CONTRACT REPORT

FV133

CARROT HYDROCOOLING

Commercial in Confidence

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AUTHENTICATION

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

J E Birkenshaw ..... Date 20/5/93

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SUMMARY

Carrots were hydrocooled to 1°C or 3°C with or without additional chlorine as either Sodium hypochlorite (bleach) or chlorine dioxide and after pre-packing cold stored for 4 days or 24 hours then placed in a shelf life room for 7 days. Weight loss, skin texture, turgidity and % area rotting were assessed. Trials were carried out at 2 sites in July, August, September and November.

Weight loss was reduced by hydrocooling to 1°C or 3°C in the August trial but not in July, September or November.

Skin texture was improved by hydrocooling to 1°C or 3°C and by the addition of hypochlorite or chlorine dioxide in the July and August trials but not in September or November.

Turgidity was improved by hydrocooling to 1°C or 3°C in July and August trials but not in September and November.

Adding hypochlorite or Chlorine dioxide to the hydrocooler did not significantly affect turgidity in any trial.

In July and September levels of rotting were low but in the August and November trials more severe rotting was observed (violet root rot and Sclerotinia) and hydrocooling to either 1°C or 3°C with additional chlorine significantly reduced mean rotting throughout the 7 day shelf life period. Hydrocooling without chlorine or chlorine without hydrocooling was not as effective at controlling rotting as the combination of hydrocooling with chlorine. Chlorine dioxide was as effective as sodium hypochlorite and hydrocooling to 3°C was as effective as hydrocooling to 1°C.

Separate assessments were made of microbiological contamination on carrots and in hydrocooling water. The % area of roots affected by fungi (Thielaviopsis, Sclerotinia and violet root rot) and counts of total viable bacteria, pectolytic bacteria and Erwinia carotovora sub sp. carotovora were all reduced by the combination of hydrocooling and additional chlorine. Both types of chlorine were equally effective but hydrocooling alone, to 1°C or 3°C, did not significantly reduce the microbiological population on carrots or in the water in the hydrocooler.

On all occasions the `core` temperature of carrots coming out of the hydrocooler was 1-2°C higher than the `set` temperature of the hydrocooler.

INTRODUCTION

The carrot industry in the UK is composed of large individual units, typically with centralised grading facilities, with throughputs of 50-100 tonnes per day for almost 11 months of the year. Most carrots are washed with water at the ambient air or borehole temperature prevailing at the time of year, and densely packed in bags or boxes after grading. They are then shipped to wholesaler or retail customer. Deterioration of roots under warm, wet conditions is a frequent cause for concern and sometimes rejection.

Hydrocooling and/or a chlorine wash could potentially increase the shelf life of pre-packed carrots and this project was carried out to evaluate the effects on shelf life from hydrocooling carrots compared with packing at ambient temperature. The addition of chlorine to water in the hydrocooler was monitored for any effects on shelf life and on levels of microbiological contamination on the surface of carrot roots.

MATERIALS AND METHODS

Treatments :

1. Ambient temperature, no chlorine.
2. Ambient temperature, with hypochlorite (as 200 ppm sodium hypochlorite).
3. Ambient temperature, with chlorine dioxide (as 25 ppm Purogene).
4. Hydrocooled to 1°C, no chlorine.
5. Hydrocooled to 1°C, with hypochlorite (as 200 ppm sodium hypochlorite).
6. Hydrocooled to 1°C, with chlorine dioxide (as 25 ppm Purogene).
7. Hydrocooled to 3°C, no chlorine.
8. Hydrocooled to 3°C, with hypochlorite (as 200 ppm sodium hypochlorite).
9. Hydrocooled to 3°C, with chlorine dioxide (as 25 ppm Purogene).

After washing and size grading, 20 samples of 10 carrots/treatment were taken from the grading line immediately after passing through the hydrocooler and placed in perforated plastic bags (prepack of 10 carrots). 10 samples were then cold stored for 24 hours and 10 for 4 days at a mean temperature of 5°C.

Following cold storage the samples were taken to the shelf life room at NIAB which was kept at 20°C, with 50% RH and lighting at 1200 lux - 12 hours on and 12 hours off. They were then assessed after 7 days by NIAB for weight loss, turgidity, skin texture and rotting.

In addition, separate samples (5 prepacks of 10 carrots) were taken to ADAS Food Team at Cambridge to assess the effects of hydrocooling and chlorine treatments on bacteria and fungi on the surface of carrot roots. Assessments were made on the day of sampling (day 0) and after 5 and 7 days in the shelf life room at 20°C.

During sampling, temperature measurements of the `core` of carrot roots were taken using a needle probe inserted into the shoulder of the carrot before and after hydrocooling and also in the trailer loading into the washer and at the point where carrots came out of the washer.

This procedure was repeated on 4 occasions (2 occasions at 2 sites) during 1992 - July 26/30, August 10/14, September 16/20 and November 16/20 - to represent warm and cool times of the year.

Details of microbiological and chemical assessment methods are presented in appendices 1 and 2.

RESULTS

1. SHELF LIFE QUALITY

Table 1 July trial

Data presented is mean of both storage periods after 7 days in shelf life room.

Treatment	% wt. loss	Turgidity scale 1-9	Skin text scale 1-9	% area rotting
Ambient no chlorine	2.71	6.28	3.90	2.47
Ambient + hypochlorite.	2.97	6.06	5.10	6.62
Ambient + chlorine diox.	2.62	6.68	5.22	1.66
1°C no chlorine	2.43	6.80	6.13	0.84
1°C + hypochlorite.	2.49	6.85	5.60	0.70
1°C + chlorine diox.	2.62	6.85	5.35	0.56
3°C no chlorine	2.41	6.93	5.57	1.08
3°C + hypochlorite.	2.68	6.88	5.70	0.36
3°C + chlorine diox.	2.79	6.90	5.75	0.56
mean	2.64	6.69	5.37	1.65
SE (Var mean)	0.1307	0.1286	0.1841	1.00
LSD (Var mean) (P = 0.05)	0.381	0.375	0.537	2.29
CV%	9.9	3.8	6.9	121.2

Table 1 shows there was no significant loss of weight from any treatment after 7 days in the shelf life room.

Turgidity was scored on scale 1 to 9, where 1 = flaccid 9 = turgid. The treatments using ambient washing scored lowest, significantly so for ambient no chlorine and ambient + hypochlorite. The scores for turgidity were similar for all treatments at 1°C and 3°C.

Skin texture (scored on scale 1 to 9, 1 = dull and silvered, 9 = smooth and bright) in the ambient treatments prior to shelf life, especially without chlorine scored significantly less than the mean. When no chlorine was used, skin texture was significantly better at 1°C or 3°C, compared with ambient. Scores were similar at all temperatures when either hypochlorite or chlorine dioxide was incorporated.

The percentage area rotting (violet root rot) was most severe in the ambient treatments. The percentage area rotting decreased when carrots were hydrocooled prior to shelf life testing, with the least amount of rotting being found in the treatment 3°C + hypochlorite.

There was no significant difference between cold storage for 24 hours and cold storage for 4 days in the hydrocooled 1°C, 3°C or chlorine treatments. However carrots stored at ambient for 4 days scored lowest for skin texture and turgidity (see bar charts on pages 10 and 11).

Table 2 August trial

Data presented is mean of both storage periods after 7 days in shelf life room.

Treatment	% wt. loss	Turgidity scale 1-9	Skin text scale 1-9	% area rotting
Ambient no chlorine	2.71	6.16	*	67.86
Ambient + hypochlorite	3.04	6.22	4.80	19.50
Ambient + chlorine diox.	2.30	6.43	5.22	24.05
1°C no chlorine	1.36	6.63	5.30	10.64
1°C + hypochlorite	1.38	6.65	5.15	2.11
1°C + chlorine diox.	1.20	6.75	5.60	3.72
3°C no chlorine	1.25	6.68	5.55	15.49
3°C + hypochlorite	1.36	6.85	5.78	0.58
3°C + chlorine diox.	1.78	6.18	5.30	3.71
mean	1.82	6.50	5.34	16.41
SE (Var mean)	0.1166	0.1916	3.401	0.23
LSD (Var mean) (P = 0.05)	0.341	0.563	9.928	0.67
CV%	3.6	7.2	41.5	25.5

* = Skin texture could not be assessed because rotting was too severe.

Table 2 shows weight loss was greatest in carrots kept at ambient, being significantly higher than the mean. Weight loss was similar for all the various treatments hydrocooled at 1°C or 3°C. In the July trial there was no significant weight loss in spite of higher background temperatures. However, weight loss was higher in the Ambient treatments.

Turgidity was significantly reduced in the unchlorinated ambient treatment and significantly improved by hydrocooling to 3°C with hypochlorite. Turgidity scores were also lower in the other ambient treatments compared to hydrocooled treatments at 1°C or 3°C. Scores for turgidity for the various treatments at 1°C and 3°C were similar, except for 3°C with chlorine dioxide where turgidity was reduced.

Skin texture scores, were lowest for treatments at ambient. It was not possible to score the control treatments (*) for skin texture because there was so much rotting. The best texture score was from the treatment 3°C with hypochlorite.

There were large differences in levels of rotting between treatments. The highest level of rotting was found in the control treatment, ambient without chlorine. Rotting was reduced three-fold when carrots were treated with either chlorine dioxide or hypochlorite even when kept at ambient temperature.

Rotting was reduced even further for both 1°C and 3°C hydrocooled treatments but the levels of rotting were similar at these two temperatures for the various chlorine treatments.

Table 3 September trial

Data presented is mean of both storage periods after 7 days in shelf life room

Treatment	% wt. loss	Turgidity scale 1-9	Skin text scale 1-9	% area rotting
Ambient no chlorine	1.75	6.97	6.22	0.26
Ambient + hypochlorite	1.78	6.68	6.05	1.46
Ambient + chlorine diox.	1.70	6.85	5.63	0.29
1°C no chlorine	1.59	7.30	6.28	0.67
1°C + hypochlorite	1.80	6.63	5.38	0.12
1°C + chlorine diox.	1.53	7.15	5.82	0.37
3°C no chlorine	1.68	6.78	4.81	0.39
3°C + hypochlorite.	1.55	6.22	5.97	0.39
3°C + chlorine diox.	1.77	6.75	6.25	0.27
mean	1.68	6.81	5.82	0.47
SE (Var mean)	0.0544	0.3013	0.6413	0.4668
LSD (Var mean) (P = 0.05)	0.159	0.879	1.872	1.363
CV%	6.5	8.8	22.0	199.7

Table 3 shows there were no significant differences between the various treatments in this trial for the characteristics recorded.

After 7 days in the shelf life room there was little deterioration due to rotting in this test, maximum recorded level being less than 2%. Any rotting present was limited to the root tips.

Table 4 November trial

Data presented is mean of both storage periods after 7 days in shelf life room

Treatment	% wt. loss	Turgidity scale 1-9	Skin text scale 1-9	% area rotting
Ambient no chlorine	2.60	7.00	5.30	48.50
Ambient + hypochlorite.	2.62	7.00	5.05	37.50
Ambient + chlorine diox.	2.14	7.05	4.20	3.50
1°C no chlorine	2.67	7.00	5.15	39.00
1°C + hypochlorite	2.75	6.90	4.95	51.00
1°C + chlorine diox.	2.38	6.80	4.20	4.50
3°C no chlorine	2.43	6.95	5.30	45.50
3°C + hypochlorite.	2.39	6.95	5.20	30.50
3°C + chlorine diox.	2.38	7.00	4.05	4.50
mean	2.49	6.96	4.82	29.39
SE (Var mean)	0.1486	0.0571	0.1556	4.86
LSD (Var mean) (P = 0.05)	0.434	0.167	0.454	14.19
CV%	12.0	1.6	6.5	33.1

Table 4 shows there were no significant differences between either the percentage weight loss or turgidity following the different treatments.

Unusually, skin texture was significantly poorer than the control in the roots treated with chlorine dioxide regardless of temperature on this occasion; the reason for this is unknown.

There was no significant effect on weight loss, turgidity, or skin texture from cold storing for 4 days compared to cold storing for 24 hours except for ambient without chlorine treatment where 4 days cold storage at ambient resulted in reduced quality scores and increased levels of rotting. (See bar charts on pages 10 and 11).

There were two types of fungal rotting observed in this trial; Sclerotinia and violet root rot. Violet root rot was present in small amounts but there were no significant differences in the percentage area rotting between the various treatments (see table 5 below).

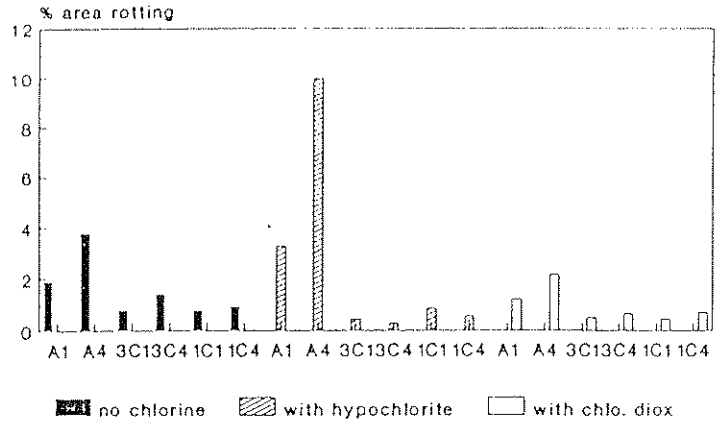
Table 5 November trial Assessment of rotting caused by Sclerotinia and violet root rot.

Data presented is mean of both storage periods after 7 days in shelf life room

Treatment	% violet root rot	Sclerotinia - scale 1-9 9 = Row incidence
Ambient no chlorine	1.91	8.03
Ambient + hypochlorite	0.17	8.06
Ambient + chlorine diox.	0.79	8.95
1°C no chlorine	1.08	8.26
1°C + hypochlorite	2.35	7.47
1°C + chlorine diox.	1.05	8.93
3°C no chlorine	0.90	8.12
3°C + hypochlorite	0.12	8.52
3°C + chlorine diox.	0.85	8.95
mean	1.03	8.36
SE (Var mean)	0.5889	0.1607
LSD (Var mean) (P = 0.05)	1.719	0.470
CV%	114.8	3.80

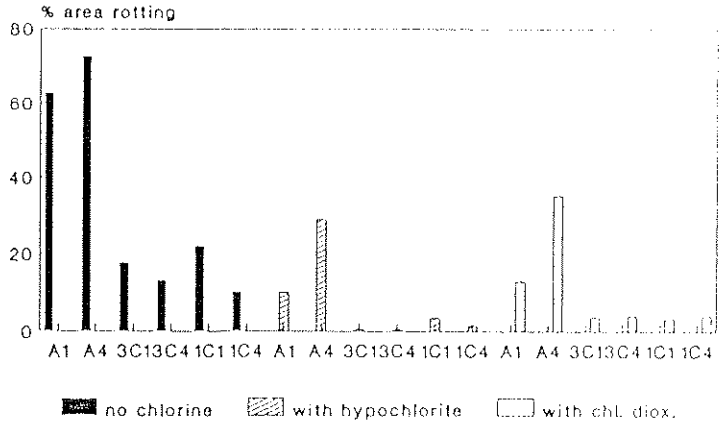
Sclerotinia rot was more severe than the mean for treatments without chlorine and hypochlorite treatments (significantly for Ambient no chlorine, 1°C with hypochlorite, and 3°C no chlorine). The samples treated with chlorine dioxide had significantly less roots affected by Sclerotinia than the other treatments. This applied to all 3 temperature treatments.

fig.1 July % area of root rotting
after 7 days in shelf life room



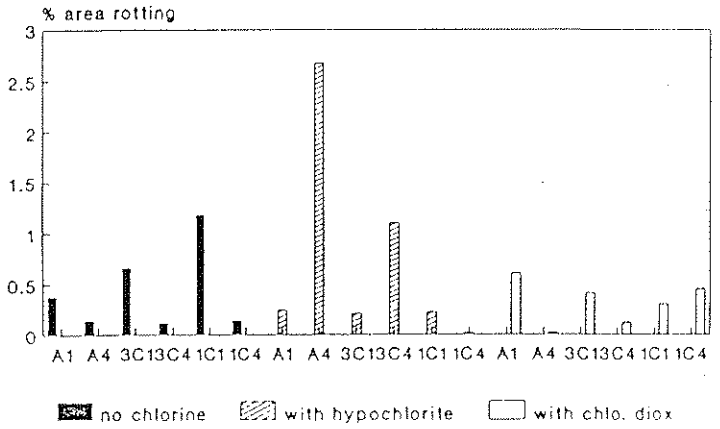
mean = 1.65 LSD = 2.92

fig.2 August % area root rotting
after 7 days in shelf life room



mean = 16.41 LSD = 0.67

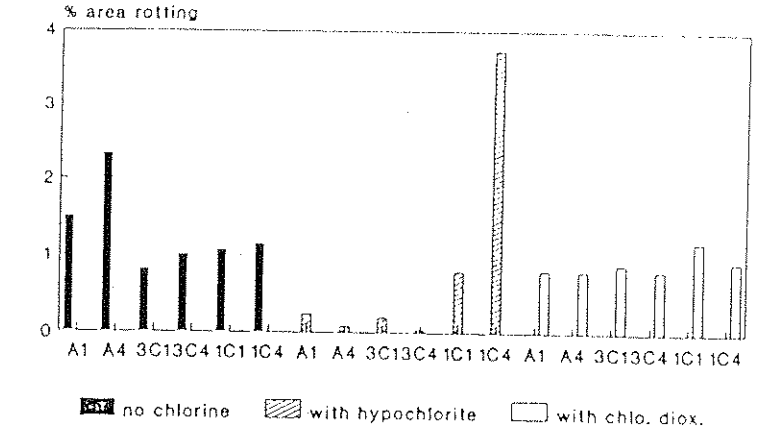
fig.3 Sept. % area root rotting
after 7 days in shelf life room



mean = 0.47 LSD = 1.36

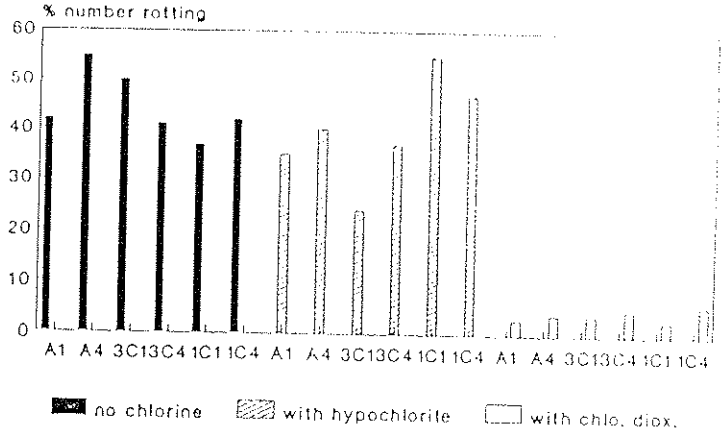
A1 = Ambient, 1 day before shelf life
A4 = Ambient, 4 days before shelf life
3C1 = Hydrocooled to 3° C, 1 day in cold store
3C4 = Hydrocooled to 3°C, 4 days in cold store
1C1 = Hydrocooled to 1°C, 1 day in cold store
1C4 = Hydrocooled to 1°C, 4 days in cold store

fig.4 Nov. Violet root rot
after 7 days in shelf life room



mean = 1.03 LSD = 1.72

fig. 5 Nov. Sclerotinia
after 7 days in shelf life room



mean = 8.38 LSD = 0.47

A1 = Ambient, 1 day before shelf life
A4 = Ambient, 4 days before shelf life
3C1 = Hydrocooled to 3°C, 1 day in cold store
3C4 = Hydrocooled to 3°C, 4 days in cold store
1C1 = Hydrocooled to 1°C, 1 day in cold store
1C4 = Hydrocooled to 1°C, 4 days in cold store

2. ROOT CORE TEMPERATURES

Root core temperatures were measured using a needle probe inserted into the shoulder of carrot roots. Samples were taken from:

1. Delivery trailer during unloading at the packhouse.
2. The exit of the barrel washer.
3. On entry to the hydrocooler.
4. After hydrocooling to 1°C or 3°C.
5. After passing through the hydrocooler held at ambient (tap water temperature)

Core temperature °C - mean of 100 roots

Test Month	Trailer	Barrel washer	Before hydro	After hydro 3°C	After hydro 1°C	After hydro at ambient
July	20.0	20.5	20.0	8.0	5.5	18.0
August	16.0	16.1	16.0	8.2	5.0	14.7
Sept	15.5	14.0	14.0	8.5	7.5	13.0
Nov	9.0	6.0	8.0	4.5	3.0	8.0

Core temperature measurements show that carrots are not cooled to the set temperature of the hydrocooler water. In July, August and September core temperature could be up to 6.5°C greater than the set temperature and even in November, when the base temperature was low, core temperatures were 1 - 2°C higher than the hydrocooler water.

After 24 hours in cold store the temperature of all treatments had stabilised at 5°C and core temperature remained at 5°C + or - 1.5°C.

In July/August/September the temperature of water in the barrel washer was higher than that of ambient water in the hydrocooler and in July was 0.5°C higher than the temperature of carrots being washed.

3. MICROBIOLOGICAL ASSESSMENT OF CARROT ROOTS

Counts of total viable bacteria (TVC), total pectolytic bacteria and, using a modification of the method of Perombelon et al (1987) Erwinia spp were assessed. (See appendix 1 for details of methods used.)

Samples were assessed on day 0, day 5 and day 7 after hydrocooling; day 5 and day 7 samples being taken from the shelf life room at NIAB.

For fungal analysis the percentage area of root affected by fungal lesions was recorded. The most common disease found was Thielaviopsis but Geotrichum candidum (sour rot) and Sclerotinia were also found in some samples.

Three replicate sub-samples of each treatment were assessed for each category of micro organism and all replicates showed very similar levels of microbiological contamination.

Fungi - Figure 6

Significant differences in fungal lesions were not observed between untreated and chlorine treated samples assessed immediately after packing. After 5 days in shelf life fungal lesions had increased significantly from day 0 regardless of treatment. However whilst the fungal decay in the untreated sample continued to increase unabated, treatment with either hypochlorite or chlorine dioxide arrested further decay and chlorine treated samples were significantly better than untreated carrots after ambient storage and 7 days shelf life.

Treatment with either hypochlorite or chlorine dioxide combined with hydrocooling to either 1° or 3°C significantly controlled development of fungal lesions compared to carrots hydrocooled but without any chlorine throughout the 7 days in shelf life.

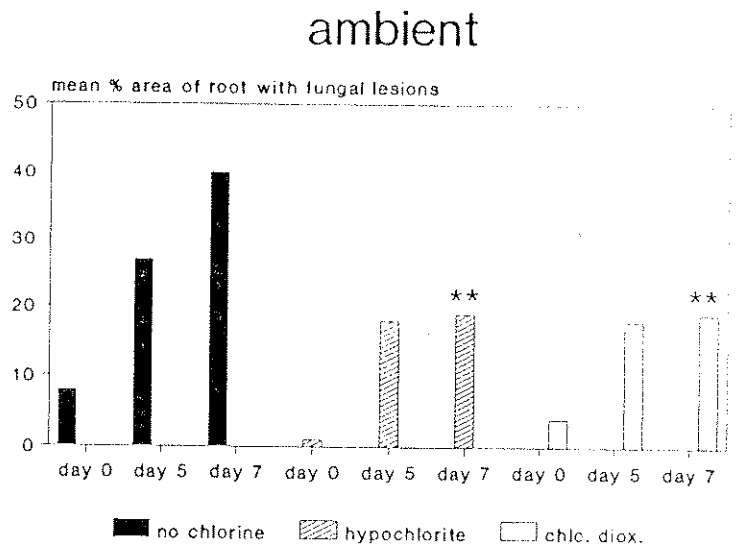
Results for chlorine dioxide treatment at 1°C and 5 days in the shelf life room was the only exception to this trend. Here fungal decay was reduced but the reduction was not statistically significant.

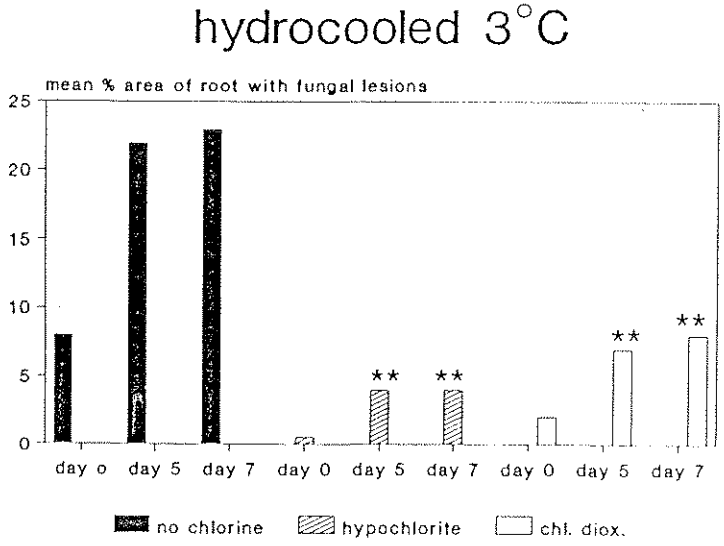
The combination of hydrocooling and the addition of chlorine controlled fungal decay at levels not significantly different to those observed on day. Hydrocooling to 1°C conferred no significant advantage, in relation to fungal decay, compared to hydrocooling to 3°C.

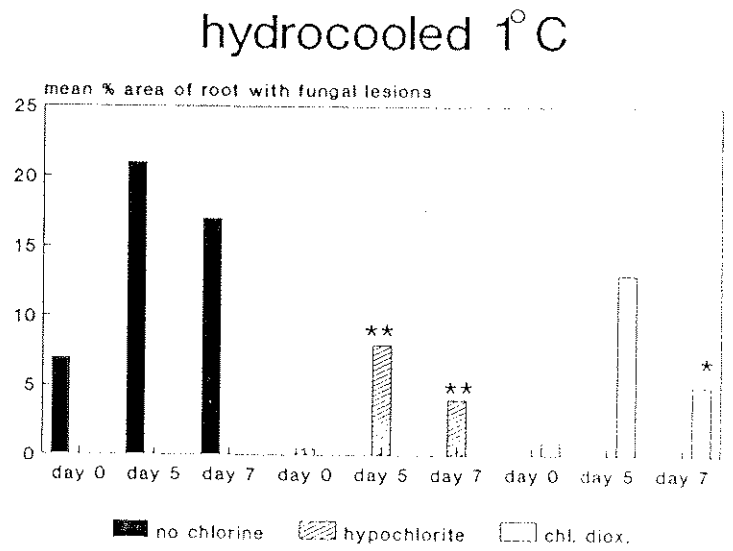
Hydrocooling without chlorine reduced fungal decay, but differences were not significant after 5 days shelf life. By day 7 hydrocooled carrots had a significantly lower level of fungal rots compared to carrots which had not been hydrocooled.

Fig.6 Effects of hydrocooling and chlorine treatments on the development of fungal rots throughout shelf life (average of all trials)

significant difference • p = 0.05 •• p = 0.01
compared to untreated controls for the same day of shelf life







Bacteria - Total viable counts (TVC) - Figure 7

Treatment with chlorine significantly reduced the TVC compared to the untreated controls at all temperatures on the day of sampling. Chlorine dioxide also significantly reduced the TVC compared to untreated controls in the ambient and 3°C hydrocooled samples.

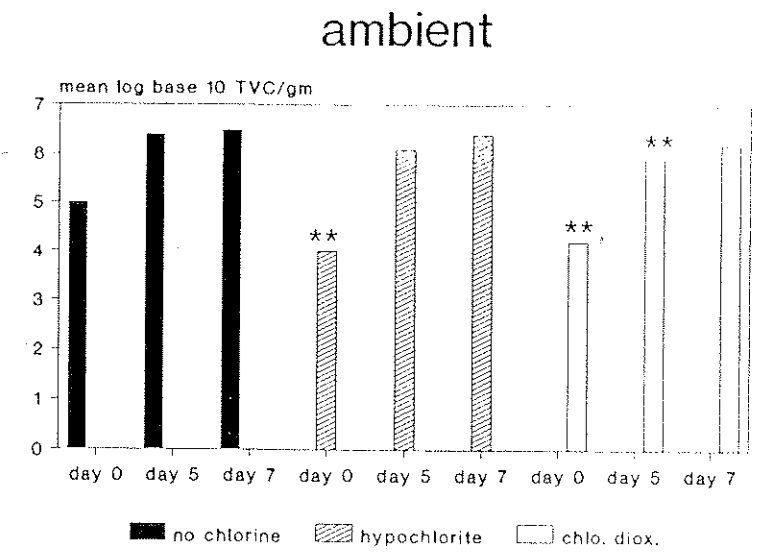
Regardless of any chlorine treatment or hydrocooling the TVC rose significantly during shelf life. Both types of chlorine combined with hydrocooling to 3°C reduced TVC significantly compared to unchlorinated controls after 5 days and after 7 days in shelf life.

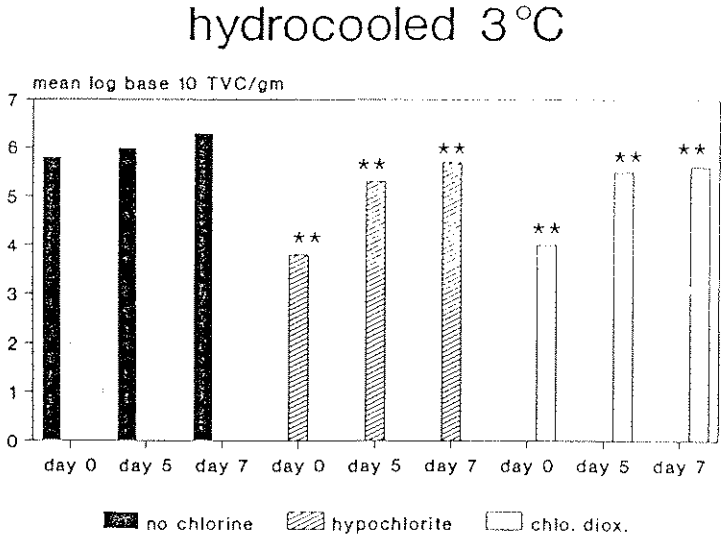
Results for hydrocooling to 1°C were ambiguous in that chlorine treatment conferred no advantage in significantly reducing TVC after 5 days but did so after 7 days in shelf life. Hydrocooling to 1°C was not significantly better at controlling microorganisms than hydrocooling to 3°C and hydrocooling alone did not significantly lower total viable counts.

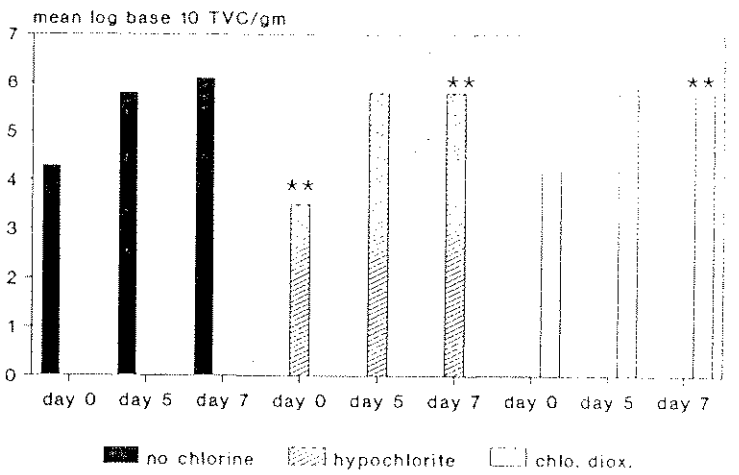
Fig.7 Effect of hydrocooling and chlorine treatments on total viable counts of bacteria throughout shelf life (average of all trials)

significant difference * p = 0.05 ** p = 0.01
compared to untreated controls for the same day of shelf life

compared to untreated controls for the same day of shelf life





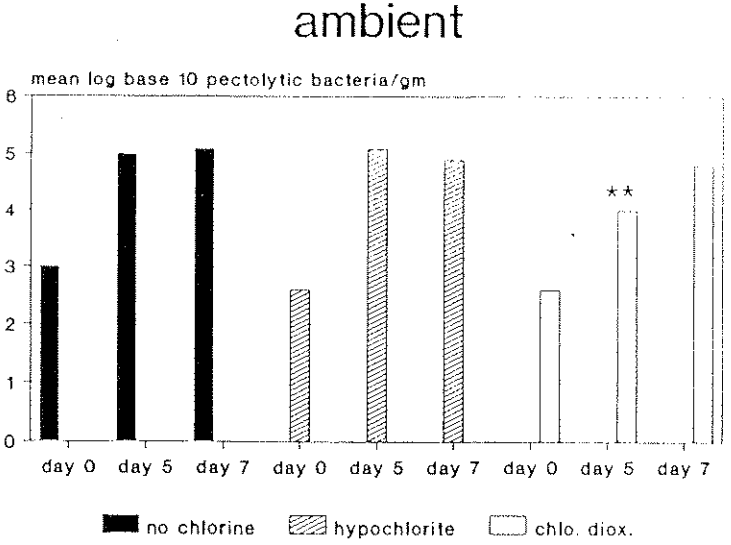


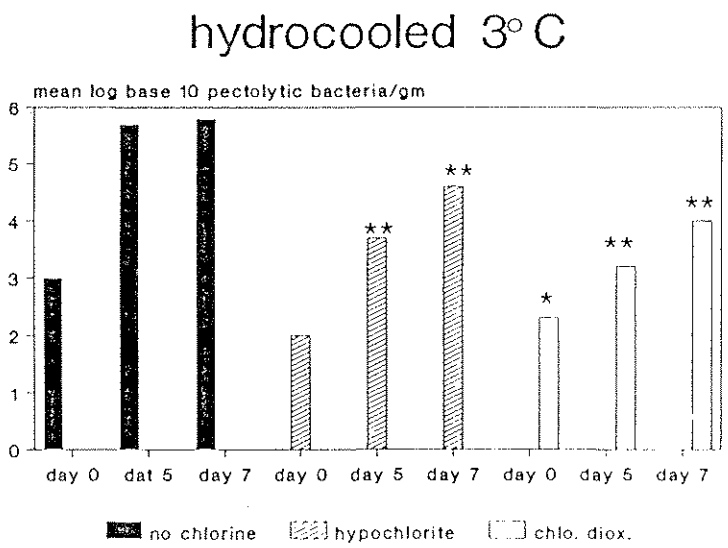
Pectolytic bacteria - Figure 8

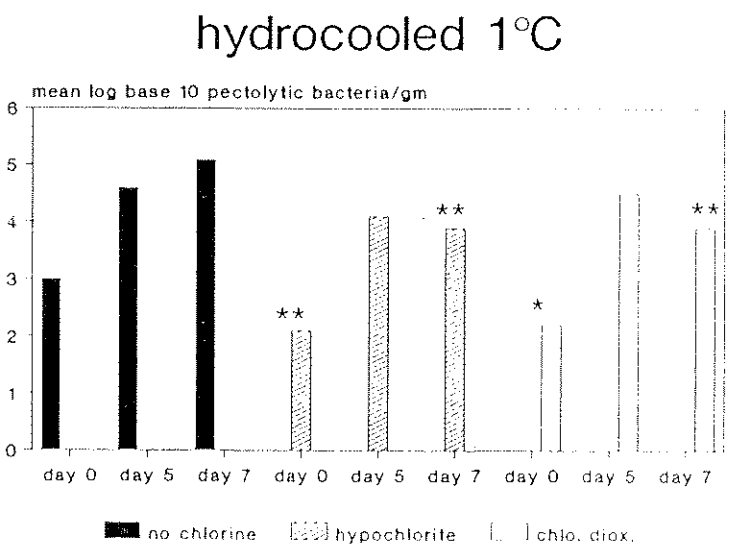
Levels of pectolytic bacteria rose unabated in the ambient treatment even when treated with chlorine, with the exception of the chlorine dioxide treatment and 5 days in shelf life. However this slight protection was lost after 7 days of shelf life. Hydrocooling without any chlorine gave no significant reduction in pectolytic bacteria counts but when combined with chlorine treatments significantly lower levels were recorded compared with corresponding controls in 9 out of 12 cooling/chlorine treatment combinations.

Fig.8 Effects of hydrocooling and chlorine treatments on the levels of pectolytic bacteria throughout shelf life (average of all trials)

significant difference * p = 0.05 ** p = 0.01
compared to untreated controls for
the same day of shelf life







Erwinia spp. - Figure 9

Both types of chlorine significantly reduced Erwinia levels on the day of sampling compared to untreated controls irrespective of hydrocooling. Hydrocooling alone did not control Erwinia levels which rose significantly during shelf life testing in all treatments without chlorine.

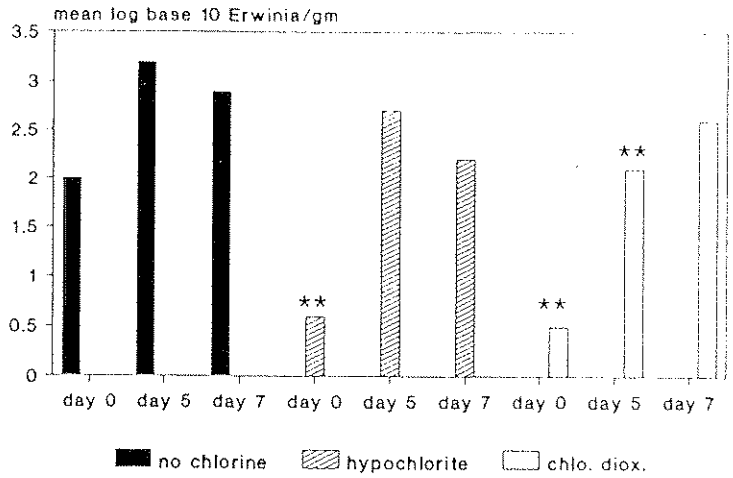
Chlorine dioxide reduced Erwinia levels in the ambient treatment after 5 days in shelf life compared to the unchlorinated control treatment but this control was lost after 7 days.

Hydrocooling to 1° or 3°C with either type of chlorine significantly controlled Erwinia levels throughout the storage and shelf life period. Chlorine dioxide appeared to be slightly more effective at controlling Erwinia than hypochlorite. Hydrocooling to 1°C with chlorine treatment was no more effective than hydrocooling to 3°C with chlorine treatment at controlling Erwinia.

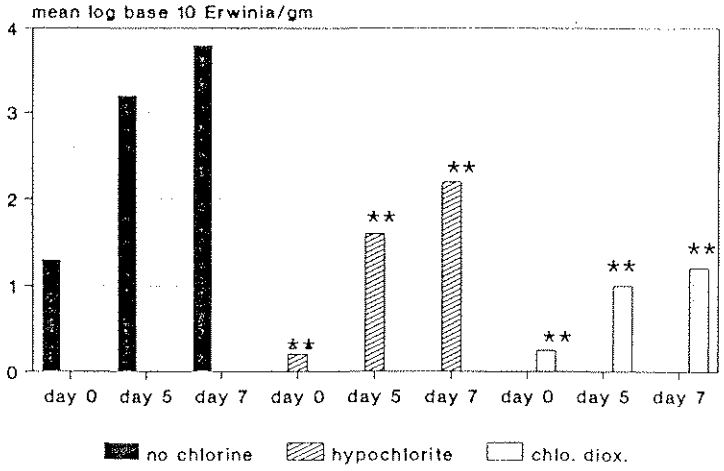
Fig.9 Effect of hydrocooling and chlorine treatments on the levels of Erwinia spp throughout shelf life (average of all trials)

significant difference * p = 0.05 ** p = 0.01
compared to untreated controls for
the same day of shelf life

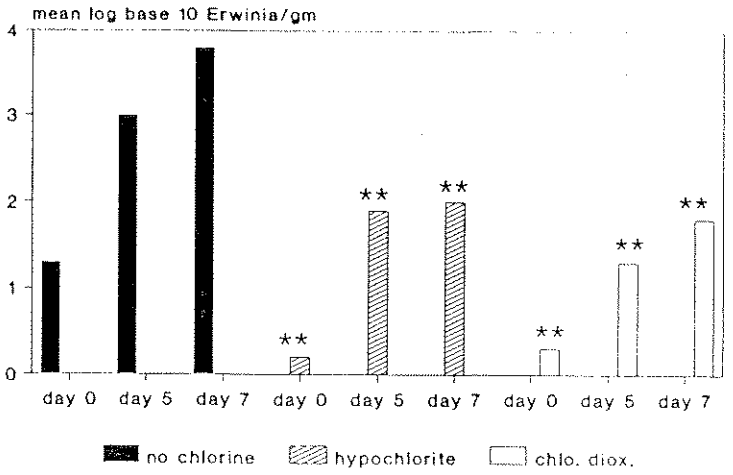
ambient



hydrocooled 3°C



hydrocooled 1°C



Effect of temperature and chlorine treatment on microbial counts

Mean of all sample day

Table 6 July Trial

(Mean of 3 replicates on each of 3 sampling days)

Treatment	Fungi (% area of root with lesions)	TVC (log base 10)	Pectolytic (log bacteria base 10)	Erwinia (log base 10)
Ambient no chlorine	10.56de	5.64g	3.51c	2.76cd
Ambient + hypochlorite	6.22bcd	5.25e	3.50c	2.03c
Ambient + chlorine diox.	11.56e	5.42f	2.86bc	2.34cd
1°C no chlorine	6.67ad	5.24e	3.32c	1.72b
1°C + hypochlorite	1.44a	3.61a	1.96a	0.37a
1°C + chlorine diox.	2.44abc	5.05c	2.36ab	0.12a
3°C no chlorine	12.33e	5.22e	3.08c	1.81bc
3°C + hypochlorite	1.78ab	4.17b	2.25ab	0.25a
3°C + chlorine diox.	2.67abc	5.13d	3.14c	1.25b

Means in the same column with the same superscript are not significantly different ($p = 0.05$).

Fungi

At ambient temperature neither type of chlorine had a significant effect compared to the untreated control although hypochlorite was significantly better at controlling fungal decay than chlorine dioxide. At 3°C both chemicals had a significant effect but at 1°C only hypochlorite had a significant effect. Hydrocooling without chlorine did not significantly lower the level of fungal decay observed.

TVC

At ambient temperatures both types of chlorine significantly lowered TVC. At 3°C and 1°C both chemicals significantly lowered the TVC but hypochlorite appeared to be slightly more effective than chlorine dioxide. Hydrocooling to 1°C enhanced the effect of chemical treatment.

Pectolytic bacteria

At ambient temperature neither type of chlorine significantly lowered counts of pectolytic bacteria. At 3°C, only hypochlorite had a consistently lowering effect on pectolytic bacteria. However chlorine dioxide did effect a reduction at 1°C. Hydrocooling without chemical treatments was ineffective in reducing levels of pectolytic bacteria.

Erwinia spp.

At ambient temperature neither type of chlorine significantly lowered the levels of Erwinia spp. At 3°C only hypochlorite gave a significant reduction compared to the untreated control. At 1°C, both types of chlorine significantly reduced Erwinia levels compared to untreated control. Hydrocooling to 1°C without chemical treatment also reduced Erwinia counts but the addition of chlorine significantly enhanced the hydrocooling effect.

Table 7 August Trial

(Mean of 3 replicates on each of 3 sampling days)

Treatment	Fungi (% area of root with lesions)	TVC (log base 10)	Pectolytic (log bacteria base 10)	Erwinia (log base 10)
Ambient no chlorine	67.1e	6.12e	4.55d	2.10e
Ambient + hypochlorite	42.9d	5.20bc	3.35bc	0.73a
Ambient + chlorine diox.	18.3abc	5.21bc	3.30bc	2.12c
1°C no chlorine	34.3cd	5.51cd	4.23d	3.10d
1°C + hypochlorite	5.2a	5.06b	2.73ab	1.01ab
1°C + chlorine diox.	22.0bc	5.10bc	3.04b	2.14c
3°C no chlorine	49.4d	5.89de	4.15cd	3.44d
3°C + hypochlorite	6.8ab	4.88b	2.85b	1.92bc
3°C + chlorine diox.	7.8ab	4.37a	1.95a	0.56a

Means in the same column with the same superscript are not significantly different ($p = 0.05$).

Fungi

Both types of chlorine significantly reduced fungal decay compared to control treatments irrespective of temperature, with the exception of the chlorine dioxide treatment at 1°C which was not significantly better than untreated control at 1°C.

Hydrocooling alone to either 1° or 3°C gave significantly less fungal decay compared to the ambient treatment. Hypochlorite at 1°C was the most effective treatment.

TVC

At both ambient and 3°C hypochlorite and chlorine dioxide reduced the TVC significantly. At 1°C hypochlorite was effective compared to the untreated 1°C control but chlorine dioxide was not. There was no additional benefit from cooling to 1°C compared to 3°C with either chlorine treatment.

Pectolytic bacteria

Cooling alone did not significantly reduce levels of pectolytic bacteria. All chlorine treatments were effective at reducing pectolytic bacteria compared to untreated controls at the same temperature. Chlorine treatments and cooling to 3°C or 1°C were effective at reducing counts, in particular chlorine dioxide treatment at 3°C .

Erwinia spp.

Hypochlorite was effective at reducing Erwinia counts compared to untreated controls irrespective of temperature. Chlorine dioxide effectively reduced counts in combination with hydrocooling to 3°C or 1°C compared with corresponding controls at each temperature. Hydrocooling alone did not result in a reduction in Erwinia contamination.

Table 8 September Trial

(Mean of 3 replicates on each of 3 sampling days)

Treatment	Fungi (% area of root with lesions)	TVC (log base 10)	Pectolytic (log base 10)	Erwinia (log base 10)
Ambient no chlorine	5.67d	5.81e	4.42c	1.95d
Ambient + hypochlorite	1.56ab	5.33d	4.40c	0.57ab
Ambient + chlorine diox.	1.00ab	5.08bcd	3.82bc	0.27ab
1°C no chlorine	3.11bc	5.30d	4.00bc	1.34cd
1°C + hypochlorite	0.56a	4.70ab	3.37ab	0.00a
1°C + chlorine diox.	0.33a	5.22cd	3.95bc	0.79bc
3°C no chlorine	4.33cd	5.32d	3.87bc	1.67d
3°C + hypochlorite	0.11a	4.32a	2.94a	0.00a
3°C + chlorine diox.	0.78ab	4.83bc	2.82a	0.53ab

Means in the same column with the same superscript are not significantly different ($p = 0.05$).

Fungi

Both chlorine treatments at all temperatures were effective in reducing levels of fungal decay compared to untreated controls. Hydrocooling to 1°C alone also resulted in significantly lower levels of disease compared to the untreated control at ambient temperature.

TVC

Both chlorine treatments significantly reduced TVCs compared to controls at all temperatures. Cooling to 3°C or 1°C without chemical treatment gave a similar result to hypochlorite at ambient temperature. Hypochlorite at 3°C and 1°C was significantly better than chlorine dioxide. Hydrocooling to 1°C did not improve results compared to hydrocooling to 3°C.

Pectolytic bacteria

Both chlorine treatments at ambient were ineffective at controlling pectolytic bacteria. However, chlorine treatments combined with cooling to 3°C gave significant control of pectolytic bacteria. Hydrocooling to 1°C did not improve results compared to 3°C. Hydrocooling alone was ineffective at controlling pectolytic bacteria.

Erwinia spp

Hydrocooling alone had no effect on controlling Erwinia levels on roots, but both types of chlorine reduced counts at all temperatures, with the exception of chlorine dioxide at 1°C where the effect was marginal compared to hydrocooling to 1°C control. Hypochlorite gave consistently better results than chlorine dioxide and hydrocooling to 1°C effected better control than hydrocooling to 3°C.

Table 9 November Trial

(Mean of 3 replicates on each of 3 sampling days)

Treatment	Fungi (% area of root with lesions)	TVC (log base 10)	Pectolytic (log bacteria base 10)	Erwinia (log base 10)
Ambient no chlorine	13.60ab	6.10bcd	5.02ab	3.78cd
Ambient + hypochlorite	0.30a	6.17bcd	5.36ab	3.84d
Ambient + chlorine diox.	23.30b	6.10bcd	5.19ab	2.19b
1°C no chlorine	10.70ab	6.06abc	5.14ab	4.30d
1°C + hypochlorite	5.10a	6.53d	5.37ab	3.59cd
1°C + chlorine diox.	1.60a	5.62a	4.86a	1.41a
3°C no chlorine	2.20a	6.30cd	5.43b	4.19d
3°C + hypochlorite	1.20a	6.29cd	5.36eb	3.12c
3°C + chlorine diox.	4.80a	5.77ab	4.89a	1.01a

Means in the same column with the same superscript are not significantly different (p = 0.05).

Fungi

Treatments with both types of chlorine failed to reduce fungal decay compared to untreated controls whether hydrocooled or not.

TVC

Neither type of chlorine significantly lowered TVCs at ambient temperature and only chlorine dioxide at 3°C gave a significant lowering of TVCs compared to the control without chlorine. Chlorine dioxide at 1°C showed a reduced TVC but this was not significant. The TVCs in this trial were generally at least 10 fold higher than in previous trials (carried out in July, August and September) and at this level of contamination neither chemical treatment nor cooling resulted in benefits in terms of reduced microbial levels.

Pectolytic bacteria

Chorine dioxide at 3°C gave a significant reduction in pectolytic bacteria compared to the untreated controls at 3°C, but neither type of chlorine nor cooling reduced counts significantly from the ambient control. Again microbial loading was high.

Erwinia spp

Chlorine dioxide significantly reduced Erwinia counts compared to untreated controls and hypochlorite treatments at all temperatures. Cooling to 1°C was not beneficial compared to hydrocooling to 3°C. Again microbial loading was high.

Table 9 All Trials Combined

(Mean of 3 replicates on each of 3 sampling days)

Treatment	Fungi (% area of root with lesions)	TVC (log base 10)	Pectolytic (log contol base 10)	Erwinia (log base 10)
Ambient no chlorine	24.23d	5.92e	4.38e	2.65d
Ambient + hypochlorite	12.75b	5.49c	4.16e	1.80c
Ambient + chlorine diox.	13.55b	5.46c	3.81c	1.75c
1°C no chlorine	13.70b	5.53c	4.20e	2.62d
1°C + hypochlorite	3.09a	4.98a	3.36ab	1.24b
1°C + chlorine diox.	6.59a	5.23b	3.56bc	1.12ab
3°C no chlorine	17.08c	5.68d	4.14de	2.79d
3°C + hypochlorite	2.47a	4.92a	3.35a	1.32b
3°C + chlorine diox.	4.00a	5.03a	3.20a	0.84a

Means in the same column with the same superscript are not significantly different (p = 0.05).

Fungi

Hydrocooling alone significantly reduced fungal decay. Both types of chlorine, but particularly hypochlorite, reduced fungal lesions even further in combination with hydrocooling. Hydrocooling to 1°C in combination with chemical treatment was not significantly advantageous over hydrocooling to 3°C with chemical treatment.

TVC

Hydrocooling reduced TVCs. Both types of chlorine were effective at reducing TVCs at all temperatures compared to corresponding untreated controls and were particularly effective in this respect in combination with hydrocooling. Hydrocooling to 1°C was as effective as either type of chlorine treatment at ambient temperature.

Pectolytic bacteria

Hydrocooling alone did not reduce counts. However both types of chlorine were particularly effective at reducing pectolytic bacteria.

Erwinia spp

Hydrocooling alone did not reduce Erwinia but both types of chlorine, and especially hypochlorite, significantly reduced Erwinia counts compared to the corresponding controls. Chlorination was particularly effective at reducing Erwinia counts when combined with hydrocooling.

4. MICROBIOLOGICAL ASSESSMENTS OF HYDROCOOLER WATER BEFORE AND AFTER PROCESSING

See tables 11 - 14

The level of microbiological contamination of the untreated water in the hydrocooler (before being used to cool carrots) was higher in the July and August assessments than in the September and November assessments. Low levels (< 10 ppm) of residual chlorine were detected prior to adding the chlorine treatments.

Microbiological contamination levels at the end of hydrocooling treatments were not significantly higher than at the start for the July and August assessment, however, there was a considerable increase in microbiological contamination levels in the September and November tests without chlorine treatments where initial levels of contamination were low.

Adding hypochlorite at 200 ppm to the hydrocooler resulted in low levels of micro-organisms and the level of contamination was controlled through out the period of hydrocooling for July, August and September tests. During the November test microbial contamination throughout hydrocooling was less well controlled but the residual levels of chlorine were lower than the specification.

Chlorine dioxide did not control microbial levels as consistently as hypochlorite.

Table 11 July Trial

Treatment	Number of microorganisms (log 10 cfu/ml)			
	TVC at 22°C	Pectolytic bacteria	Erwinia spp.	residual chlorine ppm
Water no chlorine before	5.289	2.698	2.845	1.0
Water no chlorine after	5.367	2.602	2.845	<1.0
Water with hypochlorite before	0.301	none found	none found	100/150
Water with hypochlorite after	none found	none found	none found	not tested
Water with chlorine diox. before	4.447	none found	none found	200
Water with chlorine diox. after	4.845	none found	none found	150

Table 12 August Trial

Treatment	Number of microorganisms (log 10 cfu/ml)			
	TVC at 22°C	Pectolytic bacteria	Erwinia spp.	residual chlorine ppm
Water no chlorine before	6.860	6.255	none found	<1.0
Water no chlorine after	6.889	5.845	1.903	<1.0
Water with hypochlorite before	0.176	none found	none found	200
Water with hypochlorite after	none found	none found	none found	150
Water with chlorine diox. before	none found	none found	none found	100
Water with chlorine diox. after	4.716	none found	none found	75

Table 13 September Trial

Treatment	Number of microorganisms (log 10 cfu/ml)			
	TVC at 22°C	Pectolytic bacteria	Erwinia spp.	residual chlorine ppm
Water no chlorine before	0.602	none found	none found	5.0
Water no chlorine after	5.696	4.000	1.602	<1.0
Water with hypochlorite before	1.903	none found	none found	75
Water with hypochlorite after	none found	none found	none found	25
Water with chlorine diox. before	none found	none found	none found	50
Water with chlorine diox. after	none found	none found	none found	25-50

Table 14 November Trial

Treatment	Number of microorganisms (log 10 cfu/ml)			
	TVC at 22°C	Pectolytic bacteria	Erwinia spp.	residual chlorine ppm
Water no chlorine before	none found	none found	none found	10
Water no chlorine after	5.982	4.903	2.000	5
Water with hypochlorite before	3.414	1.556	none found	20
Water with hypochlorite after	4.724	3.556	1.000	50
Water with chlorine diox. before	4.431	2.301	1.301	100
Water with chlorine diox. after	4.643	2.740	1.301	75

5. CHLORIDE RESIDUES

Table 15 Chloride residue in carrots % of dry matter

Treatment	July trial	August trial	September trial	November trial
Ambient no chlorine	0.21	0.85	0.97	0.80
Ambient + hypochlorite	0.18	0.78	0.94	0.90
Ambient + chlorine diox.	0.11	0.92	0.96	1.10
1°C no chlorine	0.21	0.81	0.96	1.00
1°C + hypochlorite	0.16	0.89	1.03	1.10
1°C + chlorine diox.	0.16	0.69	0.97	1.20
3°C no chlorine	0.16	0.73	0.90	0.90
3°C + hypochlorite	0.21	0.80	0.90	1.00
3°C + chlorine diox.	0.23	0.76	0.94	1.00

Chloride levels were determined on the day of sampling as a percentage of dry matter and are presented in table 15. The level of chloride was different for each trial but similar for the treatments within each trial. This suggests that the rates of chlorine dioxide and hypochlorite used did not increase the natural level of chloride already present in carrots.

CONCLUSIONS

SHELF LIFE

Following 1 or 4 days in cold store and 7 days in a shelf life room, percentage weight loss was reduced by hydrocooling to 1°C or 3°C in the August trial but not in July, September or November trials. Skin texture was improved by hydrocooling to 1°C or 3°C or by the addition of hypochlorite or Chlorine dioxide in the July and August trials but not in September and November trials.

Turgidity was improved by hydrocooling to 1°C or 3°C in the July and August trials but not in September and November trials. Adding hypochlorite and chlorine dioxide to the hydrocooler did not significantly affect turgidity in any trial.

However, there were significant differences in the amount of rotting between treatments.

The development of violet root rot was controlled by hydrocooling prior to shelf life testing and by either type of chlorine. The best control was obtained from hydrocooling to 3°C with hypochlorite.

Sclerotinia was controlled by adding chlorine dioxide to the hydrocooler and the most effective control of rotting was obtained from hydrocooling to 3°C with chlorine dioxide.

When present, Thielaviopsis and Geotrichum candidum (sour rot) were controlled by the combination of hydrocooling and chlorine.

MICROBIOLOGICAL CONTAMINATION

1. Fungi

Hydrocooling to 3°C in combination with either chlorine dioxide or hypochlorite gave good control of fungal decay throughout shelf life but was ineffective on its own. Hypochlorite appeared more effective than chlorine dioxide but differences between the two chemicals were not statistically significant ($p = 0.05$).

2. TVC

Hydrocooling to 3°C with additions of either chlorine dioxide or hypochlorite gave the best control of TVCs throughout shelf life. Results from chlorine dioxide treatment were not significantly better ($p = 0.05$) than from hypochlorite treatment.

3. **Pectolytic bacteria**

Hydrocooling to 3°C with either chlorine dioxide or hypochlorite gave significant control of these bacteria during shelf life ($p = 0.05$). Chlorine dioxide was more effective than hypochlorite at controlling pectolytic bacteria at this temperature by the end of shelf life.

4. Erwinia spp

Hydrocooling to 3°C in combination with either chlorine dioxide or hypochlorite gave significant control of Erwinia spp compared to untreated controls. Chlorine dioxide appeared more effective than hypochlorite at controlling Erwinia levels but differences were not significant ($p = 0.05$).

RESIDUES

Adding chlorine dioxide or sodium hypochlorite to the hydrocooler at the rates used did not increase the chloride content of carrots.

RECOMMENDATIONS

1. This project has shown that hydrocooling to 3°C increases the shelf life of prepacked carrots by reducing spoilage from fungal and bacterial rots. There was no further advantage from hydrocooling to 1°C. Adding either chlorine dioxide or hypochlorite did further increase shelf life and control of fungal and bacterial decay without causing a chloride residue problem.

2. Further work is required to establish the optimum rates of chlorine to use in the hydrocooler and to assess the effects of chlorine and hydrocooling on carrots sold as "free flow" ie not prepacked in a plastic bag, as weight loss, turgidity and skin texture may be more significantly affected.

APPENDICES

APPENDIX 1

Method for the enumeration of bacteria on carrot roots

Bacteria on carrot roots were enumerated using a modification of the method of Perombelon, Lumb and Hyman (1987) for the quantification of Ewinias on seed potatoes.

Method

Three sub-samples of ten carrots per treatment were washed in sterile quarter strength Ringers solution (Oxoid BR48) to neutralise any remaining chlorine. The weight of each sub-sample was recorded prior to peeling the carrots with a sterile "cheese grater". Sterile rubber gloves were worn to prevent cross contamination between sub-samples. Using a sterile spatula, the peel was collected onto a sterile square of nylon gauze and the sap squeezed from the peel into a sterile wide mouthed bottle. Each peeled sub-sample of carrots was weighed and the weight subtracted from the initial weight to give the total weight of peel harvested. Sap from the peel was immediately (within 5 minutes) used to prepare 10-fold dilutions to 10^{-6} and plated out on the following media:

1. Yeast extract agar (YEA), incubated at 22°C for 3 days for total viable counts.

2. Pectate gel agar (Pe), incubated at 25°C for 3 days for total pectolytic counts.

3. Crystal violet pectate (CVP), incubated at 33.5°C for 2 days.
   For presumptive Erwinia carotovora sub species carotovora and Erwinia chrysanthemi *.

   Counts from these media were calculated to give the level of bacterial loading per carrot:

   * Erwinia chrysanthemi is unlikely to be present but this method would not exclude it were it to be present.

Assessment of Carrot Roots for Fungal Disease

Materials

1. Plastic incubation boxes 160 mm * 100 mm * 270 mm.
   For this test chambers were inverted ie the lid became the base of the chamber.

2. Paper towel.
3. Distilled water.

Method

1. A paper towel was placed on the base of each incubation chamber and lightly damped with distilled water. It was important not to over saturate the towel as this would have encouraged bacterial soft rots.

2. Five randomly selected carrots were taken from the treatment sample and scored for the percentage area of root affected by fungal lesions.

3. The carrots were placed on the damp towel, the chamber labelled with the reference number and the lid fixed in place

   This procedure was repeated for each treatment.

   Chambers were incubated at ambient temperature on the laboratory bench and the carrots assessed for percentage area of rotting affected by fungal lesions after 7 days in incubation.

APPENDIX 2

Method for determination of the residual chlorine level in the hydrocooler water

Residual chlorine was determined according to the method described in HMSO Technical Bulletin No 17 (1968)

All samples of water from the hydrocooler were tested for the presence of chlorine by the method entitled - "A field test (Palin's) for the presence of residual chlorine in bacteriological rinses of dairy equipment using DPD chlorine tablets No 4".

If chlorine was detected then the chlorine level was determined using the method entitled "A field test for the estimation of residual chlorine in dairy equipment sterilising solutions".

Bacteriological examination of hydrocooler water

All samples of water from the hydrocooler were tested within 1 hour of receipt at the laboratory. Samples were tested in accordance with HMSO Technical bulletin no 71 (1982) but with the following modifications:

Ten fold serial dilutions were prepared to 10^{-6} in salt/peptone diluent. The undiluted sample and the 10 fold dilutions were plated on to the following media and incubated as indicated for specific counts:

1. Total viable count (TVC) per ml : 1 ml on to yeast extract agar at 22°C for 3 days (duplicated pourplate method).

2. Total pectolytic bacterial count per ml : 0.1 ml onto pectate gel agar (Pe) at 22°C for 3 days (spread plate method).

3. Erwinia carotovora sub spp carotovora count per ml : 0.1 ml onto crystal violet pectate (CVP) at 33.5°C for 2 days (spread plate method).

Statistical Analysis

Data from bacterial and fungal assessments were analysed as a threeway factorial analysis of variance obtained using Genstat version 5.0 (Lawes Agricultural Trust Rothamsted).

Standard errors of the means were calculated and significance tested using Duncans New Multiple Range test (1955) at the $p = 0.05$ and $p = 0.01$ levels of significance.

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