STORAGE RESPONSES OF FOUR APPLE CULTIVARS TO LOW-O_2 ATMOSPHERES

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A storage atmosphere of 2% to 3% O_2, generally established by fruit respiration or atmospheric generators over a period of 2 to 3 weeks, is used commercially in North America (2, 19) to maintain apples in reasonably good condition for 5 to 7 months after harvest. In British Columbia, a storage period of 8 to 10 months is now possible in a 2.5% O_2 atmosphere established by a "rapid CA" storage procedure (10-11). However, the large increase in apple production in recent years has created the need for lengthening the marketing period even further.

Experiments conducted during the past two decades (1, 3-10, 12-18, 20-21, 23) have shown that apples kept in 1.0% to 1.5% O_2 are firmer and maintain higher acidity than apples stored in 2% to 3% O_2 atmosphere. Commercial storage of Cox's Orange Pippin (20-21), McIntosh (14, 16), Spartan (12), Golden Delicious and Delicious (13) apples in 1.0% to 1.5% O_2 has been reported.

This paper discusses the effects of storage procedures, storage CO_2 concentrations, storage temperatures, and fruit maturity on storage quality and disorder of Spartan, Delicious, Golden Delicious, and McIntosh apples stored in low-O_2 atmospheres under laboratory and commercial conditions.

Samples of McIntosh, Golden Delicious, Spartan, and Red Delicious were obtained either from the orchards (Figure 1, Table 1:1979 & 1980 and Table 5) or from the commercial CA plants (Tables 1-4, 6-8). Fruit obtained directly from the CA plant included a wide range of orchard-to-orchard variability (e.g. cultural practices, micro-climates, exposure of fruit to sun, rain and frost in the orchard), as well as other variables such as delays in the orchard before transport to storage facilities. Replicated samples (5-48 for each storage treatment) were stored in CA cabinets (20- to 50-bushel in capacity), test room (1,000-bushel in capacity), and commercial CA rooms (25,000- to 37,500-bushel in capacity) at various concentrations of O_2 and CO_2 and temperature as specified in each table. With the exception of the experiment summarized in Table 5, all storage atmospheres were established by a "rapid CA" storage procedure (storage O_2 was reduced to 2.5% within 7 days of harvest).

Effect of Low-O_2 Atmospheres.

While Spartan and Delicious apples responded less to the rapid CA procedure than did Golden Delicious and McIntosh apples in 2.5% O_2 CA storage (11), they responded more to the 1.0% O_2 atmosphere (12N improvement in firmness for Spartan and 8N for Delicious; Table 1) than did Golden Delicious (5N; Table 1) and McIntosh (5N; Tables 6 & 8). The bulk of the firmness benefit observed in low-O_2 atmospheres was obtained when the storage O_2 concentration was reduced from 2.5% to 1.5%. Further reduction of storage O_2 concentration (e.g. to 1.0% or 0.5% O_2) led only to a small improvement of flesh firmness (Table 1).

Effect of CO_2 Concentrations.

Reduction of CO_2 from 2.0% in the standard storage atmosphere to 1.0% or 0.5% did not appreciably affect the firmness of Delicious and McIntosh apples kept in 1.0% or 2.5% O_2 (Table 3), but appreciably increased firmness loss of Spartan and Golden Delicious apples (Table 3) and core-browning in Spartan apples (Table 4) kept in 2.5% O_2. However, there was no such effect in comparable fruit lots kept in 1.0% O_2.

All B.C. apple cultivars tolerated 1.8% to 2.0% CO_2 in a 1.0% O_2 atmosphere. A storage CO_2 level of 1.0% to 1.5% is recommended for storing Spartan, Delicious, and Golden Delicious apples in 1.0-1.5% O_2.

Effect of Storage Procedures.

Spartan, Delicious, Golden Delicious, and McIntosh apples stored in low-O_2 atmospheres ranging from 1.0% to 2.5% with a "rapid CA" procedure were firmer than comparable lots stored with a "slow CA" procedure (Table 5).

In Spartan, Delicious, and Golden Delicious apples, a large firmness benefit was observed in fruit stored at 1.0-2.0% O_2 with a slow CA procedure (Table 5). In McIntosh apples, however, the beneficial effect of the 1.0% O_2 atmosphere on firmness observed in the rapid CA samples was not present in the slow CA samples (Table 5). Of significance is the observation that fruit stored in 1.0% O_2 established by a slow CA procedure were not as firm as those stored in a conventional atmosphere of 2.5% O_2 established by a rapid CA procedure. The results suggest that rapid CA is required in both standard-O_2 atmospheres (2-3%) and low-O_2 atmospheres (1-2%) for best results.

Factors Influencing Fruit Injury in Low-O_2 Storage.

Fruit injury is not a concern in Spartan, Delicious, and Golden Delicious apples harvested at commercial maturity and stored in 0° C low-O_2 atmospheres (1.0-1.5% O_2 + 0.5-2.0% CO_2) established by a rapid CA procedure. Sensory evaluations revealed no significant storage effect on the organoleptic qualities of these 3 apple cultivars (data not shown). However, storage of Spartan apples in a 0.5% O_2 atmosphere resulted in a large increase in skin discoloration (a blue or purple casting) and a small increase in flesh-browning and storage breakdown (Table 2). Fruit injury was nil in Golden Delicious and slight in Delicious apples kept in 0.5% O_2 (Table 2).

Successful storage of McIntosh apples in low-O_2 atmospheres over an extended period (e.g. beyond April or May) is critically dependent upon correct storage temperatures, storage atmospheres, and fruit maturity. A firmness benefit of about 5N was observed in this cultivar stored at 1.7° C (a standard storage temperature employed in B.C. for 2.5% oxygen storage) in a 1.0% O_2 atmosphere established by a rapid CA procedure. However, the fruit also developed a "corky" flesh-browning disorder (Table 6), which is characterized by discrete areas of diffuse speckled and corky brown tissue beneath the skin, often extending into the cortex of the fruit. It may appear in stored fruit as early as March but usually develops by late April or early May. Severity of the disorder increases when afflicted fruit is placed in warm temperatures.

The occurrence of corky flesh-browning varied considerably with source of fruit and season (Tables 6 and 7). Similar orchard-to-orchard and seasonal variability has been reported for the late-season corking disorder in Cox Orange Pippin apples stored at 1.25% O_2 (20-21). Although the use of a higher temperature (e.g. 3.0° C) eliminated or markedly reduced corky flesh-browning in most fruit lots harvested at commercial maturity (Tables 6 and 7), it was only partially effective in reducing the disorder in late-picked fruit (10% or more of the fruit with internal ethylene >1 ppm, starch-iodine index >5, and lower harvest firmness; Fig. 1). The results suggest that low storage temperatures (<3° C) promote the development of corky flesh-browning in McIntosh apples stored at low-O_2 atmopsheres. Like core-browning (22), corky flesh-browning can be regarded as a low-temperature disorder, manifested by low O_2, low temperature, and extended storage. Indications are that apples stored at low O_2 atmospheres for an extended period of time are generally more sensitive to low-temperature/low-oxygen disorders than those stored at a standard O_2 atmosphere.

A semi-commercial trial conducted in 1984 (Table 8) confirmed that McIntosh can tolerate a 1.0% O_2 atmosphere if the storage temperature is kept at 3.0° C. The fruit actually had less corky flesh-browning than those stored in 2.5% O_2 at a standard temperature of 1.7° C or those stored in 0.5% O_2 at 3.0° C.

McIntosh apples stored in 0.5% O_2 at 3.0° C had both internal (corky flesh-browning) and external (blue or purple discoloration on the skin) symtoms of low-oxygen injury (Table 8). The latter was not present in B.C.-grown McIntosh apples stored in 2.5% O_2 at 1.7° C or in 1.0% O_2 at 0.5-1.7° C (Tables 6-8, Figure 1) but it had been reported for Northeastern-grown McIntosh apples stored in 1.0% O_2 at 2.5-3.3° C (personal communication with W. Bramlage 1982, S. Lacasse 1983, and E. Lougheed 1982) or 10-20° C (14). The results suggest that development of internal low-O_2 injury (corky flesh-browning) is favored by low storage temperatures (e.g. 0.5-1.7° C) while external low-O_2 injury (skin discoloration) is favored by higher storage temperatures (e.g. 2.5-3.3° C and higher).

Conclusions.

B.C. Spartan, Delicious, and Golden Delicious apples harvested at commercial maturity can be safely stored in low-oxygen atmospheres (1.0%-1.5% O_2), with a higher firmness than comparable apples stored in a standard commercial atmopshere of 2.5% oxygen. However, these cultivars differed greatly in their firmness response to rapid CA and low-O_2 and low-CO_2 atmospheres.

Successful storage of McIntosh in 1.0% O_2 beyond April or May is highly dependent on correct storage temperature and fruit maturity. Corky flesh-browning in McIntosh appears to be a "low-temperature disorder", manifested by low O_2, advanced fruit maturity, and extended storage. McIntosh apples stored at low-O_2 atmospheres should be picked at a preclimacteric stage and must be stored at a minimum temperature of 3.0° C in order to avoid corky flesh browning.

"Low-O_2 CA" is not a substitute for good cultural practice, proper handling procedure, and correct storage condition. The rapid CA storage procedure is required for maximizing the firmness response of apples in low-O_2 atmospheres. A properly managed fruit selection program to exclude susceptible and over-matured fruit lots and a correctly maintained storage temperature and atmosphere are also needed to minimize injury in apples kept in low-O_2 CA.

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Table 1. Firmness benefit derived from low-O_2 storage[Z] of Spartan, Delicious, and Golden Delicious apples.

Storage unit	Crop year	SPARTAN Storage duration & Number of replicates	SPARTAN Firmness benefit (N) 1.0- 2.5%	1.0- 1.5%	0.5- 1.0%	DELICIOUS Storage duration & Number of replicates	DELICIOUS Firmness benefit (N) 1.0- 2.5%	1.0- 1.5%	0.5- 1.0%	GOLDEN DELICIOUS Storage duration & Number of replicates	GOLDEN DELICIOUS Firmness benefit (N) 1.0- 2.5%	1.0- 1.5%	0.5- 1.0%
EXP[Y]	1979	[176+ 0+0] 8[X]	4	1	-					[175+ 0+0] 5	7	1	-
			-	-	-						-	-	-
	1980	[231+ 0+0]10	12	0	-	[233+ 0+0]10	5	1	-	[231+ 0+0]10	3	1	-
		[231+28+7]10	9	3	-	[233+27+7]10	6	2	-	[231+26+7]10	2	0	-
	1981a	[245+ 7+0] 5	14	-	-	[253+ 4+0] 5	5	-	-	[261+ 1+0] 5	4	-	-
		[245+ 7+7] 5	15	-	-	[253+ 4+7] 5	8	-	-	[261+ 1+7] 5	8	-	-
	1982a	[284+ 7+0] 5	16	-	-	[294+11+0] 5	7	-	-	[289+ 7+0] 5	9	-	-
		[284+ 7+7] 5	19	-	-	[294+11+7] 5	12	-	-	[289+ 7+7] 5	7	-	-
E/C	1981b	[196+ 0+0]10	10	5	-					[200+ 0+0]10	1	1	-
		[196+ 8+7]10	13	9	-					[200+ 4+7]10	3	3	-
	1982b	[178+ 0+0]10	11	1	-	[206+ 8+0]10	6	1	-	[197+ 7+0]10	4	1	-
		[178+42+7]10	8	3	-	[206+ 8+7]10	11	5	-	[197+ 7+7]10	4	2	-
COM	1983	[193+ 0+0]45	-	3	-	[190+15+0]45	-	1	-	[201+13+0]45	-	1	-
		[193+78+7]45	-	1	-	[190+78+7]45	-	1	-	[201+78+7]45	-	0	-
	1984	[174+16+0]33	-	4	0	[173+13+0]33	-	1	-1	[180+14+0]33	-	3	0
		[174+77+7]33	-	3	-1	[173+80+7]33	-	2	-1	[180+76+7]33	-	2	1
AVERAGE			12	3	-1		8	2	-1		5	1	1

[Z] Storage CO_2 concn.: 1979 (1.8%); 1980 (2.0%); 1981a & 1982a (0.5-2.0%); 1981b, 1982b, 1983, & 1984 (1.0% for Delicious and 1.5% for Spartan & Golden Delicious).

[Y] EXP = conducted in 20-bushel CA cabinets; E/C = conducted in 20-bushel CA cabinets (1.0% O_2) or 25,000-bushel commercial rooms (1.5% and 2.5% O_2); and COM = conducted in 25,000-bushel CA rooms.

X No. of days in 0°C CA (1st No.), 0°C air (2nd No.), and 20°C air (3rd No.) and No. of replicates (4th No.).

Table 2. Effects of low-O_2 atmospheres on the development of disorders in Spartan (1.5% CO_2) and Delicious (1.0% CO_2) apples at 0° C (1984, n=33).

O_2 concn. (%)	SPARTAN [174+16+0][z]	SPARTAN [174+77+7]	DELICIOUS [173+13+0]	DELICIOUS [173+80+7]
	Skin coloration (% fruit)			
1.5	0	1 (0- 33)	0	0 (0- 6)
1.0	0	5 (0- 80)	0	0
0.5	0	52 (0-100)	0	5 (0-88)
	Core browning (% fruit)			
1.5	0	35 (7-88)	0	1 (0- 9)
1.0	0 (0-10)	27 (0-85)	0	1 (0- 6)
0.5	2 (0-50)	40 (0-96)	0	4 (0-29)
	Flesh browning (% rruit)			
1.5	0 (0-10)	3 (0-18)	0	1 (0- 6)
1.0	0	6 (0-30)	0	1 (0- 9)
0.5	0 (0-10)	14 (0-41)	0	1 (0-13)
	Storage breakdown (% fruit)			
1.5	0	1 (0-15)	0	1 (0- 9)
1.0	0 (0-10)	2 (0-23)	0	0
0.5	0 (0-10)	7 (0-37)	0	1 (0-25)

[z] Number of days in CA (1st number), 0°C air (2nd number), and 20°C air (3rd number).

Table 3. Effect of storage CO_2 concentrations on flesh firmness of four apple cultivars stored at 2.5% or 1.0% O_2 (1981 & 1982, n=10).

Storage CO_2 concn.(%)	Flesh firmness (N)											
	SPARTAN			GOLDEN DEL.			DELICIOUS			McINTOSH		
Initial	80			71			81			73		
	[265+7]#			[272+7]			[274+7]			[272+7]		
% O_2	2.5	1.0	(CO_2)	2.5	1.0	(CO_2)	2.5	1.0	(CO_2)	2.5	1.0	(CO_2)
2.0	70	82	(76)	68	72	(70)	72	78	(75)	60	67	(64)
1.0	64	79	(72)	64	71	(68)	70	78	(74)	57	69	(63)
0.5	61	79	(70)	61	70	(66)	70	77	(74)	55	66	(61)
(O_2)	(65)	(80)		(64)	(71)		(71)	(78)		(57)	(67)	

Number of days in 0°C CA (1st number) and 0°C air (2nd number) storage.

Table 4. Effect of storage CO_2 concentrations on core-browning disorder in Spartan apples (n=10) stored at 2.5% or 1.0% O_2 (1981 & 1982)#.

Storage CO_2 concn.(%)	Core-browning (% fruit)		
	2.5% O_2	1.0% O_2	(CO_2)
2.0	2.5	0.3	(1.4)
1.0	7.8	0.3	(4.1)
0.5	25.0	0	(12.5)
(O_2)	(11.8)	(0.2)	

Storage duration = 265 days in 0°C CA, plus 7 days in 0°C air and 7 days in 20°C air.

Table 5. Effect of storage procedures (Slow CA vs. Rapid CA) and flow-through low-O_2 atmospheres (1.0-2.0% vs. 2.5%) on flesh firmness of four apple cultivars (1980, n=10).

Storage O_2 concn.(%)	Flesh firmness (N)											
	SPARTAN			DELICIOUS			GOLDEN DEL.			McINTOSH		
Initial	80			85			75			70		
	May 13 [231]#			May 15 [233]			May 13 [231]			Apr 24 [212]		
	SCA	RCA	(O_2)	SCA	RCA	(O_2)	SCA	RCA	(O_2)	SCA	RCA	(O_2)
2.5[Z]	62	67	(65)	72	78	(75)	65	71	(68)	54	62	(58)
2.0	68	72	(70)	76	77	(77)	65	71	(68)	-	-	-
1.5	76	78	(77)	78	79	(79)	67	73	(70)	-	-	-
1.0	76	78	(77)	81	79	(80)	69	73	(71)	55	70	(63)
(Proc.)	(71)	(74)		(77)	(78)		(67)	(72)		(55)	(66)	
Significance[Y]												
O_2 concn.(A)	***			***			***			***		
Procedure(B)	***			***			***			***		
A x B	ns			***			ns			***		

Number of days in 0°C (Spartan, Delicious, and Golden Delicious) or 1.7°C (McIntosh) CA storage.

Z The desired storage O_2 concn. (with 2.0% CO_2) were established within 3 days (rapid CA) of 27 days (slow CA) of harvest.

Y Significance levels: 0.1% (***) and nonsignificant (ns).

Table 6. Effects of low-O_2 atmospheres on flesh firmness and "corky" flesh-browning in McIntosh apples stored at 1.7° or 2.8° C.

Crop year	O_2 concn. (%)	CO_2 concn. (%)	Storage temp. (°C)	Room size (bin)	Flesh firmness (N)		Flesh browning (% fruit)
1980 (n=6)					Initial [186+0+0][Z]	[186+39+5]	[186+39+5]
	2.4	2.0	1.7	960	73 59	52	5 (0-33)
	1.2	2.0	1.7	40	63	55	13 (0-68)
	Significance[Y]				***	*	ns
1981 (n=15)					Initial [186+4+0]	[186+14+7]	[186+14+7]
	2.5	5.0	1.7	960	70 67	52	5.8 (0-20)
	1.5	1.5	1.7	960	69	55	0.8 (0- 5)
	1.0	1.5	1.7	40	70	57	4.3 (0-25)
	Significance				*	***	*
1982 (n=10)					Initial [208+7+0]	[208+ 7+7]	[208+ 7+7]
	2.2	4.0	1.7	960	74 64 b[X]	53 c	20 (3-50) b
	1.5	1.5	2.8	960	65 b	54 bc	9 (0-28) b
	1.0	1.0	2.8	40	66 ab	56 b	8 (0-25) b
	1.0	1.0	1.7	1	68 a	61 a	34 (0-90) a

[Z] Number of days in CA (1st number), 0°C air (2nd number), and 20°C air (3rd number).
[Y] Significance levels: 5% (*), 0.1% (***), and nonsignificant (ns).
[X] Mean separation by Duncan's multiple range test at the 5% level.

Table 7. Effect of storage temperatures and grower source variability on the development of "corky" flesh-browning in McIntosh apples stored in 1.0% O_2 and 1.0-1.5% CO_2.

	"Corky" flesh-browning (% fruit)					
	Apr. 1982 [176+7+7][Z]			June 1983 [248+9+7]		
	Lot No.	1.0°C	3.0°C	Lot No.	1.4°C	3.0°C
	1	55	0	20	100	0
	2	48	0	21	95	0
	3	23	0	22	90	0
	4	5	0	23	90	0
	5	3	0	24	78	0
	6	0	6	25	75	0
	7	0	0	26	73	15
	8	0	0	27	63	3
	9	0	0	19	50	0
	10	0	0	28	50	13
	11	0	0	29	33	5
	12	0	0	30	33	0
	13	0	0	31	33	0
	14	0	0	32	25	3
	15	0	0	18	24	3
	16	0	0	33	15	5
	17	0	0	34	10	0
	18	0	0	35	3	0
	19	0	0	36	3	0
	20	0	0	37	0	0
Browning (%)	ns[Y]	6.7	0.3	***[Y]	47.0	2.3
Firmness (N)	ns	60	58	***	62	57

[Z] Number of days in CA (1st number), 0°C air (2nd number), and 20°C air (3rd number).

[Y] Significance levels: 0.1% (***), and nonsignificant (ns).

Table 8. Responses of 48 commercial lots of McIntosh apples to 0.5% and 1.0% O_2 at 3.0° C (1984).

O_2 concn. (%)[Y]	CO_2 concn. (%)	Storage temp. (°C)	Flesh firmness[Z] (N)		% fruit: Skin discoloration brown		Skin discoloration blue		Corky flesh browning		Core browning	
			Apr.	June[X]	Apr.	June	Apr.	June	Apr.	June	Apr.	June
2.5	5.0	1.7	60	49	0	7	0	0	4	20	26	62
1.0	1.0	3.0	65	53	0	1	0	0	1	4	28	29
0.5	1.0	3.0	62	51	0	0	18	19	7	20	28	28

[Z] Flesh firmness at harvest = 66 N.

[Y] The 2.5%, 1.0%, and 0.5% O_2 treatments were conducted in 25,000-bushel commercial CA room, 1,000-bushel test room, and 50-bushel CA cabinet, respectively.

[X] Apr. = 177 days in 1.7°C or 3.0°C CA storage + 8 days in 0°C air storage; June = 177 days in 1.7°C or 3.0°C CA storage + 72 days in 0°C and 7 days in 20°C air storage.

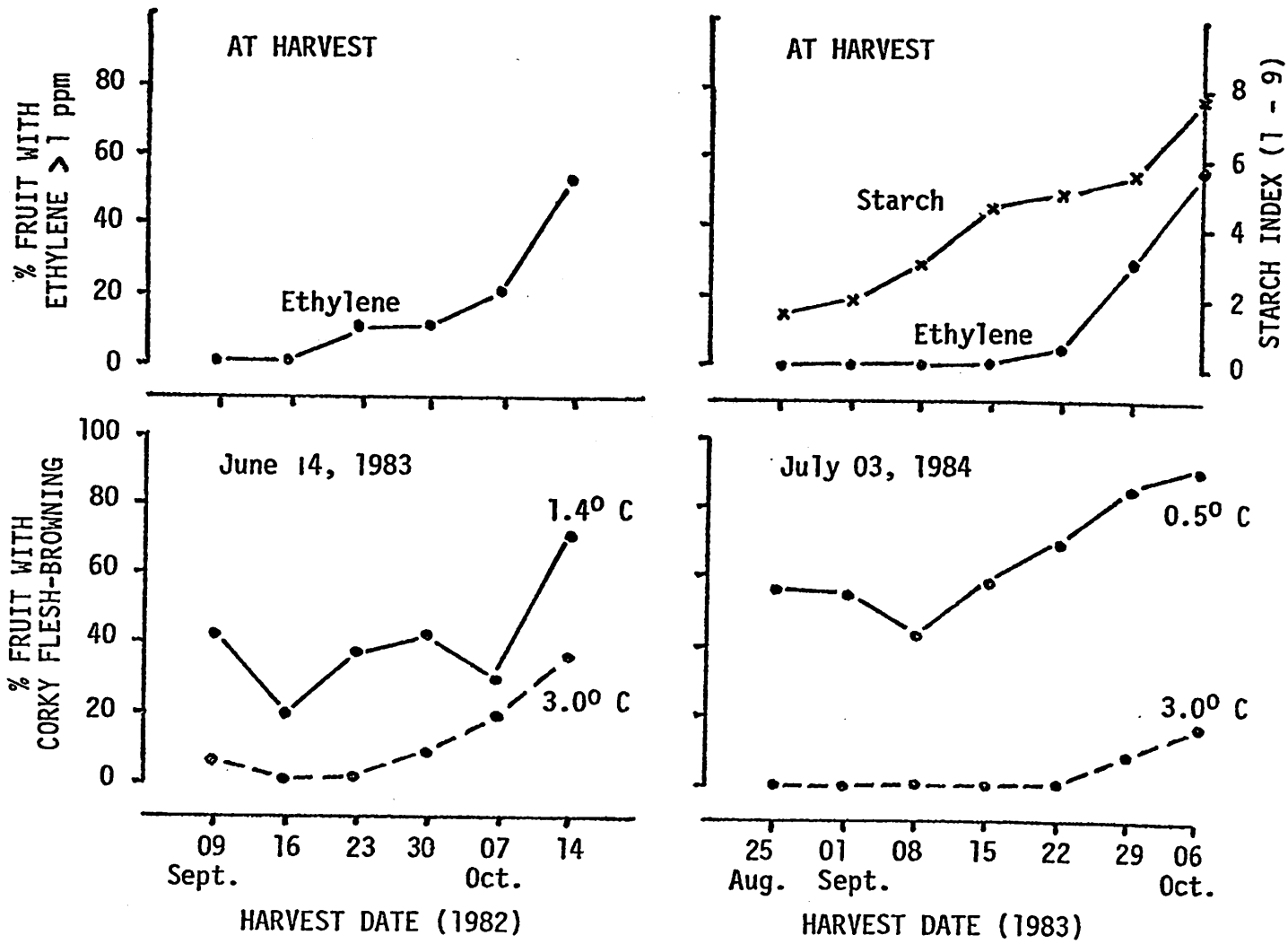

Figure 1. Influence of harvest dates, maturity indices (ethylene and starch), and storage temperatures on the development of "corky flesh-browning" in McIntosh apples stored in 1.0% oxygen.