyme kinetic equations including uncompetitive inhibition because of CO_2 (Renault et al., 1994). Therefore, the equations that represent the rate of respiration can be written as:

$$R_{O2} = \frac{R_{max,O2}[O_2]}{K_{mO2} + \left(1 + \frac{[CO_2]}{K_{iO2}}\right)[O_2]} \quad (1)$$

$$R_{CO2} = \frac{R_{max,CO2}[O_2]}{K_{mCO2} + \left(1 + \frac{[CO_2]}{K_{iCO2}}\right)[O_2]} \quad (2)$$

The gas exchange through polymeric films macroscopically follows the Fick's law. The amount of gas diffused through the package could be described as follows (Cameron et al., 1994).

$$N_{O2} = \frac{P_{O2}A([O_2]_o - [O_2])1.0133}{100X} \quad (3)$$

$$N_{CO2} = \frac{P_{CO2}A([CO_2]_o - [CO_2])1.0133}{100X} \quad (4)$$

The differential mass balances for O_2 and CO_2 in the MAP give

$$\frac{d[O_2]}{dt} = \frac{P_{O2}A([O_2]_o - [O_2])1.0133}{XV} - \left[\frac{R_{max,O2}[O_2]}{K_{mO2} + \left(1 + \frac{[CO_2]}{K_{iO2}}\right)[O_2]}\right]\frac{100W}{V} \quad (5)$$

$$\frac{d[CO_2]}{dt} = \frac{P_{CO2}A([CO_2]_o - [CO_2])1.0133}{XV} + \left[\frac{R_{max,CO2}[O_2]}{K_{mCO2} + \left(1 + \frac{[CO_2]}{K_{iCO2}}\right)[O_2]}\right]\frac{100W}{V} \quad (6)$$

The initial conditions of Eqs. (5) and (6) are as follows:

$$[O_2] = [O_2]_i \quad \text{at} \quad t = 0 \quad (7)$$

$$[CO_2] = [CO_2]_i \quad \text{at} \quad t = 0 \quad (8)$$

The parameters P_{O2}, P_{CO2}, $R_{max,O2}$, $R_{max,CO2}$, K_{mO2}, K_{mCO2}, K_{iO2}, and K_{iCO2} in Eqs. (5) and (6) were found to be varied with temperature and could be expressed with an Arrhenius-type relationship (Cameron et al., 1994; Maneerat, 1997).

Experimental Procedures

Pre-climacteric bananas (Musa (AAA group) 'Kluai Hom Thong') were obtained from Prathumthanee province, Thailand. All hands were cut into fingers, washed with water and dried by air. Fruits selected for experiments were approximately uniform in size and free from obvious defects. Closed system experiments were used to measure the respiration rate as a function of O_2 and CO_2 concentrations at different temperatures; 150 g of bananas was selected and placed inside a chamber at 10°C. The experimental chamber was an air-tight glass jar (825 ml) and the lid of the top of the chamber after being screwed on, was sealed with a sealing tape. The lid had 2 holes fitted with a rubber septum for withdrawing the sample gases inside. Five replication were used to measure O_2 consumption rate and CO_2 production rate simultaneously. After sealing, 1 ml head space gas samples from each jar were periodically analyzed for O_2 and CO_2 concentrations by gas chromatography until O_2 concentration decreased below 1%. 1 ml Hamilton air tight syringes were used for collecting the samples. The experiments were repeated at 15°C, 20°C, 25°C, and 30°C. The permeability of 24 μm polyethylene (PE) bag to O_2 and CO_2 was determined twice for each of three random samples at temperature ranging from 10°C to 30°C at 5°C intervals (Maneerat, 1997). MAP experiments were carried out at different temperatures. About 135 g of bananas was weighted and placed in a PE bag. The surface area of the PE bag used was 450 cm^2. The void volume of the package was determined to be around 100 ml. The package was sealed firmly by using an electric sealing machine and placed at 13°C. A short strip of plastic tape was glued on the surface of the package for gas sampling. Gas samples in the package were determined by withdrawing with a 1 ml Hamilton air tight syringe at time intervals and analyzed for O_2 and CO_2 concentrations by gas chromatography. The MAP experiments were repeated at 20°C and 30°C.

All the ordinary differential equations in this work were solved numerically by Gear's Method which is in the routine LSODE of the ordinary differential equations solver package titled ODEPACK (Wicks, 1988). The values of the unknown parameters P_{O2}, P_{CO2}, $R_{max,O2}$, $R_{max,CO2}$, K_{mO2}, K_{mCO2} K_{iO2} and K_{iCO2} were estimated by using the orthogonal distance regression method routine DODRC from the package ODRPACK (Boggs et al., 1992).

Results and Discussion

The respiration rates of bananas were measured in the closed system experiments at 10°C, 15°C, 20°C, 25°C, and 30°C. The results showed that the respiration rate increased when the temperature was increased. The calculated values of the respiratory quotient showed that when O_2 concentrations around bananas were below 1.76%, 1.91%, 2.33%, 2.57%, and 3.40% at 10°C, 15°C, 20°C, 25°C, and 30°C, respectively, the respiration rate of bananas was shifted to anaerobic processes (Maneerat, 1997). The rise in the lower O_2 limit with increasing temperature may be related to the changes of gas diffusion into the fruit (Beaudry and Gran, 1993) or the higher O_2 requirement for the aerobic respiration of the fruit's tissue at the higher temperature

(Boersig et al., 1988). The values of the respiration rate parameters $R_{max,O2}$, $R_{max,CO2}$, K_{mO2}, K_{mCO2}, K_{iO2}, and K_{iCO2} at different temperatures were estimated by matching the experimental data of O_2 and CO_2 concentrations (up to the points where the respiration rates changed from aerobic to anaerobic process) with the prediction values of the respiration model Eqs. (1) and (2). The values of the respiration rate parameters were found to increase with increasing temperature. The values of respiration rate parameters conformed well with the following Arrhenius equations ($r^2 \approx 0.9$)(Maneerat, 1997):

$$R_{max,O2} = 6.72 \times 10^{9} e^{(-5697.54/T)} \quad (9)$$

$$R_{max,CO2} = 5.77 \times 10^{8} e^{(-4961.34/T)} \quad (10)$$

$$K_{mO2} = 3.59 \times 10^{10} e^{(-6555.24/T)} \quad (11)$$

$$K_{mCO2} = 1.08 \times 10^{9} e^{(-5488.17/T)} \quad (12)$$

$$K_{iO2} = 3.73 \times 10^{10} e^{(-6598.78/T)} \quad (13)$$

$$K_{iCO2} = 1.09 \times 10^{13} e^{(-8274.66/T)} \quad (14)$$

The O_2 and CO_2 permeabilities of a PE film were found to be increased exponentially with increasing temperature. The film permeabilities changed with temperature in a manner consistent with the Arrhenius equations ($r^2 \approx 0.9$)(Maneerat, 1997):

$$P_{O2} = 157.34e^{(-1945.80/T)} \quad (15)$$

$$P_{CO2} = 138.90e^{(-1633.49/T)} \quad (16)$$

In Fig. 1, the experimental values of O_2 and CO_2 concentrations in the MAP of bananas at different temperatures are presented together with the results from the model. The results of the model agreed well with the experimental results with $r^2 \approx 0.9$. When the temperature increased from 13°C to 30°C, the steady state O_2 concentration within the package decreased, while the steady state CO_2 concentration within the package increased. The changes in O_2 and CO_2 concentrations at steady state when temperature increases could be the results of the respiration rate of fruit which increased more rapidly (had a greater sensitivity to temperature) than gas transmission through. The degree to which relative respiration rate or gas permeability increases in response to temperature is associated with its activity energy (Cameron et al., 1994). The deviations of the predicted values of the steady-state concentrations of O_2 and CO_2 from the experimental values at 30°C could be the result of the shift of the respiration process. At 30°C, bananas may go anaerobic because the O_2 concentration within package decreased lower than 3.4% after 21 hours, while the CO_2 concentration within package increased to 9% which was higher than the maximum CO_2 tolerance of bananas (Kader, 1994).

Conclusion

The rate of respiration of bananas was successfully modeled using the Michaelis-Menten enzymatic kinetic equations which took into account the effect of O_2 and CO_2 concentrations and temperature through an Arrhenius-type relationship. Respiration of bananas was suppressed considerably with decreasing temperature, and/or O_2 concentration and/or increasing CO_2

concentration. A mathematical model for gas exchange in the MAP was developed to predict the dynamic changes of O_2 and CO_2 gas compositions inside MAP of bananas. The predictions obtained from this model were in good agreement with the experimental data. When exposed to temperature above optimum, the MAP could cause depletion of O_2 and accumulation of CO_2, resulting from greater increase in respiration than in permeability of the PE bag.

Notation

A ≡ Film surface area (cm^2)
$[CO_2]$ ≡ CO_2 concentration inside the package (%)
$[CO_2]_i$ ≡ Initial concentration of CO_2 in the package (%)
$[CO_2]_o$ ≡ CO_2 concentration outside the package (%)
K_{mO2} ≡ Michaelis-Menten constant (%)
K_{mCO2} ≡ Michaelis-Menten constant (%)
K_{iO2} ≡ Inhibition constant (%)
Ki_{CO2} ≡ Inhibition constant (%)
N_{CO2} ≡ The total amount of CO_2 out of the film(ml/hr)
N_{O2} ≡ The total amount of O_2 into the film (ml/hr)
$[O_2]$ ≡ O_2 concentration inside the package (%)
$[O_2]_i$ ≡ Initial concentration of O_2 in the package (%)
$[O_2]_o$ ≡ O_2 concentration outside the package (%)
P_{O2} ≡ O_2 permeability of the film ($ml \cdot \mu m/cm^2 \cdot hr \cdot kPa$)
P_{CO2} ≡ CO_2 permeability of the film ($ml \cdot \mu m/cm^2 \cdot hr \cdot kPa$)
R_{O2} ≡ O_2 consumption rate (ml O_2/ kg·hr)
R_{CO2} ≡ CO_2 production rate (ml CO_2/ kg·hr)
$R_{max,O2}$ ≡ The maximum rate of O_2 consumption rate (ml O_2/ kg·hr)
$R_{max,CO2}$ ≡ The maximum rate of CO_2 production rate (ml CO_2/ kg·hr)
t ≡ Time (hr)
T ≡ Temperature (K)
V ≡ Void volume in the package (ml)
W ≡ Weight of banana (kg)
X ≡ Film thickness (μm)

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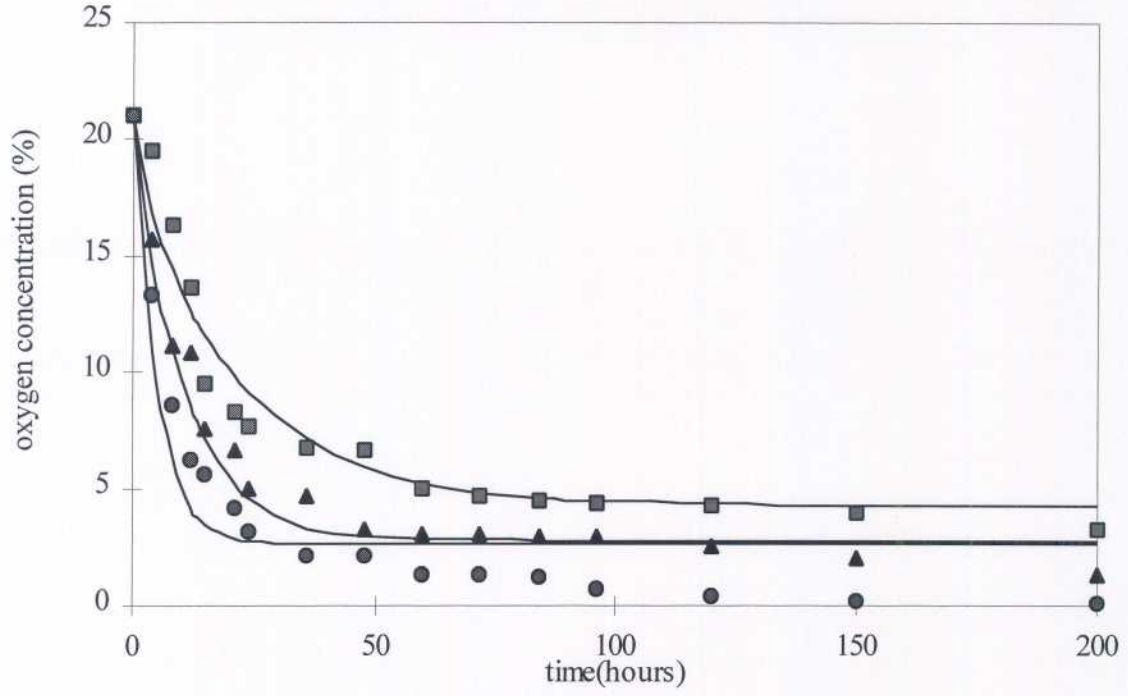
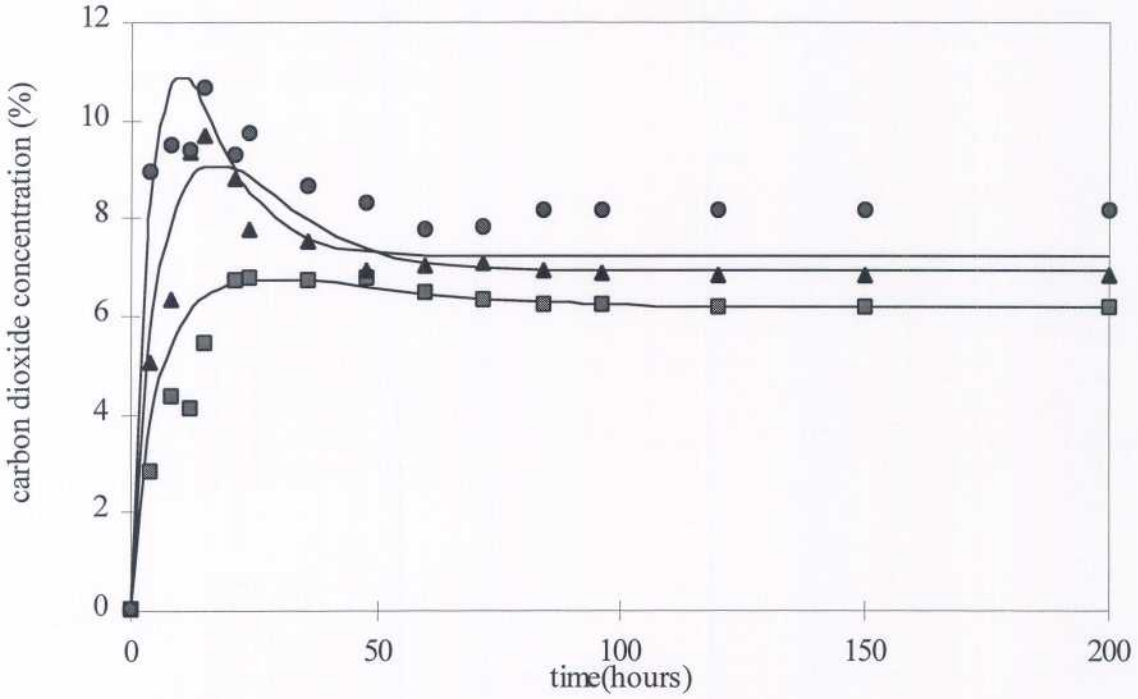


(a)



(b)

Fig. 1. O_2 and CO_2 concentration profiles in PE bag; (a) O_2 concentration profiles, (b) CO_2 concentration profiles. ■ = Experimental results at 13°C; ▲ = experimental results at 20°C; • = experimental results at 30°C; lines = results from the mathematical model.

MA Shipment of Papaya cv. Eksotika

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Additional index words. Packaging, quality, ethylene removal

Abstract. **Sea shipment of papaya (Carica papaya L.) cv. Eksotika was successfully conducted to Dubai using modified atmosphere (MA) technology. In this study 1337 boxes of fruit were successfully transported from Malaysia to Dubai, UAE in a 20-ft refrigerated container with temperature setting at 12°C. About half of the consignment was packed in 6-kg boxes containing 8-9 fruits while the other half used 3.5-kg boxes containing 5-6 fruits. MA packaging was used to control quality deterioration during handling and transportation of the fruit. The MA environment was created by wrapping the fruit in low density polyethylene bags (LDPE) with 0.04 mm thickness. One or two sachets of ethylene absorbent (20 g) was placed inside the bag to control ethylene. The packaging produced a safe environment containing 2-8% O_2 and 6-13% CO_2 with undetectable amount of ethylene. The journey to Dubai took 13 days. On arrival the overall quality of the fruit was still good with an average score of 4. The flesh temperature was maintained at 12.5°C and there was minimal change in skin color, development of chilling injury and deterioration. The fruit ripened normally within 3 days after induction with ethylene with even skin color development, good flavor and taste.**

Papaya (*Carica papaya* L.) cv. Eksotika is a new hybrid variety from Malaysia which has potential to be an export commodity. The small-sized (600-800 g), sweet tasting fruit had an attractive reddish-orange flesh which is very appealing for table consumption. There is an increasing demand for the fruit in the world market especially from Hong Kong, the Gulf States and Europe. In 1991 a total of 8395 tons of the fruit valued at RM 14.9 million was exported to these countries (Anon., 1992). In 1995 the value of export had increase to RM 16.8 million (Anon., 1996). Most of the fruit were exported by air. This method of transportation is expensive and only limited cargo space is available. To increase the volume of export it is more practical and cheaper to transport the fruit by sea. But, the fruit is highly perishable and at ambient temperature (28-30°C) the fruit deteriorates rapidly within one week.

Storage studies conducted by Lam (1990) and Ali et al. (1993) showed that the deterioration of the fruit can be retarded when stored at refrigerated temperatures between 10 and 15°C. The fruit also responded positively when stored in modified atmosphere (MA) at refrigerated temperatures. At 10°C, in atmosphere containing 5% CO_2 and 4% O_2 the storage life of the fruit was extended to 3-4 weeks (Rohani et al., 1997). The storage life can be further extended to 6 weeks when individual fruit were stored in MA (Latifah et al., 1996) containing 4% CO_2 and 8%

O_2 (Rohani et al., 1997). At 12 °C the quality of the fruit can still be maintained for 32 days even when the O_2 concentration was as low as 2% (Abd. Shukor, 1995).

With extension in storage life, MA technology made it possible to transport the fruit by sea. The suitability of using MA technology during sea transportation was demonstrated by Rohani and Zaipun (1995). In their study papaya Eksotika transported under MA to Jeddah, Saudi Arabia was found to be fresher with minimal damage, chilling injury and weight loss. Using information gathered from the various studies, this investigation was carried out with the main objective of evaluating the effectiveness of MA technology in controlling quality deterioration during sea transportation of papaya Eksotika to Dubai. This study was conducted in collaboration with the Malaysian Federal Agriculture Marketing Authority (FAMA) and the importer, Obaid & Abuseedo Co. Ltd. from Dubai.

Materials and Methods

Papaya Eksotika was bought from commercial farms in Chui Chak, Perak, about 150 km from Kuala Lumpur. The fruit were harvested at color index 2 (green with trace of yellow), packed in plastic containers and sent to the FAMA packing house complex situated nearby. The determination of the fruit color indices was based on studies conducted by Lam and Zaipun (1987).

At the packinghouse the fruit were sorted according to size, shape and color index. Fruit that were damaged, too big (>800 g), too small (<400 g) and overripe were rejected. The stems were cut and the fruit washed in running tap water to remove latex and dirt. After washing the fruit were dipped in hot water at 49°C for 10 minutes. The fruit were then cooled in running tap water for 10 minutes before dipping in propiconazole (fungicide) at 250 ppm for 5 minutes to control fungi (Sepiah et al., 1991). After the treatment they were allowed to dry, graded and packed in polyurethane sleeves.

To create the MA environment during storage the fruit were wrapped in 0.04 mm thickness low density polyethylene (LDPE) bags in which the opening were tied with rubber bands. In each bag 1-2 sachets (20 g each) of ethylene absorbent (Cleanpack) was wrapped together with the fruit to retard the ripening process during the journey. After wrapping the fruit were placed in corrugated fiberboard boxes especially designed for papaya Eksotika. In this study 2 box sizes were used viz. 3.5 kg (small) and 6 kg (standard) boxes containing 5-6 fruit and 9-10 fruit respectively. After packing the fruit were temporarily stored at 12°C prior to transportation to Port Kelang.

In this study the temporary storage period was divided into 2 groups. In the first group (Sample A) the fruit were stored one week prior to sailing time while the second group (Sample B) was only stored for two days prior to sailing time. Sample A was prepared so as to facilitate a longer storage time for the fruit which may actually happen during handling of the fruit while waiting for sufficient volume to export.

The boxes were then transported to Port Kelang in refrigerated containers at 12°C and finally arranged into a 20-ft reefer container which had been set at the same temperature before sailing. To determine the change in temperature during transportation temperature tags were randomly placed both inside and outside the boxes prior to transporting in the refrigerated container. A total of 1337 boxes of fruit were stacked in the 20-ft reefer container.

The ship sailed to Dubai via Singapore arriving after 13 days and during shipment the temperature of the container was maintained at 12°C. On arrival at the Al-Shajrah port terminal in Dubai the boxes were manually unloaded and temporarily stored at 12°C. During unloading the condition of the boxes, the stacking, the temperature of the fruit and the surrounding air were noted. The temperature tags that were placed in the reefer container were removed and the changes in temperature during transportation were evaluated. Forty boxes of Sample A and B were randomly taken and the LDPE bags were opened for fruit quality assessment. Quality attributes included skin color, freshness, occurrence of diseases, fruit damage, appearance and overall acceptability. The quality assessment was done using a scoring system as indicated in Appendix 1. Prior to opening the bags the amount of CO_2, O_2 and C_2H_4 gases present was recorded using the Kitagawa precision gas detector.

Twenty boxes of Sample A and B were induced to ripen using a catalytic generator which induced 'Ethygen' emulsion to release ethylene gas. The ripening induction was done for 24 hours at 20°C and 60% relative humidity. After induction the fruit were allowed to ripen naturally at 20°C. The other 20 boxes were placed at ambient temperature and allowed to ripen naturally. The rest of the fruit were also induced to ripen and sold to various supermarkets in Dubai.

During ripening the quality of the fruit was evaluated daily until the skin reached color index 5 (yellow with trace of green). Quality aspects included skin color, fruit damage, diseases, overall quality and acceptability. Quality of the flesh which included the pulp color, taste, acceptability and the total soluble solids was also evaluated. The quality analysis were conducted using scores as indicated in Appendix 1. The total soluble solids (%) were recorded using a digital refractometer. Fruits that were sold in the supermarket were also bought and similar quality attributes were analyzed.

Results and Discussion

The total handling time for exporting papaya Eksotika to Dubai took 21 days which included 7 days for sample preparation, one day to transport and load the fruit into the reefer container at Port Kelang and 13 days sailing period. During handling and transportation there were fluctuations in the temperature especially at the beginning of the experiment. At the packinghouse the cold room temperature fluctuated between 12-16°C especially due to frequent opening of the doors during storage. Fluctuation in temperature also occurred when the fruit were loaded into the cold truck, and during transportation to Port Kelang the temperature plunged to about 5°C for about 13 hours. This can cause the fruit to experience chilling injury. During sailing to Singapore the temperature increased to about 22°C for 3 days probably because the container refrigeration system was not functioning. The high temperature can cause disease infection and an increase in CO_2 in the LDPE bags which can cause physiological disorder in the fruit. However during sailing from Singapore to Dubai the temperature was relatively stable at 12°C.

On arrival at the AL-Shajrah port terminal the container was opened and it was found that the stacking was still in good condition even though the boxes were stacked 14 boxes high. Only 4 boxes had moved at the top of the stack. Boxes found at the bottom of the stack were still intact and no damage was visible. This showed that the boxes had sufficient mechanical strength to

withstand the impact of movement during sailing. The boxes were unloaded manually within 2 hours.

The pulp temperature was taken at random from fruit in boxes stacked at the front, middle and back of the container and it was found to have an average of 12.5°C. This indicated that the temperature of the container was stable at 12°C during the sailing period. Gas samples taken at random from 20 boxes of both sample A and B showed that the concentration of O_2 and CO_2 in the LDPE bags ranged from 2-8% and 6-13% respectively. Ethylene was not detected. This MA condition was effective in controlling the respiration process and other metabolic activities at a low rate without inducing physiological disorders. The undetectable amount of ethylene prevented the fruit from ripening. On the whole the fruit were still fresh with minimal change in skin color (color index 2.5) and the overall quality of the fruit was still good (score 4.7). The percentage of damage for fruit that had been stored for 3 weeks (Sample A) was 4.6% and 11.4% found in small (3.5 kg) and standard (6 kg) boxes, respectively. Higher percentage of damage found in the standard boxes was mainly due to fungal infection on the skin and tissues which had been chill injured during transportation from the packinghouse in Chui Chak to Port Kelang. In fruit that had been stored for 2 weeks (Sample B) no damage was observed for those packed in the small boxes and only 1.4% was observed in fruit that were packed in the standard boxes. The occurrence of brown spot was very low in Sample A and none was found in Sample B.

Fruit from Sample A and B were allowed to ripen both by ethylene induction and natural ripening. On the whole the change in skin color was faster and more even in fruit that had been induced with ethylene than those allowed to ripen naturally. The color index was about 4.0-4.5 (more yellow than green) after one day ripening induction and at this stage the fruit was suitable to be sold at the Al-Hamriya wholesale market. After 2 days induction the color index was between 4.5-5.0 (yellow with trace of green) and suitable for consumption. The skin color change in fruit that were allowed to ripen naturally was slower and the development of the skin color was not as attractive as those that were induced to ripen.

On the whole, after ripening the quality of the fruit from both Sample A and B did not show any major differences (Figure 1). The overall quality was still good with an average score of 4 after 3 days ripening induction. Only a slight decline in quality occurred as indicated in the change of scores from 4.5 to 3.5 especially for fruit that was packed in the small boxes. The decline in quality was mainly due to fungal infection which was one of the major causes of deterioration in Eksotika papaya especially those that has been chill injured during storage.

The overall percentage of damaged fruit after ripening is shown in Table 1. The average percentage of damage was found to be higher (12.7%) in fruit that had been stored for 3 weeks (Sample A). This indicated that longer storage and handling time increased the rate of deterioration. Fruit that were induced to ripen also had higher percentage of damage due to fungal infection. To reduce this incidence, ripening fruit with color index 3-4 was kept at 15°C to slow down the ripening process while waiting to be sold to the wholesale market at Al-Hamriya. The percentage of damage was also higher in fruit that was packed in the 3.5 kg boxes probably due to the compact environment which encouraged faster disease infection.

The condition of the pulp after ripening, the taste and overall acceptability is shown in Figure 2. The pulp was still in good condition, had sweet taste with total soluble solids ranging between 10.4 and 11.1% (Table 1) This showed that the fruit ripened normally even though they had been stored and transported in MA condition for 2 to 3 weeks. The orange-red flesh was still attractive with vivid color and good texture. This also showed that selection of fruit at the

recommended maturity was properly done during the packing house operation. Signs of physiological disorder such as carbon dioxide injury and anaerobic metabolism was not detected in both samples. The overall acceptability of fruit from both samples was still high with an average score of 4 (Figure 2).

Conclusion

The handling and MA shipment of Eksotika papaya to Dubai was successfully conducted. The MA environment was effective in maintaining the fruit quality during 3 weeks of handling and transportation and did not affect the ripening process. On arrival the fruit were still fresh with minimal change in skin color and disease infection. The fruit ripens normally with good color development and acceptable flavor and taste. It was better to pack the fruit in the 6 kg standard boxes since lower percentage of disease infection was observed after ripening. The percentage of damaged fruit can be reduced further by ensuring an uninterrupted cold chain throughout the handling and transportation period and at the same time maintaining a stable temperature of 12°C. Because most of the damage was due to fungal infection on fruit that has been chill injured.

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Appendix 1

Scores used for quality assessment of papaya Eksotika

A. Damaged fruit, freshness, diseases, overall quality and acceptability

1 = very bad (>50% of skin affected) 2 = bad (>25-50% of skin affected)
3 = fairly good (10-25% of skin affected) 4 = good (<10% of skin affected)
5 = very good (fruit not affected)

B. Skin color index

1 = green 2 = green with trace of yellow
3 = more green than yellow 4 = more yellow than green
5 = yellow with trace of green 6 = yellow

C. Color of pulp

1 = pale orange 2 = bright orange 3 = reddish orange 4 = red

D. Taste

1 = very bad (bitter) 2 = bad (not sweet) 3 = fairly good (fairly sweet)
4 = good (sweet) 5 = very good (very sweet)

Table 1. The percentage of damaged and total soluble solids of Eksotika papaya at ripening (color index 5) after MA shipment for 2 (Sample B) and 3 (Sample A) weeks, respectively.

		Damaged fruit (%)	
Sample	Box size	Induced ripening	Natural ripening
A	Small (3.5 kg)	17.2	13.1
A	Standard (6 kg)	10.9	9.7
B	Small (3.5 kg)	14.2	16.9
B	Standard (6 kg)	6.1	3.5
Total soluble solids (%)			
A	Small (3.5 kg)	10.74	10.82
A	Standard (6 kg)	10.42	10.76
B	Small (3.5 kg)	10.80	10.96
B	Standard (6 kg)	11.10	10.76

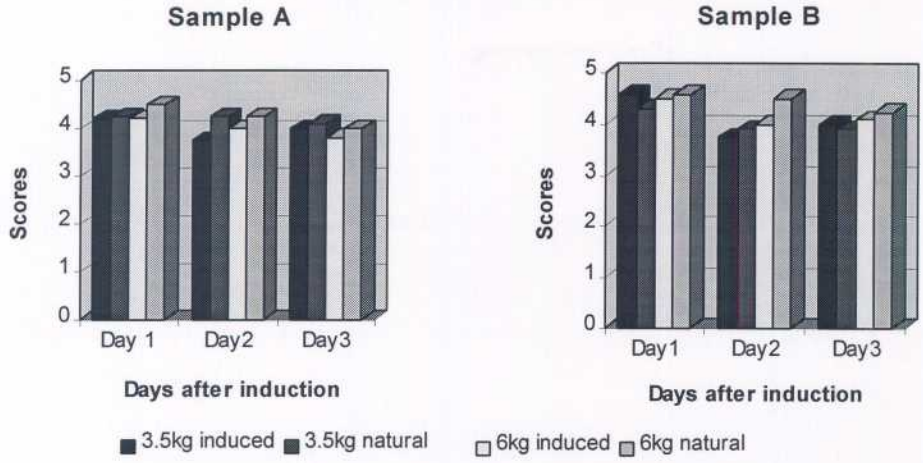

Figure 1. Average scores for overall quality of Eksotika papaya during ripening in Dubai after MA shipment

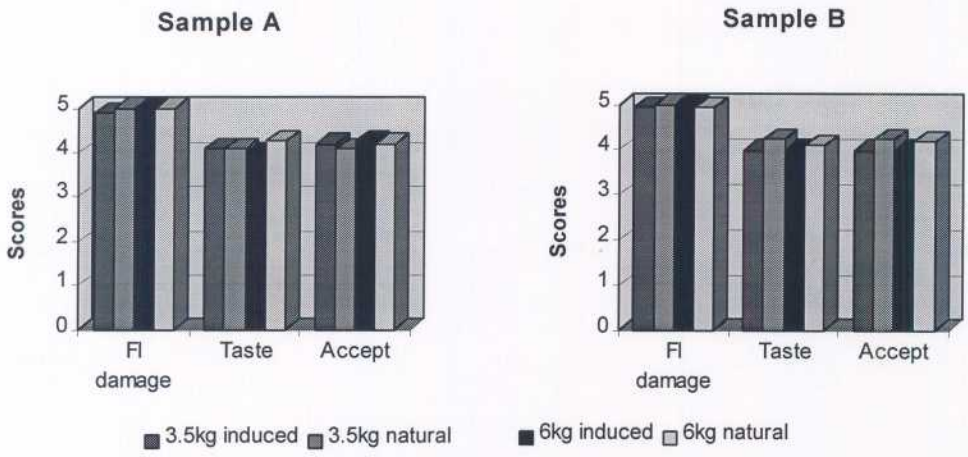

Figure 2. Average scores for flesh damage, taste and acceptability of Eksotika papaya at ripening (color index 5) after MA shipment

Study of Storage Sunrise 'Solo' Papaya Fruit Under Controlled Atmosphere

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Additional index words. Carica papaya, quality, ripening

Abstract. **The effects of controlled atmosphere (CA) on keeping quality of stored 'solo' papaya (*Carica papaya* L.) fruit was studied. Papaya fruits were stored for 31 days at 10°C and high relative humidity under a continuous stream of nitrogen containing 8% carbon dioxide and 3% oxygen, and compared with the storage without modifying the environmental air composition (Control). Samples were collected on days 15, 23 and 31. The papaya fruits were then stored for 5 days at 25°C with 75-80% RH for ripening and evaluated on days 0, 20, 28 and 36. Weight loss, skin color, texture, soluble solids, acidity, sugar content (fructose, glucose and sucrose), Vitamin C, soluble pectin and decay were analyzed. The results showed that the CA decreased the ripening process of the fruit (softening, peel color, sugar content and soluble pectin content). There was no incidence of decay in both treatments. According to the parameters mentioned above the CA was better than control. It also allowed the papaya fruit storage for total period of 36 days while keeping good quality characteristics.**

Papaya, a native fruit from Tropical America, is currently widely spread in the world, in view of its excellent sensory, nutritive and digestive qualities. In Brazil papaya occupies an outstanding position when compared to the other fruits with an annual average production of 287.810 tons from 1990 to 1992 (Frupex, 1994).

In its composition the mature-green fruit is rich in carbohydrates, minerals, aminoacids, vitamin A (β-carotene) and vitamin C, besides papain. The most commonly cultivated kind of papaya is the solo variety of *Carica papaya*, within which Sunrise stands out.

The identification of areas free from the mosaic disease has been stimulating farmers in the states of Espírito Santo and Bahia to harvest papaya. However, the perishability of the fruit along with inadequate postharvest handling systems has caused a drop in Brazilian exports of 32% from 1987 to 1992, and losses around 30% in production, which represent U$ 16 million dollars (Frupex, 1994).

Papaya shelf life is rather short, affecting shipping transport for export. The pathological agents that cause its deterioration can start acting in pre or postharvesting (Salunkhe and Desai, 1984). The papaya shipment is thus a challenge to the exporters, for even when optimum temperatures of

the fruit are kept during transportation the ripening process continues. The ripening is influenced mainly by temperature and storage atmosphere.

Refrigeration with high relative humidity is the most commonly used process for keeping quality of fruit, due to technical efficiency along with low cost. However, for some tropical fruits this process alone does not ensure long storage with quality, which calls for combination of this process with controlled/modified atmosphere (Kader, 1993).

The use of controlled atmosphere process reduces the decay and respiration metabolism and resulting losses through the decrease of O_2 concentration and of CO_2 concentration in storage condition (Hening, 1975). The O_2 and CO_2 concentration must be adjusted to avoid anaerobic respiration and fermentation of fruit, which are responsible for the development of off-odors and off-flavors (Hall et al, 1979). There is an optimum atmospheric composition for each fruit and it depends on several factors, including species, variety, and ripeness stage. Therefore, the main purpose of this work was to study the effect of controlled atmosphere on keeping quality of papaya fruit during storage.

Materials and Methods

Fruits of papaya (*Carica papaya* L. c.v. Sunrise Solo) at the mature-green stage were purchased from a private farm in the state of Espírito Santo, Brazil. The fruits were treated with hot water (47°C) for 20 min. After they were cooled in water with 500ppm thiabendazole (Tecto 600, Merck - Brazil). They were transported in refrigerated condition to the laboratory within 24h after harvesting, where experiment was initiated.

The experiment involving a group of 72 fruits, was divided in two equal lots. The fruits samples (three fruit per container of 4.5 liters) were kept for 31 days at 10°C and high relative humidity under a continuous stream of nitrogen containing 8% carbon dioxide and 3% oxygen, and they were compared to the storage in air (Control). Gases were supplied from cylinders containing custom-prepared mixture (White Martins S.A., Brazil). The atmosphere was humidified by bubbling through distilled and chlorinated water (80ppm of free Cl_2). The composition inside the containers was frequently verified with an infrared CO_2 analyzer. The flow of atmosphere was initially maintained at 0.5 L/min per set of 9 containers per treatment, arranged in parallel, and was increased when needed to prevent fluctuations in the O_2 and CO_2 levels due to the respiratory activity of the fruits. The gases were delivered through tubes to the bottom of the containers to ensure a uniform atmosphere inside the container.

The papaya fruits were then stored for 5 days at 25°C with 75-80% RH for ripening and three samples (three containers) per treatment were evaluated on days 0, 20, 28 and 36.

The fruits were analyzed for weight loss, skin color, flesh firmness, total soluble solids (TSS), titrable acidity (TA), sugar content (fructose, glucose and sucrose), Vitamin C, soluble pectin and decay.

The weight loss was determined using a digital balance. The skin color was determined at four sites near the fruit circumference by using the Sugar Hunter color computer equipment. The fruit firmness was determined using a hand help penetrometer with a plunger diameter of 1.3mm.

The total acidity (TA) which was expressed as percent citric acid was determined by titration of an aliquot of juice with 0.01N NaOH to a final pH of 8.0(AOAC, 1990). The total soluble solids was measured with a hand refractometer. The incidence of pathogenic decay was determined by percentage of infected fruits.

Ascorbic acid was extracted in 5% KH_2PO_4 pH 2.5 (5g in 100ml) and filtered though HA 0.5 membrane. The sample solution (20 μl) was applied to a HPLC reverse-phase column 5μm Spherical

C-18 (3.9 x 150 nm) and guard column 4μm Nova Pak C-18 (3.9 x 20 nm) both obtained from Waters. The mobile phase was an aqueous 5% KH_2PO_4 pH 2.5 with flow 1ml/min at room temperature (25°C). The ascorbic acid was detected by UV absorbance at 254 nm. Ascorbic acid (Merck) was used as external standard. Ascorbic acid was evaluated in a modular HPLC system and this method was adapted from Polesello & Rizzolo (1990). HPLC equipment consisted of pump Shimadzu LC-10AD, a U6K universal injector and Shimadzu SPD-10A two-channel absorbance detector. The integration system used was Work Station CLASS-CR10 and interface CBM 101.

Concerning the water-soluble pectin substances: ten grams of fresh tissue was extracted in 50 ml 95% ethanol for 30 min and filtered through a Whatman N° 4. The ethanol-insoluble residue obtained was washed twice with 75% ethanol and was suspended for 2h in 50ml destilled water. After filtered in Whatmam N°4 and then the water-soluble was diluted at 100ml (sol I). An aliquot of 10 ml was diluted at 100 ml (sol II). The uronic acid content was determined in an aliquot (1 ml) of sol II by method of Blumenkrantz and Asboe-Hansen (1973) with standard monogalacturonic acid obtained from Sigma. Absorbance at 520 nm was read on a Hewlett Packard 84151A Diode Array Spectrophotometer. A blank sample was prepared in which the hydroxydiphenol reagent was replaced by 0.5% NaOH.

Sugars were determined through 10g of fresh pulp diluted in 25ml destilled water and then added with acetronitrile up to 50ml. Then Filtered and 20μl of this filtered were applied to HPLC column μ-bondapack - NH_2. Sugars were separated in the mobile phase was aqueous with acetonitrile (80:20) and evaluated using index refraction detector (Doyon et al, 1991).

Discussion and Results

The weight loss from fruits was minimum for both treatments. Because of high relative humidity of storage air. Otherwise, there were significant differences between CA and control treatments throughout the periods. In 28 days the difference between both treatments reached 9% and in 36 days the weight loss increased to 13%. This way CA was effective in reducing the weight loss (Table 1).

Table 1. Weight loss (%) of stored papaya for both treatments.

Treatment	Storage days			
	Zero	20	28	36
CA (3% O_2/8% CO_2)	0	2.23b	2.85b	4.56b
Control	0	2.59a	3.10a	5.15a

There is no significant difference to averages of each column followed by the same letter (P = 0.05) according Tukey test.

As for skin color the differences were bigger within 20 days and were still significant in 28 and 36 days. It can also be noted that fruits under CA treatment achieved a "b" value color in 28 days, whereas under control treatment the same "b" value color was achieved in 20 days. Therefore the results showed that CA treatment reduced the development of color demonstrating a delay in the ripening process (Table 2).

Table 2. Skin color ("b" value) of stored papaya for both treatments.

Treatment	Storage days			
	Zero	20	28	36
CA (3% O_2/8% CO_2)	19.02	26.78b	31.39b	34.83b
Control	19.02	31.46a	32.78a	36.37a

There is no significant difference between averages of each column followed by the same letter (P = 0.05) according Tukey test.

The results in Table 3 shows that the fruits stored under CA still had excellent firmness in 28 days. In 36 days the difference between the two treatments decreased drastically, however the CA still resulted in better firmness of fruits than Control treatment. The corresponding studies on mango fruits also resulted in better firmness under CA treatment (Noomhorm & Tiasuwan, 1995).

Table 3. Firmness values (N) of stored papaya for both treatments.

Treatment	Storage days			
	Zero	20	28	36
CA (3% O_2/8% CO_2)	127.45	112.74a	60.95a	23.34a
Control	127.45	62.91b	29.81b	17.36b

There is no significant difference between averages of each column followed by the same letter (P = 0.05) according Tukey test.

Tables 4 and 5 show, respectively, the soluble solids and titrable acidity results. It can be noted that CA reduced the ripening of fruit during storage, with soluble solids averages below control treatment.

Concerning the results of total acidity low values were observed under CA, indicating that during the ripening of papaya the total acidity increases. The results, therefore, confirm the effect of CA in delaying the ripening of fruits. Figures 1 and 2 emphasize this retarded ripening process.

Table 4. Total soluble solids % of stored papaya for both treatments.

Treatment	Storage days			
	Zero	20	28	36
CA (3% O_2/8% CO_2)	8.5	9.0b	10.0b	10.3b
Control	8.5	10.3a	10.5a	10.6a

There is no significant difference between averages of each column followed by the same letter (P = 0.05) according Tukey test.

Table 5. Total acidity (mg citric acid/100g pulp) of stored papaya for both treatments.

Treatment	Storage days			
	Zero	20	28	36
CA (3% O_2/8% CO_2)	17,5	17,0b	17,0b	18,0b
Control	17,5	18,0a	19,5a	20,0a

There is no significant difference between averages of each column followed by the same letter (P = 0.05) according Tukey test.

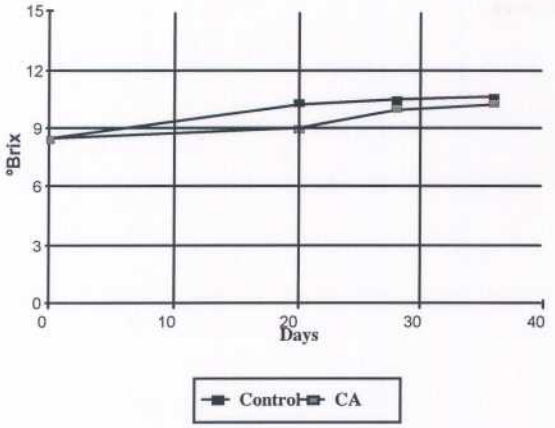

Figure 1. Total soluble solids of papaya throughout storage

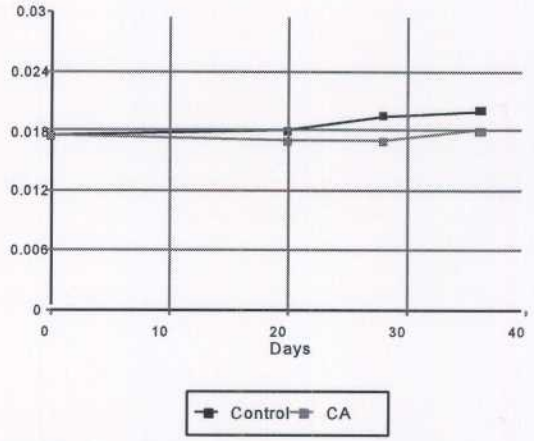

Figure 2. Total acidity of papaya throughout storage

In Figure 3 it can be noted that the fruit kept in air achieved the maximum value of vitamin C in 20 days. The fruits under CA achieved this same value within 36 days. During the ripening process there is an accumulation of vitamin C. A natural loss of vitamin C follows with the senescence (Draetta et. al, 1975).

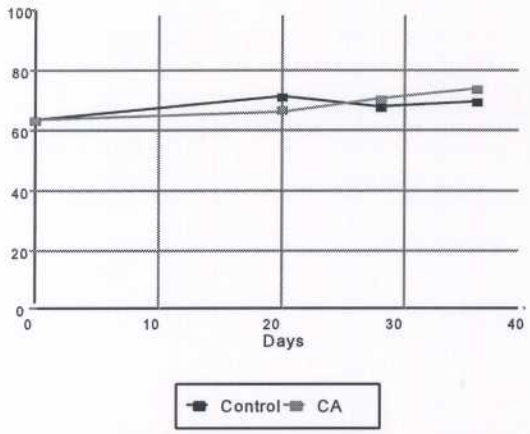

Figure 3. Vitamin C contents of papaya throughout storage

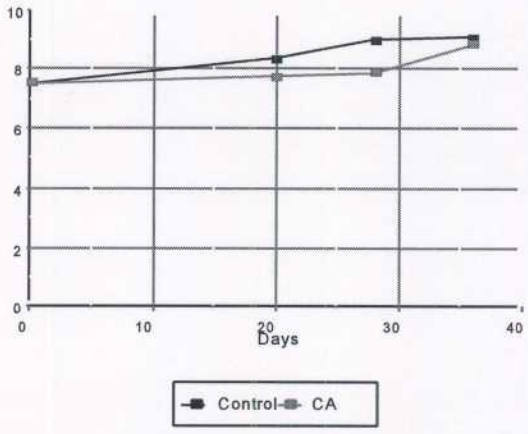

Figure 4. Sugar contents of papaya throughout storage

Sugar conversion (Figure 4) was faster under control than CA treatment. It can be noted again the reduced ripening process for fruits under CA. There is a significant difference in storage up 28 days, however within 26 days there is no difference between treatments(Table 6). The results in this report are in accordance with Draetta et. al., 1975.

Table 6. Sugar contents (glucose, fructose and sucrose - mg/100g pulp) of stored papaya for both treatments.

Treatment	Storage days			
	Zero	20	28	36
CA(3% O_2/8% CO_2)	7.53	7.77b	7.89b	8.86a
Control	7.53	8.38a	8.96a	9.07a

There is no significative difference between averages of each column followed by the same letter (P = 0.05) according Tukey test.

The soluble pectin results (Table 7) showed that fruits under control treatment ripened faster than fruits under CA. There were significant differences between treatments throughout the experiment. There were an increase in soluble pectin during storage under both treatments, with significant conversion of protopectin into soluble pectin. This way it was observed the effect of CA in the reduction of this degradation and the softness of the fruits. These results are in accordance with the values of firmness in table 3.

Table 7. Soluble pectin contents (mg/100g pulp) of stored papaya for both treatments.

Treatment	Storage days			
	Zero	20	28	36
CA (3% O_2/8% CO_2)	155.85	190.94b	212.24b	255.66b
Control	155.85	223.34a	288.21a	393.12a

There is no significant difference between averages of each column followed by the same letter (P = 0.05) according Tukey test.

There was no pathological decay in both treatments due to unfavorable climatic conditions during harvesting for the development of biotc diseases

Conclusions

The use of controlled atmosphere (3% O_2 + 8% CO_2) enable keeping papaya fruits with good shelf life quality throughout 30 days of storage. In relation to characteristics of quality evaluated, the results also demonstrated that CA reduced the ripening process of the fruits.

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Effects of CA Treatments on Guava (*Psidium guajava* L.) Fruit Quality

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Additional index words. Chilling injury, ethylene production, respiration, ripening

Abstract. **Guava is susceptible to chilling injury with symptoms including abnormal ripening, bronzing of the skin and decay. This study explored the use of CA treatments to extend the shelf-life of guava and to alleviate chilling injury. Mature-green guava fruits cv. Media China were treated with air, 5% CO_2 or 10% O_2 for 24 h at 4°C and then stored in air at 4°C and 10°C for 2 and 3 weeks. Fruit were transferred to 20°C for three days before evaluation. After 2 weeks at 10°C plus three days, all fruit had developed yellow color and were marketable, but the CO_2-treated fruit were of higher quality. After 3 weeks at 10°C, the control fruit were of poor quality in comparison to the CO_2 treated fruit. Fruit stored at 4°C had slightly higher acidity than fruit stored at 10°C. Chilling injury was not observed in control fruit at 4°C after 2 weeks. After three weeks at 4°C, chilling injury was observed in control fruits whereas little chilling injury was observed in the CO_2 treatments. The short-term CA treatments had modest effects on the respiration and ethylene production rates of fruits after transfer to 20°C for ripening. Hue and firmness values were higher in CO_2-treated fruit than in the controls, indicating that the CO_2 treatments delayed ripening after transfer. The 5% CO_2-treated fruits stored 3 weeks ripened with their normal color and were firmer than control fruits. The CO_2 treatments slightly delayed ripening of the fruits after transfer to 20°C. There was not much benefit from the other CA treatments after the 3 week storage period. The sensory evaluation showed that this treatment could maintain texture, color, taste and aroma at both 4°C and 10°C for two weeks. The guava fruit is very sensitive to modifications of O_2 and CO_2 concentrations.**

Guava is an important resource in the domestic economy of more than 50 countries in the tropics (Yavada, 1996). After India, Mexico is second in production with 200,000 metric tons per year. The guava is highly perishable, susceptible to mechanical damage and chilling injury and has a limited postharvest life.

The storage life of guava is approximately 3 days at room temperature (27-33°C), 1 week at 20°C and 2 weeks at 10°C. Storage at 10°C considerably reduced decay but there was pulp deterioration (Gupta et al., 1979; Wills et al., 1983). Reyes and Paull (1995) reported that 15°C delayed deterioration of quarter-yellow and half-yellow fruit and allowed gradual ripening of mature-green fruit to full color in 11 days. Ripening was delayed at 10°C for the mature-green fruit and fruit stored at 5°C did not ripen and developed skin bronzing after two weeks. Vázquez-Ochoa and Colinas-Leon (1990) studied guavas harvested at the color-turning stage and stored at 3.5° and 7°C for three weeks. Fruits stored at both temperatures showed symptoms of chilling injury including pitting and failure to ripen properly after storage. Relative humidity in the range of 80 to

88% did not modify chilling sensitivity.

Firmness is a characteristic maturity index in guava. Reyes and Paull (1995) reported firmness values of 300, 240 and 190 N for guava fruits cv Beaumont harvested at immature-green, mature-green and quarter-yellow stages. Using a 5 mm plunger, Mercado-Silva et al. (1997) reported firmness values 204, 102 and 61 N for mature-green, green-yellow and yellow cv Media China guavas. Changes in firmness of guava during storage have also been reported. Firmness values of Vietnamese guaves harvested at 15-16 weeks and stored at 10°C for 3 and 9 weeks were 346 and 23.8 N, respectively (Mohamed et al.,1994).

There is little information about the effect of controlled atmospheres on guava fruit. High CO_2 atmospheres prolonged shelf-life in packaged guava to 10 days compared to 6 days for control fruit (Ahlwat et al., 1978). In a related fruit, feijoa, 24 hour treatments with 0, 10, 20 and 30% CO_2 at 14°C resulted in no change in respiration (O_2 consumption), but a notable decrease in ethylene evolution (Pal and Buescher, 1993). It is generally assumed that atmospheres with high CO_2 or with low O_2 concentrations reduce respiration rates of harvested fruits and vegetables (Kader, 1986), and in some fruits can delay chilling injury (Wang, 1990).

The major export market for fresh Mexican guavas is Canada. Although fruit have been shipped mainly by air, some recent shipments have been by refrigerated truck. The main objective of this study was evaluate CA as a mean to extend the storage life of guavas and to increase their tolerance to low temperature for a 2 to 3 weeks period.

Materials and Methods

Mature-green guava fruits cv. Media china (firmness values of 22.5 ± 9 N) were obtained on the day of harvest (November) at a packing house in Calvillo, Aguascalientes, and transported to the laboratory at 10-12°C. Fruits were treated with air, 5% CO_2, 10% O_2, or the combination at a flow rate of 150 ml/min for 24 h at 4°C. After treatment the fruits were divided into 2 groups and placed in air flow at 4° or 10°C for 2 and 3 weeks. Fruits were transferred to room temperature (20-23°C) for 3 days before evaluation. There were 3 replicates per treatment and 12 fruits per replicate.

The CO_2 and ethylene production rates were measured by enclosing an individual fruit in glass jar for one hour at 20°C and head space samples were analyzed by gas chromatography (CO_2 was analyzed using a Poropack Q 80/100 capillary column and TCD; ethylene was analyzed on a 10% DEG on chromosorb w-AW, 80/100 packed column and FID).

Color was measured by a colorimeter Minolta C2002 (Minolta Camera Co. LTD, Japan), using the CIELAB system and Hue values were calculated (McGuire 1992). Fruit firmness was measured with a texture analyzer (TA-HD Texture Analyzer; Texture Technologies Corp., New York), fitted with an 5 mm diameter cylindrical stainless steel plunger, at a penetration depth of 8 mm. Total soluble solids (TSS) of homogenized pulp samples was determined by a refractometer, and acidity was determined by titration (NaOH 0.1N) and reported as citric acid. Fruit were also evaluated by a panel of 6 trained evaluators for visual quality, color, firmness, aroma and flavor.

Results

After CA treatments, respiration rates of treated fruits were higher than rates of control fruits (Fig. 1) measured at 20°C. CA treatments also resulted in modest increases in ethylene production rates.

After two weeks at 4°C, the CO_2 treated fruits had slightly reduced respiration compared to control fruits (Fig. 2, upper panels). After two weeks at 4°C, ethylene production rates of all CA-treated fruits were higher than controls. The respiration rate of fruits stored at 10° for 2 weeks were similar among CA treatments, but slightly higher than rates of fruits stored at 4°C. The production of ethylene by the fruits stored at 10°C was higher than that of fruits stored at 4°C. In this group, the 5% CO_2 treated fruit had the lowest ethylene production rates.

After 3 weeks at 4°C, respiration rates of the 5% CO_2 and 5%CO_2+ 10%O_2 treated fruit were slightly higher than rates of control fruits (Fig 2., lower panels), also higher than those observed in the 10°C fruit. The lowest respiration rates occurred in the 10% O_2 treated fruit stored at 10°C. Fruits stored 3 weeks at 10°C had lower ethylene production rates than fruits stored at 4°C, and all rates were lower than those of fruit stored for 2 weeks.

Fruits stored at 10°C continued to ripen slowly during storage, whereas ripening was essentially stopped at 4°C. Fruits stored at 4°C required 4 days to ripen at 20°C. Control fruit stored at 4°C did not show visible chilling symptoms after 2 weeks + 3 days at 20°C, but some fruits were visibly damaged (bronzed surface) and did not ripen normally after storage for 3 weeks + 3 days. The 5% CO_2-treated fruits stored 3 weeks ripened with their normal color and were firmer than control fruits. The CO_2 treatments slightly delayed ripening of the fruits after transfer to 20°C. There was not much benefit from the other CA treatments after the 3 week storage period.

The color of guava fruits stored two or three weeks at 4° or 10°C was measured immediately after storage and after transfer to 20°C for three days. Hue color values were different among fruits due to storage temperature, time and CA treatment (Table 1 and 2). Hue values were higher in fruits just removed from storage than in fruits transferred to 20°C for 3 days. Fruits from the 5% CO_2 and 5% CO_2 + 10% O_2 treatments generally had the highest hue values. After three days at 20°C, fruits stored for three weeks at 4°C (without visible symptoms of chilling injury) rapidly changed from green to yellow (lower hue values). Fruits with chilling injury retained their green color as reported by Reyes and Paull (1995) and had a 40% decay incidence.

Firmness differed between control and CA treated fruits after 2 weeks storage plus 3 days at 20°C (Table 1). Fruits stored at 4°C had an average firmness of 60.6 N while those stored at 10° had an average value of 45.3 N. The CO_2 treatments resulted in fruit with the highest firmness values, both after 4° and 10°C storage. The fruits stored at 10°C for 3 weeks had an average firmness of 33.6 compared to 52.9 N for fruits stored at 4°C. At 4°C, the highest firmness values were observed in the CO_2 treated fruits; at 10°C, only the 5% CO_2 treated fruits had firmness values higher than those of the controls. The higher firmness values were also associated with the higher hue values. The firmness values obtained in this study were generally lower than those previously reported for other guava varieties (Mohamed et al., 1994; Reyes and Paull, 1995).
The CA treatments and storage conditions did not result in important differences in soluble solids and acidity contents (Table 1,2).

The sensory scores for external (color, texture, aroma and appearance) and internal (appearance, color, aroma and flavor) characteristics differed among treatments after storage. Fruit treated with 5% CO2 received the highest scores and these were significantly better in appearance, color, texture and flavor than control fruits after storage at both for 2 and 3 weeks. The benefits of the short-term 5% CO_2 treatment have also been demostrate in subsequent experiments.

The guava fruit is very sensitive to low O_2 and high CO_2 concentrations. In an early experiment, mature-green guava were treated at 20-23°C with air, 5 and 10% O_2, and 5, 10 or 20% CO_2 for 24 hours. Three days after transfer to air, the 5% O_2 and 10 and 20% CO_2 treated fruits had off-odors, although they were not notably different in visual appearance from control fruits.

Conclusions

Mature-green guava (cv. Media China) is susceptible to chilling injury at 4°C. A 5% CO_2 treatment for 24h could be an appropriate treatment to extend storage life and to reduce chilling injury. The 5% CO_2 treatment delayed color evolution and firmness loss. Hue and firmness values were the most useful parameters to follow ripening of guavas. Sensory evaluation showed that the 5% CO_2 treatment could maintain texture, color, taste and aroma in fruit stored 2 weeks at 4°C and 10°C. The guava fruit is very sensitive to low O_2 and high CO_2 concentrations.

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Table 1. Physical and chemical parameters of CA-treated guava fruits stored for 2 weeks at 4°C and 10°C.

Storage Conditions	2 weeks	2 weeks + 3 days			
	Hue	Hue	Firmness N	TSS %	Acidity %
4°C					
Control	104.3 ± 0.6	93.7 ± 1.4	53.5 ± 2.5	11.0 ± 0.8	1.3 ± 0.2
10%O_2	104.2 ± 0.7	94.7 ± 0.4	55.0 ± 3.6	11.4 ± 1.2	1.4 ± 0.15
5%CO_2	105.3 ± 1.4	94.3 ± 1.1	63.6 ± 3.6	10.5 ± 0.7	1.4 ± 0.25
10%O_2 + 5%CO_2	106.1 ± 0.8	94.0 ± 0.9	58.6 ± 8.6	10.8 ± 1.0	1.3 ± 0.25
10°C					
Control	98.1 ± .30	92.7 ± 0.4	41.2 ± 9.1	11.2 ± 1.1	1.3 ± 0.3
10%O_2	99.5 ± 0.8	92.0 ± 0.2	42.8 ± 3.1	10.7 ± 1.0	1.2 ± 0.35
5%CO_2	100.4 ± 1.6	94.2 ± 1.0	53.4 ± 5.6	10.9 ± 0.6	1.4 ± 0.2
10%O_2 + 5%CO_2	99.2 ± 1.7	92.0 ± 0.3	45.8 ±4.1	10.6 ± 1.3	1.3 ± 0.5

Table 2. Physical and chemical parameters of CA-treated guava fruits stored for 3 weeks at 4°C and 10°C.

Storage Conditions	3 weeks	3 weeks + 3 days			
	Hue	Hue	Firmness N	TSS %	Acidity %
4°C					
Control	98.1 ± 0.3	92.7 ± 0.4	48.4 ± 4.6	11.2 ± 1.6	1.2 ± 0.2
10%O_2	99.5 ± 0.8	92.0 ± 0.2	48.9 ± 6.6	10.8 ± 1.0	1.2 ± 0.15
5%CO_2	100.4 ± 1.6	94.2 ± 1.0	60.1 ± 11.7	10.7 ± 0.9	1.4 ± 0.15
10%O_2 + 5%CO_2	99.2 ± 1.7	93.0 ± 0.3	53.0 ± 9.1	11.1 ± 1.2	1.3 ± 0.2
10°C					
Control	93.6 ± 0.7	90.8 ± 0.9	32.1 ± 8.1	11.1 ± 1.4	1.1 ± 0.15
10%O_2	94.1 ± 1.2	91.3 ± 1.6	32.1 ± 5.6	11.0 ± 1.6	1.1 ± 0.15
5%CO_2	96.9 ± 2.6	92.7 ± 1.8	40.7 ± 11.7	10.6 ± 1.6	1.2 ± 0.12
10%O_2 + 5%CO_2	96.8 ± 1.7	93.2 ± 1.4	30.0 ± 4.1	11.2 ± 1.3	1.2 ± 0.1

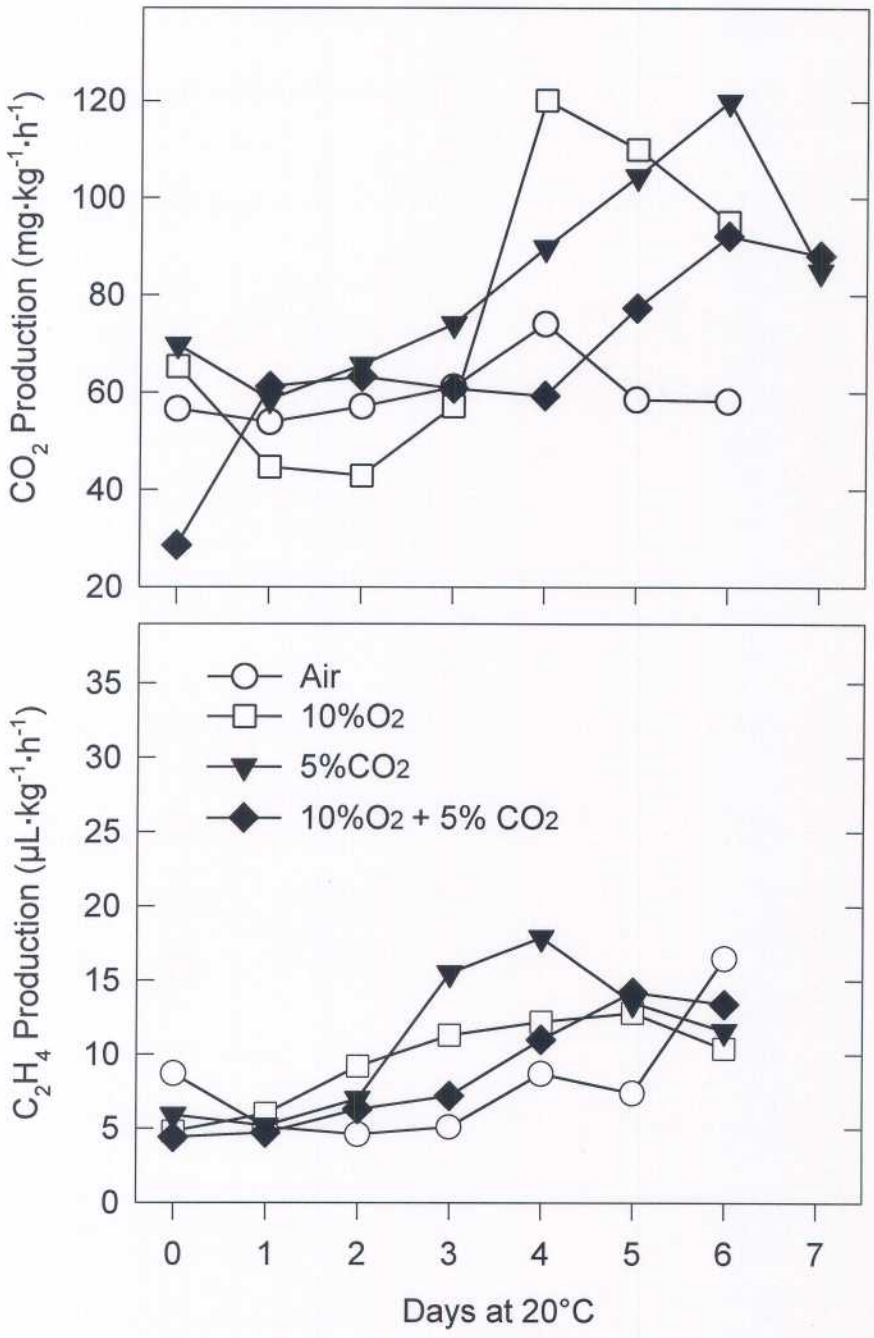

Figure 1. Respiration and ethylene production rates of guavas transferred to 20°C after CA treatments at 4°C.

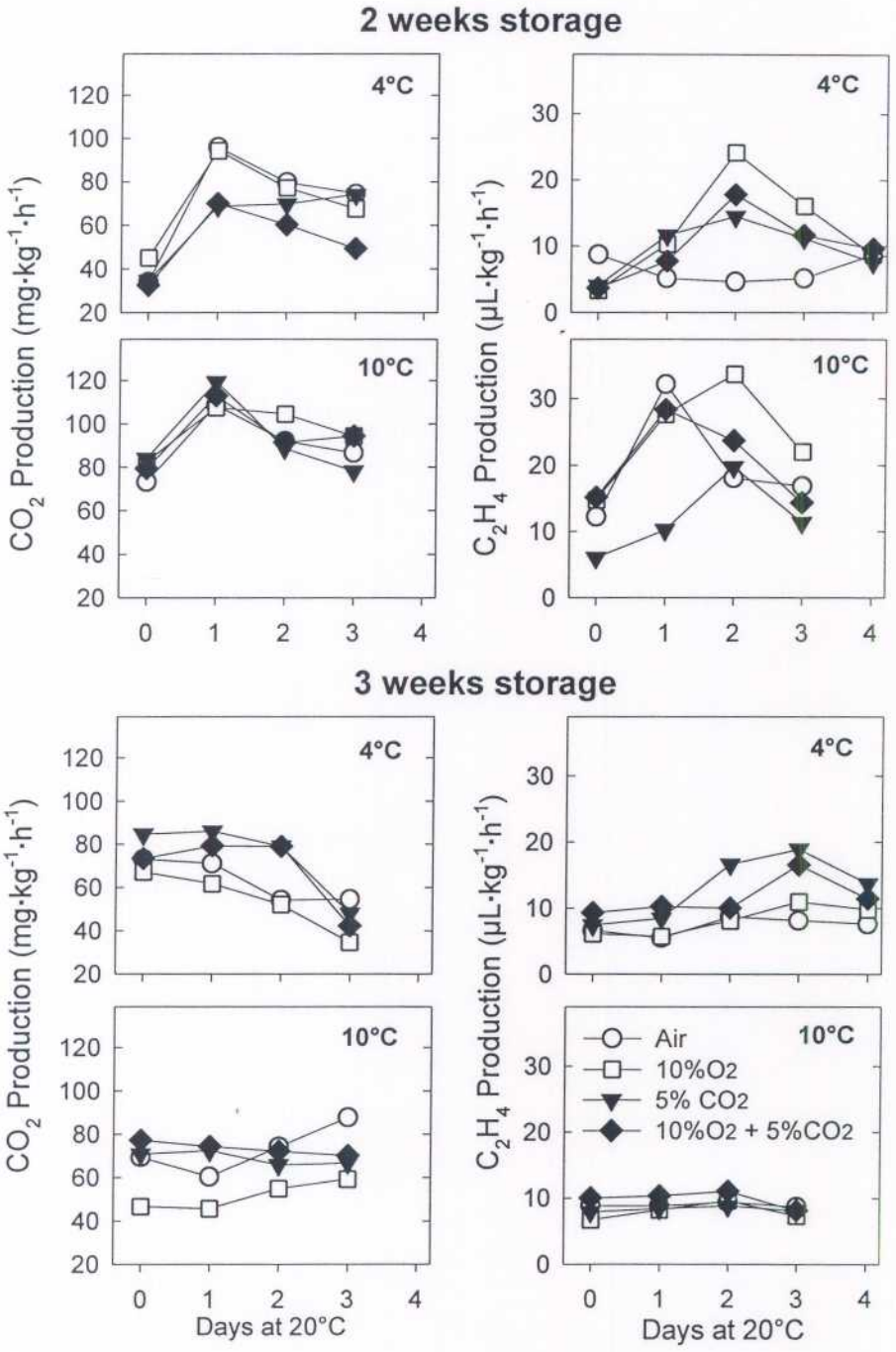

Figure 2. Respiration and ethylene production rates of guavas transferred to 20°C from storage for 2 and 3 weeks. Fruits were treated with air or CA treatments prior to storage.

Effect of Different CA on Postharvest-Life of Hass Avocado

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Additional index words. Quality, firmness, chilling injury

Abstract. **Hass avocado fruits were harvested in Quillota (Aconcagua valley) Chile and stored at 6°C and 90% RH - under the following different CA (O_2 and CO_2 combinations): 5% CO_2 + 2% O_2, 5% CO_2 + 5% O_2, 10% CO_2 + 5% O_2 and 0.03% CO_2 + 21% O_2 (check). Fruit was evaluated at 0, 35 and 50 days, (including the last 15 days at 6°C - conventional storage). After 35 days avocado fruit under conventional cold storage exhibit 0.45 kg-force firmness while fruit from any of the other CA treatments had firmness around 12.5 kg-force. After 50 days (35 days under CA and 15 days at 6°C - conventional storage). Fruit from all CA treatments had a pulp firmness around 9.8 kg-force. Physiological disorders and fungal infection were reduced in fruit under CA storage. Results indicate that long distance sea transport of Hass avocado fruit is feasible in refrigerated CA containers. In this research the best CA storage gas combinations for Hass avocado fruit was 5% CO_2 + 2% O_2 at 6°C.**

Avocado exports from Chile are increasing, with air freight as the main transport system. The limiting factors is the high cost that reduce the profit level to the grower. Refrigeration and Controlled Atmosphere appear to be a good possibility for sea transport. Berger and Auda (1982), Eksteen et al (1991) and Carrillo and Lizana (1995) had good experience with Fuerte Avocado; this last report indicated that avocado fruit can be kept at 6°C with 5 - 10% CO_2 and 3 - 5% O_2 for 35 + 5 days at 6°C and 4 additional days at 20°C, totaling 44 days. Lizana et al (1993) ware able to maintain Gwen avocado for 45 days with CA at 6°C. Hatton & Reeder (1972) kept Lula Avocado Fruit for 60 days at 10% of CO_2 and 2% O_2 at 10°C with ethylene scrubbers.

The objetives of this work was to evaluate the postharvest behavior of Hass avocado fruits stored at 6°C under different CO_2 and O_2 concentrations.

Materials and Methods

Mature avocado (Persea americana, Mill) cv Hass from Quillota (Chile) (32°53" Lat. South and 71° 15 Long West) were harvested and placed 55 fiber board box.

Fruit harvested during the first two weeks of November (15.4% to 17.5% oil, dry weight basis) were selected eliminating the ones which presented rots, wounding, damage of pests, insects, russet, bruises or lack of peduncule and were kept in Controlled Atmosphere (CA) at 6°C and 90% relative humidity (RH) for a period of 35 days; and some of them were kept in air

(control) 6ºC and 90% RH and later to a market-simulation period (shelf life) at 18ºC until fruit was ripe.

The experimental design was a complete randomized block, the treatments being the CA gas combination with 4 replications and each experimental unit was one box with 28 fruits each one.

The Gas combinations of O_2 and CO_2 were 2%+5%, 5%+5%, 5%+10% and 2% and 10%, respectively.

Evaluations, were conduced at harvest time, after 35 days at CA, after 35 days at CA plus shelf life time, after 35 days at CA plus 15 days in air (50 days) and after 35 days under CA, plus 15 days in air plus marketing time (shelf life).

The gas concentration inside of each container was checked daily by gas chromatography (SRI 86 10) with thermal conductivity detectors, and any variation was corrected immediately. The fruit oil concentrations was determined by the Lee and Coggins (1982) method, color of pulp and peel by comparison with Nickerson color chart. Resistance of pulp to penetration was determined with a firmness tester with 8 mm tip in both sides of the fruit without skin. Fruit rot, as a % of fruit affected and physiological disorders with subjective scales of 1 to 5, with 1=no damage and 5=severe damage. Fruit water loss was measured as % of weight loss.

Results and Discussion

The peel color of the fruit did not change after 35 days under CA, but the control fruit, evolved from olive green to redish black. When submitted to an additional 15 days in air some of the fruit evolved to redish black reaching the color close to the control.

The internal color was less affected by the treatments and different from the control, and the color was still evolving when the fruit was close to the ripening stage.

After 35 days of CA, the color of the fruit was very variable, but after 50 days of storage plus marketing time the color of the fruit was very uniform (green-yellow medium).

The water loss was between 2 to 3% at 35 days and increased between 3 to 6% after 50 days of treatments.

During the marketing time the water loss increased steadily reaching levels of 10 to 12 % during 13 to 15 days. Water loss reached 9 to 10 % after 50 days under treatments (Fig. 1).

Internal vascular discoloration. *Vascular* browning was light after 35 and 50 days of storage, but increased during shelf life period (18ºC) to light brown. The only treatment that did not show any browning during storage was CA of 5% CO_2 and 2% O_2; after 15 days at 18ºC only 7% of the fruit had light problems of browning. Nevertheless the intensity at the browning did not impare the marketing value of the fruit. (Fig. 2).

Internal Browning. The only treatments that did not exhibit pulp browning after storage and during room temp. period was CA, 5% CO_2 + 21% O_2 and 5% CO_2 + 5% O_2. The CA treatments gave a clear advantage over control fruit which presented 25.8% of the fruit with avarage browning of 25% of the pulp (Fig. 3).

Pulp gray spots. This type of physiological disorder that has been reported previously for Fuerte (Berger et al, 1978; Lizana et al, 1991) was very incipient in Hass, which many indicate a difference in cultivar behavior.

In general, Hass appeared to have less susceptibility to storage physiological disorders compared to Fuerte (Berger et al, 1978; Berger et al, 1982; Berger and Auda, 1982; Lizana et al,

1991, Carrillo and Lizana, 1995) and similar to cv. Gwen (Lizana et al, 1993). Moreover CA treatment of 15% CO_2 + 5% O_2 and 20% CO_2 + 5% O_2 to force CO_2-induced physiological disorders did not show any effect on Hass.

Acceptability. Fruit under 5% CO_2 + 2% O_2 had significantly higher acceptability than all other fruit after 35 and 50 days of storage. High CO_2 concentration (10% CO_2 + 5% O_2 and 10% CO_2 + 2% O_2) decreased panel evaluators preference. (Fig. 3).

Conclusions

Hass avocado fruit can be successfully maintained up to 62 days in good commercial conditions at 6°C and 5% CO_2 + 2% O_2 for 35 days followed by a shelf life period of 12 days at room temp. (18°C).

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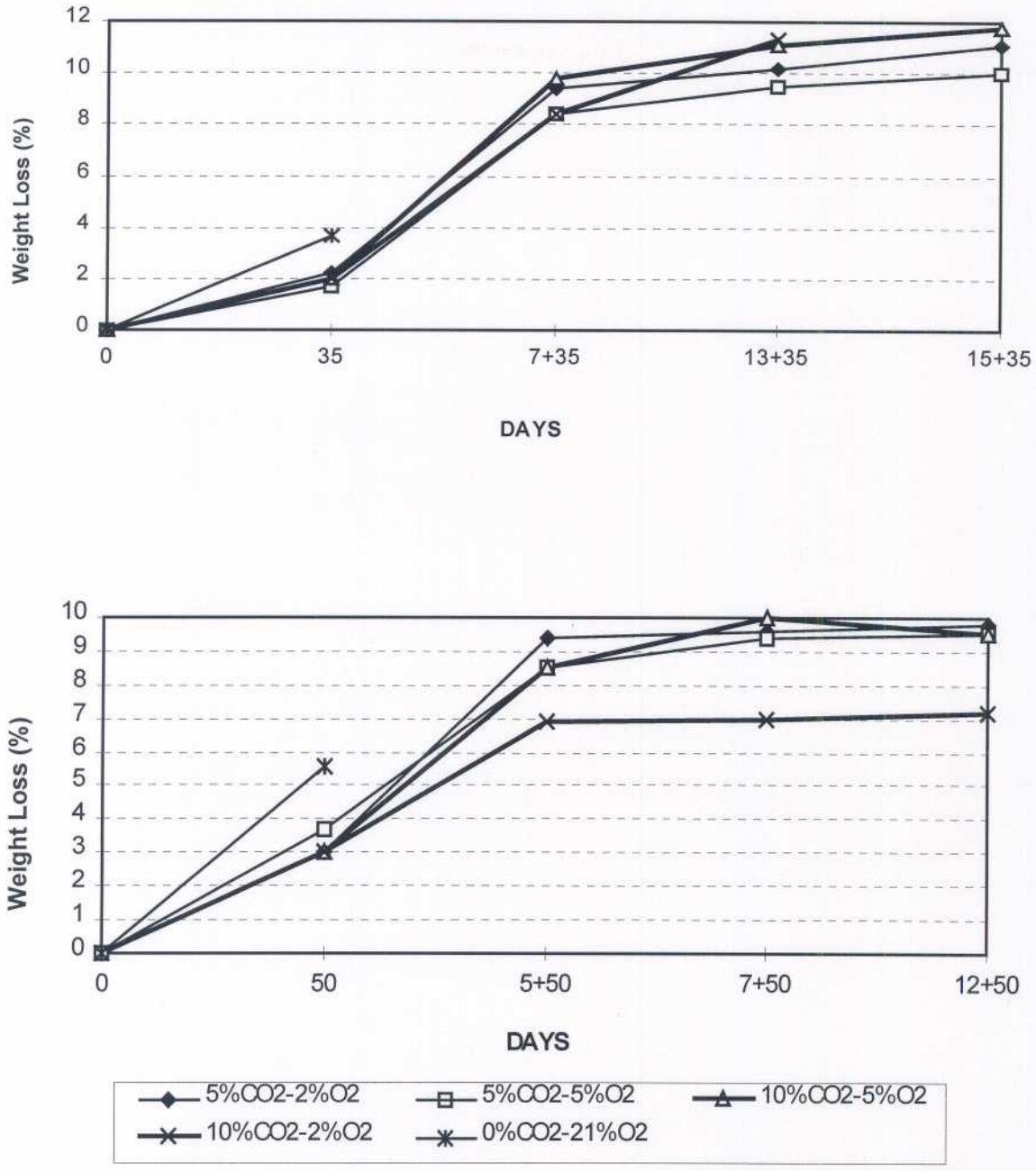

Fig. 1. Fruit water loss after 35 and 50 days of different CA storage at 6°C and subsequent days at 18°C in air.

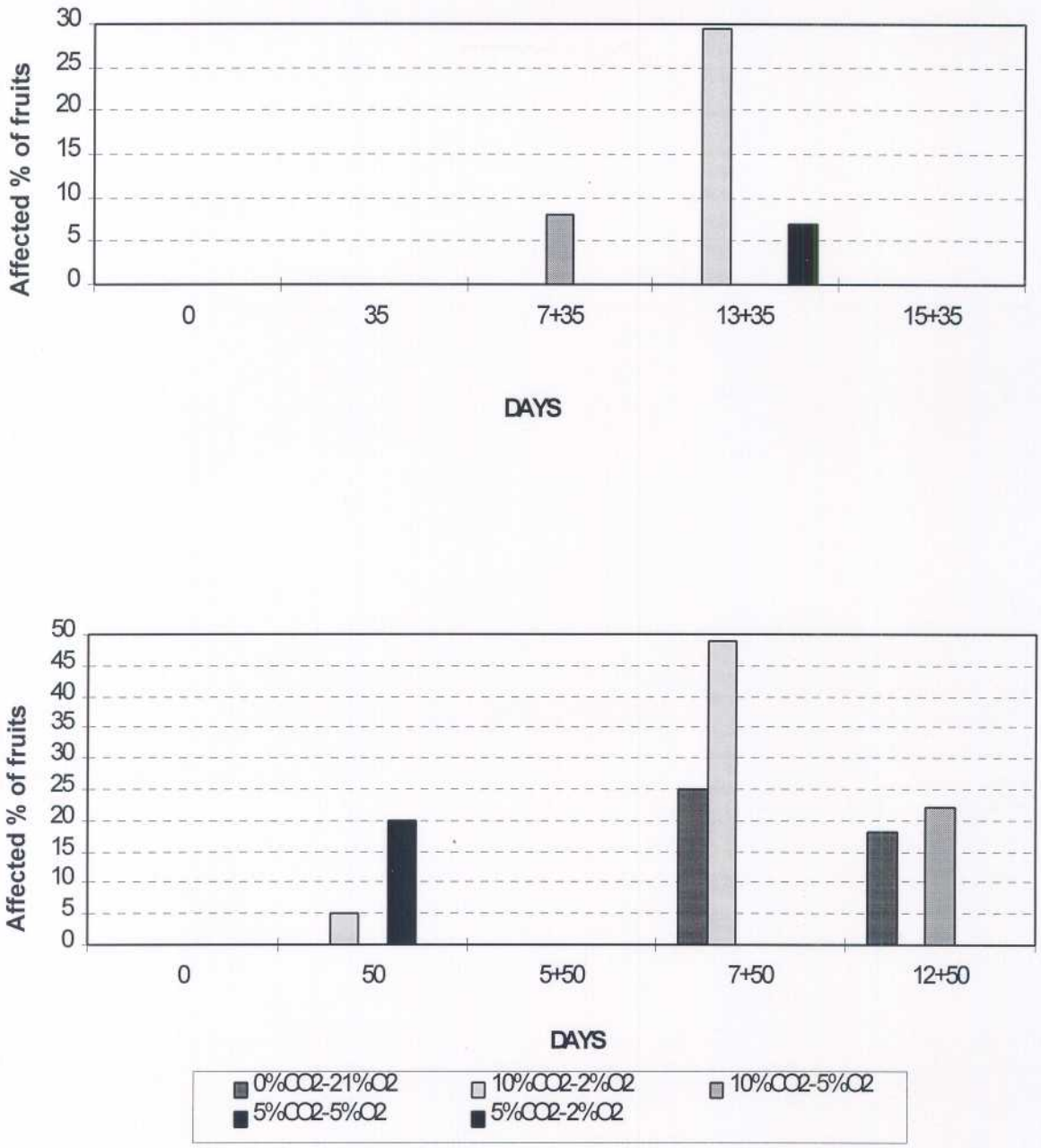

Fig. 2. Internal browning of Hass avocadoes after 35 and 50 days under CA storage at 6°C and subsequent days at 18°C in air.

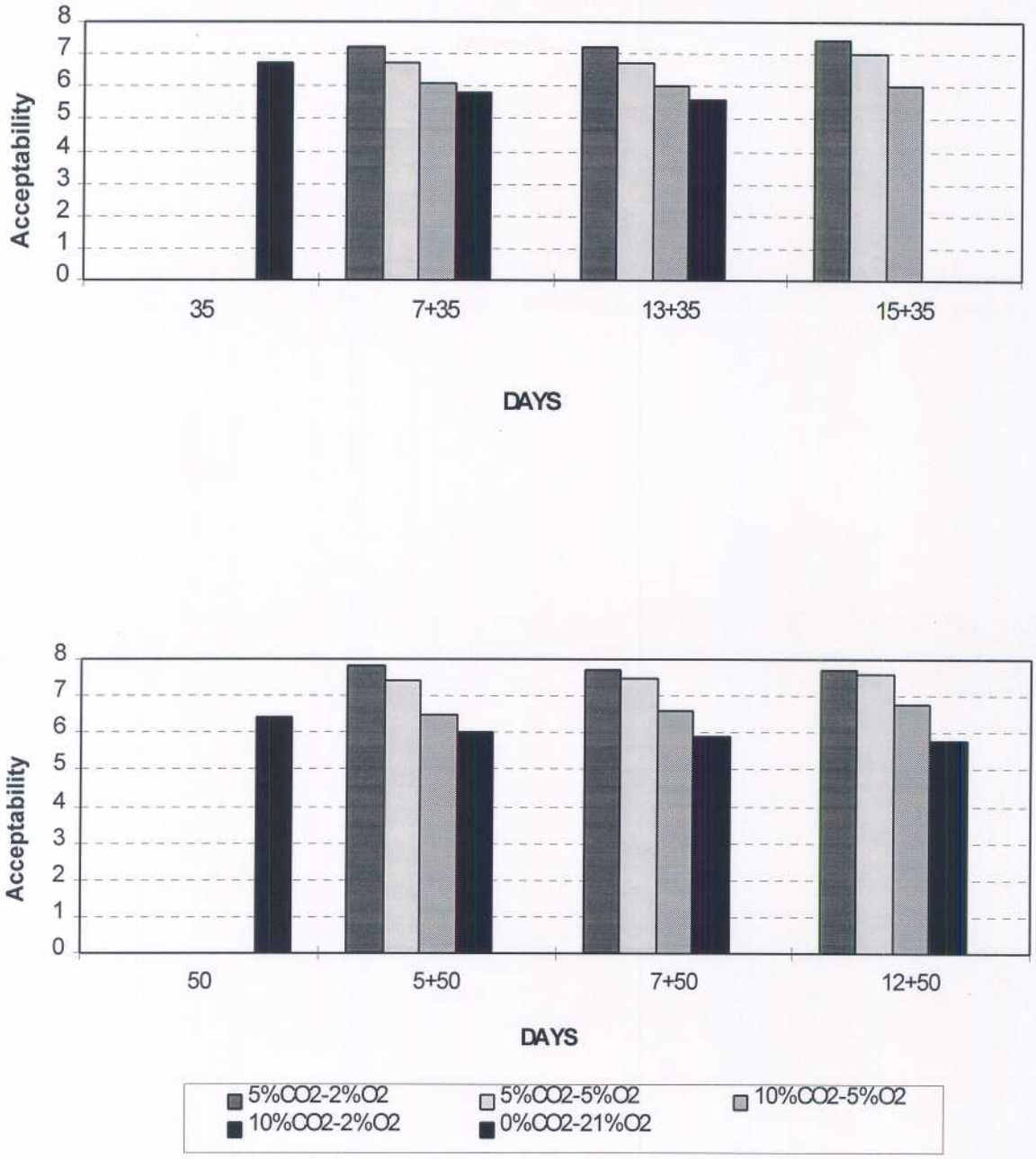

Fig. 3. Acceptability of Hass avocadoes after 35 and 50 days under CA storage at 6°C and subsequent days at 18°C. Score: 1 = dislike it much to 9 = like it much.

High CO_2-Low Temperature Interaction on Ribulose 1,5-biphosphate Carboxylase and Polygalacturonase Protein Levels in Cherimoya Fruit

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Additional index words. *Annona cherimola*, chlorophyll, color, firmness

Abstract. **Pretreatment with 20% CO_2 + 20% O_2 for 3 days during storage at 6°C maintained flesh firmness and suppressed the rise in the immunodetected PG protein content. The immunodetected levels of RuBPCase protein and total chlorophyll content were higher in CO_2-treated than in fruit stored in air. Furthermore, the characteristic yellow-green color of cherimoya was better maintained.**

The beneficial effects of elevated CO_2 on the storage life of fresh fruit and vegetables are well established (Kader, 1986). Short-term exposure to high CO_2 before storage at low temperature decreases the development of chilling injury in several commodities (Wang, 1990). In cherimoyas, which are susceptible to chilling injury, different postharvest technologies have been applied to extend their storage period (Merodio and De La Plaza, 1997). Some well known effects of high CO_2 atmosphere entails the retardation of characteristic changes of senescence and ripening, including color and softening. This work was designed to determine the effect of high levels of CO_2 during storage of cherimoya fruit at low temperature on 1) color modification, chlorophyll levels and ribulose 1,5-biphosphate carboxylase (RuBPCase) content and 2) texture modifications in terms of firmness and polygalacturonase (PG) protein.

Material and Methods

Cherimoya fruit of uniform shape and maturity stage, weighting 180 to 190 g, were stored in darkness at 6°C. Two lots of fruit were placed in separate respiration chambers in a continuous humidified air flow or in a continuous flow of 20% CO_2 and 20% O_2 for 3 days before transfer to air. Initially, and for every subsequent sampling period, peel tissues from three untreated and treated cherimoyas were randomly collected, frozen in liquid nitrogen and stored at -80°C.

Firmness was measured on equatorial position using an Instron testing machine (model 1140) fitted with a double-plate probe. Color measurement were performed using a HunterLab tristimulus colorimeter and described in terms of hue angle. Total chlorophyll in cherimoya peel was extracted with 80% (v/v) acetone and determined according to Strain et al (1971).

Total proteins, purified by the phenol-ammonium acetate-methanol method (Montero et al, 1995) were separated by SDS-PAGE on 14% polyacrylamide gels as described by Laemmli (1970) and transferred onto nitrocellulose membranes as described by Towbin et al., (1979). Proteins were immunodetected with rabbit monoclonal antibodies raised against tomato purified large subunit of

RuBPCase (LSR) (dilution 1:20,000) or antibodies against tomato PG (dilution 1:60,000). Antigens were detected with chemiluminescent substrates (Amersham) and its levels quantified using an image analyzer.

Results

Effect of high CO_2-treatment on firmness, color and chlorophyll content. Changes in firmness, color and total cholorophyll content in treated and untreated fruit are shown in Table 1.

Table 1. Firmness, chlorophyll content and color in cherimoya during storage at 6°C in the dark. Air: fruit stored in air, $+CO_2$: fruit removed from 3 days in CO_2 (20%) atmosphere and transferred to air.

	Firmness (N)		Chlorophyll ($\mu g \cdot g^{-1}$ FW)		Hue angle (tan^{-1} b/a)	
Days	air	$+CO_2$	air	$+CO_2$	air	$+CO_2$
0[z]	73.6±4.5[y]	73.6±4.5	106.2±6.4	106.2±6.4	124.0±0.1	124.0±0.1
3	72.1±2.8	75.8±2.6	ND[x]	ND	119.3±0.4	122.1±0.5
5	73.7±2.7	73.9±2.7	65.3±2.3	77.5±2.0	124.7±0.8	122.9±0.9
9	74.1±2.4	69.8±3.7	52.3±2.5	56.9±1.3	112.9±0.7	111.9±2.3
23	35.4±3.2	63.3±3.2	59.6±3.4	88.1±1.6	109.9±2.4	117.2±1.2

[z]Fruit after harvest
[y]Values indicate the means±SD
[x]ND=not determined

Firmness did not change for the first 9 days of storage at 6°C, showing no difference between treated and untreated fruit. But after this time a sharp loss of firmness is observed in the former. At the end of the experiment (23 days) firmness had decreased a 52% for untreated fruit, while treated ones values remained almost constant. During the first 9 days of storage, a significant decrease in total chlorophyll content was recorded in both treated and untreated fruit but, an important increase in chlorophyll levels was induced in treated fruit when the storage period progressed. Table 1 shows that CO_2-treated fruit retained better the characteristic yellow-green color until the end of storage period.

Effect of high CO_2-treatment on RuBPCase and PG proteins. SDS-PAGE analysis of total proteins extracted from peel of cherimoya fruit stored at 6°C with and without CO_2-treatment revealed increases, decreases, and fluctuations in the levels of several polypeptides. However, the identity of most of these proteins is not yet known. To establish the identity of some of these polypeptides, immunoblotting analysis with tomato LSR and PG antibodies were performed. The results showed that LSR antibodies cross-reacted with a 55 ku (unified atomic mass unit) polypeptide. Quantitative measurements (Figure 1A) showed that the levels of RuBPCase gradually decreased for 9 days of storage at 6°C in both untreated and CO_2-treated fruit. Furthermore, a substantial increase in RuBPCase protein content was observed in cherimoya peel of treated and untreated fruit, although the first group always maintained higher levels than the former.

As previously reported (Del Cura et al., 1996) three polypeptides with a molecular mass of 55, 46 and 36 ku cross-reacted against tomato PG antiserum. The 46 ku polypeptide, which showed the

most notable changes during cherimoya ripening at 20 °C, was proposed as the mature PG protein. The quantitative measurement of the immunodetected 46 ku polypeptide in the peel of untreated and CO_2-treated fruit of identical chronological ages (9 and 23 days) is shown in Figure 1B. When fruit were stored for nine days at 6 °C, PG protein content did not increase compared to the values of fruit after harvest (day 0). Further storage led to significant differences by day 23. Untreated fruit stored at low temperature suffered a significant increase, while this rise was counteracted by CO_2-treatment.

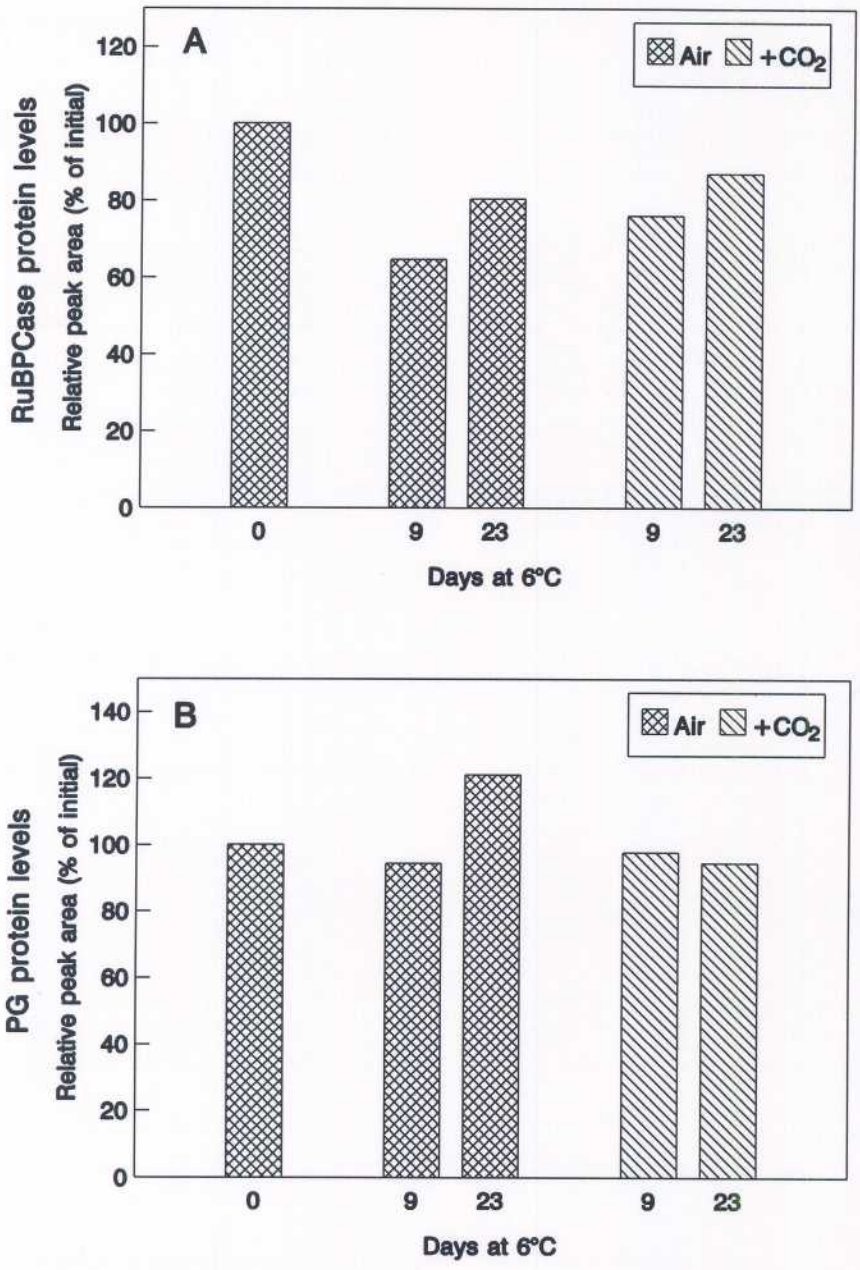

Fig. 1. Histogram representing the quantification of immunodetected RuBPCase (A) and PG (B) protein levels of untreated (air) and treated (+CO_2) fruit during storage at 6 °C. The immunoblots were quantified by densitometry and data are relative peak are (percentage of initial value at prestored fruit, 0 days). Two replicates revealed a similar pattern of protein changes in cherimoya peel.

Discussion

Chilling injury symptoms are well known to be a limiting factor to application of low temperatures to extend fruit storage life. Some of those symptoms resemble degeneration accompanying senescence. Ultrastructural analysis of cherimoya fruit stored under several chilling conditions reveal important changes in membrane systems (Gutiérrez et al., 1992). Some senescent changes involve losses in photosynthetic capacity, which are usually associated with alterations in the activity and levels of RuBPCase protein and changes in chlorophyll content (Wittenbach et al., 1980). A sharp decrease in the immunodetected RuBPCase protein levels accompains the last stage of cherimoya fruit ripening (Del Cura et al., 1996). Application of different technologies such as low temperature and pretreatment with high CO_2 levels delays the loss of RuBPCase protein levels in cherimoya fruit (Escribano et al., 1997). It has been also observed (Rao et al., 1995) that in plants exposed to stressful ambient conditions, treatment with high CO_2 levels prevents decreases in photosynthetic pigments and RuBPCase protein levels. In green leaves and vegetables, high CO_2 levels maintain the chlorophyll content a higher level than those stored in air (Aharoni et al., 1989). According to our results, the higher levels in both immunoreactive RuBPCase protein and total chlorophylls quantified in peel of CO_2-treated cherimoya fruit seem to confirm the effect of high CO_2 levels on the maintenance of photosynthetic capacity resulting from supression of senescent changes in green tissues.

Also, it has been reported that controlled atmosphere storage (high CO_2 and low O_2) prevents the synthesis and accumulation of PG and some other cell-wall degrading enzymes (Goodenough et al., 1982; Kanellis et al., 1991). In previous works we observed that pretreatment with high CO_2 delays accumulation of PG protein during storage at 20°C, although higher levels are quantified in treated fruit after transfer to air (Del Cura et al., 1996). Besides confirming the well known effect of short-term high CO_2-treatment on softening delay our results confirm that the rise in the immunodetected level of PG protein content of cherimoya was suppressed at low temperature if fruit received an initial treatment of high CO_2 for a short period of time.

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Acknowldgements

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Native Ilama Fruit *Annona diversifolia* Saff. of the State of Guerrero, Mexico, Under Controlled Atmosphere

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Additional index words. Color, firmness, quality

Abstract. **Ilama has been poorly studied in Mexico. Some postharvest and growing characteristics of Ilama Annona diversifolia Saff., fruits under Controlled Atmospheres were measured in this study. There are three colors of pulp in this Specie (pink, white and red). Fruits with pink pulp had less firmness (12.1 Kg vs. 16.6 for white and 16.4 for red type), more soluble solids (19 Bx vs. 15.7 and 17.5 in the same order), thicker skin (0.40 cm, 0.31 and 0.30 respectively), higher weight of seeds (79.9 g, 72.4 g and 70.1 respectively), and less number of seeds than the red type (49, 50 and 66 respectively). These fruits had a climacteric behavior and the growth was approximately doubled sigmoid. Respiration rate was greatly modified under controlled atmosphere, and ethylene production was 50% lower.**

Annona spp. are very important native fruit trees for locals in the state of Guerrero Mexico, linked to their food and family economic income, allowing for an empirical selection of plant material of quality and tree yield. Fruits of the family Annonaceae have been reported as the most delicious in the world (Ochse *et al.* 1965). They have great acceptance in local markets where they grow and they have a high content of vitamin C (Reyes, 1967). This family has several species present in Mexico and in other countries, including chirimoya, *Annona cherimola* Mill (Ibar, 1983), guanabana *Annona muricata* L. (Foex. 1908), Popenoe, 1956) and others.

From the same family is Ilama *Annona diversifolia* Saff, native species from Mexico still little known with very few references, even when it is one of the finest in the Annonaceae family (Ponce, 1978). Ilama fruits are collected form the wild or from very small orchards, with trees randomly distributed. They have a great potential for marketing fresh in the USA and local markets. However, it is important to notice that there are several types that are very susceptible to skin cracking.

In this family species with higher potential are: chirimoya and guanabana due to their larger plantation area (Vidal, 1993). Ilama within its family has showed a great diversification and variation in flesh color, flavor, shape and size. Very little information is available about this fruit-tree in relation to growth pattern, morphology, anatomy, productive processes, and genetic variability.

Taking in consideration the small amount of studies about this specie, the objectives of this work were to characterize a population of Ilama, in relation to postharvest and fruit behavior under controlled atmospheres.

Materials and Methods

Biological Material. Ilama fruits (*Annona diversifolia* Saff.) were taken from fruit trees in the wild, distributed randomly, without a specific plantation squeme, but with very interesting characteristics. From a family orchard 58 trees of Ilama were selected, this zone do not have irrigation installations, all the water is form the rainy season, placed in the town of Pungarabato, in the Rio Balsas Basin of the state of Guerrero. Trees were chosen for their diversity of flesh color of their fruits forming the following groups: 1) White flesh fruits (B); 2) Pink pulp fruits (RT); and 3) Bright red pulp fruits (RB).

Five trees were selected for each group, a total of 15 trees, and 100 fruits were harvested to evaluate their physiological and biochemical characteristics. Fruits were harvested 15 days before their maturity to measure their physiological development off the tree.

Description of the zone of study. This region is known as 'Tierra Caliente de Guerrero' (Hot land of Guerrero), located in parallel 18° °6' y 18° 25' of North Latitude and 100° 31' and 100° 48' of West Longitude related to the Greenwich Meridian and its altitude over sea level is 250 meters. Weather is warm humid, average temperature in December is 25°C as minimum and 30°C as maximum, and in May 36°C as minimum and 40°C as maximum. Average annual precipitation is 1100 mm, mainly in June to September (Garcia 1987).

Variables to measure. Among Biophysical variables measured are firmnes, color, total soluble solids, and shape of fruit. Chemical analysis as titratable acidity, and pH, and Physiological variables like weight loss, respiration rate and ethylene production were measured.

Controlled atmosphere treatment. Another portion of fruits were placed under controlled atmospheres at 10% CO_2 + 14% O_2 at room temperature (19°C), to study their respiration rate, ethylene production and shelf life, as well as any physiological disorder.

Results and Discussion

Firmness. This variable changed very rapidly after three days of harvest. White and red pulp fruits showed higher firmness. Skin thickness could influence firmness (Figure 1).

Total Soluble Solids. Variation among groups were minimal, but group RT presented higher values in the final analysis (Figure 2).

Number of seeds per fruit. Group Pink exhibited lower number of seeds per fruit, and group Brilliant Red had higher number of seeds (Figure 3).

Shape. Variability was low, all three groups were uniform, shape was oval (Table 1).

Table 1. Average of diameter and length of Ilama fruits.

	Diameter (cm)		Ratio
Group	Length	Diameter	D.Polar/D. Ecuatorial
White	11.52 a	10.32 a	1.11 a
Pink	12.01 a	8.66 b	1.38 b
Brilliant Red	9.65 b	9.33 b	1.03 a

Skin thickness. Very important when the time comes to handling fruit in market. Group Pink had a thicker skin (Table 2).

Table 2. Thickness of skin (cm) and weight of frutis (g) of three groups of Ilama.

Group	Thickness (cm)	Weight (g)
White	0.31 a	404.1 a
Pink	0.4 b	552.5 b
Brilliant Red	0.3 a	505.2 a

Biochemical variables. Titratable acidity of pulp was higher in group White (Figure 4). Values of pH were between 4 and 6 (Figure 4).

Physiological measures. Weight loss was uniform for all three groups (Figure 5). Respiration pattern correspond to a climacteric fruit with a climacteric peak after three days after harvest (Figure 6). Growth pattern was double sigmoid similar to the findings of Vidal (1993) (Figure 7).

Respiration Rate and Ethylene Production Under Controlled Atmosphere. Respiration rate was reduced by 30%, and the ethylene production diminished to 50%, in relation to normal atmosphere treatment, extending its shelf life 5 days more at room temperature (Figure 8).

Conclusions

Ilama fruits present a wide range of pulp colors, from white to brilliant red. Group Pink has favorable characteristics in total soluble solids, skin thickness and number of seeds per fruit. Their shape varies. Respiration was typical of climacteric fruits. Growth pattern of fruits was double sigmoid. Fruit skin cracking was one of the principal problems, especially in ripe fruits. Their shelf life is very short. Controlled atmosphere can be a way to extend it significantly, to allow shipment to distant markets.

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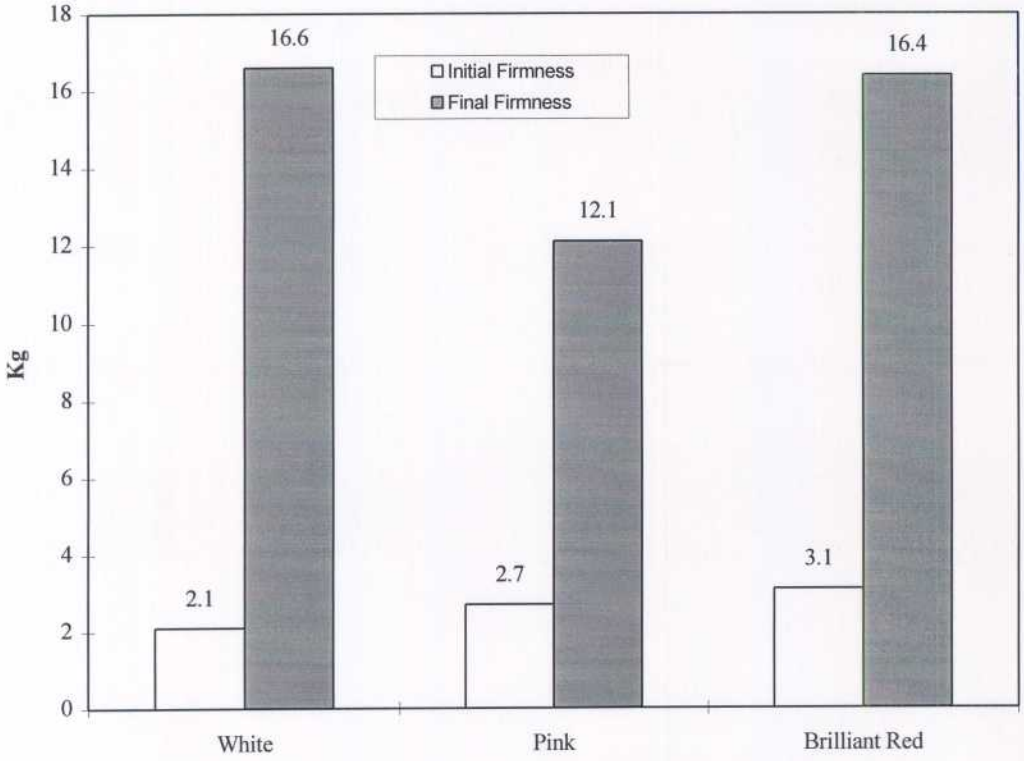

Figure 1. Initial and final Firmness of all three groups of Ilama.

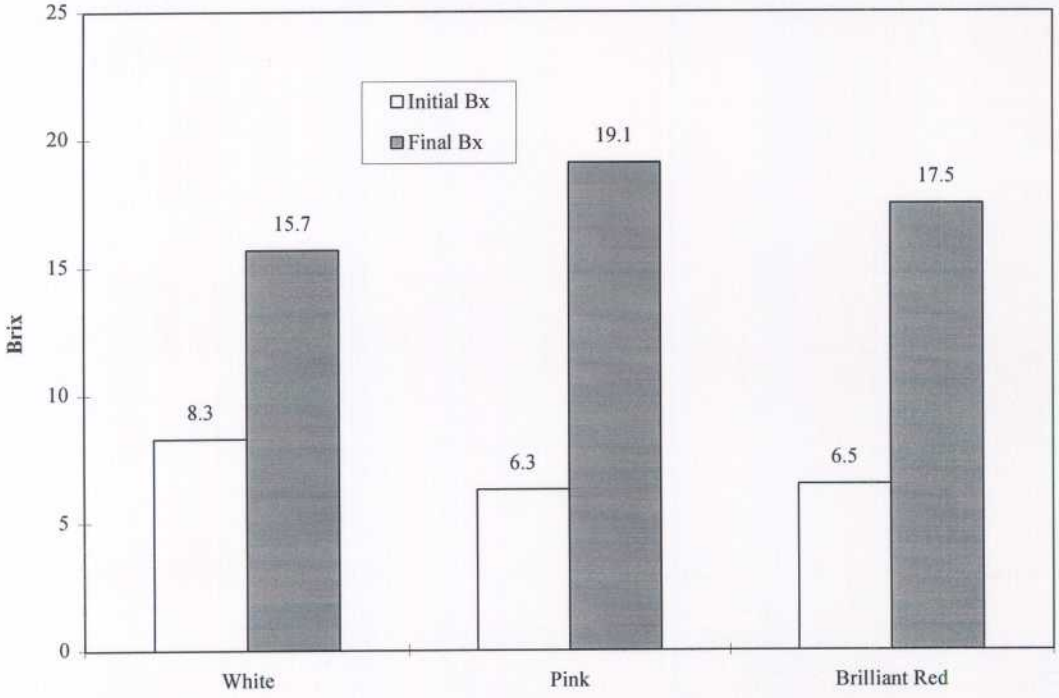

Figure 2. Brix initial and final of all three groups.

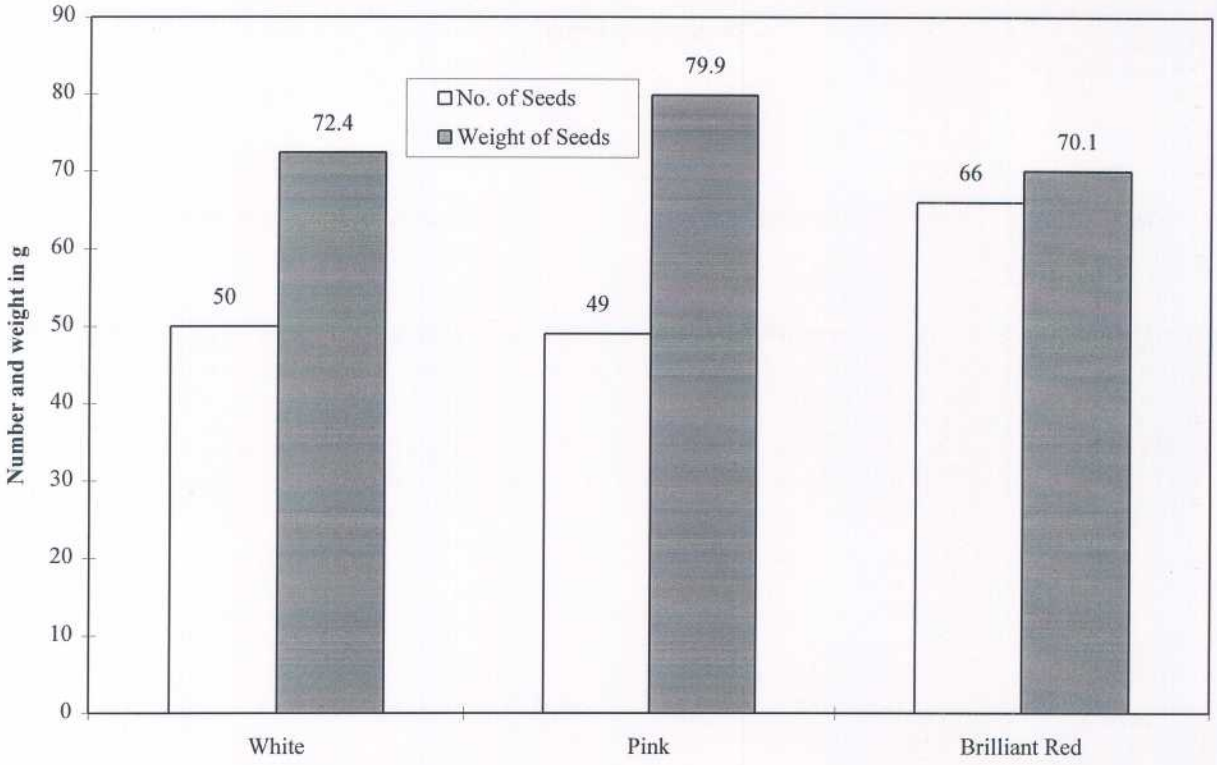

Figure3. Number and weight of seeds in all groups of Ilama.

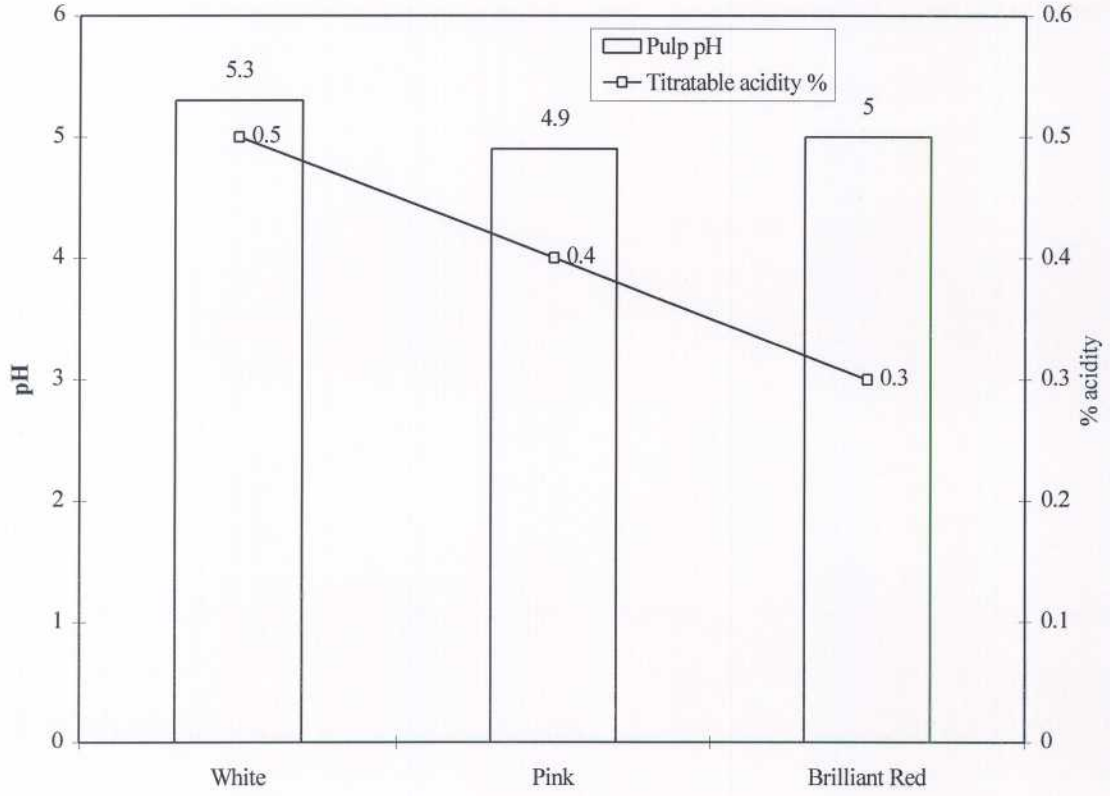

Figure 4. Pulp pH and titratable acidity of all groups of Ilama.

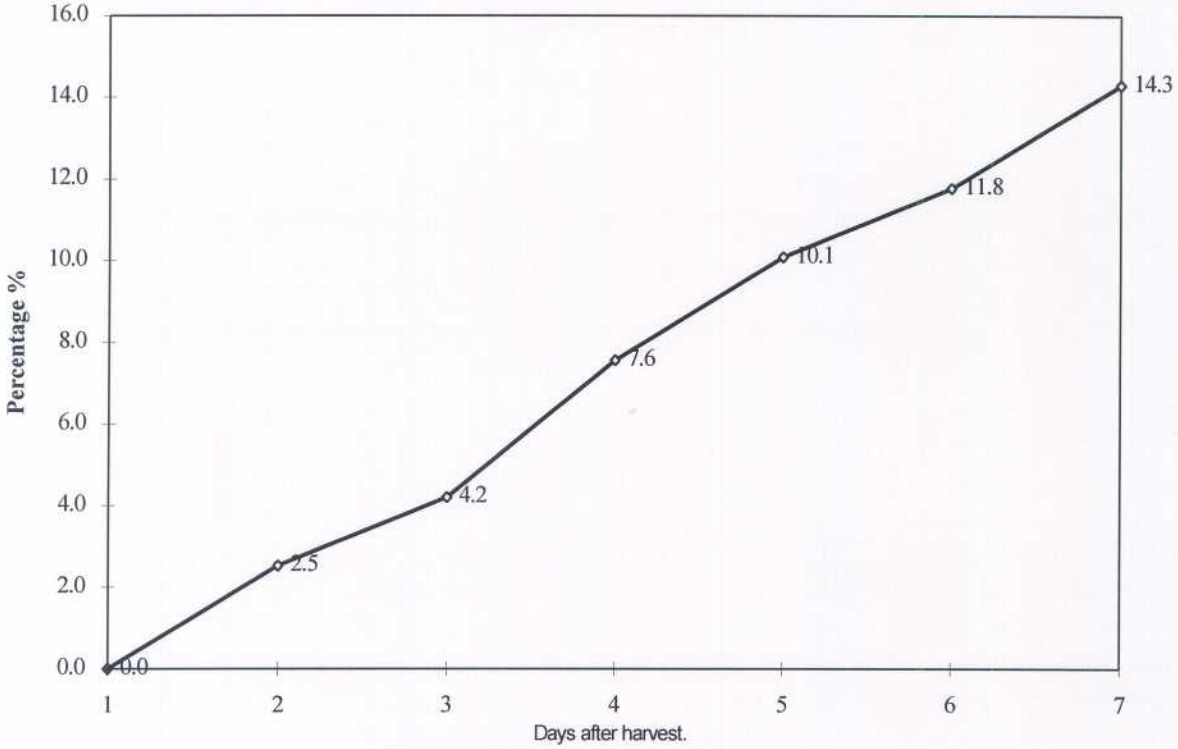

Figure 5. Weight loss % of all groups of Ilama.

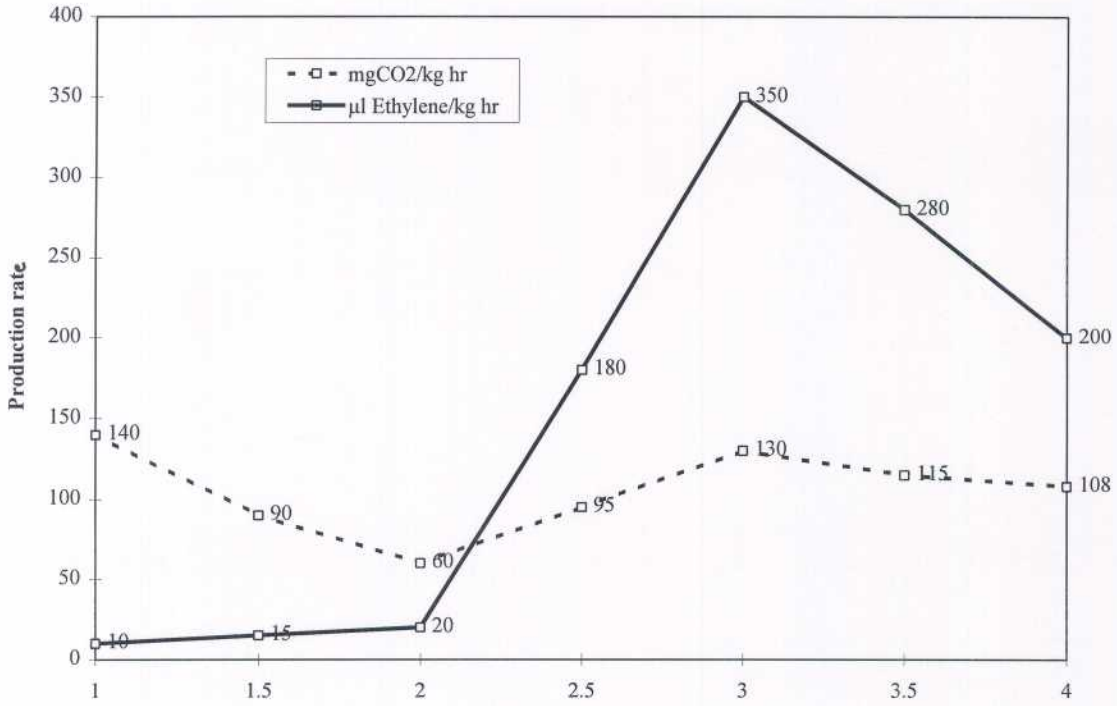

Figure 6. Respiration rate (mgCO2/kg hr) and Ethylene production (µl/kg hr).

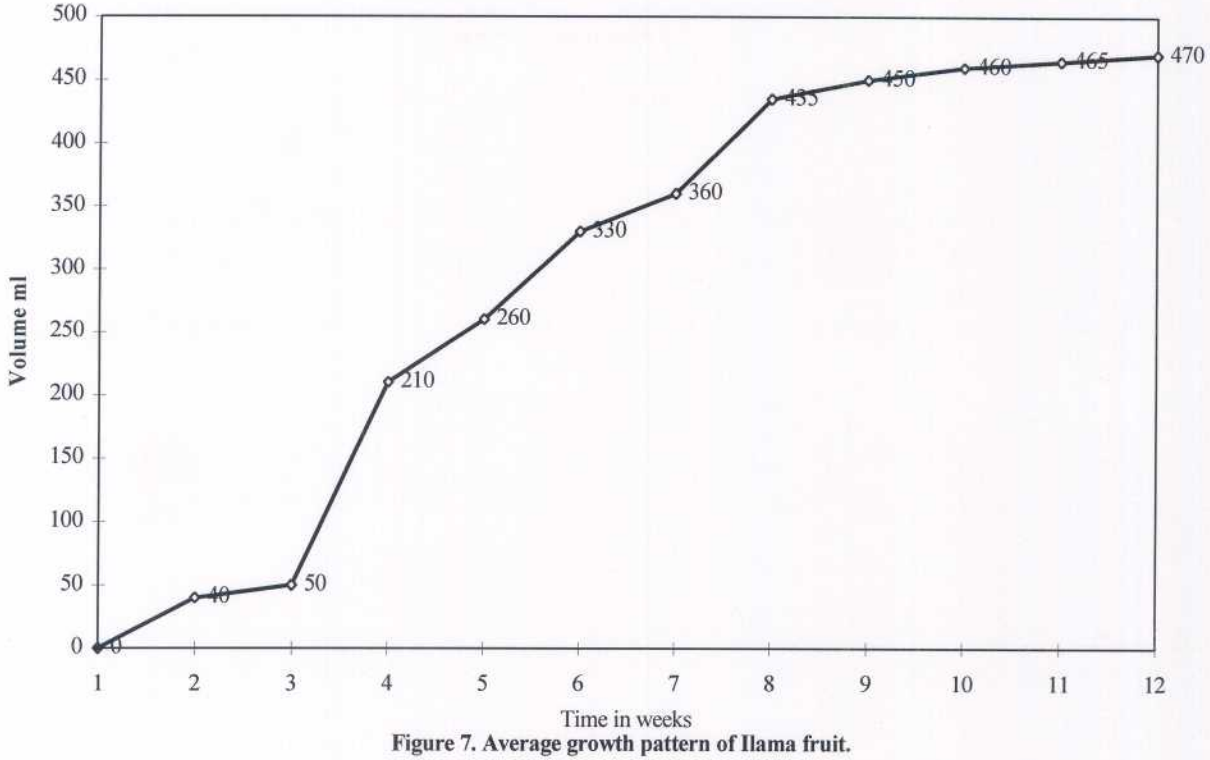

Figure 7. Average growth pattern of Ilama fruit.

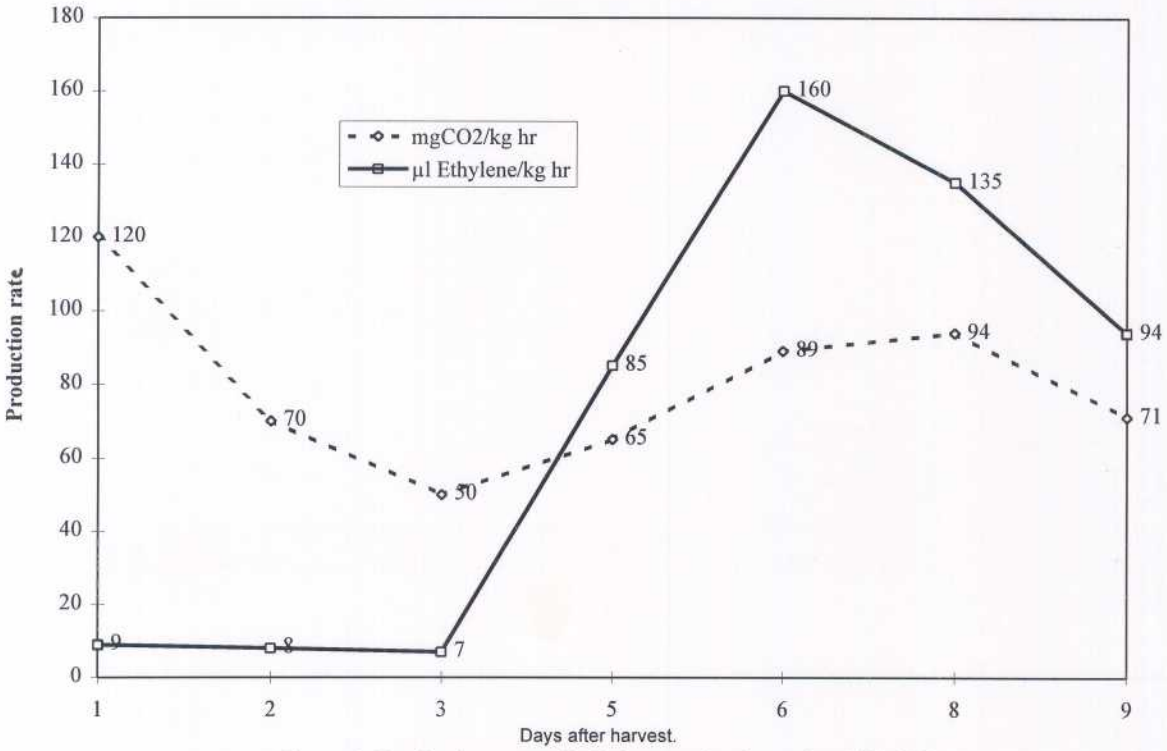

Figure 8. Respiration rate and ethylene production under 10% CO2.

Effect of Individual Film Wrapping on Quality and Storage Time of Mandarin's Fruit 'Dancy'

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Additional index words. Film wrapping, cold storage, water loss, firmness, ethanol, color index

Abstract. **Mandarin's fruit `Dancy´ with and without control individual film wrapping of polyolefin and PVC bases, were stored at commercial conditions (20 ± 2°C; 50-60% R.H.) for 6 days and the other treatment under cold storage (10 and 5°C; 85-90 R.H.) during 8 weeks plus 6 days at 20 ± 2°C. Water loss of control fruits was higher than film wrapped fruits, 4 to 6 times higher at 20°C, 6 to 7 times at 10°C and 7 to 9 times at 5°C. Firmness of control fruits was lower than film wrapped fruits, 4 times lower at 10°C and 2 times lower at 5°C. A significant reduction of fruits internal % CO_2 and ethanol level in juice was observed in film wrapping treatment, both at the same temperature, with no bad flavor and aroma. Internal quality (SSC, titratable acidity, and SSC/acidity ratio) remained unaffected for film wrapping treatment, except in color index that developed faster in controls with a poorest external quality. Results show that film wrapped 'Dancy' mandarin can be stored under cold storage up to 8 weeks, best results at 5°C, 85-90% R.H.**

Production of Citrus in Mexico has been estimated in 3.9 millions tons, 60.8% of oranges, 28.1% of limes and lemon, 7.4% of mandarin, and 11.1% of other kind of citrus fruits (Ramirez 1991). In case of mandarins and tangerines, only 6.7% is for exportation (mainly to the Unites States and Canada), mainly for sale on internal market. Mandarin 'Dancy' (Citrus reticulata blanco) is one of the most important due to its production level and its market value.

Actually internal market of mandarin and tangerine faces several problems, including the high concentration of production (with its problems of overproduction and lower prices), poor use of postharvest handling techniques, lack of cold storage and knowledge of the optimum cold storage temperature (about temperature, relative humidity, time and use of alleviated substances). Storing fruits on the tree has a lot of problems of fruit dropping, senescence and several physiological disorders that reduce appearance and quality of fruits.

Generally the optimum cold storage temperature is 5-8°C during 3-5 weeks, having differences among several cultivars (Yahia and Baez Sañudo, 1988). Long periods of cold storage reduce quality of thes fruits due to skin shrinking, decay and loss of flavor, firmness and physiological damage (Chilling injury).

According to several researchers, use of plastic and film wrapping based in polymeric substances, shelf life of citrus can be extended preserving its commercial quality (Kazuhice-

Kawada, et al. 1981). With this techniques senescence can be delayed, water loss reduced and decay and damage of skin due to chilling injury can be diminished (Ben-Yehoshua et al. 1981). Those advantageous effects are related to a micro-atmosphere created between fruit and film, which alleviate water stress and senescence damages (Ben-Yehoshva et al. 1983). Film efficiency depends of its thickness and gas permeability, in relation to the fruit physiology (Saucedo Veloz 1989). Objectives of this research were to study the effect of film wrapping on senescence and preservation of fruit quality of 'Dancy' mandarin, under cold storage during different periods of time.

Materials and Methods

Mandarin fruits 'Dancy' were harvested in January, 1991 with a maturity index of 10.8 (acidity ratio), washed, cleaned and classified according to its size, to establish the next treatments:
1) Control (No film wrapped); 2) Film Polyolefin, wrapped individually (Polyolefin multi-layer 19 μ thick); and 3) Film PVC, wrapped individually (25 thick).

Stored at commercial conditions (20 +- 2°C; 50-60% RH) during 12 days (control), and 20 days for film wrapped fruit. Others were stored at 10 and 5°C during 4 to 8 weeks and transferred to 20 ± 2°C. Variables measured were: Weight loss (%), firmness (deformation in mm under a force-weight of 254.7 g during 10 seconds, reporting data as % of loss of firmness related to their initial values), total soluble solids, titratable acidity reported as % citric acid/ 100ml of juice (AOAC, 1980), maturity index (SSC/acidity ratio), color index (1000 a/bL using a Hunter Lab equipment) reporting data as % of color enhanced related to its initial values (Jimenz-Cuesta et al. 1981), ethanol content using Davis and Chace method (1986), and internal content of % CO_2 (Saltveit, 1982). In each measure a 10 fruits sample was used, and a single fruit was the experimental unit. To analyze data a statistical software SAS was used to run Tukey test (α= 0.05).

Results and Discussion

Weight loss under commercial conditions using film wrapping was low (Table 1.), which after 20 days was 2.2% for polyolefin and 3.2% for PVC, against 14.1% for control fruits after 12 days of storage. The same tendency was noticed in fruits under cold storage at 10°C (34.2, 5.3 and 6.2% for control, Polyolefin and PVC respectively), at 5°C (29.1, 4.0, and 3.7 in the same order). Statistically significant was the lower temperature and PVC film treatment with lower weight loss (Table 2). This positive results confirm those reported for Cuquerella et al. (1988) and Ben-Yehoshua (1985) explaining that is due to a micro atmosphere saturated of water vapor between film and the fruit surface reducing the stress of water loss, and abating skin shrinking delaying senescence.

Table 1. Effect of two film wrapping materials on weight loss, firmness and color index of 'Dancy' mandarin, under commercial storage conditions [x].

Treatment	Weight Loss (%)	Firmness Loss (%)	Color Index (%)
Control[y]	14.1 a [z]	141.7 a	36.8 a
Polyolefin [w]	2.2 b	37.5 b	12.8 b
PVC	3.2 b	8.3 b	13.5 b

[x] = Environmental conditions: 20 ± 2°C; 50 - 60% RH.
[y] = 12 days of storage.
[w] = 20 days of storage.
[z] = Mean within each columns with the same letter are not significantly different with Tukey test (5%).

In relation to firmness loss, a significant reduction was observed in film wrapped treatment kept under room temperature as well as in cold storage (Table2). This was more evident at 5°C where fruits exhibited firmness loss in relation to its initial values in the amount of: 87.5, 41.6 and 54% for control, polyolefin and PVC respectively. This confirms the findings of Ben-Yehoshua et al. (1985) about the interrelationship between weight loss, firmness, water potential of tissues and cellular membrane integrity.

Table 2. Effect of two film wrapping materials on weight loss, firmness and color index of 'Dancy' mandarin, under cold storage conditions [x].

Treatment	Weight Loss (%)	Firmness Loss (% of initial value)	Color index (% of initial value)
10°C			
Control	34.2 a [y]	300.0 a	208.4 a
Polyolefin	5.3 b	125.0 b	197.0 a
PVC	6.2 b	187.5 a	274.5 a
5°C			
Control	29.1 a	87.5 b	84.6 b
Polyolefin	4.0 b	41.6 c	42.1 b
PVC	3.3 b	54.0 c	62.7 b

[x] = Data acquired after 8 weeks of storage plus 6 days under room temperature or commercial handling.
[y] = Mean values with the same letter within a column are not significantly different, with Tukey test (5%).

Color index increased with time and at higher storage temperature, following its normal evolution, and value 'a' of Hunter was more sensitive to measure color change of fruits as a loss of Chlorophyll pigment. Film wrapped treatment was not important under the same cold storage temperature in relation to the control treatment. However under commercial handling at room

temperature film wrapping achieve a lower color index (Table 1). The higher color evolution at 10°C probably was due to an accumulation of ethylene in the micro-atmosphere enough to induce a degreening effect, or maybe higher temperature allowed a higher gas CO_2 diffusion through the Film (Ahrens and Balmore, 1988).

Changes of internal quality during storage (commercial and cold storage), are presented in Tables 3 and 4.

Table 3. Effect of two film wrapping materials on internal quality of mandarin 'Dancy', under commercial storage conditions [x].

Treatment	Total Soluble Solids (%)	Titratable acidity (g citric acid/100 ml)	Maturity index (SSC/acidity ratio)
Initial	10.82	1.016	10.7
Control[y]	12.5 a [z]	1.01 a	12.4 a
Polyolefin [w]	12.5 a	1.04 a	11.9 a
PVC [w]	12.4 a	1.25 a	9.9 a

[x] = Environmental conditions: 20 ± 2°C; 50-60% HR
[Y] = 12 days of storage.
[w] = 20 days of storage.
[z] = Mean values with the same letter within a column are not significantly different, with Tukey test (5%).

Table 4. Effect of two film wrapping materials on internal quality of mandarin 'Dancy', under cold storage conditions [x].

Treatment	Total Soluble Solids (%)	Titratable acidity (g citric acid/100 ml)	Maturity index (SSC/acidity ratio)
Initial	10.82	1.016	10.7
10°C			
Control	14.5 a[y]	0.90 a	16.1 c
Poliylefin	11.4 b	0.40 b	29.0 a
PVC	11.8 b	0.43 b	27.5 ab
5°C			
Control	14.2 a	0.83 a	17.1 bc
Poliylefin	11.6 b	0.94 a	12.3 c
PVC	11.7 b	0.69 ab	16.9 bc

[x] = Data obtained after 8 days of storage plus 6 days at room temperature.
[y] = Mean values with the same letter within a column are not significantly different with Tukey test (5%).

Results of internal atmosphere measures of fruit under cold storage, allowed to know the efficiency of Film wrapping treatment in relation to CO_2 diffusion, where its CO_2 concentration were significantly lower, 4 to 9 times lower than controls, at 10 and 5°C (Table5). Ethanol content

in juice was higher in control (139.4 and 125.6 mg/100 ml for 10 and 5°C), than in film wrapping treatment. Lower levels of CO_2 and ethanol of Controlss showed evidence of higher senescence to the end of the storage time period.

Table 5. Effect of film wrapping treatments on internal atmosphere and ethanol content of 'Dancy' mandarin fruit under cold storage [x].

Treatment	Internal Atmosphere (% CO_2)	Ethanol (mg/100 juice)
10°C		
Control	1.97 a [y]	139.4 a
Polyolefin	0.30 b	48.7 b
PVC	0.32 b	52.12 b
5°C		
Control	0.95 a	125.6 a
Polyolefin	0.24 b	59.0 b
PVC	0.27 b	54.5 b

[x] = Data obtained after 8 days of storage plus 6 days at room temperature.
[y] = Mean values with the same letter within a column are not significantly different with Tukey test (5%).

Conclusions

1) Utilization of individual film wrapping materials allows extension of shelf life of 'Dancy' mandarin fruit, stored room temperature and under cold storage conditions.
2) Film effects include minimizing weight loss, retaining firmness, reducing accumulation of ethanol and CO_2, and maintaining internal quality.
3) Lower storage temperature enhanced the positive effect of films.
4) 'Dancy' Mandarin fruits can be stored at 5°C, 85-90 % RH for 8 weeks plus 6 days at 20 $\pm$ 2°C, 50-60 % RH, in acceptable conditions of appearance and quality.

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Identification of Optimum Preprocessing Storage Conditions to Maintain Quality of Black Ripe 'Manzanillo' Olives

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Black ripe olives (*Olea europaea* cv. Manzanillo), used for processing into canned olives or oil, were stored at 0°C, 2.2°C and 5°C in air or 2% O_2 (balance N_2). Olive samples were analyzed initially, and after 2, 4 and 6 weeks for fruit quality based on color (L* a* b*) and firmness. CO_2 and C_2H_4 production of the olives were monitored during the storage period. Weight loss (%), and decay incidence (%) were recorded. Visual quality of the olives was assessed on a 1-9 Hedonic scale. Fatty acid composition of the olives were determined by gas chromatography.

Fruit firmness declined by 15.4 to 22.5% after 2 weeks storage in both the air and 2% O_2 treatments irrespective of storage temperature. Olive fruit firmness was not significantly different between the air and 2% O_2 stored fruit. Ethylene production and respiration rates were much higher at 5°C than at 0°C or 2.2°C. Ethylene and CO_2 production rates of olives stored in air were significantly higher than those of olives stored in 2% O_2. Decay incidence increased with storage temperature and duration but it was lower in black ripe olives kept in 2% O_2 than those stored in air. After 6 weeks all treatments had more than 25% decay rendering them unacceptable from a commercial point-of-view. The percent decay after 4 weeks in 2% O_2 was 9.2, 8.2, 7.7 in olives kept at 0, 2.2, and 5°C, respectively. In conclusion, black-ripe 'Manzanillo' olives can be stored at 2.2°C to 5°C in 2% O_2 for up to 4 weeks between harvesting and processing.

Changes in Pomegranate Anthocyanins, Phenylalanine Ammonia Lyase and Glucosyltransferase in Response to Carbon Dioxide Treatments

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Additional index words. Color, quality

Abstract. **We investigated the influence of CO_2 on the changes in aril pigmentation in pomegranate and on activity of phenylalanine ammonia lyase (PAL; EC 4.3.1.5) and UDP-glucose:flavonoid 3-O-glucosyltransferase (GT; EC 2.4.1.91) in California-grown 'Wonderful' pomegranates. Pomegranates were placed in jars and ventilated with air or air enriched with 10% CO_2 at 10°C and were analyzed initially, and after 1, 2, 4 and 6 weeks. Six anthocyanins (delphinidin 3-glucoside and 3,5-diglucoside, cyanidin 3-glucoside and 3,5-diglucoside and pelargonidin 3-glucoside and 3,5-diglucoside) were identified and quantified by HPLC. CO_2 treatments inhibited the growth of decay organisms compared with air stored fruits. CO_2 had no effect on pH, titratable acidity and soluble solids content of pomegranate juice. However, the total anthocyanin concentration of the fruit increased during storage in air, and to a lesser extent in air+10% CO_2, but not in air+20% CO_2. Monoglucoside derivatives from pomegranates held in air and air +10% CO2 increased during storage while the diglucosides showed no changes. PAL activity, expressed as pkat/mg protein, increased with time at 10°C for fruit stored in air and air+10% CO_2, reaching a maximum at 4 weeks. On the contrary PAL activity of fruit stored in air+20% CO_2 decreased during storage. The activity of GT did not differ among treatments and storage durations.**

Controlled atmosphere (CA) storage (modification of O_2 and/or CO_2 concentrations) has been used to extend the postharvest life of fruit and vegetables, reduce decay and the incidence of certain physiological disorders. Preservation of the color of pomegranate arils is an important quality attribute for consumers. However, the effect of CO_2-enriched atmospheres on the stability of anthocyanins is not well known. Our objective was to investigate the influence of CO_2-enriched atmospheres on aril pigmentation and the activity of phenylalanine ammonia lyase (PAL; EC 4.3.1.5) and UDP-glucose:flavonoid 3-O-glucosyltransferase (GT; EC 2.4.1.91). An overview of our results is presented in this report; for more details see paper by Holcroft et al., 1998.

Materials and Methods

'Wonderful' pomegranates (*Punica granatum* L.) were obtained from a packinghouse near Fresno (California, USA) and stored in air or air enriched with 10% or 20% CO_2 at 10°C for 6 weeks. Three replicates of five pomegranates each were used per treatment and placed in jars ventilated with a continuous flow of humidified air or the desired gas mixtures by using flow boards and capillary tubing. Samples were analyzed initially, and after 1, 2, 4 and 6 weeks of

storage. External skin color was assessed at four equatorial points on the fruit with a Minolta colorimeter (model, CR 300), expressed as L* a* b* color values and chroma was calculated from these data. Juice absorbance was evaluated at 510 nm for anthocyanin content after a 1:5 dilution with citric acid buffer (pH 3.4). The different anthocyanins were identified by the UV spectra and retention times, and quantified by HPLC relative to cyanidin 3-glucoside (Holcroft et al., 1998). To study the activities of enzymes in the phenylpropanoid pathways, PAL and GT were extracted and assayed according to Lister et al. (1996). Protein concentration was determined by the microassay method of Bradford (1976).

Results and Discussion

The intensity of the skin color (chroma) was maintained better when the fruits were stored for 4 or 6 weeks at 10°C in air enriched with CO_2 than in air alone (Fig. 1). In contrast, the color of the arils was darker red in air-stored pomegranates compared to those subjected to the CO_2-enriched treatments (data not shown). In accordance with the visual appearance, there was an increase in the juice anthocyanins in pomegranates held in air and air+10% CO_2, but there were no significant ($P<0.05$) changes in absorbance of juice from fruit stored in air+20% CO_2 (Fig. 2). The observation that pomegranates with more intense skin color contained seeds with a juice which is less rich in anthocyanins confirmed the data from a previous report on changes of pomegranate juice pigmentation with ripening (Gil et al., 1995).

The HPLC analyses of the juice confirmed the previous identification of anthocyanins for other pomegranate cultivars (Du et al., 1975). Six anthocyanins are responsible for the red color in 'Wonderful' pomegranate seeds and have been identified as delphinidin (Dp) 3-glucoside and 3,5-diglucoside, cyanidin (Cy) 3-glucoside and 3,5-diglucoside and pelargonidin (Pg) 3-glucoside and 3,5-diglucoside. The total anthocyanin concentration increased during storage in air and in air+10% CO_2 but not in air+20% CO_2 (Fig. 3).

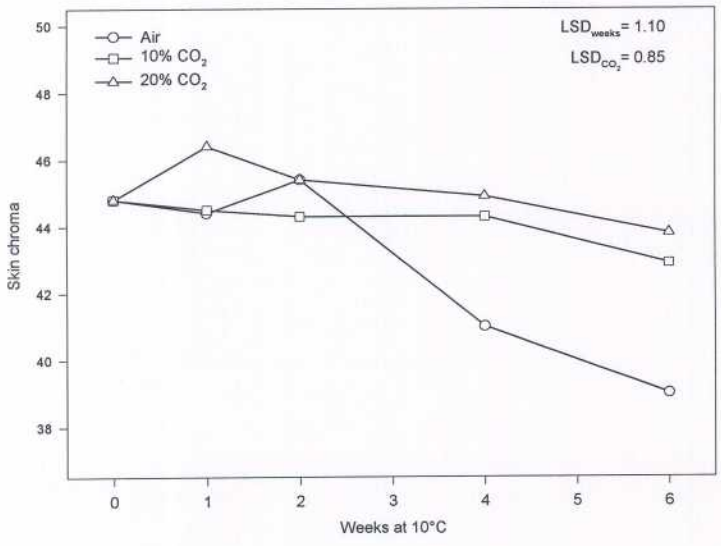

Fig. 1 Chroma value of the skin of 'Wonderful' pomegranate, initially and after 1, 2, 4 or 6 weeks at 10°C in air or CO_2-enriched air.

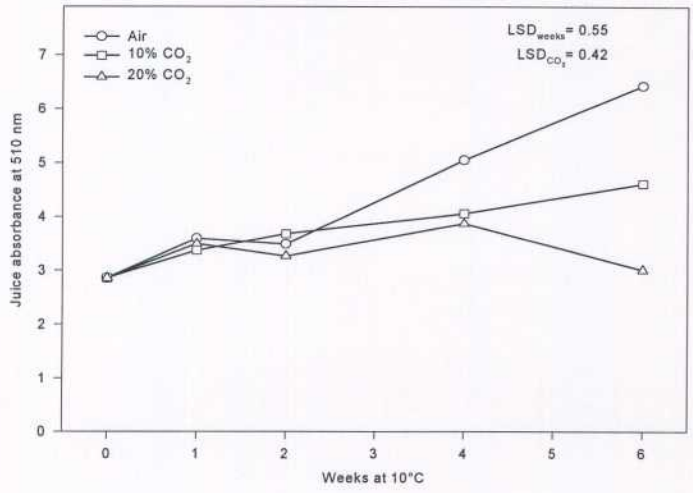

Fig. 2 Absorbance (510 nm) of the juice of 'Wonderful' pomegranate, initially and after 1, 2, 4 or 6 weeks at 10°C in air or CO_2-enriched air.

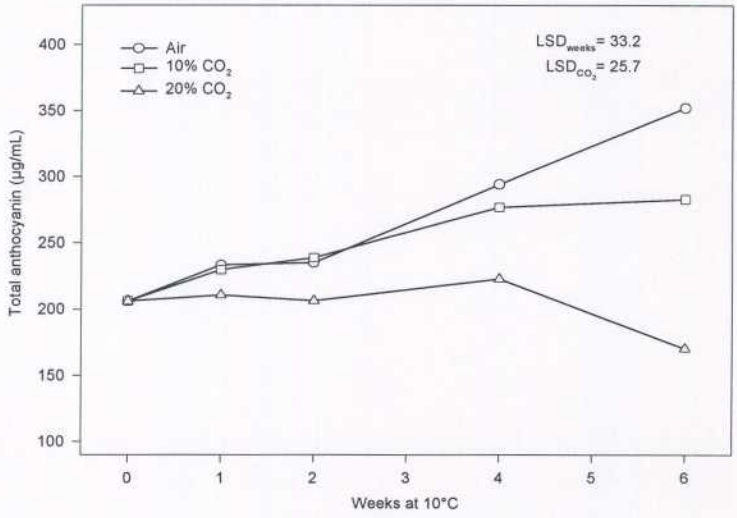

Fig. 3 Total anthocyanin concentration (µg/mL) of 'Wonderful' pomegranate juice, initially and after 1, 2, 4 or 6 weeks at 10°C in air or CO_2-enriched air (from Holcroft et al., 1998).

PAL activity, expressed as pkat/mg protein, increased with time for pomegranates stored in air and air+10% CO_2, reaching a maximum at 4 weeks, but decreased in those kept in air+20% CO_2 (Fig. 4). Similarly, high PAL activity has been associated with the accumulation of anthocyanins in strawberry (Cheng and Breen, 1991). The activity of GT did not differ among storage treatments and durations (Fig. 4). Future research should include CO_2 effects on other enzymes involved in anthocyanin biosynthesis.

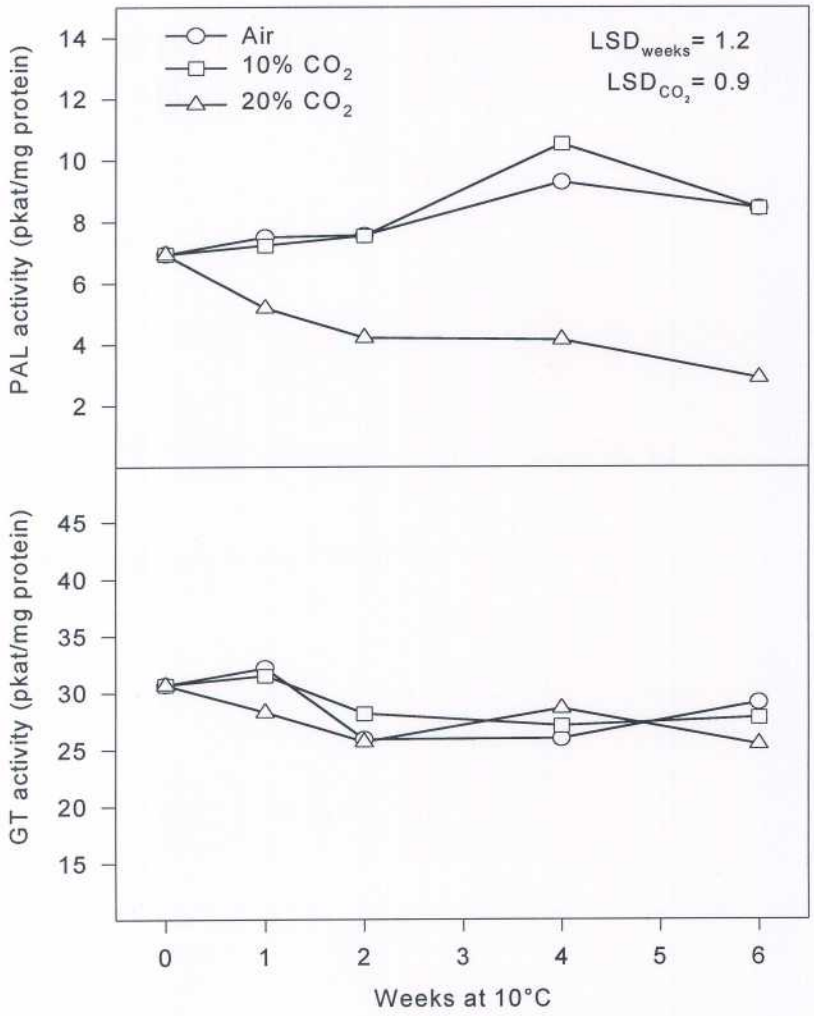

Fig. 4 Changes in PAL and GT activities (pkat/mg protein) of 'Wonderful' pomegranate arils, initially and after 1, 2, 4 or 6 weeks at 10°C in air or CO_2-enriched air (from Holcroft et al., 1998).

In conclusion, pomegranates can be exposed to moderate (up to 10%) CO_2 atmospheres which are fungistatic (inhibit the growth of decay-causing fungi) while only resulting in a small reduction in aril anthocyanins and red color intensity.

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Controlled Atmosphere Storage of the Pomerac

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Additional index words. Malay apple, quality

Abstract. **The Pomerac, botanically identified as *Syzygium malaccense* is also called the French Cashew, Malay, Malacca or Otaheite Apple. This fruit is brilliantly red in appearance with a crisp texture and a lightly sweet flavour. Previous research has shown that the Pomerac is a non-climacteric fruit and may be satisfactorily kept in refrigerated storage at 5°C for 20 days. The response of the Pomerac to CA Storage conditions at 5°C of 1% O_2 and 5, 8, 11 and 14% CO_2 was investigated in a storage trial lasting 30 days, in which a control, refrigerated (5°C) treatment was also included. Control fruits showed an average weight loss of 0.087%/day compared to 0.037%/day for CA fruits. CA stored fruits were much firmer than control fruits and with the exception of one treatment (1% O_2, 5% CO_2), fruits were as firm or firmer than freshly harvested fruits, even after 30 days. CA storage demonstratively maintained the bright red colour and sugar of the Pomerac, as measured by the Hunter 'a' value and the TSS content, compared to control fruits, which faded and lost their sweetness much more rapidly. CA storage of the Pomerac has considerable possibilities for the maintenance of fruit quality in storage.**

A delight to the eye in every respect, the Malay apple is much admired for the beauty of the tree, its flowers and its colourful, glistering fruits (Morton, 1987). Identified as Syzygium malaccense, this species has been called by other common names in the Caribbean (Devi Prasad, 1986) including Pomerac (Trinidad & Tobago, Barbados), Otaheita apple (Jamaica) and Plum rose, Malacca apple or French cashew (Eastern Caribbean Islands). The fruit is typically bellshaped, 5-10 cm long and 2.5-7.5 cm wide at the base with a strikingly attractive colour, rose-red or crimson or sometimes white with streaks of red and pink. The fruit has a thin, smooth waxy skin and a single oblate or nearly round seed, 1.6-2.0 cm in diameter and with a white fruit flesh, usually crisp and juicy with the juice being of a mild, sweetish flavour (Morton, 1987).

The Pomerac is an unexploited Caribbean fruit of considerable potential. Besides its use as a fresh table fruit, it is increasingly being used in wine manufacture and may also be stored and served as a dessert among other food uses. The fruit has poor keeping qualities, a few days under ambient conditions, during which time there is rapid softening. There is usually severe wastage of fruits, with fruits ripening on the trees and falling to the ground. As appropriate harvest and post-harvest system including for example fruit maturity at harvest has not yet been developed for the Pomerac, and little is known about the fruit's postharvest behavior. Such a system can facilitate its local marketing and particularly export possibilities. Basanta and Sankat (1995) reported that the Pomerac had a shelf life of 4-6 days under ambient conditions, while fruits stored under refrigeration at 10°C and 15°C were shrivelled and decayed with loss of skin colour after 10-15 days in storage. However fruits stored at 5°C were acceptable even after 20 days in storage. Akamine and Goo (1979) reported on the non-climacteric nature of this fruit, with CO_2 production declining from 54.2 ml/kg.h to 20.1 ml/kg.h in the first 3 days at 24.0-25.7°C, then remaining more or less constant with no detection of C_2H_4 production. Basanta and Sankat

(1996) also reported on the non-climacteric respiratory patterns of the Pomerac when stored under ambient (28°C), 15°C, 10°C and 5°C.

Atmospheres with reduced 0_2 and/or elevated CO_2 levels can supplement refrigeration and are known to extend the storage life of fruits and vegetables (Kader, 1992). This study looks at certain facets of the postharvest behaviour of red-ripe, Pomerac stored under controlled atmosphere (CA) conditions of 1% O_2 and varying CO_2 levels and at 5°C.

Materials and Methods

Two hundred (200) firm red-ripe, Pomeracs were randomly separated into 5 experimental storage treatments as follows:

Treatment 1: 1% O_2, 5% CO_2 at 5°C
Treatment 2: 1% O_2, 8% CO_2 at 5°C
Treatment 3: 1% O_2, 11% CO_2 at 5°C
Treatment 4: 1% O_2, 14% CO_2 at 5°C
Control: Normal refrigerated conditions at 5°C

Approximately 40 fruits each were placed into airtight 10L plastic buckets whose covers were filled with inlet and outlet gas valves for the CA treatments. Desired levels of O_2 and CO_2 were obtained and maintained through a gas handling and sampling system connected to cylinder of O_2, N_2 and CO_2. Oxygen levels were measured by a Servomex Oxygen Analyzer - Type 570A (Servomex, Sussex, England) while carbon dioxide levels were measured by an ADC Infrared Gas Analyzer - Model SB-305 (ADC, Herts, England). All buckets were placed in a Bally walk - in refrigerated storage room (Bally Engineering, Virginia, USA) at 5°C and at approximately 85%rh.

Fruits were stored for a maximum of 30 days, and at 5 day intervals, 4 fruits from each treatment were analyzed for quality changes. Three identified fruits in each bucket were kept for weight loss monitoring only. Measurements made were:

(i) The % weight loss of fruits during storage was calculated from the weights of fruits immediately before (W_1) and after storage (W_2), i.e.,

$$\text{Weight loss \%} = \left(\frac{W_1 - W_2}{W_1} \right) \times 100$$

(ii) Fruit firmness was evaluated through the penetration depth of a 33g cone (17mm base diameter and 37mm high) plus an added weight of 50g using a Stanhope-Seta Model 1700/3 penetrometer (Stanhope-Seta, Surrey, England).

Fruit Firmness was expressed as :

$$\frac{1}{\text{penetration depth of cone}} (\text{mm}^{-1})$$

(iii) Fruit colour was measured by a Hunter Labs 45°/0° Model D25 - PC2Δ colorimeter (HunterLab, Virginia, USA)

(iv) Total Soluble Solids (TSS) was measured by an Atago-N Series hand held refactometer (Atago, Tokyo, Japan).

(v) Fruit taste/flavour was sensorially evaluated by a 10 member panel using the following scale:

Score	Flavor & Special Attributes
1	Excellent, full, distinctive Pomerac flavour
2	Good, typical Pomerac flavour
3	Satisfactory, flavour loss detected and hint of off flavour
4	Poor, unpleasant, lacking in flavor
5	Inedible.

All experimental measurements were made in duplicate and the entire experiment was repeated. All results were statistically analyzed by ANOVA.

Results and Discussion

Weight loss in storage (Figure 1) was significantly affected ($p<0.001$) by storage time and treatment. Control fruits showed the highest % weight loss averaging 0.087 %/day ($r^2 = 0.85$) whereas CA stored fruits behaved similarly, with an average % weight loss value for all treatments being 0.037%/day ($r^2 = 0.85$). These are expected results as CA fruits are isolated from the refrigerated storage environment and are not being subjected to any air movement, compared to refrigerated stored fruits and hence transpirational losses are minimal. Suppression of respiration in CA will also contribute to this water loss reduction.

Fruit firmness in storage was significantly affected ($p<0.001$) by storage time and treatment. When freshly harvested, fruits had a firmness rating of 0.17 mm^{-1}. Fruit firmness increased for all treatment until the 20^{th} day after which fruit softening occurred (Figure 2). CA stored fruits were much firmer than control fruits for the entire trial, and with the exception of the $1\%O_2$: 5% CO_2 treatment were all as firm as freshly harvested fruits even after 30 days. Wills et al. (1981) noted that CA, particularly those containing high CO_2 inhibit the breakdown of pectic substances so that a firmer fruit texture is retained for a longer period.

The bright, red skin colour of the Pomerac as measured by the Hunter 'a' value was significantly ($p<0.001$) affected by storage time and treatment. While control fruits showed a rapid decline in 'a' value (Figure 3) from an initial value of 32.2 to 26.6 after 30 days, CA fruits showed a much more gradual decline in 'a' value, with the treatments with the highest CO_2 levels 11% and 14% showing the lowest rate of red colour loss with 'a' values being 31.5 and 31.1 respectively after 30 days in storage. All CA stored fruits were still attractively bright. It is noted that as the red skin colour faded in the stored Pomerac, a yellow, tan skin colour developed. Ke and Kader (1992) noted that when red nectarines were stored in CA, there were no significant changes to the skin colour. Markakis (1980) noted that oxygen is generally considered detrimental to the anthocyanin coloration of foods.

TSS of stored fruits were significantly affected ($p<0.001$) by storage time and treatment. Control fruits or fruits stored in a normal, refrigerated 5°C atmosphere showed the largest decline in TSS, falling from 12% to 7.2% after 30 days. This result demonstrated that the Pomerac loses its sweetness after being harvested at the red ripe stage. On the other hand, fruits under CA storage showed very small changes in TSS and at 5, 8 and 11% CO_2 were 11.4%, 11.4%, and

11.6%, respectively after 30 days (Figure 4). These results demonstrate the effect of CA in reducing sugar loss, may be through the suppression of respiration.

Fruit taste/flavour was also significantly affected by storage time and treatment (Table 1). All fruits including control fruits, had a satisfactory taste by day 30 indicating some flavour loss detected with a hint of off-flavour. The taste/flavour loss is consistent with the decline in TSS as stated earlier. At high CO_2 concentrations (15% or more), off flavour is usually produced in strawberry, banana, oranges, apples and other commodities (Ulrich, 1975). This does not appear to have occurred to any significant extend here, at least for this duration of storage. At 20 days however taste/flavour could be described as good to excellent.

Conclusion

The quality of the Pomerac was enhanced when stored under CA storage conditions of 1% O_2 and 5-14% CO_2 at 5°C compared to fruits stored under normal, refrigerated storage (5°C). Specifically, changes in weight loss, fruit firmness, fruit colour (and particularly the striking red colour of the Pomerac) as well as TSS content were retained in CA compared to control fruits. While CA storage is used principally to prolong the shelf life of certain perishables, in the case of the Pomerac, the influence of CA on its storage behaviour at 5°C is more clearly linked to quality maintenance rather than shelf life extension.

Acknowledgment

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Table 1. Taste/flavour ratings of pomerac stored under CA and control fruits at 5°C

	Taste/Flavour Score[z]						
	Days in Storage						
Treatment O_2%:CO_2%	0	5	10	15	20	25	30
1:5	1.0	1.0	1.0	1.0	2.0	2.0	3.0
1:8	1.0	1.0	1.0	1.0	2.0	3.0	3.0
1:11	1.0	1.0	1.0	1.0	1.0	1.0	3.0
1:14	1.0	1.0	1.0	1.0	2.0	2.0	3.0
Control	1.0	1.0	1.0	1.0	2.0	2.0	3.0

[z] 1 - Excellent, 5 - Inedible

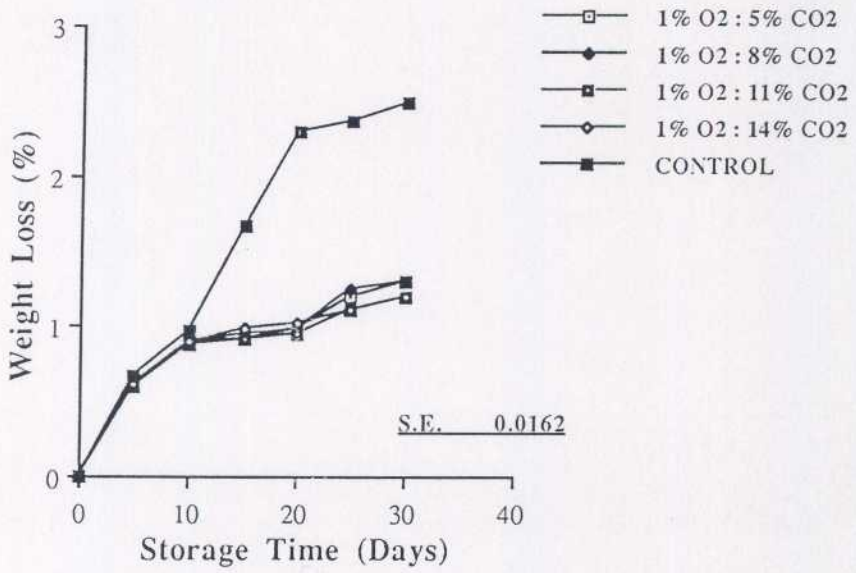

Figure 1. Weight loss of pomerac in CA and refrigerated Storage at 5°C

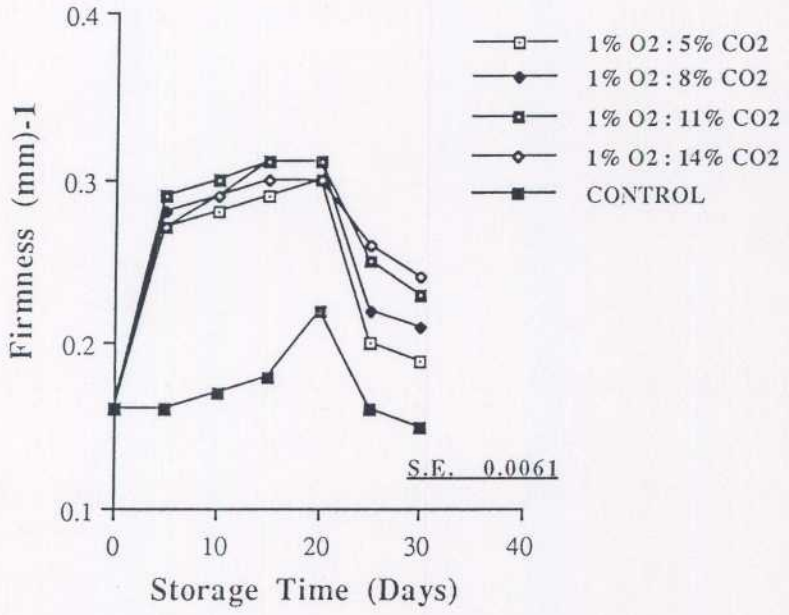

Figure 2. Firmness as measured by a penetrometer of pomerac kept in CA and refrigerated Storage at 5°C.

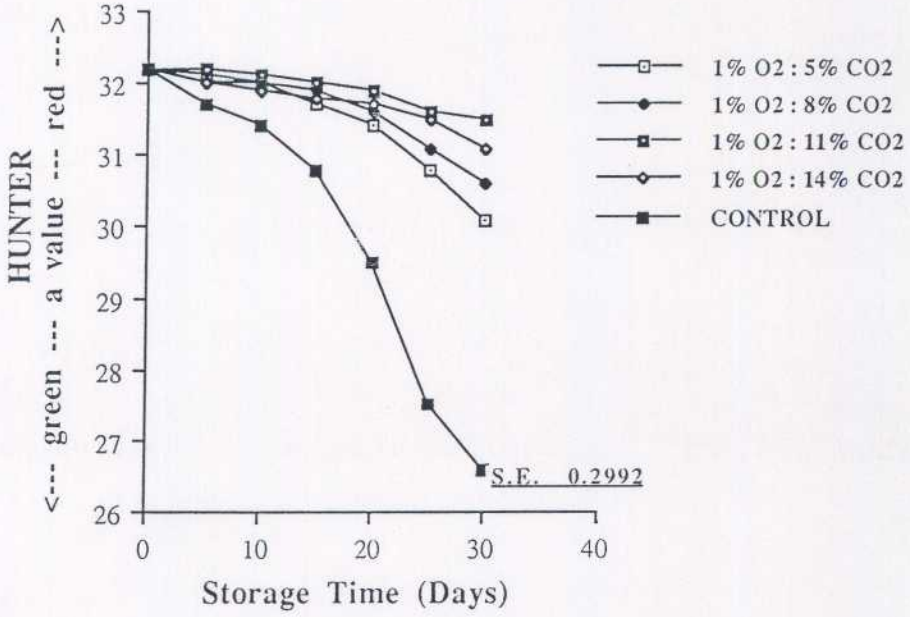

Figure 3. Hunter 'a' values of colour of the pomerac for CA and refrigerated storage at 5°C

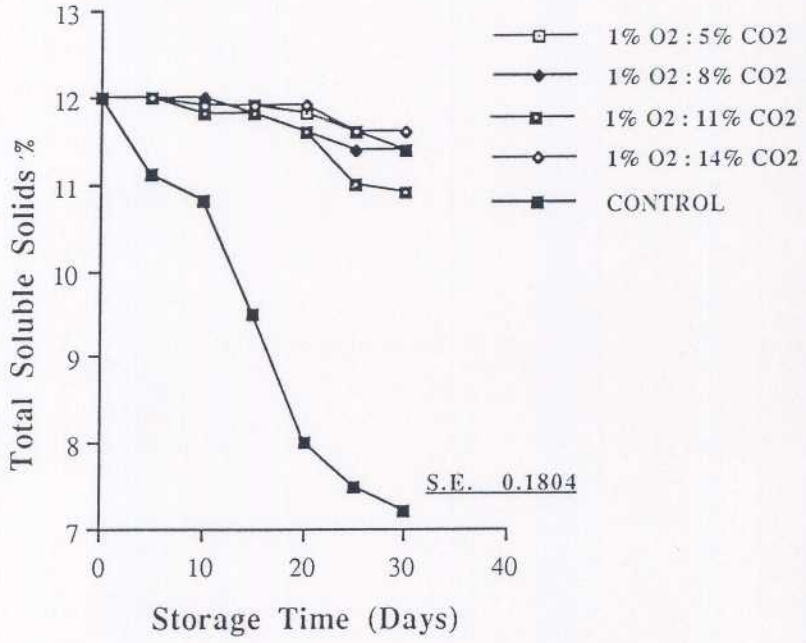

Figure 4. Total Soluble Solids (TSS) content of pomeracs in CA and refrigerated storage at 5°C

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