AGRICULTURAL DEVELOPMENT AND ADVISORY SERVICE

Report to:	Horticultural Development Council 18 Lavant Street Petersfield GU32 3EW
ADAS Contract Manager:	R C Balls ADAS Mechanisation Unit Wrest Park Silsoe Bedford MK45 4HS
Period of investigation:	August-December 1991
Date of issue of report:	March 1992
Number of pages in report:	Twenty-five
Number of copies of report:	Seven (four held by ADAS)
This is ADAS copy number:	FOUR OF SEVEN.

CONTRACT REPORT

Number SMA/2046
CO 11032

Rapid Cooling of Vegetable Produce Using "Hydrair" Method

HDC ref FV/108

Commercial in Confidence

PRINCIPAL WORKERS

David Bartlett, NDAgrE, MIAgrE, Mechanisation Specialist, ADAS
Robert Hirons, PhD, Horticultural Specialist, HRI

AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report repsrsents a true and accurate record of the results obtained.

.... R C Balls, Contract Manager

..............5/3/92.................. Date

Report authorised by:

....

S W Perkins
HDC Account Manager
Block B
Government Buildings
Brooklands Avenue
Cambridge
CB2 2DR

Tel: 0223 455752

CONTENTS

SUMMARY

A practical system can be designed to cool cauliflowers of marketable size from a field temperature of 22°C to 6°C within three hours. The minimum practical time for cooling cauliflowers from field temperature to 6°C, using cold air or a "Hydrair" type system is two hours.

The improvement in cooling times over current methods was achieved by the increased airflows; the water sprays had little effect. Much of the sprayed water remained in the cauliflowers and this was considered commercially unacceptable by the packers. It was impractical to regulate a water spray to ensure that all the water supplied would be evaporated and none left in the cauliflower at the end of the cooling period.

The optimum airflow for achieving a cooling rate to 6°C in three hours would be 10 kg of air per hour per kg of produce. There was little benefit from increasing the airflows further. At very rapid cooling rates, variations in cooling time due to the size of a cauliflower and its position in the stack become significant.

There was no measurable change in shelf-life between any of the treatments and the controls. It was apparent during the shelf-life work that physical damage to the produce occurring when handling and cutting had a greater effect on shelf-life than any of the cooling treatments.

OBJECTIVE

To investigate the minimum practical time for cooling freshly cut cauliflowers from field temperature to 6°C, using a combination of positive airflow and sprayed water known in the USA as the Hydrair system.

To investigate whether accelerated cooling with a Hydrair based system would affect quality or shelf-life.

BACKGROUND AND COMMERCIAL OBJECTIVE

There is an increasing interest that reducing cooling times of fresh produce could offer the possibility of increasing its shelf-life. Conventional packaging and handling methods affect the rate at which products can be cooled and makes the temperature at the end of the cooling period non uniform. Practical cooling methods need to be quick, produce uniform product temperature with minimum weight loss and to involve minimal management.

Conventional refrigerated stores do not provide a rapid enough reduction of temperature to meet the trend to tighter cold chain specifications. For example, positive ventilation of the produce will enable cooling times to be reduced but the problem becomes one of ensuring adequate contact between the produce and the cooling air. The influence of market containers that are often designed with handling and damage protection rather than cooling in mind can result in a wide range of cooling times for the same product.

Hydrocooling is known to give very rapid cooling of produce because the cooling fluid, water, has a very large thermal capacity and the heat transfer coefficient at the product surface is large compared with air cooling. The main commercial disadvantage of hydrocooling is that the produce ends up wet and potentially heavily contaminated with bacteria and moulds present in the cooling water. The containers must also be able to withstand being wet.

The "Hydrair" technique has been developed and documented in the USA for cooling a variety of products, including celery and sweetcorn. In the Hydrair system, the normal circulation of cold air is supplemented with a spray of chilled water and the product is cooled by a combination of direct contact and evaporation. Because the water quantities used were significantly below those used for conventional hydrocooling, there should be less water to treat or to pre-cool. Because the American system of air cooling and the products handling were different from UK practice, there was reluctance to adopt the system in the UK based solely on US data.

The main benefit to the UK grower was foreseen as the ability to upgrade existing icebank or direct expansion stores to meet tighter cooling specifications without the need to invest in totally new systems. Additional benefits could accrue from better utilisation of existing packhouse and storage equipment and improved flexibility in the period over which produce could be available for despatch.

TRIAL SITE AND FACILITIES

All trials were carried out at HRI, Kirton, using the existing icebank cool store and shelf-life facilities.

Specialist cooling equipment (Appendix I, fig I) was constructed by the HRI, Kirton, workshops using materials supplied by East Midlands Electricity plc.

Monitoring equipment and data analysis were provided by ADAS Mechanisation Unit, Silsoe.

MATERIALS

Cauliflowers, various cultivars, supplied by two local co-operatives directly from their field cutting gangs, and packed in supermarket trays. The samples were from late morning/early afternoon cuts when the crop was at its maximum field temperature.

Cauliflowers not required for sampling were returned to the co-operative at the end of the trial run.

DISCUSSION OF RESULTS

All the trials were carried out on single pallet loads of 35 supermarket plastic trays. The cooling rig drew air and water sprays downwards through the pallet load; water flows were varied between zero and 0.67 kg of water per hr per kg of produce; air flows were varied between 1 and 15 kg of air per hr per kg of produce.

The cooling time varied with airflow, from 319 minutes at 1 kg/kg h, zero water, to 109 minutes at 15 kg/kg h, 0.67 kg/kg h water. The cooling time was found to decrease as the airflow increased, but the sprayed water gave only a marginal improvement in cooling time, mostly at the lower airflows (table 2, Appendix I). At the highest cooling rates, the cooling time for individual heads within the stack was found to be variable, and seemed to depend on the position of the head within the stack and its size.

A large proportion of the water droplets sprayed into the airstream coalesced in the product and remained as free water. This seriously wetted the product and was considered totally unacceptable by the cauliflower packing companies as their packing and handling systems were geared to a dry product.

Air resistance through the pallet stack increased with increasing airflow. As the increase in air resistance between 10 and 15 kg/kg h was greater than the decrease in cooling time, it is suggested that airflows around 10 kg/kg h will offer the most practical parameters for cooler design.

Changes in weight (tables 3 & 4, Appendix I) were negligible, with a slight loss at zero water flow and slight gains when water was applied.

No loss of quality was apparent when the "dry run" samples were unloaded. The shelf-life trials (Appendix II) did not show any difference between experimental runs which used water and those which did not.

The shelf-life experiments were carried out on similar pallet loads, but separate lots were used to ensure compatibility with the "control" cooling in the co-operative cold store.

The results of the shelf-life do not indicate a significant change in shelf-life over conventionally cooled cauliflowers. There was a general deterioration in quality during the period in the shelf-life room, common to all experimental lots. It was suggested that this loss of quality was largely attributable to handling damage of the heads during cutting and trimming and that this would tend to mask any slight beneficial effects in shelf-life from the rapid cooling.

RECOMMENDATIONS FOR FURTHER WORK

1 The trial should be repeated using carefully harvested produce to examine any benefits of rapid cooling when the potential masking effects of post harvest damage are removed.

2 As Hydrair cooling is quite vigorous and could have adverse effects on some crops, the shelf-life trial should be repeated with other produce, especially more leafy species such as spring cabbage and spinach.

3 Exploration of the practical means of applying the increased airflows found in the trials, to a crop in a uniform manner and with the minimum of management effort.

4 Using the cooling rig and trial procedures to measure the relative cooling performance of a range of packaging materials and methods, leading to optimised design of packaging.

ACKNOWLEDGEMENTS

The high standard of technical assistance from Miss S A Minns, Miss S Gilbert and Mr G Steele (HRI) and Mr P Gough (Silsoe) is much appreciated.

We are indebted to the assistance given by East Lincolnshire Growers Ltd (ELGRO) and United Vegetables (Universal) Ltd in the provision of cauliflower for the trials.

East Midlands Electricity plc for supply of components for the rig, and to their contractors, Messrs Triac Ltd for the specialist wiring.

STORAGE OF DATA

The cooling data will be kept at Silsoe and the shelf-life data will be kept at HRI, Kirton, for a minimum of five years. Neither sets of data are to be disposed of without prior consultation with the client.

APPENDIX I

RAPID COOLING OF CAULIFLOWERS PERFORMANCE MEASUREMENTS

SUMMARY

Single pallet loads of 35 supermarket plastic trays of cauliflowers were cooled in an experimental Hydrair cooling rig. Water and air were drawn downwards through the load. Air flow rates ranged from 1 to 15 kilogrammes of air per kg of produce per hr (kg/kg h) and water flow rates ranged from 0 to 0.67 kg/kg h. The standard cooling time for each treatment was calculated and ranged from 102 to 319 minutes.

The water spray made very little difference to the cooling times. The practical maximum air ratio is 10 kg/kg h which will give a standard cooling time of 120 minutes.

OBJECT

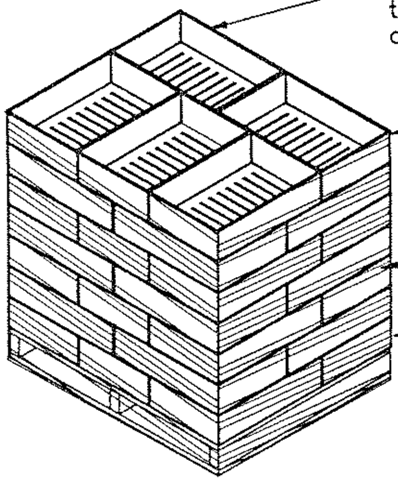
To show the effect of a range of air and water rates on the cooling time for a commercial unit load of cauliflowers and to establish the optimum combination of air and water rates.

MATERIALS AND METHODS

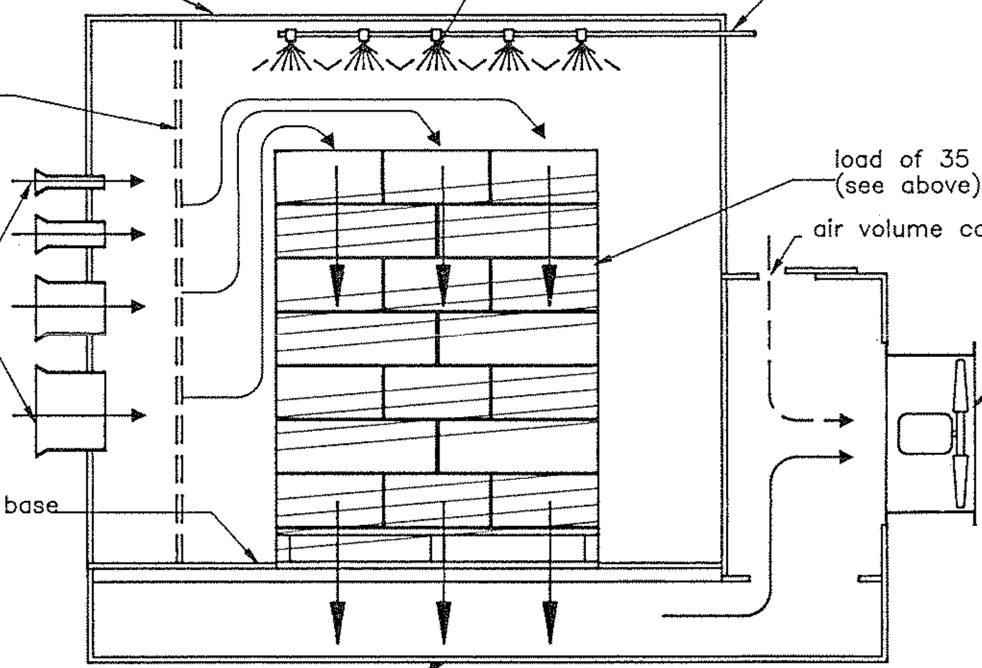
A test chamber was constructed in plywood as illustrated in Fig 1. The chamber was designed to hold a single 1200 x 1000 mm pallet load of produce and to stand inside the ice-bank store at HRI, Kirton. The design allows for air to be moved through the load vertically or horizontally and for a water spray to be introduced from above.

Air movement

Air from the store was drawn into the cooling chamber through one of four calibrated inlet cones. In this series of experiments it was then drawn down through the pallet load of produce into a sump below the pallet and thence to a fan plenum. One or two axial fans sucked the air from this plenum and delivered it back to the store to be re-cooled in the ice-bank. The volume of air drawn through the produce was regulated by allowing store air to enter the fan plenum through a controlled inlet.



PALLET LOAD OF 35 TRAYS AS MADE UP FOR TESTING



TEST RIG SHOWING LOAD IN POSITION

FIG.1 DETAILS OF TEST RIG AND METHOD OF ASSEMBLING THE LOAD

Water spray

Water was introduced into the test chamber by banks of crop spraying nozzles mounted on a ring main just below the chamber ceiling. Cold water from the ice bank was supplied at constant pressure to this ring main. The water application rate was governed by the number of spray nozzles in use during a test. Surplus water passed from the bottom of the pallet load into the sump and from there was pumped back to the tank of the ice-bank.

Instrumentation

Produce temperature and the temperature of the cooling water/air mixture was measured using 4 mm dia x 150 mm long thermistor probes. The cauliflower temperatures were measured in the centre of the head. The thermistor probe being carefully inserted to an appropriate depth. Three heads were measured in each load at the second, fourth and sixth layer of trays. A thermistor temperature probe was placed next to each of the measured heads to determine the coolant temperature.

The temperature of the water entering the spray nozzles, and the air and water after passing through the load were measured. The wet and dry bulb temperature of the air entering the test chamber was also measured. All the temperature measurements were recorded at two minute intervals throughout each test by an automatic data logger.

The air pressure difference between the test chamber and the sump was recorded for each test. The air flow into the test rig was calculated from the depression at the inlet cone. All pressure measurements were made with an inclined tube manometer.

EXPERIMENTAL PROCEDURE

Before each test the air and water rates were selected by blanking any surplus spray nozzles and uncovering the appropriate air inlet cone.

For each test crates of warm cauliflowers were weighed and stacked in the cooling chamber. As the stack was built the temperature probes were inserted. The completed stack was sealed to the floor and its sides covered with industrial cling-film (Fig 1). The side of the cooling chamber was sealed into place.

The recording equipment was started and the air flow rate adjusted to give the required air ratio. Cooling continued until all the produce temperatures were at or below 6°C.

After cooling the produce was de-stacked, inverted to drain any remaining water, and re-weighed.

It was clear from early tests that the water spray was making little difference to the cooling times so some of the planned combinations of air and water flow were not investigated. In table 1 'x' shows which combinations are reported.

Table 1
Cooling Treatments

Air ratio kg/kg h	1	3	6	10	15
Water rate kg/kg h					
0	x	x		x	x
0.13				x	x
0.27					x
0.40		x	x	x	x
0.54			x		x
0.67	x		x		x

RESULTS AND DISCUSSION

Presentation of results

The temperature records from each test have been analysed to produce individual cooling coefficients and lag factors. In order to make it easy to compare the results of tests where the initial product temperature and coolant temperature were non standard, these parameters have been used to calculate a "Standard Cooling Time". Standard Cooling Time is defined as the time that would be taken to reduce the head centre temperature from 16°C to 6°C with the cooling medium at 2°C.

Table 2
Average Standard Cooling Time (minutes) for each Test

Air ratio kg/kg h	1	3	6	10	15
Water rate kg/kg h					
0	319	230		103	123
0.13				125	102
0.27					102
0.40		189	156	145	113
0.54			161		112
0.67	208		162		109
Average	263	209	160	124	110

Fig 2 shows these results in graphical form. The range of results at each air ratio is indicated by the vertical bar.

The cooling results show a wide variation in cooling time. Small errors in positioning the temperature probe could lead to significant variation. The exposure of an individual head to the coolant stream will vary depending on how variable the packing density of the tray is. It is not possible to identify variation in head size as a cause of cooling rate variation in these results.

Fig 3 provides clear evidence that the distance of the head downstream of the coolant entry point affects the cooling time. Fig 4 also shows how the coolant temperature quickly falls towards the sink temperature while the head centre temperature falls much more slowly. This is a clear indication of the limitation on cooling rate imposed by conduction within the cauliflower.

Fig 2 HDC Cauliflower Cooling Average Cooling Time V Air Ratio

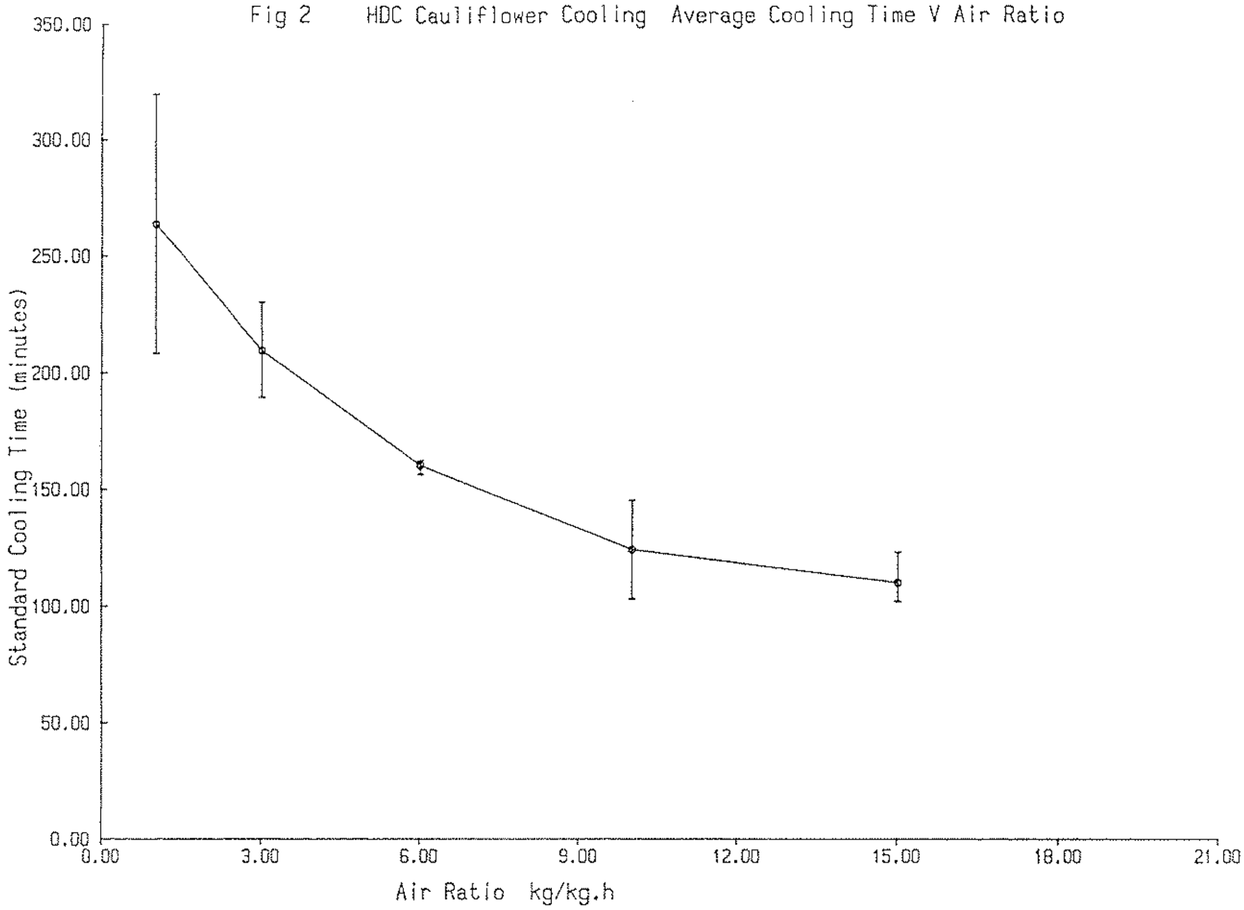
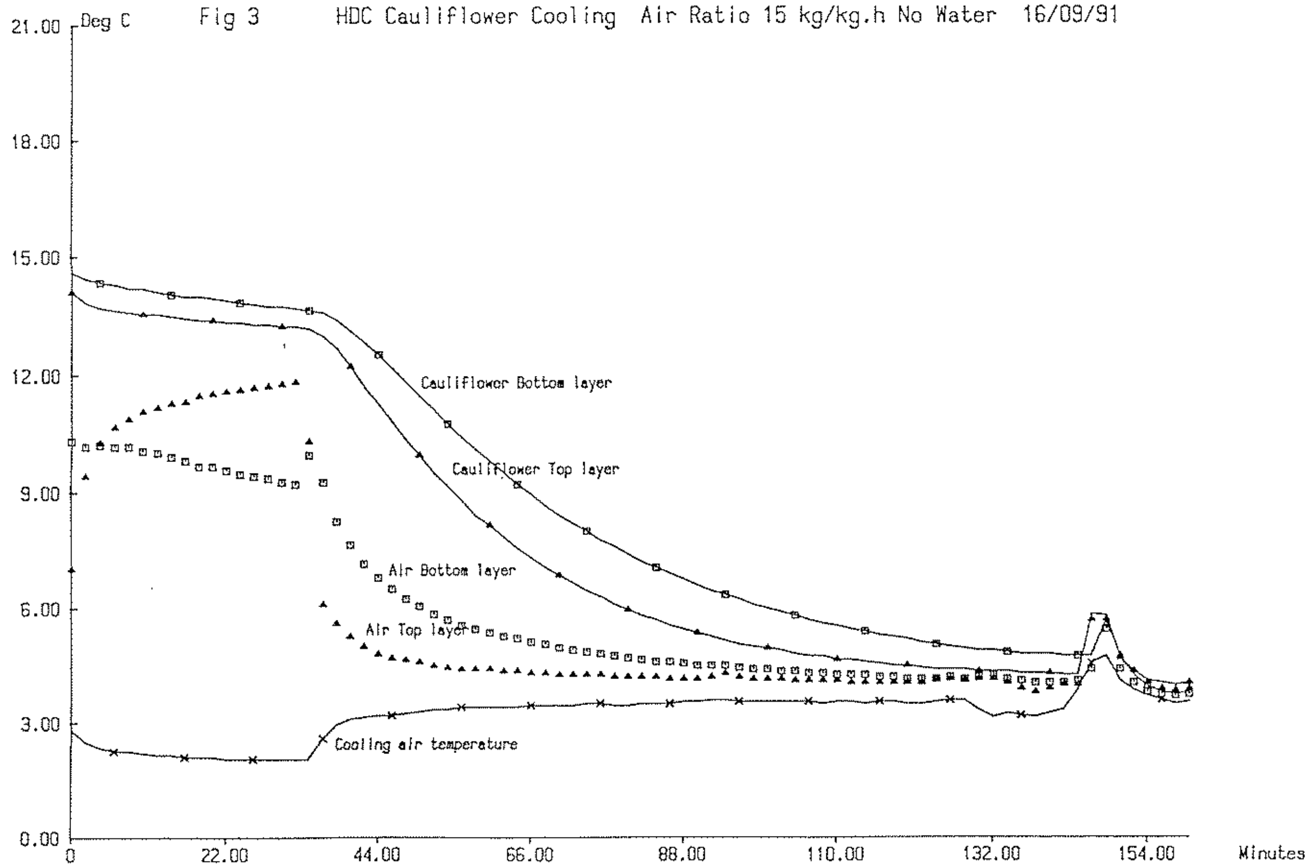


Fig 3 HDC Cauliflower Cooling Air Ratio 15 kg/kg.h No Water 16/09/91



Resistance to Air flow

The resistance of the pallet load to air flow is illustrated in Fig 4. The range of observed values at high air ratios is much greater than at low air ratios. Minor variations in tessellation of the heads and small differences in the stacking/sealing become much more important at high flow rates.

Water retention/weight loss

Table 3
% Change in weight during cooling

Air ratio kg/kg h	1	3	6	10	15
Water rate kg/kg h					
0	-.74	-.59		-.18	-.33
0.13				4.31	1.06
0.27					1.72
0.40		0.93	0.87	1.29	1.03
0.54			0.72		1.41
0.67	1.06		1.43		1.32

Table 4
% Weight Loss per Degree of Temperature Reduction - Dry cooling

Air Ratio kg/kg h	1	3	6	10	15
Weight loss %/Deg C	0.079	0.059		0.014	0.033

The average water retention after the wet cooling treatments was 1.02% of the initial dry weight. Water retention is not affected by either air flow or water flow rates.

Table 4 suggests that low air ratios (slow cooling) leads to higher rates of water loss. It is possible that very high air ratios may lead to higher water loss rates.

CONCLUSIONS

There is no significant reduction in cooling time as a result of wetting the crop at high air ratios and only a marginal advantage at low air ratios.

Cooling time decreases with increasing air ratio. The present data suggest that an infinite air ratio would result in an average cooling time of 100 minutes.

The variability of cooling time is greatest at low air ratios.

The pressure drop through the load will limit the maximum practical air flow to 10 kg/kg h. This air flow rate can be expected to give a standard cooling time of 120 minutes.

The air pressure drop becomes more variable at high air ratios

The cooling time within a stack is variable and depends on the position of the head within the load.

The average water retention by the cauliflowers after draining was 1.02% of the dry weight. There was no correlation between water or air rate and water retention.

The water loss rate in dry cooling treatments was highest at low air ratios.

APPENDIX II

CROP SHELF-LIFE

OBJECTIVE

To evaluate the effect of rapid removal of field heat using high volumes of cool moist air on the subsequent shelf-life of the product (cauliflowers) when compared with conventionally cooled produce.

METHOD

Cauliflowers from a number of "Hydrair" treatments were compared with conventionally cooled (8-10 hrs) under simulated supermarket shelf-life conditions for percentage weight loss and quality downgrading.

In a separate experiment, the effect of Hydrair rapid cooling on extended holding storage was compared with conventional cooling by looking at shelf-life characteristics following 1, 3, 5, 7, 9 days in a holding store at 6°C.

Trial 1 Comparisons of shelf life characteristics of high volume "Hydrair" cooled produce with conventionally cooled produce

Cauliflower were cut commercially by co-operative employees on the morning of each experimental test run and packed into supermarket crates, eight cauliflowers per crate. One hundred and five crates were used for each experiment; 70 crates being delivered to HRI, Kirton, for Hydrair cooling whilst the remaining 35 were put into conventional cool store at the co-operative for 24 hours (control). Thirty-five of the HRI batch of crates were placed in the rig in the ice bank and the main store was left closed for 30 mins to allow air temperature to drop to 0.5°C. The produce was then cooled with an airflow of 15 kg air/hr/kg produce, in the absence of water until all produce was reduced to a temperature of 6°C or below. Once the produce temperature had reached 6°C it was removed to a cool store set at 6°C to be held until the following day. In the afternoon the process was repeated on the other 35 crates, with the same air flows but with the addition of a medium cold water spray rate. Produce upon reaching 6°C was again removed to the holding store overnight.

The following morning the control pallet of 35 crates was delivered from the co-operative and six crates of each of the three treatments were weighed into the shelf-life room. The shelf-life room was set at 20°C, 50% RH and had a high light intensity to simulate typical supermarket conditions. At 24 hr intervals the crates were reweighed, any cauliflower no longer Class 1 removed and the crate weighed once more to allow subsequent weight loss to be calculated. This was done for a maximum of 10 days after which the weight of the crate was recorded. This trial was done three times but only one set of data is given.

Trial 2 Comparison of shelf-life characteristics of low volume "Hydrair" cooled produce with conventionally cooled produce

Trial 1 was repeated using an air flow of 1 kg air/hr/kg produce, with and without a low volume spray of cooled water. This trial was also done three times.

Trial 3 Comparisons of shelf-life characteristics that high volume airflow and conventional cooling would produce following extended time in holding store at 6°C

Trial 1 was repeated but omitting the added water cooling regime, therefore 24 hr after cutting there were 35 crates of Hydrair rapidly cooled and a control of 35 crates of conventionally cooled produce in the 6°C direct expansion holding store. This was termed Day 1, on Day 1, 3, 5, 7 and 9 six crates of each treatment were weighed into the shelf-life room and inspected for Class 1 produce as described above. This trial was only done once.

Records taken during trials

i Percentage weight loss during shelf-life

ii Number remaining as Class 1 during shelf-life

iii Comment on reasons for downgrading of produce

Results and Discussions

Trial 1 Comparisons of shelf-life characteristics of high volume "Hydrair" cooled produce with conventionally cooled produce

Tables 1 & 2 show the percentage weight loss and decline in quality of produce cooled either by high air flow, with or without water or by conventional cooling over a longer period. Care has to be taken when comparing these results as post cutting, pre shelf-life treatments of the three processes were different. However it is systems, not details within them, that are being compared. It was not possible to apply statistics to these results but it appears that rapid cooling with a high volume Hydrair system has neither a deterious nor an advantageous effect upon subsequent shelf-life.

Table 1 Percentage weight loss

Treatment	Marketable produce from cooling treatments during accumulated weight loss from shelf-life over time							
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Mean
15 kg cold air/kg produce per h	0	6.25	9.56	13.56	17.05	20.38	24.16	15.16
15 kg cold air/kg produce per h plus water	0	6.18	9.69	14.23	17.43	21.00	24.61	15.52
Control (conventional cooling)	0	5.53	8.84	12.78	16.31	20.33	24.24	14.67
Mean	0	5.99	9.36	13.52	16.93	20.57	24.34	

Table 2 Number of heads in Class 1

Treatment (cooling air ratio/hr)	Number of Class 1 cauliflowers remaining (out of 8) over time							
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Mean
15 kg cold air/kg produce per h	8	8	8	8	7.7	4.8	2.0	6.6
15 kg cold air/kg produce per h plus water	8	8	8	8	6.7	3.8	1.3	6.3
Control (conventional cooling)	8	8	7.7	7.0	6.0	2.0	0.7	5.6
Mean	8	8	7.9	7.7	6.8	3.5	1.3	

Trial 2 Comparisons of shelf-life characteristics of low volume "Hydrair" cooled produce with conventionally cooled produce

Tables 3 and 4 show the equivalent to tables 1 and 2 above but for low volume Hydrair cooling, the trends in the results are very similar to Trial 1 and showed that there was no effect of cooling system upon subsequent shelf-life

Table 3 Percentage weight loss

Treatment (cooling air ratio/hr)	Accumulated percentage weight loss from marketable produce from cooling treatments during shelf-life over time							
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Mean
15 kg cold air/kg produce per h	0	3.54	8.09	11.73	15.27	19.30	*	11.59
15 kg cold air/kg produce per h plus water	0	2.76	7.36	10.53	14.50	18.76	*	10.78
Control	0	3.83	8.20	11.68	15.40	19.46	*	11.71
Mean	0	3.38	7.88	11.31	15.06	19.17	*	

* No Class 1 produce left

Table 4 Number of heads in Class 1

Treatment (cooling air ratio/hr)	Number of Class 1 cauliflowers remaining (out of 8) over time Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Mean
15 kg cold air/kg produce per h	8	8	8	7.7	4.7	1.3	0	6.3
15 kg cold air/kg produce per h plus water	8	8	7.8	6.5	2.0	0.5	0	5.5
Control	8	8	8	7.8	5.7	2.0	0	6.6
Mean	8	8	7.9	7.3	4.1	1.3	0	

Note: The main reasons for downgrading was the expression of bruising caused by harvesting, trimming, packing, soft rot developing or flaccidity during the latter stages. This applied to both Trial 1 and Trial 2. Whilst it is not possible to compare Trial 1 with Trial 2 as the starting material came from a different population of cauliflower, during the execution of the 6 trials that constituted the above investigation it was apparent that although the trends between treatments was similar in all trials the rates of downgrading varied between trials and could be visually related to the severity of bruising and damage during harvesting and handling pre-cooling.

Trial 3 Comparisons of shelf-life characteristics of "Hydrair" and conventionally cooled produce following extended time in holding store at 6°C

Even if Hydrair cooling gave no immediate beneficial effect on shelf-life characteristics it was postulated that the rapid removal of field heat could extend the holding store life of cooled produce. Tables 5 and 6 show percentage weight loss and decline in quality of both types of cooling in shelf-life following one to nine days in holding store at 6°C.

Although produce quality declined in holding store there were no differences between the two cooling methods and so no advantage could be attributed to rapid cooling. Again downgrading was mainly due to expression of pre-cooling damage to heads during harvesting, trimming and packing.

Table 5 Percentage weight loss

Treatment cooling time in store	Accumulated weight loss from marketable produce from cooling treatments during shelf-life over time Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Mean
1 day in store:							
rapid cooled	0	6.22	10.35	14.88	20.61	24.70	15.35
conventionally cooled	0	6.30	10.18	14.54	19.49	23.78	14.86
3 day in store:							
rapid cooled	0	4.42	9.64	13.38	21.40	*	12.21
conventionally cooled	0	4.39	9.04	13.36	18.38	*	11.29
5 day in store:							
rapid cooled	0	4.71	11.38	15.78	*	*	10.62
conventionally cooled	0	4.67	11.00	14.75	[18.56]	*	10.14
7 day in store:							
rapid cooled	0	4.05	8.78	13.71	19.22	*	11.44
conventionally cooled	0	3.00	8.27	13.13	18.95	[25.32]	10.84
9 day in store:							
rapid cooled	0	4.46	10.05	16.49	27.70	*	14.68
conventionally cooled	0	4.73	9.52	13.91	21.90	*	12.52

* No Class 1 produce remaining
[ ] Number in brackets not included in mean due to lack of equivalent number in the rapid cooled comparison

Table 6 Number of heads in Class 1

Treatment cooling time in store	Number of Class 1 cauliflowers remaining (out of 8) over time Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Mean
1 day in store:							
rapid cooled	8.0	8.0	5.0	2.3	1.7	0.0	4.1
conventionally cooled	8.0	8.0	5.7	2.8	1.7	0.0	4.4
3 day in store:							
rapid cooled	8.0	6.0	5.0	0.7	0.0	0.0	3.3
conventionally cooled	8.0	6.3	4.5	0.8	0.0	0.0	3.3
5 day in store:							
rapid cooled	8.0	4.5	1.0	0.0	0.0	0.0	2.3
conventionally cooled	8.0	4.3	0.8	0.3	0.0	0.0	2.2
7 day in store:							
rapid cooled	7.2	5.7	2.3	1.3	0.0	0.0	2.8
conventionally cooled	7.0	6.0	3.1	0.8	0.3	0.3	2.9
9 day in store:							
rapid cooled	6.5	3.7	0.5	0.3	0.0	0.0	1.8
conventionally cooled	7.0	4.7	1.3	0.5	0.0	0.0	2.3

CONCLUSIONS

The rapid cooling of cauliflower using the Hydrair method had neither an adverse nor beneficial effect on the shelf-life of produce when compared with conventionally cooled produce. This was because any potentially beneficial effect resulting from rapid cooling was probably masked by expressions during the early stages of shelf-life, of damage caused during harvesting, pre-cooling, trimming and packing.

Fig 4 HDC Cauliflower Cooling Average Static Pressure V Air Ratio