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Transport simulation test with avocados and bananas in controlled atmosphere containers

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ABSTRACT

Avocados and bananas were stored in two Freshtainer controlled atmosphere (CA) 40 ft containers. Storage conditions in the containers were microprocessor controlled.*

The set conditions for avocados were: 7,5 ± 0,5°C for eight days followed by 5,5 ± 0,5°C for seven days, 2,0 ± 0,5 per cent O_2 and a maximum of 10,0 ± 0,5 per cent $C0_2$.

The set conditions for bananas were: 12,7 ± 0,5°C for eight days followed by 13,5 ± 0,5°C for eleven days, 2,0 ± 0,5 per cent 0_2 and a maximum of 7,0 ± 0,5 per cent CO_2.

Temperatures and container atmosphere were continually monitored and fruit quality was assessed after the predetermined storage period.

The results of this trial confirm that:

- *The containers are capable of controlling both temperature and atmosphere very accurately within the conditions specified, and*
- *Fruit quality is improved in comparison with RA-stored fruit.*

**Freshtainer: (Welz, Ernst Thun Strasse 8, A-5020 Salzburg, Austria)*

PROCEDURE

Material

Avocados of good quality (graded as Class II only because of external appearance) and Class I bananas were picked at optimum maturity as is the standard requirement for a three week shipping period. In both cases the fruit was packed and precooled to the storage temperature on the day of picking.

Postharvest treatments

The avocados were washed and lightly waxed with a water soluble polyethylene wax before packing. The bananas were also washed with clean water before the bunches were sprayed with a 50 ppm Prochloraz fungicide solution.

Packaging

Both avocados and bananas were packed into ventilated corrugated cardboard boxes. The bananas that were stowed in the CA container were packed without any inner polyethylene bag, whereas those stored in the conventional 20 ft porthole container (control fruit) were packed in a polyethylene bag in a carton. The polyethylene bag is the standard packaging for RA shipment. Excess air was sucked from the bags before the bags were tightly closed with ties. Avocados and bananas were then immediately precooled to 7,5°C and 13,5°C respectively, before transported by road to Cape Town at the optimum temperatures.

Containerisation

Pretripping of containers

Two Freshtainer 40 ft CA containers (nos FRTU 200 074/3 and FRTU 200 061 /4) were calibrated, programmed and refrigerated for 48 hours to 7,5°C (avocados) and 13,5°C (bananas) before the experiment commenced. The storage tank of each container was charged with 750ℓ of liquid nitrogen at the time of loading and refilled 48 hours later (estimated time of shipping).

Temperature monitoring

Thermocouples (TC) were installed in the fruit in the bottom, centre and top of six pallets (18 TC's), to accurately measure pulp temperature. The pallets in turn were stowed in different positions in the container. Three thermocouples were also installed in the delivery air and another three were installed in the return air. The positions of all the thermocouples were the same for both the avocado and banana CA experiments and are given in Figure 1.1.

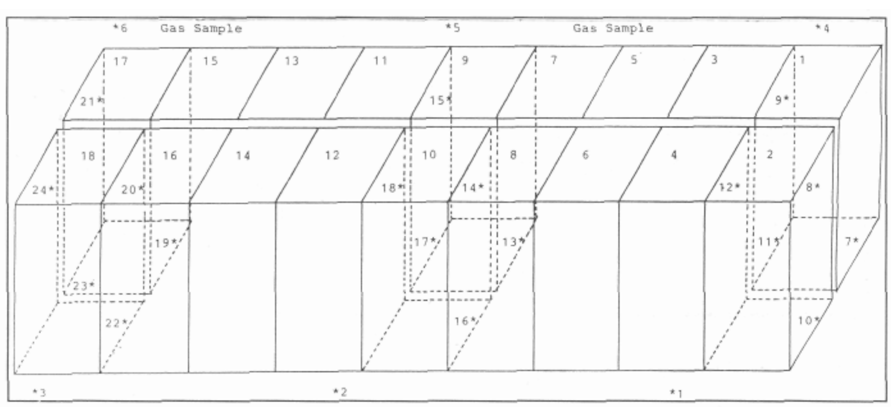


Fig 1.1 Location of thermocouples in pallets of avocados and bananas and in delivery and return air in containers FTRU 200 074/3 and FRTU 200 061/4 respectively.

*Thermocouples 1 to 3 air delivery; 4 to 6 air return and 7 to 24 pulp temperatures.

Control fruit for the CA banana experiment was stored in an insulated ducted 20 ft container, connected to the central refrigeration system (similar to that of the SAECS container vessels) in the Cape Town harbour holding store. Thermocouples were placed in the same positions as outlined for the CA container. Details are shown in Figure 1.2. These thermocouples were connected to a calibrated automatic Honeywell temperature recorder for continuous recording of temperature. Temperatures for air entering (delivery) and leaving (return), in the control banana container, were continuously recorded on the computerised holding store temperature data logging system.

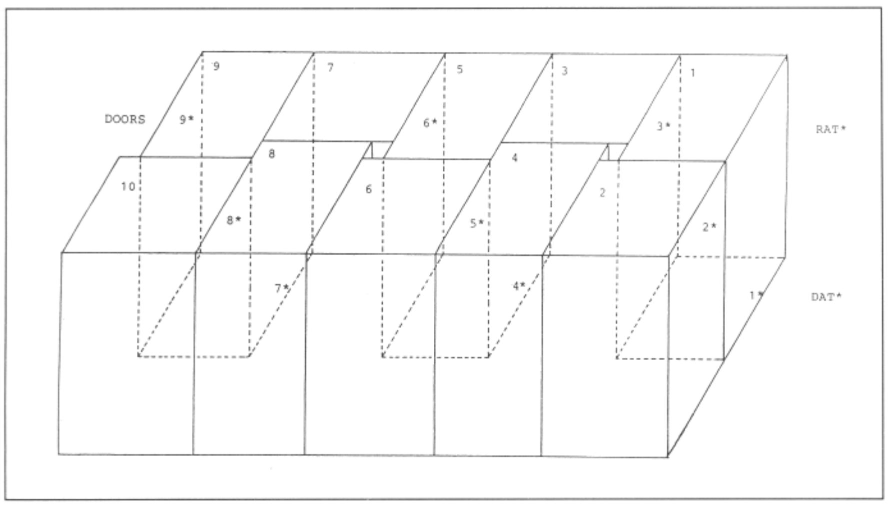


Fig 1.2 Location of thermocouples in pallets of avocado fruit in container GBIU 284 625/5.

*Thermocouples 1 to 9 pulp; DAT delivery air and RAT return air temperature.

Gas monitoring

Two separate gas sampling tubes were installed in each of the two CA containers. The open (sampling) ends of these tubes were 1 000 mm above floor level on the centre line between pallets 5 and 6 and pallets 15 and 16 respectively (See Figure 1.1). Gas samples were taken from each tube daily at 08h00 and 16h00 and analysed with a paramagnetic 0_2 and an infrared $C0_2$ meter. Both instruments were calibrated before and after each analysis with standard calibration gas containing 1,9 per cent O_2 and 2,1 per cent $C0_2$.

Storage conditions

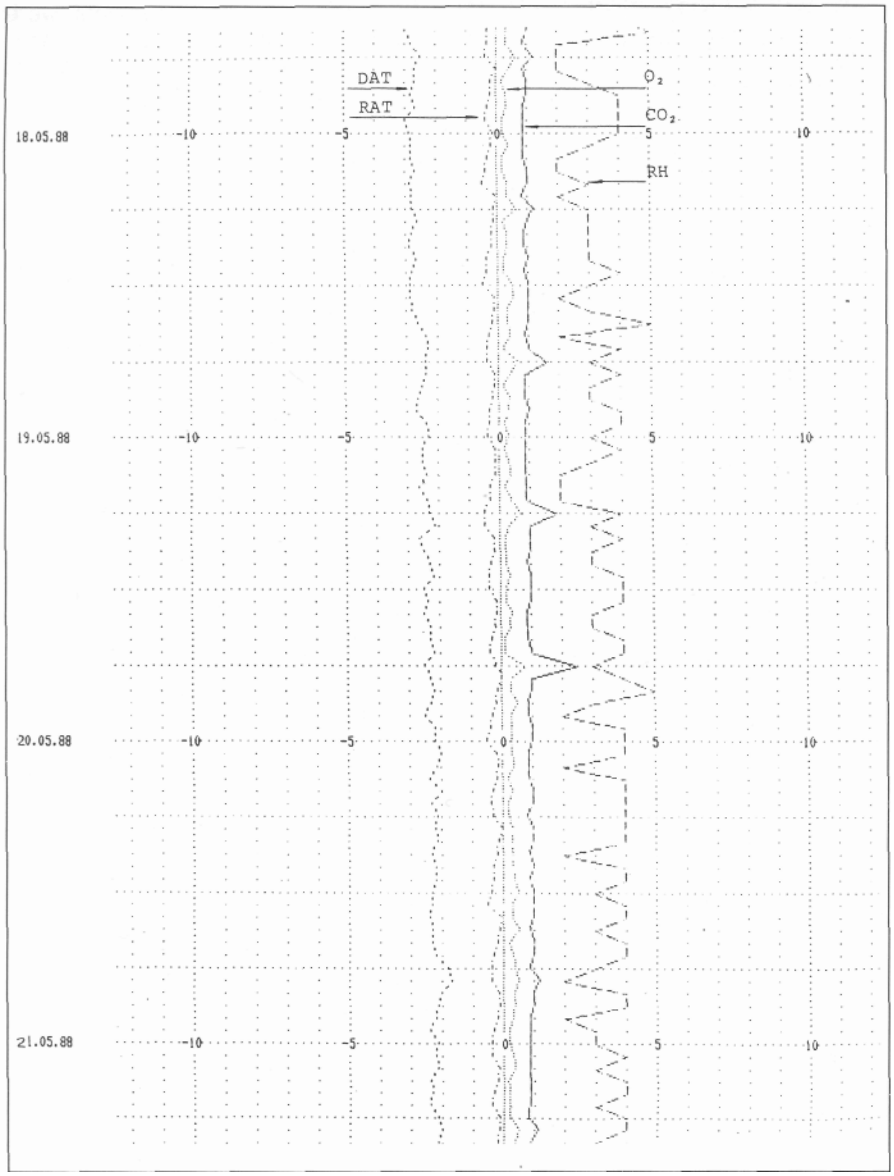
Avocados were stored in Freshtainer FTRU 200 074/3 and the electronic control was set to deliver air at 7,5 ± 0,5°C for the first eight days (May 3 to May 11) and then to reduce the air delivery temperature to 5,5 ± 0,5°C for the rest of the storage period (May 11 to May 18). The set-point for O_2 was 2,0 ± 0,5 per cent. Although CO_2 can be added automatically from an external gas cylinder to the container atmosphere, this was not done in both experiments, so that the natural buildup and equilibrium concentration in the containers could be determined under shipping conditions. The control system was set not to exceed 10 per cent CO_2 in the atmosphere.

The deviation from the set-point for delivery air temperature (DAT), return air temperature (RAT), O_2 and CO_2, is continuously calculated and stored in the inboard computer. The relative humidity (RH) is also calculated from the DAT and RAT. The stored data can be retrieved at any time in a printed (Annexure 1) and graphic (Annexure 2) form.

ANNEXURE 1 Printout of storage data in CA container with avocados (deviation from set-point).

Date	Time	RAT	O_2	CO_2	
02:05	+ 1,1	+ 0,4	− 9,3	+ 0,2	+ 3
03:05	+ 1,1	+ 0,4	− 9,2	− 0,2	+ 4
04:05	+ 1,2	+ 0,4	− 9,0	− 0,3	+ 3
05:05	+ 1,2	+ 0,7	− 8,8	− 0,5	+ 3
06:05	+ 1,1	+ 0,4	− 8,5	− 0,1	+ 4
07:05	+ 1,2	+ 0,5	− 8,1	− 0,1	+ 3
08:05	+ 1,6	+ 0,7	− 7,8	− 0,2	+ 5
10:18	+ 1,4	+ 0,8	− 8,1	+ 1,4	+ 3
11:18	+ 1,5	+ 0,8	− 7,9	+ 1,4	+ 3
13:54	+ 1,6	+ 0,5	− 7,8	+ 2,3	+ 4
17:57	+ 1,6	+ 0,6	− 7,7	+ 2,2	+ 3
18:57	+ 1,3	+ 0,4	− 7,8	+ 1,1	+ 3
19:57	+ 1,2	+ 0,3	− 8,2	+ 0,2	+ 4
20:57	+ 1,2	+ 0,3	− 8,1	− 0,1	+ 4
21:57	+ 1,2	+ 0,5	− 7,9	− 0,2	+ 3
22:57	+ 1,1	+ 0,4	− 7,7	− 0,4	+ 4
23:57	+ 1,2	+ 0,6	− 7,6	− 0,5	+ 3
18.06.88:					
00:57	+ 1,5	+ 0,7	− 7,4	− 0,4	+ 3
01:57	+ 1,1	+ 0,3	− 7,4	+ 0,0	+ 4
02:57	+ 1,2	+ 0,6	− 7,3	− 0,1	+ 2
03:57	+ 1,1	+ 0,6	− 7,2	− 0,3	+ 3
04:57	+ 1,1	+ 0,4	− 7,0	− 0,4	+ 4
05:57	+ 1,1	+ 0,5	− 6,9	− 0,4	+ 4
06:57	+ 1,1	+ 0,4	− 6,8	− 0,5	+ 4
07:57	+ 2,0	+ 0,9	− 6,7	− 0,5	+ 4
08:57	+ 1,2	+ 0,4	− 6,9	− 0,1	+ 4
09:57	+ 1,2	+ 0,5	− 6,8	− 0,1	+ 4
10:57	+ 1,5	+ 0,8	− 6,8	− 0,2	+ 3
11:57	+ 1,6	+ 0,7	− 6,7	− 0,3	+ 3
12:57	+ 1,6	+ 0,8	− 6,7	− 0,4	+ 4
13:57	+ 1,7	+ 0,8	− 6,7	− 0,5	+ 4
14:57	+ 3,1	+ 1,2	− 6,6	− 0,1	+ 4
15:57	+ 1,7	+ 0,7	− 6,5	− 0,1	+ 3
16:57	+ 1,4	+ 0,4	− 6,3	− 0,2	+ 4
17:57	+ 1,4	+ 0,7	− 6,1	− 0,3	+ 3
18:57	+ 1,2	+ 0,3	EE.E	EE.E	+ 4
20:28	+ 1,2	+ 0,5	− 6,7	+ 1,0	+ 4
21:28	+ 1,1	+ 0,4	EE.E	EE.E	+ 4
19.06.88:					
00:31	+ 1,2	+ 0,4	− 6,7	+ 1,7	+ 3
01:31	+ 1,2	+ 0,6	− 6,5	+ 1,6	+ 4
02:31	+ 1,1	+ 0,4	− 6,6	+ 1,4	+ 4
03:31	+ 1,2	+ 0,6	− 6,5	+ 1,3	+ 2
04:31	+ 1,2	+ 0,7	− 6,6	+ 1,1	+ 3
05:31	+ 1,1	+ 0,5	− 6,5	+ 0,9	+ 4
06:31	+ 1,2	+ 0,5	− 6,5	+ 0,7	+ 3
07:31	+ 1,5	+ 0,7	− 6,4	+ 0,6	+ 4
08:31	+ 1,2	+ 0,4	− 6,3	+ 0,4	+ 4
09:31	+ 1,2	+ 0,5	− 6,3	+ 0,3	+ 3
10:31	+ 1,2	+ 0,6	− 6,3	+ 0,1	+ 4
11:31	+ 1,2	+ 0,4	− 6,2	− 0,1	+ 4
12:31	+ 1,3	+ 0,7	− 5,9	− 0,2	+ 3
13:31	+ 1,1	+ 0,4	− 5,5	− 0,4	+ 4
14:31	+ 1,6	+ 0,8	− 5,4	− 0,5	+ 4
15:31	+ 1,2	+ 0,4	− 5,4	− 0,2	+ 4

ANNEXURE 2 Graphic presentation of storage data in CA container with avocados (deviation from set-point).



Control avocado fruit (60 cartons of count 14 and 16) were taken at random from pallets that were to be used for the CA storage experiment in the container. These control fruit were stored at the FFTRI in Stellenbosch in an experimental cold store, at a constant air temperature of 5,5°C for two weeks and regular atmosphere (RA) conditions.

Bananas were stored in Freshtainer FTRU 200 061/4 and the electronic control was set to deliver air at 12,7 ± 0,5°C for the first eight days (May 2 to May 10) and then to increase the temperature to 13,7 ± 0,5°C for the rest of the storage period (May 10 to May 22). The set-point for O_2 was 2,0 ± 0,5 per cent. As for avocados, no external CO_2 was added, in order to establish the rate and level of CO_2 build up in the container. The control system was, however, set not to exceed 7 per cent CO_2.

Control banana fruit was stored in a 20 ft ducted container (GBIU 284 625/ 5). The air delivery temperature was set at 13,5 ± 0,5°C for the duration of storage. Details of temperature monitoring positions are given in Figure 1.2. (See also Temperature monitoring.)

Quality Evaluation

Avocados

Fruit from 20 cartons (of the 60 cartons control fruit, 'Storage conditions') were ripened immediately at 20°C. Fruit from the remaining 40 cartons was stored at 5,5 ± 0,5°C for 14 days in regular atmosphere, before ripening at 20°C.

Forty cartons were again sampled after termination of the storage test in the CA container. These cartons were taken at or in close proximity to the various thermocouple positions. The fruit from these cartons were ripened at 20°C.

The avocados were evaluated after nine days ripening (peak eating-ripe stage). The incidence of anthracnose rot, stem-end rot, cold injury and physiological disorders such as grey spot, pulp spot and condition of vascular bundles were evaluated.

Bananas

Thirty cartons of bananas were sampled after storage from both the CA and RA containers. Five cartons were taken from each container from each of six rows of cartons spaced at regular intervals starting from the back of the container.

The polyethylene bags were removed from the control fruit before ripening. All banana fruit were placed in the same ripening room at 16°C. Ethylene gas (1 000 ppm) was introduced into the ripening room at the beginning and again 24 hours later to initiate ripening. After seven days at 16°C, the ripening temperature was increased to 18°C for four days.

The bananas were evaluated after 11 days ripening (peak eating-ripe stage). Quality factors were scored by a panel.

RESULTS AND DISCUSSION

Avocados

Temperature

The average air delivery temperature and average air return temperature at the front, centre and back of the container FTRU 200 074/3, are given in Figures 1a and 2a respectively. The average pulp temperatures of fruit in cartons at the bottom, centre and top of the pallets are given in Figure 3a.

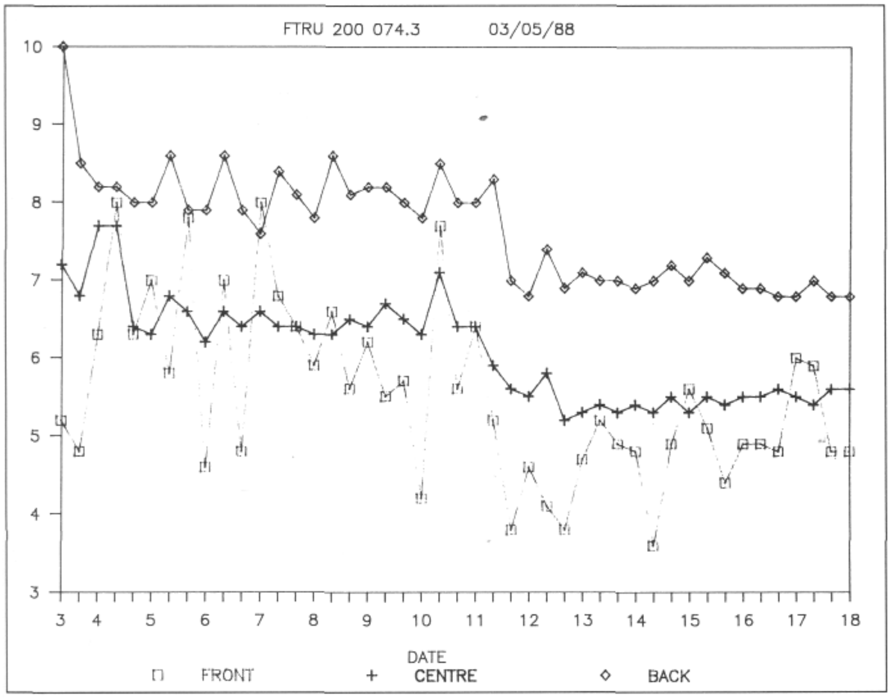


Fig 1a Average air delivery temperature.

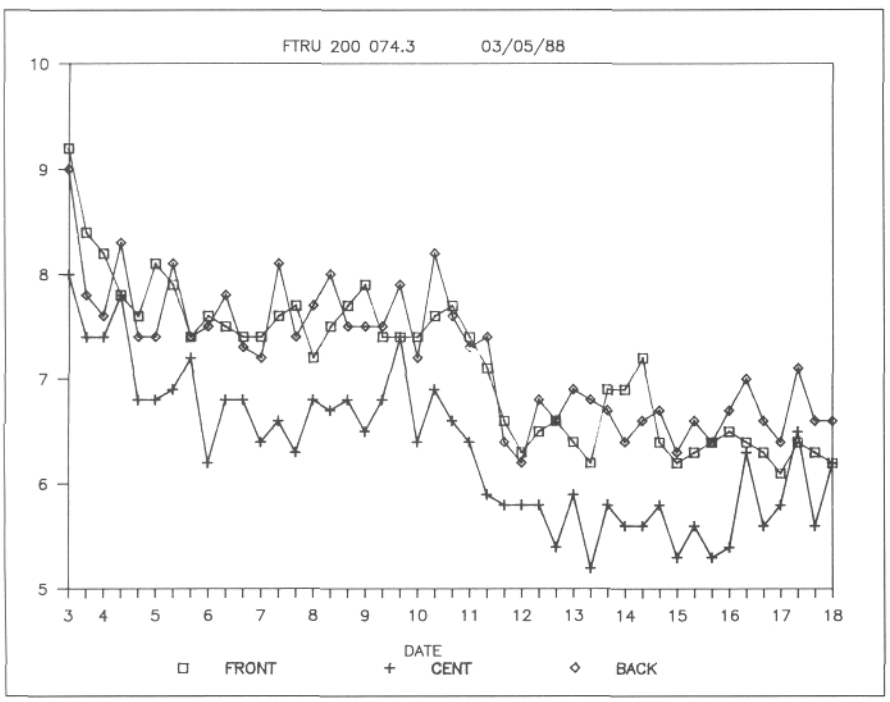


Fig 2a Average air return temperature.

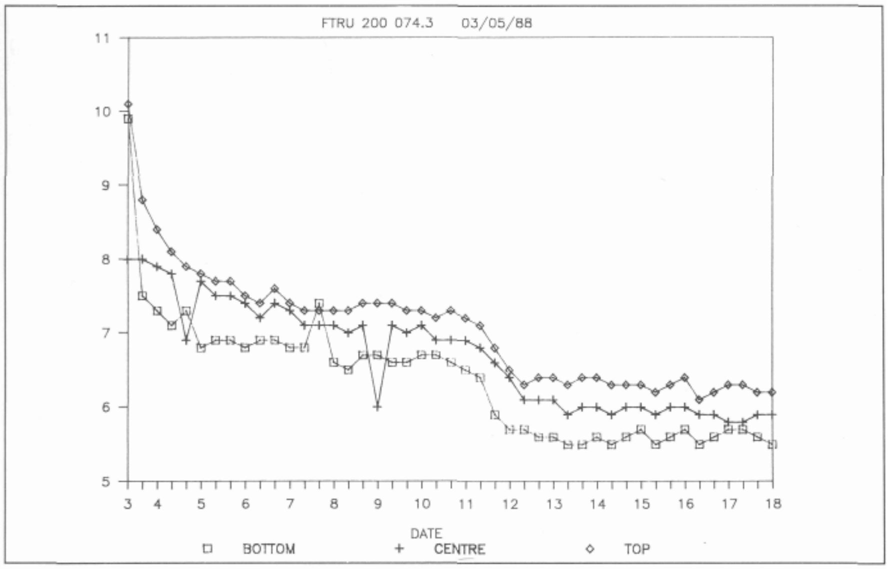


Fig 3a Average pulp temperature.

The average air delivery temperature evened out at approximately 7°C during the first eight days (May 3 to May 11). The inboard computer was preprogrammed to drop the delivery temperature to 5,5°C after eight days. The air delivery temperature then stabilised at between approximately 5,5°C and 6,0°C.

As can be expected, the delivery temperature at the front end (closest to the cooling coil) was lower and also varied more than at the centre of the container. The average air delivery temperature at the door end was approximately 1°C above the average delivery temperature in the centre of the container, which was a very close reflection of the overall average delivery air temperature.

It can be concluded from the data in Figure 1a, that the air delivery temperature was controlled within the practical and normal commercial standards. This, despite a fairly big temperature variation (±3°C) directly off the cooling coil.

The average air return temperatures evened out between approximately 7°C and 8°C for the first eight days and then dropped to between approximately 6°C and 7°C. Air return temperatures at the front and back corresponded very well and were approximately 1°C above the air return temperature in the centre of the container.

Under commercial carrying conditions a 2°C difference between air delivery and air return can be regarded as standard. This difference in the experimental container was on average approximately 1°C. This fairly small difference between air delivery and air return temperatures indicates a fairly constant pulp temperature.

The aim was to carry the fruit at approximately 7,5°C for the first eight days (May 3 to May 11) and 5,5°C for the following seven days (May 11 to May 18). It is also clear that the average pulp temperature variation between the bottom, centre and top fruit was not more than ± 0,5°C. An overall view of the pulp temperatures indicates constant temperature around the actual set-point.

Gas Concentrations

The average carbon dioxide (CO_2) and oxygen (O_2) readings for container FTRU 200 074/3 is given in Figure 4a. From this data it is clear that it took about five days (until May 8) for both CO_2 and 0_2 to stabilise. No external $C0_2$ was added and the CO_2 stabilised between 5 per cent and 6 per cent. This was 4 per cent to 4,5 per cent below the optimum required for avocados and could have resulted in some quality deterioration. The 0_2 concentration was fairly accurately controlled between 2 per cent and 3 per cent. This was within acceptable limits.

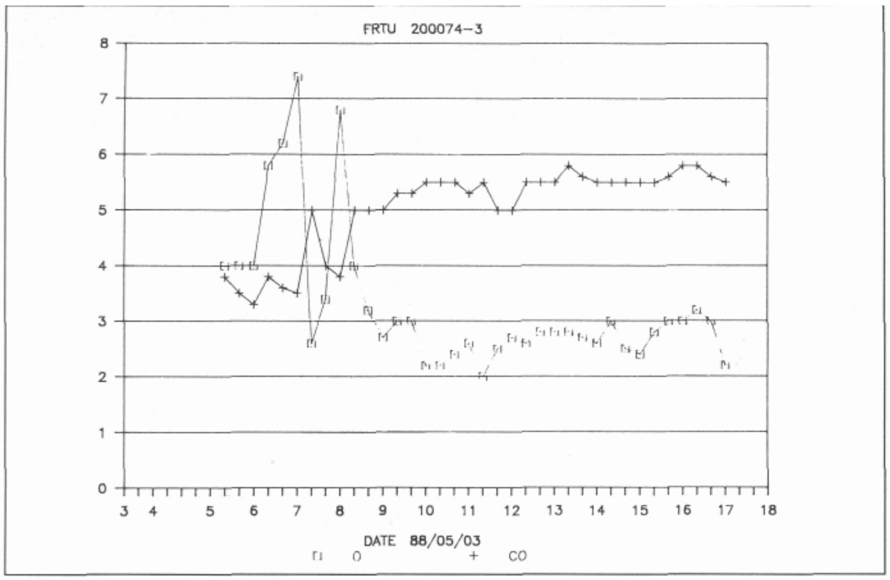


Fig 4a Average percentage O_2 and CO_2.

Fruit Quality

The quality of avocado fruits stored at 5,5°C RA conditions and fruit stored in the container at 2 per cent O_2, 10 per cent CO_2 and 7,5°C/5,5°C for 15 days plus nine days ripening at 20°C, is given in Table 1.

TABLE 1 The quality of avocados stored for 15 days in CA (2 per cent O_2, 10 per cent CO_2 7,5°C/5,5°C) and RA (5,5°C) plus nine days ripening at 20°C

Storage time	Anthrac-nose	Stem-end rot	Cold injury	Grey spot	Pulp spot	Browning of the vascular bundles
Ripened before storage	14,4 a	4,1 a	0,9 a	4,4 a	0,3 a	18,8 a
15 days RA plus 9 days 20°C	21,8 b	5,7 a	0 b	15,4 b	20,8 b	10,4 b
15 days CA plus 9 days 20°C	13,1 a	6,0 a	0 b	6,6 a	0 c	8,5 b

Figures followed by the same letter do not differ significantly at P=0,05.

Only Class II avocados were available for the experiment. A high incidence of anthracnose rot was also expected, due to heavy rains and moist conditions prior to harvest. It was therefore decided to ripen some of the fruit immediately, to determine the anthracnose potential. From Table 1 it can be seen that 14,4 per cent of the fruit developed anthracnose when ripened within one week after harvest. It was consequently decided to store the experimental fruit for 15 days only.

The data in Table 1 clearly shows that the storage conditions inside the CA container resulted in significantly less anthracnose, cold injury, grey spot and pulp spot, than RA stored fruit. This confirms the results of Truter & Eksteen (1986).

If all the defects for CA and RA fruit, as listed in Table 1, are both added up, it is clear that CA-stored fruit developed a total of 34,2 per cent disorders. This represents about half as much as the 74,1 per cent RA-stored fruit.

It can be concluded that optimum storage conditions, except for CO_2, could be maintained in container FRTU 200 074/3 and that this resulted in a 50 per cent improvement in post-storage quality. If CO_2 could be maintained at 10 per cent, better results could probably be obtained.

Bananas

Temperature

The average air delivery temperature and average air return temperature at the front, centre and back of container FTRU 200 061 /4, are given in Figures 1b and 2b respectively. The inboard electronic control system computer was programmed to deliver air into the container at 12,7 ± 0,5°C for the first eight days and then to increase the temperature to 13,5 ± 0,5°C for the rest of the storage period. The actual delivery temperatures varied between approximately 12,5°C to 14,5°C during the first week (May 2 to May 10), but stabilised between 13,5°C and 14°C when the set-point was increased by 1°C. It is very clear from this table that there was practically no variation in delivery air temperature along the entire length of the container.

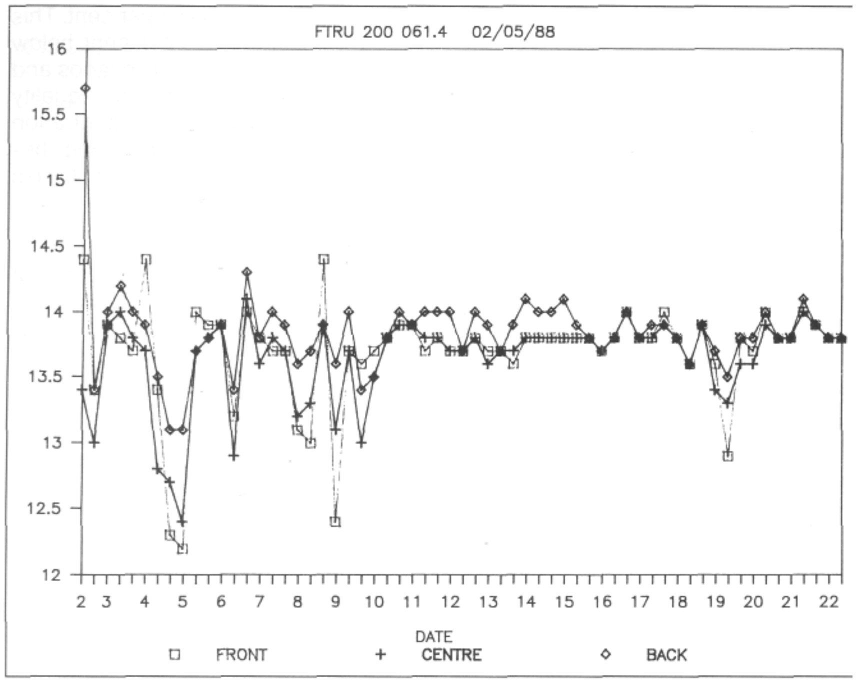


Fig 1b Average air delivery temperature.

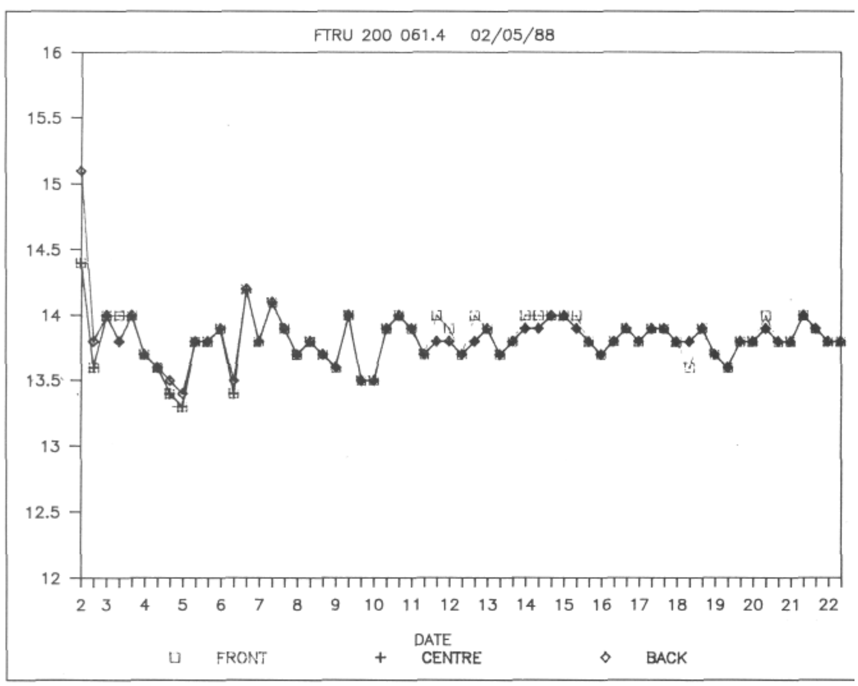


Fig 2b Average air return temperature.

The air return temperatures (Figure 2b) stabilised between 13,5°C and 14°C. In addition, the air return temperatures were much more stable and showed even less variation along the length of the container, than the air delivery temperature.

The average pulp temperatures of bananas stored under CA conditions in container FTRU 200 061/4 is given in Figure 3b. From this it can be seen that the pulp temperatures were very constant throughout the container and stabilised at approximately 13,5°C to 14°C.

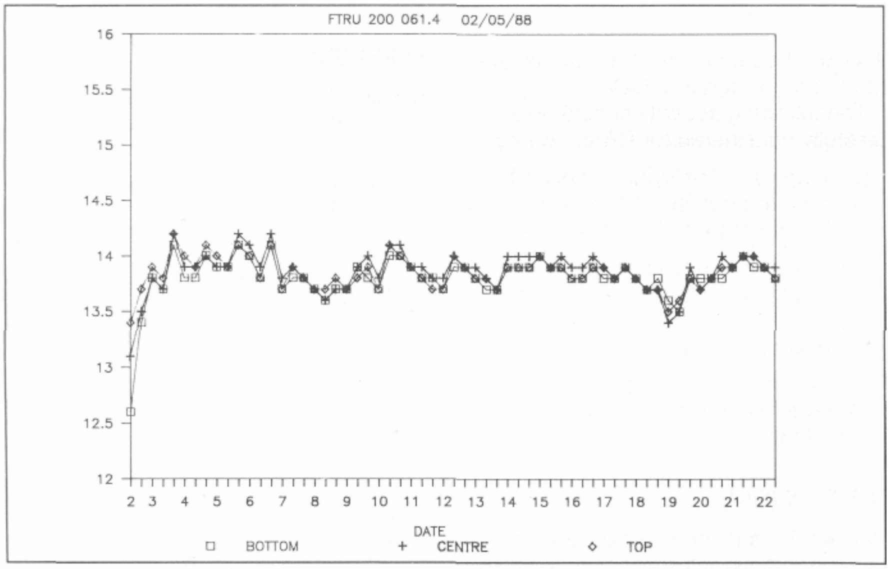


Fig 3b Average pulp temperature.

Although it was decided to store the bananas at a pulp temperature of 13,5± 0,5°C, the delivery air temperature was increased to 13,5°C after eight days, to lessen possible chilling injury and also to check the accuracy of the electronic control system. The control bananas were packed in polyethylene bags in cartons and on pallets. Ten pallets of bananas were stowed into container GBIU 284 625/5.

The delivery air temperature (DAT) to this container was set at 13,5 +/- ,5°C. Fairly big variations occurred (eg May 10 and 17:14,2°C and May 13 and 15:13°C). This was mainly due to loading and unloading of the holding store (500 containers in total) and the refrigeration plant cycling before equilibrium was reached again.

It can be seen from the data in Figure 3.1, that the bananas were stored in polyethylene bags at a pulp temperature varying between approximately 13°C and 14°C. This was within the decided experimental parameters.

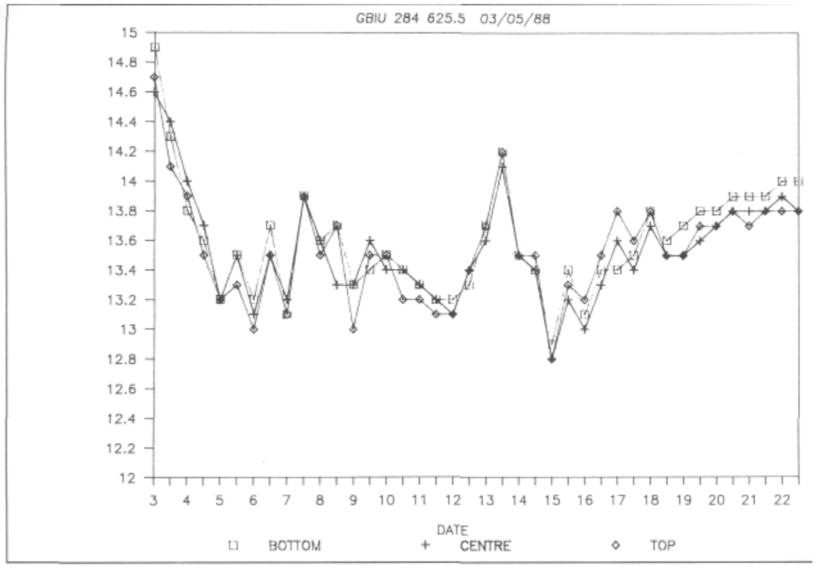


Fig 3.1 Average pulp temperature.

Gas concentrations

The average CO_2 and 0_2 readings for container FTRU 200 061/4 are given in Figure 4b. From this it can be seen that O_2 was effectively flushed out with liquid N_2 and stabilised between 2 per cent and 3 per cent for the duration of the experiment. The CO_2 built up to approximately 5 per cent within three days from closing the container. No external $C0_2$ was added to arrive at the seven per cent preset level. The sudden lowering of CO_2 (and slight increase of O_2) on May 12, was the result of an emergency fresh air vent opening during a short power failure to the container.

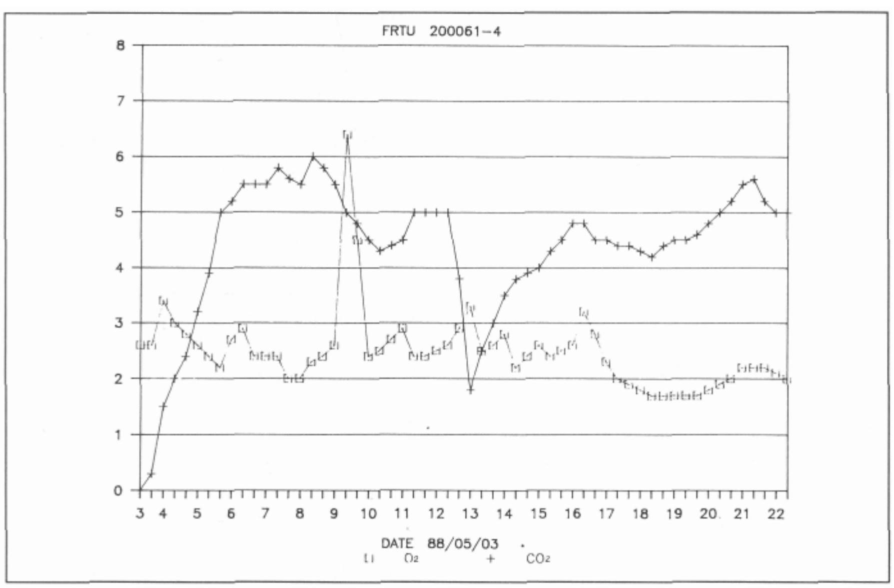


Fig 4b Average percentage O_2 and CO_2.

Fruit Quality

The results of the bananas stored under CA in container FRTU 200 061/4 and under RA in container GBIU 284 625/5 are given in Table 2. The banana fruit was stored for three weeks plus ripening for 11 days before fruit quality was assessed.

TABLE 2 The condition of Williams bananas from different positions in two containers after three weeks storage at 13,5°C plus seven days at 16°C and four days at 18°C

Position in container	Controlled atmosphere container		Regular atmosphere container	
	Colour (Scale 1-7)	Collar rot (Scale 0-5)	Colour (Scale 1-7)	Collar rot (Scale 0-5
Door	3,87	0,46	3,72	0,11
2nd Row	3,88	0,35	3,58	0,02
3rd Row	3,49	0,04	4,16	0,02
4th Row	3,63	0,25	3,42	0
5th Row	3,69	0,27	3,75	0,09
LSD (P=0,05)	ns*	ns	ns	ns

*ns = not significant

From the data in Table 2, it is clear that the bananas subjected to the different storage conditions were equal in quality at the eating-ripe stage.

The polyethylene bag system was developed after an intensive research programme on CA storage of bananas. Research results of this study were confirmed with both experimental and commercial exports of bananas to the United Kingdom and Europe. It was established that polyethylene bag packaging resulted in better colour retention and a drastic decrease in the incidence of collar rot compared to fruit not packed in polyethylene (Truter & Eksteen, 1986).

However, CA storage offers a number of advantages over polyethylene bag storage. The three most important advantages are:

- The absence of a polyethylene bag makes precooling much easier and faster.
- Warming and treatment with ethylene after storage is much less of a practical problem because there is no bag that has to be removed.
- Eliminates latex exudation from bananas when packed in polyethylene bags.

Storage and transport in the CA container can be regarded as a big improvement over conventional RA transport. It can therefore be stated that the CA storage conditions, as carried out in container FRTU 200 061/4, resulted in a commercially and practically accepted method of transport.

General aspects

Economic aspects of CA transport were not investigated in this study. Many factors affect the economic feasibility of this type of transport. Potential quality improvement, handling and transport costs and final value of product are a few of the important aspects to be considered.

If CA shipping is economically feasible, the products to be shipped should be carefully considered. Apples, pears, grapes and citrus fruits for instance, have a relatively long storage period and can be shipped successfully under RA conditions. It is therefore unnecessary to use the more expensive transport systems for these products. Stone fruits such as peaches, plums and nectarines develop more physiological disorders with CA storage (Eksteen & Truter, 1987). This aspect, however, needs further research as indicated by F G Mitchell, University of California, Davis (pers comm).

The best response to CA storage conditions can be expected from climacteric products (fruits, flowers and vegetables that continue ripening after harvest). South African products with the most potential for CA exports are avocados, bananas, and mangos. The optimum conditions for South African grown mangos, however, are not known. Other products that may also react favourably to CA transport are melons, tomatoes, some of the protea and maybe other flower species. Strawberries, however respond very well to CA conditions of 4 per cent 0°C and 6 per cent $C0_2$ at a temperature of -0,5°C. Citrus, grapes, litchees and pineapples are not climacteric fruit, but undergo limited colour changes after harvest. There products may therefore, not react at all or change to anaerobic fermentation, when exposed to low oxygen and/or high carbon dioxide.

In addition, special care will have to be taken when carrying grapes and litchees, because these products are packed or treated with CO_2.

The following aspects should be very carefully considered for CA transport:

• Economics of the system, taking into account the quality and market price improvement that may be obtained.

• The optimum conditions required the accuracy associated with which these conditions can be applied and the associated risk factor.

• The volume of product available to warrant investment into and application of the CA transport system.

CONCLUSIONS

The two Freshtainers tested with avocados and bananas respectively, could maintain the preset carrying temperature conditions within the parameters laid down.

The O_2 in both containers was controlled at approximately 0,5 per cent above set-point. The $C0_2$ stabilized at approximately 4,5 per cent and 2,5 per cent lower than set-point for avocados and bananas respectively. This is a serious shortcoming and everything possible must be done to put it right.

The quality of CA-stored avocados was superior to that of RA-stored fruit.

The quality of CA-stored bananas was equal to modified atmosphere (polyethylene bag) storage developed specially for long distance transport.

The economical feasibility of the CA transport concept must still be evaluated, but technically the system has much potential for transport of subtropical and certain other fruit.

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