Preliminary study on controlled atmosphere storage of squash

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February 1997

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HortResearch Client Report No. 97/13

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1. EXECUTIVE SUMMARY

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The response of squash (*Cucurbita maxima* cv Delica) grown in Hawkes Bay or South Auckland to CA storage was assessed by exposing fruit of commercial maturity to atmospheres comprising air, 2% O_2 plus 0, 3 or 5% CO_2, 5% O_2 plus 0, 3 or 5% CO_2, or 5% CO_2 in air. After 6 weeks CA storage plus 2 weeks air storage at 12°C, differences between fruit stored in different atmospheres were less than differences between fruit from different regions, and overall, differences between air-stored and CA-stored fruit were not marked. Nevertheless, CA-stored fruit maintained a fresh green appearance, and CA storage tended to reduce the loss of dry matter and starch but increase the loss of firmness during storage. The occurrence of fruit with warts was reduced by CA storage. However, the incidence of fruit with body rots was higher amongst CA-stored fruit than air-stored fruit, possibly because of the saturating humidity used during CA storage. At the end of CA and air storage, weight loss was approximately 8%. An optimum atmosphere for the storage of squash was not readily identified because of the lack of marked differences between the responses to different atmospheres. However, an optimum atmosphere for the CA storage of squash is likely to be in the range 2-3% O_2 plus 5-7% CO_2 with a RH of 80-85%.

It is concluded that storage in air at 12°C for periods of up to 8 weeks is as effective as CA storage, and that no marked beneficial or detrimental effects occur from CA storage. However, for longer storage periods and/or when temperatures after CA storage are higher than 12°C, CA storage is likely to be beneficial to fruit quality. In particular, fruit are likely to maintain a fresh green colour and have a reduced rate of dry matter and starch loss. It is recommended that at an industry level, a small scale trial be undertaken this season.

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2. INTRODUCTION

The New Zealand squash industry is subject to volatile returns as a result of fluctuations in production, within season supply of product, and the sole dependence on the Japanese market. The harvest period can begin in late December and extend through to the end of April, but most squash is harvested during February and March. Market returns, which reflect production volumes, are highest during early (December-January) and late (April-May) periods of the harvest season, and lowest during February-March. Climate or weather effects during the growing season have marked effects on the supply of squash and together with delays in planting can lead to production gluts.

Presently, based on yields, production costs are lowest for squash harvested during late February - mid March and higher for squash harvested later. If squash harvested in March could be stored and marketed in May-June, some monetary benefits are likely because production gluts and high production costs are minimised. To achieve benefits, squash need to be stored for a total of up to 10 weeks: 6 weeks storage, 2 weeks shipping and 2 weeks loading and distribution. The limitation to storage of squash is the loss of the fresh green colour and the development of rots. Squash fruit ripen slowly after harvest and the degradation of starch and accumulation of soluble sugars is a major ripening event. The response of squash to CA is not known but given that the green colour of several vegetables can be maintained by CA storage, and that CA facilities are readily available, the use of CA storage may be a viable option. In this preliminary study, the potential benefits from the CA storage of squash is assessed.

3. METHODS

Fruit: Squash (*Cucurbita maxima* cv Delica), grown in Hawkes Bay or South Auckland, were harvested at commercial maturity during the week beginning March 18th. From each region, similar and fruit free of defects were selected and randomly allocated into 6 groups of 36 fruit. Each set of 36 fruit was distributed into 2 B17 bins.

Treatments: Within 2 days of harvest, the bins of fruit were placed into 0.6m^3 polyethylene tents and held at 12°C in one of 8 controlled atmospheres (CA's) which were generated by mixing air, carbon dioxide and/or nitrogen. Each controlled atmosphere (CA) was humidified to near saturation before entry into a tent. The atmospheres generated were: air, 2%O_2 + 0% CO_2, 2%O_2 + 3% CO_2, 2%O_2 + 5% CO_2, 5%O_2 + 0% CO_2, 5%O_2 + 3% CO_2, 5%O_2 + 5% CO_2, and 5% CO_2 in air. Fruit were held in controlled atmospheres for 6 weeks and subsequently in air for 2 weeks.

The CA tents were erected in 2 coolstores which had different refrigeration capacities and systems. Four tents were erected in each coolstore: The air and the 2% O_2 treatments were in one coolstore and the 5% O_2 and 5% CO_2 treatments in the other.

Assessments: Fruit quality was assessed at harvest, at the end of CA storage, and again after 2 weeks storage in air. Fruit characteristics assessed were: skin, groundspot and flesh colour, outer and inner flesh firmness, dry matter, starch content, weight loss and presence of rots and warts.

A Minolta chromameter was used to measure colour as described by the determinants L, a and b, where L represents a measure of the lightness of the colour (0 = black, 100 = white), a is the green to red co-ordinate, and b the yellow to blue co-ordinate. The a and b values were used to determine Chroma and Hue° (hue angle), which represent the saturation and mix of colours, respectively.

A hand-held penetrometer (Effigi) fitted with a 3mm head was used to determine flesh firmness, which was determined on 2 regions of the fruit. The first was on pared surfaces of the fruit after a 2mm slice of skin was removed from five locations around the equator of the fruit. These firmness determinations were termed outer firmness. The second region, was on a radial surface of the fruit at an area mid way between the outside and inside surfaces of the flesh. Three determinations were made in this area and these were termed inner firmness.

Starch was determined using an enzyme-based assay system, on freeze-dried samples, which comprised tissue from 3 fruit. Dry matter was determined on grated samples of 3 fruit by determining weight before and after drying for 16-18 hours in an oven set at 60°C.

Data analysis: Other than determining means no statistical analysis was undertaken.

4. RESULTS.

Changes during storage and differences between regions: Fruit from Hawkes Bay and South Auckland regions had significantly different maturity characteristics prior to storage and therefore results for each are presented separately.

Hawkes Bay fruit were more advanced in maturity at harvest than South Auckland fruit and these differences were maintained throughout the storage period. A major difference between regions was the colour of the skin. Hawkes Bay fruit were darker green than South Auckland fruit (Table 1). The groundspot colour of Hawkes Bay fruit was more red and less green than that of South Auckland fruit (Table 2).

For both regions, skin colour became greener, more yellow and less dull with storage (Table 1). The groundspot colour became less yellow and green, more red, and duller during storage (Table 2). Flesh colour became more red during storage (Table 3).

At harvest, Hawkes Bay fruit were firmer and had higher dry matter than South Auckland fruit. However, starch content was lower in Hawkes Bay fruit than in South Auckland fruit. Near the surface of the fruit, flesh became less firm during storage, but internally there was little change in flesh firmness of fruit from either Hawkes Bay or South Auckland (Table 4).

Both dry matter and starch content decreased during the first 6 weeks of storage. Weight loss was up to 8% and was less for Hawkes Bay fruit than in South Auckland fruit (Table 4).

Warts developed after CA storage on both Hawkes Bay and South Auckland fruit but these warts were not major since most were less than 5mm in diameter. Similarly, up to 70% of the fruit developed body rots during storage but most of these were minor (Table 4).

Effect of CA storage: Although colour changes occurred during storage, CA storage had little or no effect on skin, groundspot or flesh colour. Any differences between controlled atmospheres and air were slight and/or not consistent over the storage period (Tables 5, 6 and 7). Differences in colour between air and CA storage for each region are given in tables A1, A2 and A3 of the appendix.

Relative to air-stored fruit, CA-stored fruit were less firm but the differences in firmness were restricted to the surface region of the fruit (Table 8). Although CA storage affected firmness, there were no marked differences between 2 and 5% O_2 .

Table 1. Skin colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of both CA-stored and air-stored fruit. n=24.

	Skin colour									
Storage	Hawkes Bay					South Auckland				
period	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
At harvest	29.9	-5.3	6.5	8.4	130.0	27.9	-4.9	5.8	7.6	131.2
6 weeks	30.4	-5.4	8.2	9.9	125.2	28.1	-5.0	6.5	8.3	128.4
8 weeks	31.3	-6.2	10.2	12.4	122.1	30.8	-6.5	10.3	11.9	122.9

Table 2. Groundspot colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of both CA-stored and air-stored fruit. n=24

	Groundspot colour									
Storage	Hawkes Bay					South Auckland				
period	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
At harvest	70.2	7.7	77.3	77.7	84.3	75.0	-0.7	76.1	76.1	90.5
6 weeks	61.4	6.1	47.6	48.2	83.2	59.2	4.1	48.9	49.5	85.9
8 weeks	61.7	9.8	50.0	51.2	79.0	60.6	7.8	49.8	51.3	81.5

Table 3. Flesh colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of both CA-stored and air-stored fruit. n=24

	Flesh colour									
Storage	Hawkes Bay					South Auckland				
period	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
At harvest										
6 weeks	64.7	15.6	72.2	73.9	77.8	66.1	13.0	72.2	73.4	79.7
8 weeks	63.6	18.9	71.0	73.5	75.0	65.8	16.8	72.1	74.1	76.8

Table 4. Characteristics of squash fruit from Hawkes Bay or South Auckland at harvest, and after 6 and 8 weeks air storage at 12°C. Values are means of both CA-stored and air-stored fruit and based on 6 fruit per treatment.

Fruit characteristic	Region	Storage period		
		At harvest	6 weeks	8 weeks
Firmness outside (kgf)	Hawkes Bay	10.3	9.7	8.5
	South Auckland	8.1	7.5	6.7
Firmness inside (kgf)	Hawkes Bay	6.6	6.9	5.9
	South Auckland	5.7	6.2	5.4
Dry matter (%)	Hawkes Bay	28.7	24.5	23.0
	South Auckland	27.5	24.6	22.3
Starch (% d.w.)	Hawkes Bay	42.7	26.8	27.3
	South Auckland	53.2	33.6	33.4
Weight loss (%)	Hawkes Bay	-	4.9	6.1
	South Auckland	-	6.7	8.3
Warts (%)	Hawkes Bay	0	8	56
	South Auckland	0	2	39
Body rots (%)	Hawkes Bay	0	53	45
	South Auckland	0	70	70

After 6 weeks storage, the dry matter and starch content were higher in CA-stored fruit than in air-stored fruit but after another 2 weeks storage in air, there were no differences between CA- and air-stored fruit (Tables 9 and 10). The effect of low O_2 on dry matter and starch appeared to be concentration dependent since the dry matter and starch content was higher in Hawkes Bay fruit subjected to 2% O_2 than in fruit held in 5% O_2 atmospheres.

Weight loss was higher in CA-stored fruit than in air-stored fruit (Table 11). This difference may not be a treatment difference but rather a difference arising because CA and air fruit were held in different coolstores.

Relative to air storage, the development of warts was inhibited by CA storage but there was no marked difference between fruit stored in 2% O2 atmospheres and 5% O2 atmospheres. Inhibition of wart development was greatest when fruit were held in a 5% CO_2 atmosphere (Table 12). Approximately 70% of the CA-stored fruit and approximately 50% of the air-stored fruit developed body rots (Table 13). The diameter of most of the rots was less than 5mm and were considered minor. It should also be noted that CA fruit were kept under near saturating humidity conditions.

Table 5. Skin colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of 2 replicates of 3 fruit per treatment.

		Skin colour									
		6 weeks CA storage					6 weeks CA + 2 weeks air storage				
Region	Treatment	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
Hawkes Bay	air	30.1	-5.5	8.3	10.0	124.2	29.6	-5.8	8.3	14.6	120.4
	2%O_2 + 0% CO_2	30.8	-6.2	8.8	10.8	125.7	28.8	-5.9	8.2	11.7	122.5
	2%O_2 + 3 %CO_2	30.3	-3.4	8.0	9.7	124.7	30.6	-5.8	9.9	13.5	118.6
	2%O_2 + 5% CO_2	30.0	-5.5	7.3	9.2	127.1	35.9	-6.6	12.7	12.3	121.0
	5%O_2 + 0 %CO_2	30.5	-5.8	8.1	10.0	125.8	31.4	-6.5	11.4	11.3	124.2
	5%O_2 + 3% CO_2	29.5	-5.0	6.9	8.5	126.7	31.3	-5.9	9.4	12.1	122.4
	5%O_2 + 5% CO_2	30.1	-5.7	8.4	10.2	123.9	30.8	-6.7	10.5	11.9	123.9
	5%CO_2 in air	31.9	-6.1	9.4	11.2	123.3	32.2	-6.7	11.4	11.7	123.4
South Auckland	air	28.1	-4.8	6.1	7.8	128.8	29.6	-6.9	10.4	12.0	124.3
	2%O_2 + 0% CO_2	27.0	-4.9	6.1	7.9	129.1	28.9	-6.5	9.7	11.6	124.0
	2%O_2 + 3 %CO_2	27.1	-4.3	5.2	6.8	130.1	31.2	-7.0	11.3	14.0	118.3
	2%O_2 + 5% CO_2	26.9	-5.1	6.4	8.2	129.2	29.4	-5.4	7.5	11.5	121.1
	5%O_2 + 0 %CO_2	28.6	-5.3	7.2	8.9	126.8	31.8	-6.3	10.2	11.7	122.5
	5%O_2 + 3% CO_2	28.7	-4.9	6.1	7.8	128.5	34.0	-6.7	11.9	8.9	128.5
	5%O_2 + 5% CO_2	31.9	-6.5	10.0	12.0	124.3	28.5	-6.3	9.0	12.5	123.4
	5%CO_2 in air	26.9	-4.4	5.2	6.8	130.1	33.0	-6.8	11.9	12.6	121.3
Means	*Air*	*29.1*	*-5.2*	*7.2*	*8.9*	*126.5*	*29.6*	*-6.4*	*9.3*	*13.3*	*122.4*
	CA	*29.3*	*-5.2*	*7.4*	*9.1*	*126.8*	*31.3*	*-6.4*	*10.4*	*11.9*	*122.5*
	2% O_2	*28.7*	*-5.2*	*7.0*	*8.7*	*127.7*	*30.8*	*-6.2*	*9.9*	*12.4*	*120.9*
	5% O_2	*29.9*	*-5.5*	*7.8*	*9.6*	*126.0*	*31.3*	*-6.4*	*10.4*	*11.4*	*124.1*
	5% CO_2	*29.6*	*-5.5*	*7.8*	*9.6*	*126.3*	*31.6*	*-6.4*	*10.5*	*12.1*	*122.4*

Table 6. Groundspot colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of 2 replicates of 3 fruit per treatment.

		Groundspot colour									
		6 weeks CA storage					6 weeks CA + 2 weeks air storage				
Region	Treatment	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
Hawkes Bay	air	63.4	7.4	49.5	50.1	81.7	64.9	10.1	51.9	52.8	80.7
	2%O_2 + 0% CO_2	63.4	5.8	52.5	52.8	83.7	57.7	9.8	51.5	52.3	78.4
	2%O_2 + 3 %CO_2	64.4	9.7	48.9	50.0	78.6	58.2	8.3	47.3	50.9	75.6
	2%O_2 + 5% CO_2	63.1	9.2	49.3	50.3	79.6	66.2	11.6	52.4	51.7	75.5
	5%O_2 + 0 %CO_2	57.6	2.2	42.0	42.3	87.6	62.8	11.2	51.4	54.2	79.4
	5%O_2 + 3% CO_2	60.9	5.9	47.2	47.6	83.2	65.8	10.4	51.2	52.4	78.7
	5%O_2 + 5% CO_2	58.8	6.1	47.1	47.7	83.2	57.8	6.5	48.2	49.4	83.6
	5%CO_2 in air	59.6	2.6	44.1	44.8	87.9	60.3	10.7	46.4	45.4	80.3
South Auckland	air	62.5	3.2	47.1	47.3	86.5	56.2	1.7	48.1	50.9	86.7
	2%O_2 + 0% CO_2	60.5	8.7	53.0	53.8	80.6	58.5	8.0	48.7	50.2	81.8
	2%O_2 + 3 %CO_2	59.7	8.1	53.6	54.3	81.3	62.8	8.6	50.0	50.5	79.9
	2%O_2 + 5% CO_2	59.4	2.5	50.7	51.2	88.3	62.3	7.6	52.6	56.2	75.9
	5%O_2 + 0 %CO_2	57.6	1.6	48.0	48.5	88.6	62.5	11.4	52.0	48.9	81.3
	5%O_2 + 3% CO_2	57.9	2.9	45.9	46.3	87.4	61.0	10.2	47.2	53.5	81.8
	5%O_2 + 5% CO_2	56.0	1.4	43.4	43.8	89.0	58.6	5.7	47.0	43.6	88.7
	5%CO_2 in air	60.2	4.2	49.6	50.3	85.6	62.7	9.2	52.8	56.4	75.7
Means	*Air*	*62.9*	*5.3*	*48.3*	*48.7*	*84.1*	*60.5*	*5.9*	*50.0*	*51.9*	*83.7*
	CA	*59.9*	*5.1*	*48.2*	*48.8*	*84.6*	*61.2*	*9.2*	*49.9*	*51.1*	*79.8*
	2% O_2	*61.8*	*7.3*	*51.3*	*52.1*	*82.0*	*60.9*	*9.0*	*50.4*	*52.0*	*77.8*
	5% O_2	*58.1*	*3.4*	*45.6*	*46.0*	*86.5*	*61.4*	*9.2*	*49.5*	*50.4*	*82.3*
	5% CO_2	*59.5*	*4.3*	*47.4*	*48.0*	*85.6*	*61.3*	*8.5*	*49.9*	*50.5*	*80.0*

Table 7. Flesh colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of 2 replicates of 3 fruit per treatment.

		Flesh colour									
		6 weeks CA storage					6 weeks CA + 2 weeks air storage				
Region	Treatment	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
Hawkes Bay	air	66.4	14.0	73.1	74.4	79.2	65.5	18.1	71.2	73.5	75.7
	2%O_2 + 0% CO_2	64.2	17.8	70.3	72.5	75.8	62.7	19.3	69.7	72.4	74.5
	2%O_2 + 3 %CO_2	64.4	16.8	72.6	74.5	77.0	63.4	20.9	69.2	72.4	73.1
	2%O_2 + 5% CO_2	64.0	16.5	72.3	74.3	77.1	63.9	17.9	70.9	73.2	75.7
	5%O_2 + 0 %CO_2	63.5	15.1	71.3	72.9	78.1	62.9	19.0	70.7	73.2	74.9
	5%O_2 + 3% CO_2	64.6	14.3	71.3	72.8	78.7	64.0	18.1	72.3	74.5	76.0
	5%O_2 + 5% CO_2	64.1	15.7	72.7	74.4	77.8	63.0	19.1	70.1	72.7	74.7
	5%CO_2 in air	66.4	14.4	74.1	75.5	79.1	63.7	18.9	73.8	76.2	75.7
South Auckland	air	70.0	13.3	75.3	76.5	80.0	64.4	18.0	70.9	73.2	75.7
	2%O_2 + 0% CO_2	64.8	14.8	73.3	74.8	78.5	66.6	19.0	71.3	73.8	75.0
	2%O_2 + 3 %CO_2	65.9	10.5	72.3	73.1	81.7	66.2	15.8	72.3	74.1	77.6
	2%O_2 + 5% CO_2	65.5	12.2	72.7	73.8	80.4	67.2	17.8	74.0	76.2	76.4
	5%O_2 + 0 %CO_2	66.3	13.8	70.7	72.1	78.9	66.6	15.7	72.7	74.4	77.8
	5%O_2 + 3% CO_2	65.7	13.6	70.9	72.3	79.1	62.6	16.0	70.1	71.9	77.1
	5%O_2 + 5% CO_2	63.6	14.3	68.6	70.2	78.1	62.8	17.7	68.9	71.3	75.4
	5%CO_2 in air	67.1	11.5	73.5	74.5	81.0	70.0	14.4	76.5	77.9	79.3
Means	*Air*	*68.2*	*13.7*	*74.2*	*75.5*	*79.6*	*64.9*	*18.1*	*71.1*	*73.4*	*75.7*
	CA	*65.0*	*14.4*	*71.9*	*73.4*	*78.7*	*64.7*	*17.8*	*71.6*	*73.9*	*75.9*
	2% O_2	*64.8*	*14.8*	*72.3*	*73.8*	*78.4*	*65.0*	*18.5*	*71.2*	*73.7*	*75.4*
	5% O_2	*64.6*	*14.5*	*70.9*	*72.4*	*78.4*	*63.7*	*17.6*	*70.8*	*73.0*	*76.0*
	5% CO_2	*65.1*	*14.1*	*72.3*	*73.8*	*78.9*	*65.1*	*17.6*	*72.4*	*74.5*	*76.2*

Table 8. Firmness (kgf) of flesh of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are based on 5 determinations per fruit for outer firmness, 3 determinations for inner firmness, and are means of 2 replicates of 3 fruit per treatment.

		firmness (kgf)			
		6 weeks CA		CA + 2 wks air	
Region	Atmosphere	outside	inside	outside	inside
Hawkes Bay	air	10.8	6.8	9.3	5.8
	2%O_2 + 0% CO_2	8.8	6.4	8.2	5.7
	2%O_2 + 3 %CO_2	10.7	7.5	8.8	6.0
	2%O_2 + 5% CO_2	10.0	6.9	8.5	6.5
	5%O_2 + 0 %CO_2	9.0	6.7	8.2	6.0
	5%O_2 + 3% CO_2	8.7	7.2	8.0	6.0
	5%O_2 + 5% CO_2	10.1	6.8	8.0	5.3
	5%CO_2 in air	9.5	7.1	9.1	6.3
South Auckland.	air	7.8	5.9	7.9	5.8
	2%O_2 + 0% CO_2	7.5	6.6	6.9	5.0
	2%O_2 + 3 %CO_2	6.9	6.1	7.1	6.1
	2%O_2 + 5% CO_2	7.4	6.2	5.2	5.1
	5%O_2 + 0 %CO_2	8.1	6.4	5.8	5.3
	5%O_2 + 3% CO_2	7.3	6.2	6.7	6.0
	5%O_2 + 5% CO_2	7.5	6.0	6.7	6.1
	5%CO_2 in air	8.0	6.0	7.6	4.2
Means	*Air*	*9.3*	*6.3*	*8.6*	*5.8*
	CA	*8.5*	*6.6*	*7.5*	*5.7*
	2% O_2	*8.5*	*6.6*	*7.4*	*5.7*
	5% O_2	*8.4*	*6.5*	*7.2*	*5.8*
	5% CO_2	*8.7*	*6.5*	*7.5*	*5.6*
	Hawkes Bay Air	*10.8*	*6.8*	*9.3*	*5.8*
	Hawkes Bay CA	*9.5*	*6.9*	*8.4*	*6.0*
	South Auckland Air	*7.8*	*5.9*	*7.9*	*5.8*
	South Auckland CA	*7.5*	*6.2*	*6.6*	*5.4*

Table 9. Dry matter (%) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of 2 replicates of 3 fruit per treatment.

		Dry matter (%)	
Region	Atmosphere	End of 6 weeks CA	End CA + 2 wks air
Hawkes Bay	air	22.1	22.2
	2%O_2 + 0% CO_2	26.0	25.4
	2%O_2 + 3 %CO_2	25.5	23.8
	2%O_2 + 5% CO_2	26.0	22.9
	5%O_2 + 0 %CO_2	24.6	23.4
	5%O_2 + 3% CO_2	24.1	21.2
	5%O_2 + 5% CO_2	24.5	21.5
	5%CO_2 in air	23.2	23.7
South Auckland.	air	21.7	23.8
	2%O_2 + 0% CO_2	25.5	20.6
	2%O_2 + 3 %CO_2	25.2	23.2
	2%O_2 + 5% CO_2	25.7	18.8
	5%O_2 + 0 %CO_2	25.6	20.5
	5%O_2 + 3% CO_2	26.4	24.0
	5%O_2 + 5% CO_2	23.8	24.8
	5%CO_2 in air	23.2	22.5
Means	*Air*	*21.9*	*23.0*
	CA	*24.9*	*22.6*
	2% O_2	*25.6*	*22.4*
	5% O_2	*24.8*	*22.6*
	5% CO_2	*24.4*	*22.4*
	Hawkes Bay Air	*22.1*	*22.2*
	Hawkes Bay CA	*24.8*	*23.1*
	South Auckland Air	*21.7*	*23.8*
	South Auckland CA	*25.1*	*22.1*

Table 10. Starch content (% dry weight) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of 2 replicates of 3 fruit per treatment.

		Starch (% dry weight)	
Region	Atmosphere	End of 6 weeks CA	End CA + 2 wks air
Hawkes Bay	air	25.9	28.2
	2%O_2 + 0% CO_2	33.8	26.6
	2%O_2 + 3 %CO_2	26.3	26.8
	2%O_2 + 5% CO_2	29.5	31.6
	5%O_2 + 0 %CO_2	29.0	22.8
	5%O_2 + 3% CO_2	23.6	38.6
	5%O_2 + 5% CO_2	23.6	22.1
	5%CO_2 in air	22.6	21.8
South Auckland.	air	29.0	31.7
	2%O_2 + 0% CO_2	37.0	36.5
	2%O_2 + 3 %CO_2	35.1	26.0
	2%O_2 + 5% CO_2	34.9	34.7
	5%O_2 + 0 %CO_2	31.7	33.4
	5%O_2 + 3% CO_2	39.6	35.4
	5%O_2 + 5% CO_2	36.6	40.4
	5%CO_2 in air	25.1	28.9
Means	*Air*	*27.5*	*30.0*
	CA	*30.6*	*30.4*
	2% O_2	*32.8*	*30.4*
	5% O_2	*30.7*	*32.1*
	5% CO_2	*28.7*	*29.9*
	Hawkes Bay Air	*25.9*	*28.2*
	Hawkes Bay CA	*26.9*	*27.2*
	South Auckland Air	*29.0*	*31.7*
	South Auckland CA	*34.3*	*33.6*

Table 11. Weight loss (%) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are means of 2 replicates of 2 fruit per treatment.

		Weight loss (%)	
Region	Atmosphere	End of 6 weeks CA	End CA + 2 wks air
Hawkes Bay	air	4.8	5.4
	2%O_2 + 0% CO_2	5.5	6.8
	2%O_2 + 3 %CO_2	4.6	6.2
	2%O_2 + 5% CO_2	4.6	6.1
	5%O_2 + 0 %CO_2	5.8	7.5
	5%O_2 + 3% CO_2	4.5	5.5
	5%O_2 + 5% CO_2	5.1	6.1
	5%CO_2 in air	4.6	5.4
South Auckland.	air	6.1	6.9
	2%O_2 + 0% CO_2	6.0	7.7
	2%O_2 + 3 %CO_2	7.5	9.5
	2%O_2 + 5% CO_2	6.0	8.3
	5%O_2 + 0 %CO_2	7.6	9.1
	5%O_2 + 3% CO_2	7.4	8.8
	5%O_2 + 5% CO_2	7.6	9.2
	5%CO_2 in air	5.7	6.8
Means	*Air*	*5.5*	*6.1*
	CA	*5.9*	*7.4*
	2% O_2	*5.7*	*7.4*
	5% O_2	*6.3*	*7.7*
	5% CO_2	*5.6*	*7.0*
	Hawkes Bay Air	*4.8*	*5.4*
	Hawkes Bay CA	*5.0*	*6.2*
	South Auckland Air	*6.1*	*6.9*
	South Auckland CA	*6.8*	*8.5*

Table 12. Incidence (%) of warts amongst squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are based on 2 replicates of approximately 16 fruit per treatment.

		Warts (%)	
Region	Atmosphere	End of 6 weeks CA	End CA + 2 wks air
Hawkes Bay	air	14	75
	2%O_2 + 0% CO_2	3	43
	2%O_2 + 3 %CO_2	9	48
	2%O_2 + 5% CO_2	0	81
	5%O_2 + 0 %CO_2	3	41
	5%O_2 + 3% CO_2	6	56
	5%O_2 + 5% CO_2	3	37
	5%CO_2 in air	0	21
South Auckland.	air	2	37
	2%O_2 + 0% CO_2	0	35
	2%O_2 + 3 %CO_2	2	29
	2%O_2 + 5% CO_2	0	47
	5%O_2 + 0 %CO_2	0	23
	5%O_2 + 3% CO_2	0	25
	5%O_2 + 5% CO_2	0	43
	5%CO_2 in air	3	21
Means	*Air*	*8*	*56*
	CA	*2*	*39*
	2% O_2	*2*	*47*
	5% O_2	*2*	*37*
	5% CO_2	*1*	*42*
	Hawkes Bay Air	*14*	*75*
	Hawkes Bay CA	*3*	*46*
	South Auckland Air	*2*	*37*
	South Auckland CA	*1*	*32*

Table 13. Incidence (%) of body rots amongst squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. Values are based on 2 replicates of approximately 16 fruit per treatment.

		Body rots (%)	
Region	Atmosphere	End of 6 weeks CA	End CA + 2 wks air
Hawkes Bay	air	66	61
	2%O_2 + 0% CO_2	85	82
	2%O_2 + 3 %CO_2	74	79
	2%O_2 + 5% CO_2	81	96
	5%O_2 + 0 %CO_2	91	81
	5%O_2 + 3% CO_2	81	72
	5%O_2 + 5% CO_2	97	83
	5%CO_2 in air	79	71
South Auckland.	air	40	29
	2%O_2 + 0% CO_2	50	47
	2%O_2 + 3 %CO_2	41	74
	2%O_2 + 5% CO_2	53	75
	5%O_2 + 0 %CO_2	71	60
	5%O_2 + 3% CO_2	55	47
	5%O_2 + 5% CO_2	76	57
	5%CO_2 in air	50	59
Means	*Air*	*53*	*45*
	CA	*70*	*70*
	2% O_2	*64*	*76*
	5% O_2	*78*	*67*
	5% CO_2	*73*	*74*
	Hawkes Bay Air	*66*	*61*
	Hawkes Bay CA	*84*	*81*
	South Auckland Air	*40*	*29*
	South Auckland CA	*57*	*60*

5. DISCUSSION

The absence of marked differences between air- and CA-stored fruit makes it difficult to identify the benefits from CA storage of squash. However, the lack of marked differences is not unexpected because the storage period was only 6 weeks and outwardly squash appear to have a relatively slow rate of ripening. Therefore, any benefits from CA storage are more likely to be detected after long term storage rather than short term storage. Benefits from CA storage may also have been more apparent if fruit were held at 20°C rather than 12°C after CA storage. It is significant that none of the CA treatments induced injury and that the CA-stored fruit maintained a fresh green appearance.

If squash, that are produced during periods of over supply, are to be stored prior to shipment to Japan then it is imperative that they maintain a fresh green appearance. An increase in sweetness and the subsequent development of a dry texture upon cooking would also be desirable outcomes of storage. Skin colour was maintained during storage but low temperature, ie. storage at 12°C, appears to be an adequate method for achieving this during short term storage since differences between air and CA storage were slight (Table 5). Similarly, groundspot and flesh colour continued to develop in both CA and air storage at 12°C (Tables 6 & 7), and therefore, it appears there is little advantage or disadvantage to colour of squash from short term CA storage.

After harvest, an increase in sweetness of squash occurs as a result of the conversion of starch to soluble sugars such as sucrose, fructose and glucose. Starch degradation is a normal process of ripening. During 6 weeks storage in air over 40% of the starch was lost, and this was assumed to be converted to soluble sugars and hence result in an increase in sweetness (Table 10). Starch degradation was slightly less in CA-stored fruit than in air-stored fruit, and similarly, dry matter loss was less in CA-stored fruit (Table 9). Therefore, short term CA storage did affect the rate of ripening but not markedly. The lack of a major effect of short term CA storage on starch degradation is desirable because of the relationship to sweetness, and although it was not determined in the present study, it is likely that soluble sugars content was higher in CA-stored fruit than in air-stored fruit because of the effect of low O_2 and/or high CO_2 on respiration. The slightly higher loss in dry matter in air stored fruit compared to CA stored fruit suggests respiration was lower in CA-stored fruit. However, to identify increased sweetness as a benefit of CA storage further research is needed.

Firmness of the flesh in the outer region of the fruit decreased during storage. The rate of loss was higher in CA-stored fruit than in air-stored fruit. This effect is unexpected and difficult to explain. During fruit development on the vine, firmness increases and it is possible that CA storage inhibits this process in harvested fruit and thereby leads to an increase in the loss in firmness. If the loss in firmness was a normal event of ripening, then CA storage should have reduced and not increased the loss in firmness.

Whether the effect of CA storage on firmness affected fruit texture after cooking was not determined in the present study but it may be of interest because of the Japanese preference for a dry texture.

In the present study, fruit were held under very high humidity conditions during storage, and these conditions are likely to have encouraged the development of body rots. In commercial CA stores, RH is likely to be lower than in the tents, and therefore, the occurrence of rots is not likely to be as high as that observed in the present study. Similarly, the higher incidence of rots and weight loss amongst CA-stored fruit is likely to reflect differences between stores rather than differences between CA and air storage. Although the optimum RH for the storage of squash has not been identified, many commercial CA stores are capable of maintaining a RH of 80-90%, and therefore, it is suggested that this RH be used.

Although the effect of low O_2 and/or elevated CO_2 atmospheres on dry matter and starch levels was slight, the respective responses suggest that an optimum atmosphere for CA storage of squash is likely to be 2-3% O_2 plus 5-7 % CO_2. None of the atmospheres tested caused injury and it is possible O_2 levels lower than 2% and CO_2 levels higher than 7% may be suitable.

In summary, there was no major detrimental or beneficial responses to short term CA storage. It is not industry practice to store squash prior to export, but squash may be held under ambient conditions for several days prior to packing and shipping. In addition, low temperature storage is not commonly used during shipments of squash, and therefore, squash are likely to be held at temperatures higher than 12°C after CA storage. If so, the benefits from short term CA storage are likely to be more apparent than that observed in the present study. If low temperature (12°C) is used throughout storage and shipping then CA storage may be unnecessary.

6. CONCLUSION

Short term CA storage appears to be useful for minimising the negative effects of a production glut during the mid stages of the harvest period. Fruit held in CA storage maintain a fresh green colour and ripening is delayed. After removal from CA storage and subsequent storage in air, fruit continue to ripen normally. Atmospheres in the range 2-3%O_2 + 5-7%CO_2 appear to be suitable for the CA storage of squash. It is recommended that a commercial trial be undertaken in 1997 using an atmosphere of 2%O_2+7%CO_2. and a RH of 80-85%.

7. ACKNOWLEDGEMENTS

We are grateful to Grocorp for providing the squash fruit and funding the study. We acknowledge and are grateful for the assistance provided by Kevin Stone of South Auckland Squash Packers, and to Shelley Forbes, Cherie Wiklund and Donna McLeod, for assistance with fruit assessments. David Billing, Anthony Hayes and Barry McDonald helped with advice and guidance on CA storage.

8. APPENDIX

Table A1. Skin colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. For air, values are means of 2 replicates of 3 fruit per treatment (ie. n=6), and for CA, values are means of 7 treatments, each with 2 replicates of 3 fruit (ie. n=42).

		Skin colour									
		6 weeks CA storage					6 weeks CA + 2 weeks air storage				
Region	Treatment	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
Hawkes Bay	Air	30.1	-5.5	8.3	10.0	124.2	29.6	-5.8	8.3	14.6	120.4
	CA	30.5	-5.4	8.1	9.9	125.3	31.6	-6.3	10.5	12.1	122.3
South Auckland	Air	28.1	-4.8	6.1	7.8	128.8	29.6	-6.9	10.4	12.0	124.3
	CA	28.1	-5.1	6.6	8.3	128.3	31.0	-6.4	10.2	11.8	122.7

Table A2. Groundspot colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. For air, values are means of 2 replicates of 3 fruit per treatment (ie. n=6), and for CA, values are means of 7 treatments, each with 2 replicates of 3 fruit (ie. n=42).

		Groundspot colour									
		6 weeks CA storage					6 weeks CA + 2 weeks air storage				
Region	Treatment	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
Hawkes Bay	Air	63.4	7.4	49.5	50.1	81.7	64.9	10.1	51.9	52.8	80.7
	CA	61.1	5.9	47.3	47.9	83.4	61.3	9.8	49.8	50.9	78.8
South Auckland	Air	62.5	3.2	47.1	47.3	86.5	56.2	1.7	48.1	50.9	86.7
	CA	58.7	4.2	49.2	49.8	85.8	61.2	8.7	50.0	51.3	80.7

Table A3. Flesh colour (L, a, b, Chroma, Hue°) of squash fruit from Hawkes Bay or South Auckland after CA storage and subsequent air storage at 12°C. For air, values are means of 2 replicates of 3 fruit per treatment (ie. n=6), and for CA, values are means of 7 treatments, each with 2 replicates of 3 fruit (ie. n=42).

		Flesh colour									
		6 weeks CA storage					6 weeks CA + 2 weeks air storage				
Region	Treatment	L	a	b	Chroma	Hue°	L	a	b	Chroma	Hue°
Hawkes Bay	Air	66.4	14.0	73.1	74.4	79.2	65.5	18.1	71.2	73.5	75.7
	CA	64.4	15.8	72.1	73.9	77.6	63.4	19.0	70.9	73.5	74.9
South Auckland	Air	70.0	13.3	75.3	76.5	80.0	64.4	18.0	70.9	73.2	75.7
	CA	65.5	13.0	71.7	73.0	79.7	66.0	16.6	72.3	74.2	77.0