Project Title	Long term refrigerated storage of washed, graded and hydrocooled carrots
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The results and conclusions in this report are based on a series of experiments conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

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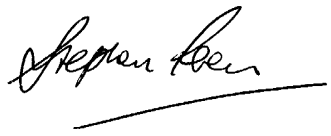

Signature Date 19 October 2007

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Grower Summary

Headline

- It is possible to store washed, polished and hydrocooled carrots in long-term refrigerated storage (at 0-1^{o}C, 97%RH), with less rotting than field-stored carrots (by May).
- This method of storage is potentially cheaper than the standard continental standard method of storing ungraded carrots with soil.
- Taste and sugar content are preserved, but a significant increase in post-storage polishing is required to restore the skin finish; the final appearance of carrots is currently inferior to the field-stored product.

Background and expected deliverables

UK carrot crops are field-stored overwinter, by covering with soil, plastic or straw, to exclude light and protect from cold temperatures. They are harvested directly from the field for marketing from November to May. This provides a product with a high quality skin finish, ensuring year round availability of UK carrots and a product that is always fresh for consumers. However, previous research has shown that sugar content and taste of field-stored carrots deteriorates from mid-March. Growers are therefore seeking ways of improving customer taste experience in this latter part of the season. Notwithstanding the good quality skin finish of field-stored roots, the recent introduction of polishing machines in grading lines has enabled growers to remove levels of blemish, such as scab, improving the appearance further and enhancing packout rates.

Recent winters have been warmer than average and climate change predictions indicate this is likely to be a long term-trend. Mild winters lead to a reduction in the quality and longevity of field-stored carrots; hence growers are considering long-term refrigerated storage as an alternative. If a graded, washed, polished and hydrocooled product could be successfully stored using refrigerated storage, then the estimated cost/tonne would be substantially reduced.

The expected deliverables from this project include:

1. A detailed assessment of the following storage treatments :

- Carrots stored dirty with soil
- Washed and hydrocooled only
- Washed, polished and hydrocooled, product prepared for market
- Washed, polished and hydrocooled, product prepared for market, placed in a modified atmosphere polythene bag, (MAP)
- Field storage

2. An economic evaluation of refrigerated storage compared with field storage.

Summary of the project and main conclusions

- Project FV 306 has demonstrated that it is possible to store washed, polished and hydrocooled carrots in long-term refrigerated storage with less rotting than field stored crops (by May), but that the final appearance was inferior to the field stored treatment. This method of storage has the potential to significantly reduce the cost/tonne for refrigerated storage, compared with the continental standard of storing ungraded carrots with soil.

- The additional cost of production for the overwinter storage period is estimated at £3000/ha or £50/tonne marketed.

- The capital requirement for refrigerated storage is estimated at some £205,000 for a 1000 tonne store. Running costs for November to May inclusive are estimated at **£**30,000 or £30/tonne, giving a total of £58.5/tonne placed in store. This figure will increase depending on the post-storage pack out rate achieved. For example, calculations indicate approximate costs of £69.50 / tonne for carrots stored dirty and £67.30 / tonne for graded, washed and polished carrots stored to May.

1. Carrots stored dirty with soil

This treatment preserved taste and sugar levels though to the May removal date, but all the unmarketable portion of the crop is stored as well as the soil adhering to the roots. Assessment of the stored crop showed that (up to) 17.3% of the carrots were unmarketable due to mechanical damage, fanging, stunts and misshapes.

2. Washed and hydrocooled only

This treatment preserved taste and sugar levels until the May removal date but, as with treatment 1, the unmarketable portion of the crop is stored along with the marketable portion. Assessment of the marketable portion showed that (up to) 17% of the carrots were unmarketable due to mechanical damage fanging, stunts and misshapes.

3. Washed, graded, polished and hydrocooled, final product for market

Negligible quantities of unmarketable carrots are placed in store with this treatment, increasing the effective storage capacity and potential marketable output from a refrigerated store. 86.9% of roots were marketable by the following May; taste and sugar content were preserved, but 5 minutes in a Wyma polisher were required to restore the overall appearance. This had a detrimental effect on shelf life assessment beyond 5 days.

4. Washed, graded, polished and hydrocooled, final product for market, placed in a modified atmosphere polythene (MAP) bag

Long-term refrigerated storage in a modified atmosphere polythene bag (MAP) failed due to high levels of rotting, 68.7% by March and 93.08% by May. However, this treatment warrants further research, to prevent yeasts developing in store, since high scores were maintained for skin finish, taste and sugar levels in those carrots which did not rot.

The most common rot symptom on roots at each of three sampling dates was a severe soft rot from which a yeast species and a *Fusarium* species were consistently isolated. The yeast was identified (tentatively) as a species of *Candida.*

5. Field storage

The 2006/7 winter was mild with a higher than average soil temperature. This had a detrimental effect on carrots field stored beyond April and by May 46.66% of the sample was unmarketable due to rotting.

Taste scores and sugar levels also declined significantly. However, field storage preserved the 'fresh lifted' appearance of the marketable portion until May.

Financial benefits

- The financial benefits to individual businesses that could accrue to individual business are dependent on store construction and logistical considerations. A decision to invest will need to be taken in the light of customer demand for improved flavour and the feasibility of continuing to field store the crop into the late spring period.

- Refrigerated storage, which preserved flavour and sugar content, has the potential to significantly reduce the cost/tonne for refrigerated storage compared with the continental standard of storing ungraded carrots with soil.

Action points for growers

- It is not currently possible to recommend changes to current grower practice for long-term storage on carrots. The current project has shown good potential for the development of refrigerated storage of carrots, but further development is required to build industry confidence before moving forward.

Science Section

Introduction

Research by FRI (Norwich) and ADAS in the 1980s and 90s showed that carrot flavour and texture is preserved by refrigerated storage of unwashed carrots harvested directly from field to store. This technique is standard practice in Canada, Scandinavian and northern European countries where cold weather causes damage to roots and/or heavy soils prevent harvesting directly from the field through the winter.

On 9 and 10 March 2006, 12 British Carrot Grower Association (BCGA) members undertook a study visit to the Holstein region of Germany, where large-scale refrigerated storage (e.g. 3,000 tonnes/store) is used. A comparison of the costs of field storage in the UK with refrigerated storage in Germany showed that refrigerated storage cost approximately £6/tonne more than field storage. However, carrots are refrigerated with soil and with minimal root selection, which reduces the marketable output by between 30 and 50% of the total tonnage placed in store. However, if washed, graded, polished and hydrocooled carrots could be shown to store well and the recently introduced carrot 'polishers' could restore a fresh appearance, then the product cost/tonne of refrigerated storage could be significantly reduced.

There are several additional benefits to refrigerated storage:

- Flavour and texture are maintained through the storage period
- Pest (carrot fly) and disease (cavity spot) development is retarded Land is released early for the next crop with a potential saving of rent
- Marketing of the carrot crop can be extended beyond that from field storage. i.e. up to the end of June
- Reduced need to grow crop in northern UK counties, so reducing transport costs

The overall aim of the project was to establish if washed, graded and hydrocooled carrots store as well as, or better, than field stored carrots or carrots stored dirty in a refrigerated store, as is practised in the countries mentioned above.

Materials and Methods

The objective of determining the feasibility of long-term refrigerated storage of carrots was studied by comparing the following treatments:

1. Refrigerated storage of carrots stored dirty, with soil
2. Refrigerated storage of washed and hydrocooled carrots
3. Refrigerated storage of washed, graded, polished and hydrocooled carrots
4. Refrigerated storage of washed, graded, polished and hydrocooled carrots placed in a modified atmosphere polythene bag (MAP)
5. Field stored carrots – UK standard practice

Crop Selection

Samples for the trial were drawn from a commercial crop, grown in Norfolk and sown on 10 May 2007. The variety was Nairobi. The usual practice for carrots destined for overwinter field storage is to harvest strips across the field prior to strawing down, which are subsequently used for access. Roots harvested from these strips provided samples for the refrigerated storage treatments. 200 kg samples of carrots per treatment were collected from the field and packhouse on 10 November 2006 and transported to a refrigerated store at East Malling Research (EMR) in Kent, using a temperature controlled vehicle set at 5°C. The refrigerated store contained 8 individual cabinets, with a maximum 300kg capacity allowing for 4 duplicated storage treatments. For the MAP treatment, 12 MAP bags were used; each contained 25 kg of carrots placed in the modified atmosphere plastic bag immediately after hydrocooling. The atmosphere in the bags was modified by the respiration of the carrots and subsequently monitored, but not controlled. Carrots for the washed, graded and hydrocooled treatment were collected from the grading line in nets and subsequently transferred to the hydrocooler, avoiding the Wyma polisher. In addition to the treatments placed in refrigerated store, observations were made and records of percentage marketable and skin finish were taken at each removal date (March, April, May) from the remaining over-wintered field stored crop, which was used as the control treatment. All treatments were weighed in and out of store at each removal date.

Storage cabinets – refrigerated store

Temperature and humidity were recorded in the store and the atmosphere in the MAP bags was recorded.

Storage Conditions

Carrots were contained in 20 kg plastic crates and 6 crates/ treatment placed randomly in individual plastic cabinets (300kg capacity) in the refrigerated store. The store conditions were set to 0 to 1 °C with a relative humidity of 97%. Each cabinet has an air circulation fan designed to keep the temperature and humidity uniform within each cabinet. At each removal date 2 crates (40kg) /treatment was taken out of each cabinet for assessment.

Carrot samples in storage cabinets

Sampling and Records

Treatments were placed in the high humidity store on 10 November 2006 and removed from store on 3 dates, 7 March, 22 April and 22 May 2007. At store loading taste and shelf life assessments of each treatment were carried out by PGRO to establish a benchmark.

Following each removal from store, the marketable roots and unmarketable roots were sorted. The marketable roots were scored for skin finish and a sample of 12 marketable roots was taken to PGRO for assessment of taste, shelf life and sugar content. The remaining marketable roots were roots were taken to a commercial packhouse for post-storage polishing, after which each treatment was re-assessed for skin finish and a subsample of 12 roots taken to PGRO for assessment of taste, shelf life and sugar content.

At each removal date assessments were made of:

a) Marketable and unmarketable portion of each treatment, using a sample of 20 kg of roots, with causes of unmarketability recorded immediately on removal from store.

b) Appearance as a skin finish score, on a 1 to 5 scale, where 5 is of a 'fresh lifted' appearance, immediately on removal from store.

c) Sub samples of 12 marketable roots were then taken both before and after post storage polishing and transported to PGRO in insulated containers for assessment of Skin finish, taste, sugar content and shelf life.

Following removal from store, a minimum of 15kg of marketable carrots from each treatment were transported in insulated containers to a carrot polisher at IFP Ltd. (Cambs.) for the 7 March and 22 April removal dates and to Freshgro Ltd. (Notts.) on 23 May for this process. Assessments were made on root quality and further samples were taken to PGRO in insulated containers for taste and shelf-life assessment.

PGRO Test Facilities

Protocols used were as follows:

Taste tests – sliced carrots (Nantes)

5 representative roots were taken, sliced at 5-6mm width and inserted in 350mls of boiling water. After bringing carrots back to the boil, they were simmered for 6 minutes.

The PGRO Taste Panel comprised 5 persons, a mix of sexes and ages

Sugar levels

5 representative roots were taken (where possible), put through a juicer, and 3 readings of each sample were made, using a refractometer. Results presented are an average of the 3.

Shelf life assessment

Roots from each treatment were stored for the required length of time at ambient/laboratory temperature.

Quality Scores used in PGRO Shelf Life Assessments

Appearance

Score	Colour*	Brightness**	Uniformity
5	Dark orange	n.a.	Uniform, orange, perfect
4		n.a.	Slightly less uniform
3		n.a.	Lack of uniformity, pale hues
2		Bright	Lack of uniformity, yellow hues
1	Pale orange	Dull	Uneven, unattractive, discoloured

* Colour chart used for reference ** 2 scores only bright or dull

Other Quality Parameters

Score	Breakdown	Skin silvering	Suitability
5	Extreme	None	Extreme
4	Very	Slight	Very
3	Moderate	Moderate	Moderate
2	Slight	Very	Slight
1	None	Silvered	Unsuitable

Taste test scores used for flavour and texture

Score	Sweetness	Strength	Firmness	Suitability
5	Extremely sweet	Extremely strong	Extremely firm	Extremely suitable
4	Very sweet	Very	Very	Very
3	Moderate	Moderate	Moderate	Moderate
2	Slight	Weak	Slight	Slight
1	None	None	None	None

Results

Store Operation - Temperature

For the first 2 weeks of storage, the sample temperature was 0.5-1^{o}C. On 24 November, the store temperature was reduced to -0.5^{o}C, which lowered sample temperature to 0-0.2^{o}C. Unfortunately, the lower store temperature caused operational difficulties with freezing of sample lines, humidifiers and cabinet lids. Consequently, on 12 December 2006, the store temperature was returned to 0^{o}C. For the remainder of the storage period, the temperature of the samples was in the range 0-0.5^{o}C. The changes in temperature over the period from loading through to December are reflected in the readings from the 'Tinytag' logger inserted in each cabinet (Figure 1).

Store Operation - Atmosphere

Since it was not known whether it would be possible to prevent carbon dioxide accumulation within the cabinets by ventilation with compressed air, all cabinets were connected to hydrated lime scrubbers for the first month of storage to prevent this. (Overseas practice is to provide ventilation). On 13 November 2006 (3 days after loading) the flow of venting air was increased to maximum. The venting air for each cabinet was humidified by bubbling through sealed containers of water located adjacent to each storage cabinet.

The automatic atmosphere measurement and control system was set at 6 cycles per day. On each occasion cabinets received the maximum ventilation time of 57 minutes with a nominal flow of venting air of 2 litres per minute. This mode of ventilation, equivalent to about 2 cabinet volume changes per day, was sufficient to maintain oxygen concentrations above 20%. Scrubbing the air through the hydrated lime scrubbers maintained carbon dioxide concentrations at 0-0.2%.

On 15 December 2006, the carbon dioxide and oxygen concentrations in the cabinets were measured directly using portable gas analysers, and results were compared with those produced by the automatic monitoring system. Manual readings were generally within 0.1% of those from the automated system. The 'Tinytag' temperature / RH logger was removed from a container of market grade carrots and interrogated. Relative Humidity (RH) had been recorded at 100% during November, but readings ceased in early December probably due to water condensing on the probe (Figure 1).

On 21 December 2006, the carbon dioxide scrubbers were disconnected from the cabinets and for the remainder of the storage period the carbon dioxide concentrations were kept below 0.5% by ventilation alone.

First removal of carrots - 7 March 2007

Weight loss was excessive in 2 treatments, washed, hydrocooled, polished and washed hydrocooled only but low in product stored in MAP plastic bags. It appears that there was local drying where the outputs from the circulation fans re-entered the cabinets. Interestingly, in a cabinet where the circulation fan had failed the weight loss was under 2%. It was decided to switch off the circulation fans on 7 March for the remainder of the storage period in order to conserve moisture in the carrots. The average concentrations of carbon dioxide and oxygen in the MAP plastic bags were 9.7 and 5.5% respectively.

Second removal of carrots 22 April 2007

As expected, weight loss of carrots increased slightly since the first removal. Average carbon dioxide concentrations inside the MAP plastic bags had increased to 14.7% and oxygen had depleted further to 2.0%.

Third (final) removal of carrots 22 May 2007

Further weight loss was low for all treatments, although weight loss appeared to be higher for the stored dirty treatment. Average carbon dioxide concentrations inside the MAP plastic bags had increased to 19.2%

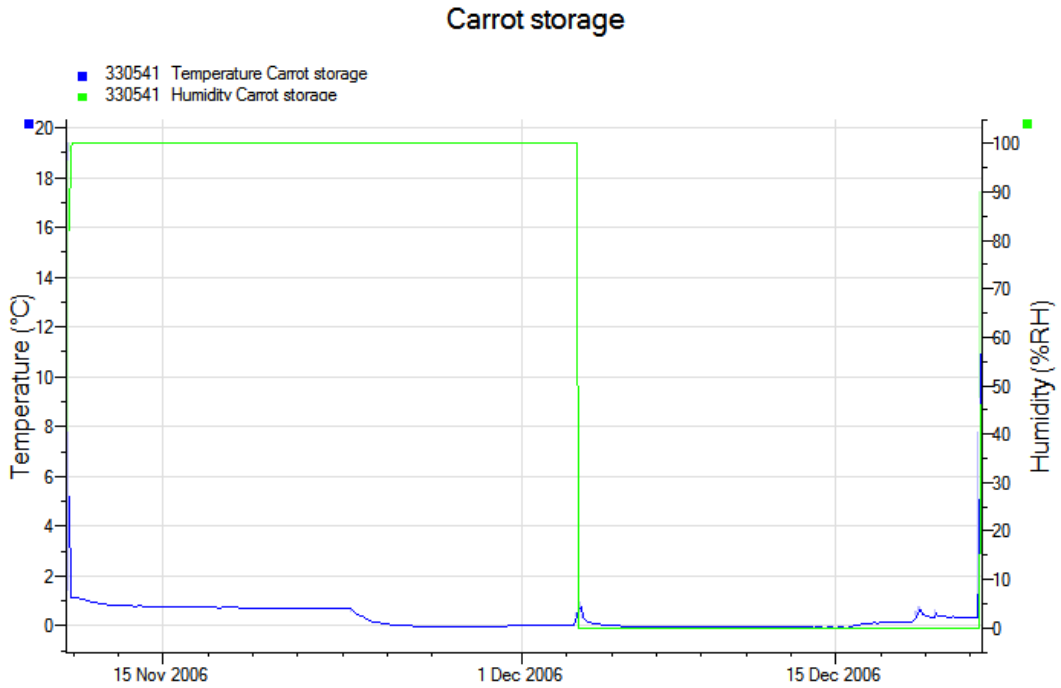
Table 1 Weight loss (%) in carrots stored in air at 0-0.5°C

	7 March 2007		22 April 2007		22 May 2007	
	Mean	Range	Mean	Range	Mean	Range
Stored dirty	-	-	2.5	-	2.8	-
Washed only	1.5	0.8-2.2	1.8	1.5-2.0	0.7	0.2-1.2
Washed, and polished	6.6	1.9-12.8	2.0	0.5-5.0	1.0	0.7-1.2
MAP	0.3	0.2-0.3	0.6	0.4-0.7	1.7	0.6-4.7

Table 2 Carbon dioxide and oxygen concentration in sealed polyethylene bags containing washed carrots

	7 March 2007		22 April 2007		22 May 2007	
	$\%CO_2$	$\%O_2$	$\%CO_2$	$\%O_2$	$\%CO_2$	$\%O_2$
Average	9.7	5.5	14.7	2.0	19.2	2.5
Range	8.5-10.1	4.3-6.4	10.7-17.1	1.0-3.0	12.9-25.4	0.4-6.7

Figure 1. Output from 'Tinytag' logger placed in boxes of stored carrots.



March Removal from Store

Table 3 Quality assessments ex store – 7 March removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
% Marketable	79.2	77.8	62.0	31.3	72.5	31.02
% rots	3.5	12.7	20.6	68.7	5.5	11.99
% fangs, stunts, broken	17.3	9.5	17.4	0.0	22.0	33.17
Skin finish index, pre-polish	1.00	2.03	1.80	3.18	2.99	3.450
Skin finish index post polish *	2.14	3.22	2.49	4.00	4.92	1.737

* mean score after 1 minute in Wyma Polisher, as set for commercial crop.

The percentage marketable was similar for all treatments except the modified atmosphere pack (MAP) treatment, where 68.7% had rotted. Yeast was identified as the main cause of rotting. Skin finish was improved by post-storage polishing, but the sample from the field-stored treatment was notably superior to all the treatments in refrigerated store for this parameter.

Table 4 Taste Assessments pre-polishing ex store - 7 March removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
Colour	3.688	3.675	3.462	3.613	3.538	0.3584
Brightness	1.450	1.900	1.650	1.000	1.650	0.1697
Uniformity	3.15	3.33	3.92	3.70	3.70	0.470
Skin Silvering	2.638	3.575	3.325	2.537	2.500	0.3240
Sweetness	2.81	2.67	2.99	3.34	2.59	0.493
Strength	3.09	2.73	2.62	2.97	2.78	1.007
Firmness	2.712	2.825	2.837	2.825	2.988	0.4402
Suitability	2.86	2.51	3.10	3.39	2.61	0.466
Sugar	8.000	7.250	8.000	8.000	8.000	0.2948

Results of taste and flavour assessments in the previous table show significant differences in

brightness, skin silvering and sugar content for the 7 March removal date. The treatment washed only was the brightest. The washed only and washed and polished treatments showed more skin silvering than field-stored carrots or refrigerated carrots stored dirty.

Sugar content was similar for all treatments except for washed only carrots, where a lower figure was recorded.

Table 5 Assessments post-polishing ex store – 7 March removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
Colour	3.812	3.525	3.645	N/A	3.150	0.8015
Brightness	1.225	1.775	1.525	N/A	1.100	0.3794
Uniformity	3.48	3.26	3.55	N/A	3.97	1.051
Skin Silvering	2.738	3.212	2.850	N/A	1.275	0.7246
Sweetness	2.38	2.20	2.23	N/A	2.41	1.101
Strength	3.14	2.77	2.50	N/A	3.11	2.251
Firmness	3.075	3.037	3.100	N/A	3.250	0.9842
Suitability	2.42	2.21	2.71	N/A	2.49	1.042
Sugar	7.000	7.000	7.500	N/A	7.250	0.6591

Polishing for 1 minute post-storage improved the appearance of carrots in all treatments (except MAP where there was insufficient material to polish due to the high levels of rotting). Results in the above table show washed only had a significantly higher score for brightness; all the refrigerated store treatments assessed showed more skin silvering than field-stored carrots. Sugar content was similar for all treatments.

Table 6 Shelf Life Assessments ex store – Weight loss (g) for 12 root sample – 7 March removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	646	691	658	709	692	107.4
5 days	644	688	655	705	689	107.3
7 days	644	686	654	705	689	106.7
10 days	644	686	654	705	689	106.7
Weight loss after 10 days	2	5	4	4	3	

Washed or washed and polished treatments in refrigerated store appear to have lost more weight than field stored carrots or carrots stored dirty in refrigerated store but differences were not statistically significant.

Table 7 Shelf Life Assessments - Skin Silvering – 7 March removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.375	4.000	3.125	1.750	1.625	0.2622
5 days	2.12	4.12	3.25	2.62	2.38	0.932
7 days	2.50	4.75	3.38	3.25	2.88	1.114
10 days	3.00	5.00	4.12	4.00	3.88	0.965

Skin silvering increased for all treatments during the 10 day shelf life period. Washed only, washed and polished and MAP were significantly more silvered than field stored carrots or carrots stored dirty.

Table 8 Shelf Life Assessments - Foliage re growth scores (0-5) – 7 March removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.50	1.00	1.00	1.00	1.00	*
5 days	2.250	2.125	1.375	1.250	1.250	0.6591
7 days	3.12	3.25	2.38	1.75	1.75	1.142
10 days	4.38	4.75	4.12	3.12	2.75	1.233

Field stored carrots had significantly less foliage re growth than all the refrigerated stored treatments, except MAP, after 10 days of shelf life conditions.

Table 9 Shelf Life Assessments- Root hair regrowth scores (0-5) – 7 March removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.50	1.00	1.00	1.00	1.00	*
5 days	1.875	2.000	1.500	2.000	1.125	0.4982
7 days	1.88	2.25	1.62	2.50	1.38	0.845
10 days	3.25	3.25	2.88	2.88	2.25	1.474

The amount of root hair regrowth was similar for field stored carrots, MAP and washed and polished carrots. Carrots stored dirty and washed only had more root hair re growth after 10 days in shelf life.

Table 10 Shelf Life Assessments – Breakdown – 7 March removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.00	1.00	1.00	1.00	1.00	*
5 days	2.00	1.62	1.00	2.25	1.12	1.220
7 days	3.00	2.00	1.38	3.25	1.38	1.431
10 days	4.12	3.00	2.00	4.62	3.25	1.431

The MAP treatment and carrots stored dirty in refrigerated store broke down more rapidly in the shelf life conditions than other treatments. Washed and polished carrots broke down more slowly than all other treatments.

Table 11 Shelf Life Assessments – Suitability (0-5) – 7 March removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	3.75	2.50	3.25	3.25	4.25	0.863
5 days	2.75	2.25	3.00	2.62	3.75	1.012
7 days	1.88	1.75	2.62	1.88	3.25	1.100
10 days	1.38	1.25	1.75	1.25	1.25	0.881

“Suitability” was defined as a composite measure of overall marketability. From day 1 the treatment washed only was scored least suitable. After 10 days in shelf life conditions, the highest score was recorded by the washed and polished treatment.

April Removal from Store

Table 12 Quality Assessments ex store – 22 April removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
% Marketable	84.39	84.43	93.99	7.82	84.35	5.882
% rots	1.04	2.84	6.01	92.18	1.83	5.396
% fangs, stunts, broken	10.57	12.73	0.00	0.00	13.82	1.612
Skin finish index pre-polish	2.335	1.567	2.352	4.000	4.964	0.1048
Skin finish index post-polish *	3.146	2.544	3.480	N/A	4.954	0.4670

* mean score after 3 minutes in Wyma Polisher (commercial standard = 1 minute)

The percentage marketable was preserved by refrigerated storage and field storage except for the MAP treatment. The percentage marketable for washed and polished treatment was significantly higher than all the other treatments.

Samples of April removal treatments, post-polishing

Table 13 Taste Assessments pre-polishing ex store – 22 April removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
Colour	3.862	3.500	3.312	3.625	3.500	0.2784
Brightness	1.500	1.625	2.000	1.659	1.375	0.2458
Uniformity	3.000	3.688	3.500	3.250	3.375	0.2796
Skin Silvering	2.75	3.69	3.25	2.12	1.94	0.596
Sweetness	2.312	2.250	2.938	3.375	1.812	0.3346
Strength	3.375	3.125	3.312	3.000	3.062	0.4130
Firmness	3.125	3.125	3.188	2.937	2.562	0.3224
Suitability	3.000	2.875	2.938	3.500	1.688	0.3626
Sugar	6.000	6.500	6.000	7.250	5.000	0.2385

By April, the field stored sample had deteriorated, with significantly worse scores for sugar, sweetness and overall suitability compared with the treatments in refrigerated store.

Table 14 Taste Assessments post polishing ex store – 22 April removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
Colour	3.438	3.312	3.625	3.583	3.583	0.6225
Brightness	1.375	1.625	2.000	1.659	1.375	0.5496
Uniformity	3.188	3.188	3.250	3.253	3.812	0.6252
Skin Silvering	2.31	3.25	3.31	1.94	1.12	1.333
Sweetness	2.500	1.812	2.688	2.989	1.562	0.7481
Strength	3.500	3.125	3.438	3.101	3.062	0.9235
Firmness	2.938	3.062	3.500	3.059	3.000	0.7209
Suitability	2.93	2.000	2.812	3.151	2.000	0.8108
Sugar	6.750	4.750	6.250	6.794	5.000	0.5332

Polishing for 3 minutes improved the appearance of all treatments but, as may be expected, the field stored sample still showed significantly worse scores for sugar, sweetness and overall suitability, compared with the treatments in refrigerated store.

Table 15 Shelf Life Assessments - Weight loss (g) – 22 April removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	725.	725.	827	783	711	108.2
5 days	725.	675.	827	783	711	108.2
7 days	725	674	826	782	710	107.7
10 days	725	674	826	751	710	106.7
15 days	721	670	822	N/A	704	105.8
Weight loss after 15 days	4	5	1	N/A	1	

The field stored and stored washed and polished treatments lost the least weight after 15 days in shelf life conditions.

Table 16 Shelf Life Assessments - Skin Silvering – 22 April removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.62	4.12	3.00	3.79	1.25	1.484
5 days	2.00	4.12	3.38	4.06	1.38	1.359
7 days	2.62	4.50	3.88	4.45	1.50	0.884
10 days	2.750	4.625	4.000	4.109	1.625	0.7061
15 days	2.875	4.750	4.375	N/A	1.750	0.6445

Field stored carrots and carrots stored dirty showed markedly less skin silvering than the other treatments in refrigerated store.

Table 17 Shelf Life Assessments - Foliage regrowth scores– 22 April removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.500	1.000	1.000	0.857	1.375	0.1885
5 days	1.875	1.750	1.500	1.127	1.500	0.5961
7 days	2.380	2.620	2.620	1.260	1.880	0.754
10 days	3.000	3.380	3.120	2.110	2.120	0.735
15 days	3.380	4.250	3.620	N/A	2.500	0.956

Foliage regrowth was least rapid in field stored carrots and MAP treatments and significantly different when scored at day 10 and 15. However, up to 5 day scores were similar for all treatments.

Table 18 Shelf Life Assessments - Root hair regrowth scores – 22 April removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.25	1.00	1.00	0.81	1.50	*
5 days	1.375	1.375	1.375	0.884	1.750	0.5655
7 days	2.12	2.12	1.88	1.15	2.12	1.015
10 days	2.25	2.25	2.00	1.76	2.25	1.116
15 days	2.50	2.25	2.25	N/A	2.25	1.352

The MAP treatment had significantly less root hair growth when scored on day 5, but all other treatments were similar.

Table 19 Shelf Life Assessments – Breakdown – 22 April removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.000	1.000	1.000	4.042	1.000	0.1885
5 days	1.125	1.125	1.000	4.188	1.250	0.4618
7 days	1.880	1.380	1.750	5.040	2.250	1.099
10 days	2.250	1.750	2.000	5.680	2.750	1.116
15 days	3.000	2.380	2.500	N/A	3.250	1.539

The MAP treatment was significantly worse when scored for breakdown through out the shelf life period.

Table 20 Shelf Life Assessments – Suitability – 22 April removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	4.12	1.81	2.75	1.42	4.50	1.166
5 days	3.50	1.50	2.38	1.21	3.75	0.980
7 days	2.50	1.38	2.12	0.99	3.00	1.333
10 days	2.25	1.38	1.75	0.80	2.50	1.135
15 days	1.50	1.25	1.50	N/A	2.00	0.706

Field stored carrots and carrots stored dirty in the refrigerated store were significantly more suitable on day 1, but by day 5 these deteriorated to equal the washed only and polished storage treatments.

May removal from store

Table 21 Quality Assessments ex store – 22 May removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
% Marketable	84.17	75.61	86.90	6.92	42.24	7.970
% rots	2.71	14.89	11.98	93.08	46.66	7.855
% fangs, stunts, broken	13.12	9.49	1.12	0.00	11.10	3.829
Skin finish index pre-polish	2.424	1.613	2.327	4.000	3.264	0.4746
Skin finish index post-polish *	3.26	3.47	4.11	N/A	4.26	1.047

*mean score after 5 minutes in Wyma Polisher.

Field stored carrots and MAP treatment had deteriorated further compared with the April assessment, with 42.24% and 6.92% marketable roots respectively. The MAP treatment preserved the appearance significantly better than all other treatments, but the high levels of rots, due to yeast development, provided insufficient material for post-storage polishing.

Increasing the length of time in the post-storage Wyma polisher improved the skin finish for all tested treatments, with the washed and polished treatment almost equal to field stored carrots

Samples of May removal treatments, post-polishing

Table 22 Taste Assessments pre-polishing ex store – 22 May removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
Colour	3.312	3.250	3.375	3.312	2.750	0.3140
Brightness	1.500	1.750	1.750	1.500	1.375	0.2065
Uniformity	3.625	3.250	3.500	3.562	2.562	0.2859
Skin Silvering	2.875	3.688	3.000	2.625	2.562	0.4319
Sweetness	2.69	2.00	3.31	3.13	1.50	0.482
Strength	3.50	3.31	3.00	2.94	3.00	0.542
Firmness	3.000	2.750	3.000	2.250	2.312	0.4340
Suitability	2.50	1.75	3.00	2.62	1.19	0.459
Sugar	6.000	5.500	6.000	6.750	4.500	0.2920

By May, the field stored sample had deteriorated further, with significantly worse scores for sugar, sweetness and overall suitability compared with the treatments in refrigerated store.

Table 23 Taste Assessments post-polishing ex store – 22 May removal

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
Colour	3.688	3.000	3.500	N/A	3.500	0.7022
Brightness	1.625	1.625	1.750	N/A	1.625	0.4618
Uniformity	3.812	3.188	3.375	N/A	2.875	0.6393
Skin Silvering	2.125	2.750	2.875	N/A	1.875	0.9658
Sweetness	2.62	2.31	2.69	N/A	1.81	1.077
Strength	2.50	2.81	2.88	N/A	2.88	1.213
Firmness	2.500	2.688	2.438	N/A	2.688	0.9704
Suitability	2.50	2.25	2.75	N/A	1.38	1.026
Sugar	6.250	5.000	6.000	N/A	4.500	0.6530

Polishing for 5 minutes post-storage restored the appearance of the treatments in refrigerated store compared with field stored samples. Field stored carrots had deteriorated with significantly worse scores for sugar, sweetness and overall suitability compared with the treatments in refrigerated store.

Table 24 Shelf Life Assessments - Weight loss (g)- 22 May removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	661	747	820	1170	707	279.5
5 days	659	746	818	1166	705	170.2
7 days	629	745	818	904	686	99.4
10 days	630	740	818	893	N/A	151.6
Weight loss	31	7	2	277	13 +	

Weight loss after 10 days in shelf life was more severe than for the March and April removal dates from store with MAP and field stored treatments losing most weight. The treatment washed and polished lost the least weight after 10 days in shelf life.

Table 25 Shelf Life Assessments Skin Silvering – 22 May removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	2.00	3.25	2.25	2.46	1.00	0.631
5 days	2.625	3.875	3.125	3.034	1.875	0.3372
7 days	2.75	4.25	3.25	4.17	2.50	0.342
10 days	3.60	4.75	3.50	4.10	N/A	0.982

Field stored carrots and carrots stored dirty in refrigerated store had markedly less skin silvering than the other treatments in refrigerated store on day 1 to day 7.

Table 26 Shelf Life Assessments - Foliage regrowth scores – 22 May removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.125	1.000	1.000	0.980	1.000	0.1192
5 days	1.500	1.500	1.625	0.965	1.250	0.2920
7 days	1.880	2.000	2.000	1.360	1.250	0.569
10 days	2.968	3.000	3.750	2.218	N/A	0.5487

Foliage regrowth was least rapid in the field stored carrots and MAP treatment, being significantly different when scored at day 7.

Table 27 Shelf Life Assessments Root hair regrowth scores – 22 May removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.000	1.000	1.000	1.000	0.959	0.2385
5 days	1.000	1.125	1.250	1.399	1.500	0.3577
7 days	1.000	1.500	1.620	1.660	2.000	0.569
10 days	1.820	2.250	2.380	2.820	N/A	0.736

Root hair growth was significantly less in carrots stored dirty in refrigerated store, with no significant differences between the other treatments.

Table 28 Shelf Life Assessments – Breakdown – 22 May removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	1.000	1.000	1.000	2.340	1.000	0.2385
5 days	2.750	1.500	1.000	4.150	2.750	0.924
7 days	3.000	2.000	1.250	3.890	4.500	1.302
10 days	3.720	2.750	2.750	4.720	N/A	1.202

Breakdown was almost total for MAP and field stored carrots after 10 days in shelf life conditions. There was no difference between the other treatments.

Table 29 Shelf Life Assessments – Suitability – 22 May removal (mean of both sample sets)

	Stored dirty	Washed only	Washed and Polished	Washed and Polished MAP	Field Stored	l.s.d.
1 day	3.50	2.12	3.75	1.75	3.50	0.725
5 days	2.12	1.50	2.88	1.32	1.50	0.809
7 days	2.00	1.00	2.00	1.26	1.00	0.632
10 days	1.00	1.00	1.00	1.00	N/A	*

Field stored carrots, washed and polished carrots and carrots stored dirty in the refrigerated store were significantly more suitable than the other treatments on day 1. But by day 5, field stored carrots had deteriorated more rapidly than the stored dirty and washed and polished treatments.

Summary and Discussion

This project has shown that the marketable portion of field-stored carrots significantly declined from 72.5% in March to 42.4 % by May. Assessments for taste, sugar and shelf life also show a decline but, in line with industry observation, overall appearance of the marketable fraction was preserved by harvesting fresh from the field. If mild winters become more usual for UK, then the season for field storage of carrots will be shorter in future and consideration will need to be given to building refrigerated stores if UK supply into the spring is to be maintained.

1. Carrots stored dirty with soil in refrigerated store

This method of storage preserved taste and sugar levels until the May removal date, but has the drawback that the entire unmarketable portion of the crop is also stored, as well as the soil adhering to the roots. Assessment of the marketable portion showed that up to 17.3% [May] of the carrots were unmarketable due to mechanical damage, fanging, stunts and misshapes. Nevertheless, this treatment had the lowest percentage of rots by May, at 2.71%.

2. Carrots washed and hydrocooled only stored in refrigerated store

This method of storage also preserved taste and sugar levels until the May removal date but, as with treatment 1, the unmarketable portion of the crop is stored along with the marketable portion. Assessment of the marketable portion showed that up to 17% of the carrots were unmarketable due to mechanical damage, fanging, stunts and misshapes. Rotting was also high at 14.89% by May.

3. Carrots washed, polished and hydrocooled, final product for market, stored in refrigerated store

Negligible quantities of unmarketable carrots are placed in store with this treatment, increasing the effective storage capacity and potential marketable output from a refrigerated store. 86.9% was marketable by the following May, about twice the proportion of the field-store crop, taste and percentage sugar content was preserved, but 5 minutes in a Wyma polisher were required to restore the root's overall appearance. This had a detrimental effect on shelf life beyond 5 days. The percentage rotting by May was higher than for carrots stored with soil, at 11.89%.

4. Carrots washed, polished and hydrocooled, final product for market, placed in a modified atmosphere polythene bag, MAP stored in refrigerated store

Long term refrigerated storage in a modified atmosphere polythene bag (MAP) failed in this experiment, as yeasts developed, increasing the percentage of rots to 93.08% by the May removal. However, this treatment warrants further research to prevent yeast developing in store, since high scores were achieved for post-storage skin finish, taste and sugar levels. The most common symptom on roots from the modified atmosphere and polished (MAP) treatment at each of three sampling dates was a severe soft rot from which a yeast species and a *Fusarium* species were consistently isolated. As the rots were mainly in an advanced stage of development, it was not clear which was the primary causal organism. The yeast was identified (tentatively) as a species of *Candida.* Rots due to yeasts on stored carrots are not frequently found in commercial practice. From scientific literature, Snowdon (1991) reported a yeasty rot of carrots in storage that had been subjected to inadequate cooling and ventilation. Stelfox (1966) described the development of a yeast rot (due to *Candida kruzei*) in association with *Sclerotinia sclerotiorum* on carrots that had been cold-stored (low temperatures, very high relative humidity).

5. Field storage

The 2006/7 winter was mild with a higher than average soil temperature. This had a detrimental effect on carrots field stored beyond April and by May 46.66% of the sample was unmarketable due to rotting. A range of micro organisms was identified including: Cavity spot, Pythium violae, Sclerotinia, Fusarium, fast growing Pythium species and bacterial soft rot. Taste scores and sugar levels also significantly declined. However, field storage preserved the fresh lifted appearance of the marketable portion until May.

ECONOMIC EVALUATION

Field Storage

The cost of carrot production for the overwintered storage period is very high and, in addition to the usual crop production costs, there is the extra cost of winter protection i.e. provision of straw and plastic, coupled with the laying and disposal costs. Land rental for overwinter field storage is also often higher because late harvesting restricts the choices for following crops. Variable costs associated with field storage of carrots total some £3006/ha equivalent to £50/tonne of marketed crop. This is composed from the following elements:

Table30 Variable costs per hectare for field storage

Item	£/tonne	£ /Ha
Straw including bailing, transport and spreading	£25/bale, 50 bales/ha	1,250
Black plastic		650
Straw removal/disposal		200
Disposal of plastic to landfill		147
Loss of margin for following crop		750
Total		**2997**
Cost/tonne with 60 tonne/ha class I marketed	50	

Refrigerated Storage

The cost of refrigerated storage is also high, with additional harvesting and transport costs for loading the store in a short time period. There are also tax implications, since all the costs associated with field storage are an allowable expense in one year but the capital cost of a store and equipment is not.

Table 31 Capital costs for a 1000 tonne store

Item	£/tonne	£ for 1000 tonne store
1 tonne boxes	65 to 70	70,000
Insulation, 100mm panels	70	70,000
100kw refrigeration equipment	55	55,000
Control and electricity supply	10	10,000
Total	**205**	**205,000**

Table 32 Running costs

Item	£/tonne	£ for 1000 tonne store
Initial temperature pull down	5 to 10	10,000
Electricity November to February inclusive, £2/month	8	8,000
Electricity March to May inclusive, £4/month	12	12,000
Total	**30**	**30,000**

If the building insulation is written off over 10 years and equipment written off over 5 years then the cost/tonne is estimated at £58.5/tonne. However, this could be as high as £200/tonne if site, buildings, access, supply of services and financial capital are not already available.

Table 33 Estimated Cost per Marketable Tonne Carrots, May removal

Treatments	Gross cost of storage £/tonne	% marketable, May removal date	Net cost of storage/marketable tonne
Stored dirty	64	84.17	76
Washed only	64	75.61	84
Washed and polished	64	86.90	74
Washed, polished MAP	64	6.92	925
Field stored	40 - 50	42.24	95 - 118

* based on % Marketable, May removal date

Conclusions

Project FV 306 has demonstrated that it is possible to store washed, polished and hydrocooled carrots in long term refrigerated storage with less rotting than field stored crops (by May) but the final appearance and shelf life was inferior to the field stored treatment. This method of storage preserved flavour and sugar content and has the potential to significantly reduce the cost/tonne for refrigerated storage compared with the continental standard of storing ungraded carrots with soil.

The cost of production for the overwinter storage period was estimated at £3000/ha or £50/tonne marketed in 2006/7 season.

The capital requirement for refrigerated storage is estimated at £205,000 for a 1000 tonne store. Running costs for November to May inclusive are estimated at **£**30,000 or £30/tonne, giving a total of £64/tonne stored. This will increase depending on the post storage pack out. The project indicates £69.50 for carrots stored dirty and £67.30 for washed, polished and hydrocooled carrots stored to May.

Carrots stored dirty had the least rotting in store, 2.71% by May. If the unmarketable portion (fangs, stunts, misshapes) is graded out prior to store loading then this treatment will remain the best method of long term refrigerated storage when skin finish, appearance and shelf life equivalent to fresh lifted carrots is required by the market outlet. However, flavour and sugar levels were not preserved to the same extent as carrot stored in a refrigerated store.

Carrots stored washed but not polished proved to be more costly at £84/tonne marketed due to a high 14.9 % rotting by May and a high 9.5% unmarketable portion due to fangs and misshapes. There was no measurable benefit from flavour, sugar levels or shelf life compared with the treatment - washed, polished and hydrocooled.

Long term refrigerated storage in a modified atmosphere polythene bag (MAP) failed due to yeast increasing the % rotting to 93.08% by May. However, this treatment warrants further research to prevent yeast developing in store since high scores were achieved for post storage skin finish, taste and sugar levels.

Post Storage Polishing

Following removal from store in March all treatments were subjected to 1 minute in a commercial carrot polisher and this failed to restore the skin finish compared with fresh lifted field stored carrots. Following removal from store in April all treatments were subjected to 3 minutes in a commercial carrot polisher and this improved the skin finish compared with fresh lifted field stored carrots but reduced shelf life. Following removal from store in May all treatments were subjected to 5 minutes in a commercial carrot polisher and this improved the skin finish further compared with fresh lifted field stored carrots but again reduced shelf life.

Polishing had the effect of improving the appearance of carrots following removal from store, though the treatments applied did not quite reach the look of field-stored carrots. Although appearance has been the pre-dominant factor governing consumer appeal, the importance of factors such as taste and texture has increased and this may tip the balance towards cold-stored carrots. The increased use of carrots in convenience packs and ready meals where appearance *per se* is not apparent offers an immediate opportunity to improve sensory quality for this period of the year.

The continuing ability of the industry to continue to supply high quality carrots through to May from the field with the prospect of more frequent mild and wet winters could also be a deciding factor in the development of this technology in the future. Further refinement of techniques (such as MAP) and procedures will be required to avoid the possibility of major losses occurring following heavy capital investment, though these offer the opportunity to increase quality further.

Technology transfer

Results were presented to members of BCGA at their meetings on 25 April and 12 July 2007. An article was written for HDC News, October 2007 issue.

Glossary

FRI -	Food Research Institute, Norwich
BCGA -	The British Carrot Grower's Association
PGRO -	The Processed Growers Research Organisation, Cambs.
EMR -	East Malling Research Centre, Kent
MAP -	modified atmosphere polythene
Wyma polisher -	a machine for controlled scrubbing of carrots to enhance their appearance.

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