Crop & Food Research Confidential Report No. 888

Effects of cultural practices at harvest on onion bulb quality and the incidence of bacterial soft rot, thrips, and fungal moulds after simulated shipping

P J Wright[1], N A Martin[2], P A Workman[2] & C M Triggs[3]

June 2003

A report prepared for
New Zealand Onion Exporters Association

Copy 13 of 13

New Zealand Institute for Crop & Food Research Limited
[1] *Pukekohe Research Centre, Cronin Road, RD1, Pukekohe, New Zealand*
[2] *Mt Albert Research Centre, Private Bag 92 169, Auckland, New Zealand*
[3] *Department of Statistics, University of Auckland Private Bag 92 019, Auckland, New Zealand*

Contents

1 Executive summary

The object of this study was to investigate the effects of cultural practices at harvest, and moisture conditions during field curing, on onion bulb quality and the incidence of storage rots, fungal moulds, and thrips after simulated shipping.

Factors investigated were:

1. physiological maturity of onions at harvest,
2. time of leaf removal,
3. moisture conditions during field curing, and
4. temperature and moisture conditions during simulated shipping.

Onion plants were lifted at one of two stages of maturity: 25 or 90% leaf collapse (top-down). Foliage was removed (topped) either before or after field curing, and bulbs were subjected to one of three field curing treatments: field curing with additional water (wet), field curing without additional water (dry), or field curing under ambient conditions (ambient). Field curing was for four days. Curing was completed under forced air drying at ambient temperatures. Bulbs were then placed under one of two simulated shipping conditions: refrigerated (7°C) or ambient (18-35°C).

After simulated shipping, onion bulbs were dissected and numbers of thrips, their location in each bulb and the presence of feeding damage were recorded. Bulb quality characteristics examined included skin colour, skin retention, skin splitting, incidence of surface fungal moulds, and bacterial rots.

Findings included:

- Refrigerated shipping reduced the incidence of rots and surface moulds of bulbs, but resulted in a larger proportion of bulbs with green-yellow skins.
- Wet conditions during field curing increased the incidence of rots in ambient-shipped onions while dry conditions increased the incidence of skin splitting in onions lifted at 90% top-down, but not in onions lifted at 25% top-down.
- Lifting at 25% top-down resulted in a greater proportion of bulbs with two or more intact outer skins, and reduced the incidence of skin-splitting. Topping before field curing generally increased the number of rots in ambient-shipped bulbs.

Modification of husbandry practices, monitoring the weather during harvest, and refrigerated shipping are recommended as measures to reduce the incidence of bacterial soft rot and improve the quality of onion bulbs in storage and transit.

Onions subject to refrigerated shipping had fewer thrips, fewer bulbs infested and fewer bulbs with thrips damage, than bulbs subject to ambient shipping. Time of lifting, time of topping and curing conditions had no impact on thrips populations or bulb damage. These findings emphasise the importance of keeping bulbs as cool as practical at all stages from removal from the field, in storage and in transit, in order to minimise thrips damage.

2 Introduction

The production of high quality onion bulbs capable of withstanding long transportation distances to export markets is fundamental to the New Zealand onion export industry. Desirable quality characteristics of harvested onions include bulbs that are free of diseases and have skins that are clean, unblemished and not split or loose, and have a colour appropriate to the cultivar concerned. Research carried out locally and overseas has demonstrated that the methods by which onions are harvested and cured, and weather conditions during harvest, can have important effects both on onion quality characteristics and storage life.

The commercial value of onions is largely determined by their appearance. The most desirable colour for Pukekohe Longkeeper (PLK) bulbs is a deep golden-brown. Although skin colour does not affect storage performance, onions with blemished or pale, greenish skins are considered inferior. Temperature conditions after harvest can influenced the colour of the outer skins of onion bulbs. Loss of outer skins of harvested onions not only detracts from their appearance but also accelerates desiccation of bulb tissues, reducing storage life and thereby lowering commercial value.

Skin stains and blemishes, mainly caused by fungi that develop on the surfaces of bulbs when they are exposed to wet conditions during field curing and storage, also reduce the visual appeal of onion bulbs without affecting their storage life. Other fungi, including *Aspergillus niger* (black mould), *Penicillium* spp. (blue mould), and *Botrytis allii* (neck rot), can infect fleshy bulb scales in storage at warm temperatures and high relative humidity, causing decay of onions. Copious quanties of fungal spores on and under the papery scales of bulbs significantly reduce the visual appeal of bulbs. Refrigerated storage slows the development of these diseases, although fungal growth resumes upon return to higher temperatures.

Soft rot, caused by several species of bacteria, is a major postharvest disease of onions grown in New Zealand. Soft-rotting bacteria exist as saprophytes in plant debris in the soil, and invade onion bulbs through wounds, senescent or dead leaves, or improperly dried necks. The early stages of soft rot are not noticeable at grading and, as a consequence, export of infected onions can occur. Infected onions will rot in transit if storage and shipping conditions favour soft rot development.

Thrips gain access through onion necks and splits in bulb skins. The insects remain on and in bulbs during harvest and persist in storage. Thrips damage bulb tissue, causing shrinkage, loose skins and a roughened appearance of fleshy scales. Thrips feeding damage can also serve as an entry point for storage diseases, including black, blue and grey moulds.

During the past few years, in order to meet consumer demand and to obtain premium prices, many New Zealand growers have used non-traditional harvest practices to produce onions of higher quality. Perhaps as a result of this, the incidence and severity of bulb rots, the presence of thrips in bulbs, and the numbers of bulbs with poor skin quality (split skin, staining, fungal moulds) on arrival at export destinations have also markedly increased in recent years.

It is important to determine the factors (cultural and environmental) at harvest and in storage (and transit) that affect bulb quality characteristics and postharvest diseases that cause poor out-turn of onions exported from New Zealand.

The aim of the present project was to determine the effects of physiological maturity of onion plants at lifting (percent top-down) and method of curing, on skin colour, skin retention, the incidence of moulds (black, blue and grey), the incidence bacterial rots, and the incidence of splits in the dry skins (which allow thrips access), and the numbers of thrips adults, larvae and eggs, in onion bulbs grown in the Pukekohe district.

3 Methods

3.1 Onion crop

A trial was carried out at the Crop & Food Research Centre at Pukekohe on a Patumahoe mottled clay loam. Seeds of the onion cultivar PLK (May and Ryan Regular strain) were direct-seeded on 18 July 2002 using a Stanhay precision seed planter in four beds (each of five rows), and each bed was 60 m long and 1.5 m wide. Plant density 1 month after seedling emergence was 55-65 plants/m of bed. Base fertiliser, weeds, pests and diseases were managed using local commercial practice. Nitrogen (N) was applied at 120 kg N/ha (as urea) in two equal applications at early crop emergence and eight weeks later. In order to create soft, succulent foliage favourable for bacterial soft rot infection, onions were given further applications of 60 kg N/ha on 9 December and 30 December, and were irrigated on 30 December and 2 January. The final insecticide spray was applied on 8 January 2003.

3.2 Treatments

There were 24 treatments (Table 1). In the field, the matching shipping conditions treatments shared the same plots (e.g. treatments 1 and 13, 2 and 14, etc.). Each treatment pair had four replications (plots) that were randomised within four blocks (Table 2). The plot size was 5 m long x 1.5 m wide. The experiment was of complete factorial design with four replicates of each treatment combination.

Table 1: Experimental treatments, and treatment numbers (1-24).

Shipping conditions	Harvest method		Moisture conditions during field curing		
	Lifting time	Topping time	Dry	Ambient	Wet
Ambient	25% top-down	Before curing	1	2	3
		After curing	4	5	6
	90% top-down	Before curing	7	8	9
		After curing	10	11	12
Refrigerated	25% top-down	Before curing	13	14	15
		After curing	16	17	18
	90% top-down	Before curing	19	20	21
		After curing	22	23	24

Table 2: Trial plot randomisations (treatment numbers as in Table 1, representing a pair, see text).

Block 1			Block 2			Block 3			Block 4		
1	5	2	3	6	4	7	8	11	9	12	10
7	4	9	2	12	10	1	6	5	8	3	11
6	8	11	9	1	5	12	3	10	2	4	7
3	10	12	8	7	11	4	2	9	5	6	1

Onion bulbs were lifted at two stages of physiological maturity (Figure 1). Half of the onions were lifted on 27 January 2003 when 25% of the plants had collapsed foliage (top-down). The other half were lifted on 10 February 2003 when they had 90% top-down.

Hand shears were used to remove the foliage to 2-3 cm above each bulb either before or after a field curing period of four days. Field curing was carried out at three locations, each under different moisture regimes. In the 'wet' conditions during field curing treatment, plants were placed back on the soil where they had grown and were watered by overhead irrigation for 30 minutes each morning and late-afternoon. In the 'ambient' conditions during field curing treatment, the onions were moved 10 m so that they were out of range of irrigation water. No rainfall occurred during the ambient curing period. In the 'dry' treatment, onions were moved to a fully vented greenhouse.

After the lifting, curing and topping treatments, random samples of 50 bulbs (for disease and bulb quality assessments) and 20 bulbs (for thrips assessments) of 60-90 mm diameter from each plot were placed in nylon string bags and moved to forced-air dryers to complete the curing process. Unheated outside air was forced through the onions at a rate of 14 m^3/minute by a blower fan for seven days. Onions were held in a ventilated shed at ambient temperature (range 12-22°C) and humidity (range 70-85% RH) until all lifting, curing and topping treatments and forced air curing had been completed.

Onions were then subjected to one of two storage treatments, each lasting 31 days, simulating shipping to Europe in either ambient or refrigerated conditions. In the 'ambient' shipping treatment, temperatures started at 20°C, steadily increased to 30°C after 20 days, then declined to 23°C during the next 10 days. Relative humidity was 80-95% for the first 23 days, and 55-65% RH during the next 8 days. The 'refrigerated' shipping treatment was in a coolstore where the temperature was 7°C and the relative humidity c. 85%.

3.3 Onion quality and soft rot assessments

After simulated shipping, each bulb was visually assessed for skin colour (Figure 2), number of skins, presence of splits in skins (exposing fleshy bulb scales) (Figure 3), surface mould (Figure 4), soft rot (Figure 5), signs of thrips entry through the neck, and the presence of thrips eggs, larvae and adults.

The primary skin colour of each bulb was scored using the following 1 to 5 scale: 1 = green-yellow, 2 = straw-yellow, 3 = golden brown, 4 = brown, 5 = dark brown (Figure 2). Surface moulds were assessed using a 1 to 5 scale, where 1 = 0% of the bulb covered with mould, 2 = 1-10% mould-covered, 3 = 11-25% mould-covered, 4 = 26-50% mould-covered, 5 = >50% mould-covered (Figure 4). All bulbs from each treatment sample were cut in half. The number of intact outer dry skins of each bulb was counted and the bulbs examined for soft rot. Rot was classified into two categories: either 'major' rots, where rot extended more than half-way down one or more fleshy bulb scales; or 'minor' rots, where rot extended less than half-way down one or more fleshy bulb scales (Figure 5).

The percentage of bulbs with rots in each bag of 50 onions was analysed with analysis of variance after first transforming the percentages with the arc-sine transformation to stabilise the variance. Major % and minor % were analysed separately.

Figure 1: Two plots showing onions lifted at 25% top-down and field onions cured under ambient moisture conditions. One plot was topped before field curing, the other plot was topped after field curing.

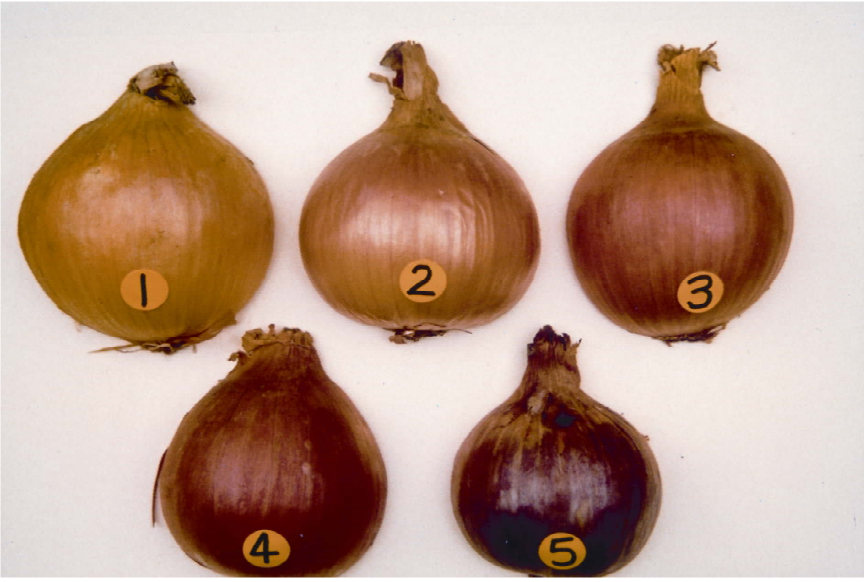

Figure 2: Bulb skin colour scores. 1 = green-yellow, 2 = straw-yellow, 3 = golden brown, 4 = brown, 5 = dark brown.

Figure 3: Outer skins of the onion bulb are split, exposing fleshy bulb scale.

Figure 4: Onion bulb showing mould on surface.

Figure 5: Onion bulb with 'major' soft rot.

3.4 Onion thrips in bulbs

After simulated shipping, 20 bulbs per plot and condition were dissected to determine the number of thrips at different life stages, the location of thrips in the bulb, and the extent of thrips damage in each bulb. The presence of rots and splits in the outer dry skins was also recorded.

Thrips were recorded as larvae, pupae or adults, but for the analysis pupae were classed as larvae. Eggs were not searched for. The location of each thrips was recorded. The possible sites included the base of the bulb, in splits that accessed live scales, in between dead skins, between the innermost dead skin and the first live scale, and between each pair of live scales.

Thrips damage and its location was recorded if the area damaged extended more than 20 mm from the tip of the live scale in the neck.

The data were not analysed formally, and were tabulated and summarised by treatments.

4 Results

4.1 'Major' rots

The effect of shipping conditions had the biggest effect on 'major' rots (rot extending more than half-way down one or more bulb scales). The incidence of 'major' rots was much lower (mean 0.04%) in the bulbs from the refrigerated-shipped treatment compared with the ambient-shipped bulbs (mean 4.7%) (Table 3).

In refrigerated bulbs, there were no statistically significant differences ($P < 0.05$) in the incidence of 'major' rots between all three conditions of moisture during field curing, with levels of soft rot all between 0 and 0.3% (Table 3). However, in ambient-shipped bulbs, those that were subjected to additional water during field-curing had a greater incidence ($P < 0.05$) of 'major' rots (mean 11%) than those subjected to ambient (2%) or dry (3%) field curing conditions.

Table 3: Differential effect of moisture during field curing on incidence of 'major' rots of PLK bulbs during simulated shipping under ambient or refrigerated conditions. Percent bulbs with 'major' rots back transformed from means on arc sine scale. LSDs refer to means of arc sine transformed data (in brackets). $LSD_{0.05}$ (df = 71) = 1.3, 1.5, 2.2 for shipping, moisture and shipping x moisture means respectively.

	Moisture during field curing			
Shipping conditions	Dry	Ambient	Wet	Mean
Ambient	2.7 (9.4)	2.4 (8.9)	11.0 (19.4)	4.7 (12.6)
Refrigerated	0.0 (0.0)	0.0 (0.5)	0.3 (3.0)	0.04 (1.2)
Mean	0.7 (4.7)	0.7 (4.7)	3.8 (11.2)	

Onions topped before field-curing had a higher ($P > 0.05$) incidence of 'major' rots (6.6%) than onions topped after field-curing (3.2%) and held in ambient but not refrigerated shipping conditions (Table 4). There was no statistically significant interaction between time of topping and moisture during field curing and the incidence of 'major' rots in shipped bulbs.

Table 4: Differential effect of time of topping on incidence of 'major' rots of PLK bulbs during simulated shipping. Percent bulbs with 'major' rots back transformed from means on arc sine scale. LSDs refer to means of arc sine transformed data (in brackets). $LSD_{0.05}$ (df = 71) = 1.3, 1.3, 1.8 for shipping, topping and shipping x topping means respectively.

	Time of topping		
Shipping conditions	Before	After	Mean
Ambient	6.6 (14.9)	3.2 (10.3)	4.7 (12.6)
Refrigerated	0.1 (1.3)	0.0 (1.0)	0.04 (1.2)
Mean	2.0 (8.1)	1.0 (5.6)	

There was no statistically significant interaction between the time of onion lifting and time of topping and moisture conditions during field curing (P > 0.05) on the incidence of 'major' rots.

4.2 *'Minor' rots*

For 'minor' rots, shipping conditions was the most important factor. The incidence of 'minor' rots was greater ($P < 0.05$) in bulbs shipped under refrigerated conditions (mean 7.2%) than in bulbs shipped in ambient conditions (0%) (Table 5). Moisture during field curing was the next most important factor. Onions subjected to wet field curing conditions had the highest incidence of 'minor' rots in refrigerated-shipped bulbs (mean 3.7%). Dry and ambient conditions during field-curing resulted in 0.5 and 1.2% 'minor' rots respectively in refrigerated-shipped bulbs.

Table 5: Differential effect of moisture during field-curing on incidence of 'minor' rots of PLK bulbs during simulated shipping. Percent bulbs with 'minor' rots back transformed from fitted means on arc sine scale. LSDs refer to means of arc sine transformed data (in brackets). $LSD_{0.05}$ (df = 71) = 1.0, 1.3, 1.8 for shipping, moisture and shipping x moisture means respectively.

	Moisture			
Shipping conditions	Dry	Ambient	Wet	Mean
Ambient	0 (0)	0 (0)	0 (0)	0 (0)
Refrigerated	0.5 (4.1)	1.2 (6.3)	3.7 (11.1)	1.5 (7.2)
Mean	0.1 (2.0)	0.3 (3.2)	0.9 (5.6)	

Time of onion lifting and time of topping did not significantly affect ($P < 0.05$) the incidence of 'minor' bulb rots.

4.3 *Skin colour*

Shipping conditions had the greatest effect on bulb skin colour with 45.1% of refrigerated onions having skin colour scores of 1 (commercially undesirable green-yellow colour) compared to 6.6% of ambient-shipped onions (Table 6). The predominant bulb skin colour in refrigerated-shipped onions was green-yellow (score 1), and the percentage of bulbs in each successive skin colour category decreased (Figure 6). With ambient shipping, the predominant bulb skin colour was golden brown (score 3). The time of lifting, method of topping, and moisture conditions during field curing did not affect ($P < 0.05$) bulb skin colour.

Table 6: Effect of shipping regime on incidence of yellow-green skin colour (score 1) of PLK bulbs. Percent bulbs with yellow-green skin colour back transformed from means on arc sine scale. LSD refers to means of arc-sine transformed data (in brackets).

	Shipping conditions		$LSD_{0.05}$ (df = 71)
	Ambient	Refrigerated	
Mean	6.6	45.1	
	(14.9)	(42.2)	(1.4)

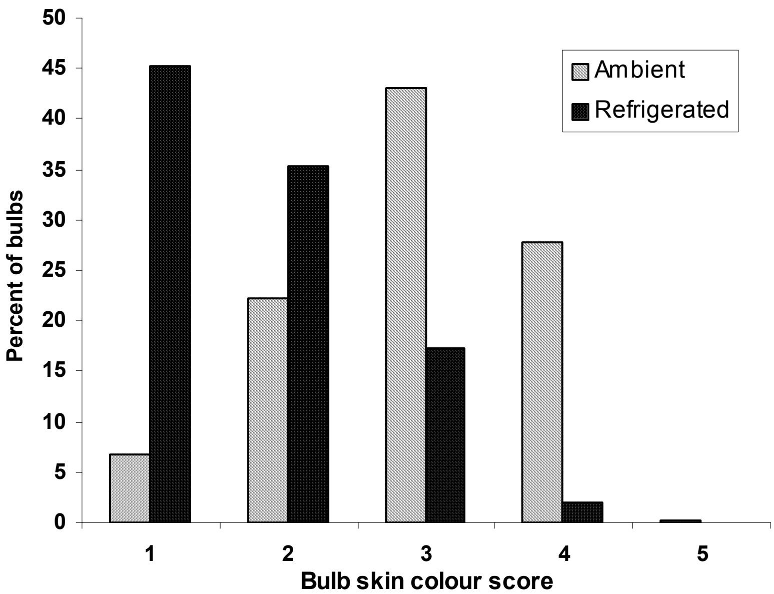

Figure 6: Distribution of skin colour grades of PLK bulbs after ambient and refrigerated shipping.

4.4 *Surface moulds*

Shipping conditions had the biggest effect on the severity of skin surface moulds, with a greater proportion (P = 0.001) of bulbs with severe surface moulds (mould scores of 4 and 5) in bulbs shipped in ambient conditions compared to those in refrigerated conditions (Table 7). The predominant mould score in refrigerated-shipped bulbs was 2 (1-10% of surface of bulb covered with mould), and the percentage of bulbs in each successive mould category decreased (Figure 7). With ambient shipping, the percent of bulbs with mould scores of 2, 3, 4 and 5 ranged between 20 and 29%. Time of lifting, time of topping, and moisture conditions during field-curing did not significantly affect (P > 0.05) the severity of surface moulds.

Table 7: Effect of shipping conditions on incidence of bulbs with surface mould score of 4 and 5 (commercially undesirable). Percent bulbs with mould score of 4 and 5 were back transformed from means on arc sine scale. LSD refers to means of arc sine transformed data (in brackets).

	Shipping conditions		$LSD_{0.05}$ (df = 71)
	Ambient	Refrigerated	
Mean	54	21	
	(47.2)	(27.0)	(2.6)

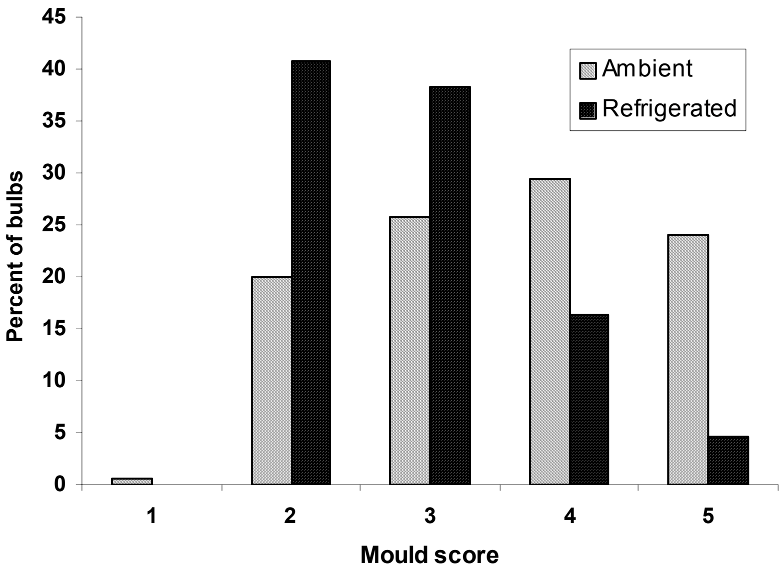

Figure 7: Distribution of mould scores of PLK bulbs after ambient and refrigerated shipping.

4.5 Number of skins

The major influences on the number of intact skins were time of lifting and time of topping. Both time of bulb lifting and time of topping gave large differences in the proportion of bulbs with no or one intact outer skin. Onions lifted at 25% top-down had fewer (2.5%; $P < 0.05$) onions with 0-1 intact skins than onions lifted at 90% top-down (6.8%) (Table 8). Onions topped before field curing had a lower incidence of bulbs with 0-1 skins (3.6%; $P < 0.05$) than onions topped after field curing (5.2%) (Table 9). Moisture during field curing and shipping conditions did not significantly affect ($P > 0.05$) the retention of outer bulb skins.

Table 8: Effect of time of lifting on incidence of bulbs with 0-1 intact outer skins. Percent bulbs with 0-1 intact outer skins back transformed from means on arc sine scale. LSD refers to means of arc sine transformed data (in brackets).

	Time of lifting		$LSD_{0.05}$ (df = 71)
	25% top down	90% top down	
Mean	2.5	6.8	
	(9.1)	(15.2)	(1.3)

Table 9: Effect of time of topping on incidence of bulbs with 0-1 intact outer skins. Percent bulbs with 0-1 intact outer skins back transformed from means on arc sine scale. LSD refers to means of arc sine transformed data (in brackets).

	Time of topping		$LSD_{0.05}$ (df = 71)
	Before curing	After curing	
Mean	3.6	5.2	
	(11)	(13)	(1.3)

4.6 *Split skins*

Time of lifting, moisture conditions during field-curing, and shipping conditions all significantly affected incidence of split skins in shipped bulbs. Onions lifted at 25% top-down had fewer bulbs with split skins (0.8%; $P < 0.05$) than onions lifted at 90% top-down (6.2%) (Table 10). Onions field-cured under dry conditions had a higher incidence of skin splits (4.7%; $P < 0.05$) than onions cured under ambient (2.8%) or wet (1.6%) conditions (Table 11). Bulbs shipped under ambient conditions had more spilt skins (3.3%; $P < 0.05$) than bulbs shipped under refrigeration (2.5%) (Table 12). Time of topping did not significantly affect ($P > 0.05$) the incidence of skin splitting.

Table 10: Effect of time of lifting on incidence of split skins of PLK bulbs. Percent bulbs with split skins were back transformed from means on arc sine scale. LSD refers to means of arc sine transformed data (in brackets).

	Lifting		$LSD_{0.05}$ (df=71)
	25% top down	90% top down	
Mean	0.8	6.2	
	(5.2)	(14.5)	(1.3)

Table 11: Effect of moisture during field-curing on incidence of split skins of PLK bulbs. Percent bulbs with split skins were back transformed from means on arc sine scale. LSD refers to means of arc sine transformed data (in brackets).

	Moisture			$LSD_{0.05}$ (df = 71)
	Dry	Ambient	Wet	
Mean	4.7	2.8	1.6	
	(12.7)	(9.7)	(7.2)	(1.3)

Table 12: Effect of shipping conditions on incidence of split skins of PLK bulbs. Percent bulbs with split skins were back transformed from means on arc sine scale. LSD refers to means of arc sine transformed data (in brackets).

	Shipping		$LSD_{0.05}$ (df = 71)
	Ambient	Refrigerated	
Mean	3.3	2.5	
	(10.5)	(9.1)	(1.3)

4.7 Summary of commercially undesirable characteristics

The results of the experiment on onion bulb quality, rots, and fungal moulds are shown in Table 13. The following bulb quality characteristics were deemed to be undesirable: a bulb had (1) less than two intact outer skins, (2) green-yellow skins, (3) split skins, (4) greater than 25% of the bulb's surface covered with mould; (5) major rot, or (6) minor rot.

A subjective rating based on the percentage of bulbs in each bulb quality characteristic was applied to the data and is shown as coloured shading behind each figure. Green = a "desirable" result; Yellow = "acceptable"; Orange = "undesirable", Red = "unacceptable".

Table 13 is intended as a "grower guide" only as these data are from one trial and further work will be needed to see if the results are reproducible. Based on the ratings, growers can see the effects of each of the harvest and shipping treatments on the incidence of undesirable bulb quality characteristics.

4.8 Thrips infestation and damage

A summary of the thrips infestation and thrips damage for each of the 24 treatments is given in Table 14, while the overall effect of the four factors are summarised in Table 15. The only factor to reduce the numbers of thrips, the numbers of infested bulbs and the amount of thrips damage was refrigerated shipping compared to ambient shipping. The mean number of thrips per infested bulb was 6.80 thrips for ambient shipping and 4.01 thrips for refrigerated shipping.

Timing of lifting, time of topping and conditions during field curing appear to have no significant effects on thrips infestation and thrips damage.

Table 13: Summary of commercially undesirable characteristics of PLK onion bulbs following different harvest, curing, and shipping conditions.

Shipping conditions	Top-down at lifting	Time of topping	Field curing conditions	<2 intact outer skins	Green-yellow skins	Split skins	>25% surface mould	Major rots	Minor rots
1. Ambient	25%	Before Curing	Dry	2	8	2	58	3	0
2.			Ambient	1	6	1	44	5	0
3.			Wet	2	6	1	52	18	0
4.		After Curing	Dry	2	8	2	64	2	0
5.			Ambient	3	6	1	56	1	0
6.			Wet	4	7	1	47	9	0
7.	90%	Before Curing	Dry	8	4	9	48	4	0
8.			Ambient	5	6	6	42	3	0
9.			Wet	6	9	4	61	11	0
10.		After Curing	Dry	7	4	9	64	1	0
11.			Ambient	8	7	7	59	1	0
12.			Wet	7	9	4	50	7	0
13. Reefer	25%	Before Curing	Dry	2	46	1	20	0	1
14.			Ambient	1	44	1	21	0	1
15.			Wet	2	42	0	17	0	3
16.		After Curing	Dry	3	46	1	22	0	1
17.			Ambient	3	46	1	22	0	1
18.			Wet	5	46	0	20	1	2
19.	90%	Before Curing	Dry	7	45	10	23	0	1
20.			Ambient	6	45	5	22	0	1
21.			Wet	5	42	3	17	1	2
22.		After Curing	Dry	7	45	9	22	0	1
23.			Ambient	8	49	6	22	0	1
24.			Wet	7	44	4	19	0	1
Subjective quality categories									
Unacceptable				>9	76-100	>9	>50	>9	>9
Undesirable				6-9	51-75	3-9	25-50	3-9	3-9
Acceptable				3-5	26-50	1-2	11-25	1-2	1-2
Desirable				0-2	0-25	0	<10	0	0

Table 14: Percentage of bulbs infested with thrips for PLK onion bulbs following different harvest, curing, and shipping conditions.

Shipping conditions	Percent top-down at lifting	Time of topping	Field curing conditions	Mean number per bulb: Thrips nymphs	Thrips adults	Thrips mobile stages	Percent bulbs with feeding damage	Percent thrips-infested bulbs
Ambient	25%	Before Curing	Dry	1.16	0.41	1.58	6	25
			Ambient	0.40	0.41	0.81	9	23
			Wet	0.26	0.21	0.48	4	20
		After Curing	Dry	1.99	0.91	2.90	8	39
			Ambient	1.06	0.69	1.75	9	25
			Wet	1.29	0.59	1.88	15	29
	90%	Before Curing	Dry	1.63	0.33	1.95	6	23
			Ambient	0.90	0.49	1.39	14	23
			Wet	1.19	0.54	1.73	18	20
		After Curing	Dry	1.03	0.48	1.50	6	26
			Ambient	0.33	0.18	0.50	5	11
			Wet	2.30	0.86	3.16	11	28
Refrigerated	25%	Before Curing	Dry	0.71	0.16	0.88	0	19
			Ambient	0.23	0.35	0.58	4	15
			Wet	0.50	0.38	0.88	6	19
		After Curing	Dry	0.36	0.25	0.61	4	9
			Ambient	0.26	0.29	0.55	0	14
			Wet	0.33	0.48	0.80	0	16
	90%	Before Curing	Dry	0.21	0.15	0.36	1	11
			Ambient	0.08	0.09	0.16	3	11
			Wet	0.20	0.06	0.26	1	8
		After Curing	Dry	0.13	0.04	0.16	1	6
			Ambient	0.26	0.13	0.39	5	16
			Wet	0.36	0.31	0.68	5	13

Table 15: Overall effect of four storage and harvesting methods on the percentage of PLK bulbs infested with thrips.

Transit conditions	Percent top-down at lifting	Time of topping	Field curing conditions	**Mean number per bulb** Thrips nymphs	Thrips adults	Thrips mobile stages	Percent bulbs with feeding damage	Percent thrips-infested bulbs
Ambient				1.14	0.53	1.7	8.8	25
Refrigerated				0.30	0.23	0.5	2.8	13
	25%			0.71	0.43	1.1	5.4	21
	90%			0.72	0.31	1.0	6.3	16
		After curing		0.62	0.30	0.9	6.0	18
		Before curing		0.81	0.43	1.2	5.7	19
			Wet	0.90	0.34	1.2	4.0	20
			Dry	0.46	0.36	0.8	6.0	18
			Ambient	0.80	0.43	1.2	7.5	19

5 Discussion

The trial demonstrated that the temperature that onions are subjected to after harvest (during shipping/storage) is a very important factor in the development of bulb soft rot. At cooler temperatures (7°C) soft rot develops slowly in infected onions. When infected onions that have been stored at low temperatures are returned to warmer ambient temperatures, bulbs continue to rot more rapidly – ‘minor’ rot in a bulb will become a ‘major’ rot.

Timing of removal of foliage (topping) and the moisture conditions prevailing during the field curing period are also important rot factors. Cutting onion tops at harvest facilitates infection by soft-rotting bacteria, and warm wet conditions during field curing will likely increase the incidence of postharvest rots. Wounding at topping is more common in onions that are not sufficiently field-cured as the necks of these onion bulbs are often not completely sealed (dried). Once bacteria have entered the fleshy tissue of a bulb, deterioration can be very rapid, especially at storage temperatures higher than 25°C.

The effect of temperature during curing and storage on the development of onion skin colour has been well documented and was confirmed by this experiment. Bulbs subjected to temperatures higher than 27°C develop darker colours than those at cooler temperatures. At higher temperatures the concentration of natural pigments in the outer skins of onions is enhanced, resulting in darker bulbs. Although skin colour does not affect storage performance, the intensification of skin colour of cv. PLK to a dark gold or brown is regarded as a desirable characteristic. Bulbs stored at cool temperatures after harvest will 'darken up' when they are returned to warmer temperatures.

Fungal moulds on the surfaces of bulbs in storage develop rapidly if conditions are moist and warm. Bulbs should be dried promptly after harvest and stored in conditions where relative humidity is as low as possible. Good ventilation is important to prevent moisture from condensating on the surfaces of bulbs. Temperatures below 15°C will reduce growth of black mould, and below 6°C will reduce growth of blue mould.

The experiment confirmed earlier work demonstrating that timing of harvest affected skin retention of onions, with later-harvested bulbs having fewer intact outer skins than those harvested earlier. Time of lifting, moisture during field curing and shipping conditions can all affect the incidence of skin splitting. Continuous dry conditions during field curing can result in increased numbers of harvested bulbs with split skins.

Humidity in store is a major factor affecting several bulb quality characteristics including rots, surface moulds, and skin retention. Onions differ from most other horticultural produce in requiring a relative humidity of only 70-75%. Respiring onions give off water vapour and the relative humidity within a mass of bulbs is commonly over 90%. Because the available air at sea is usually moisture-laden, it can be more difficult than on land to achieve and maintain a low enough relative humidity regardless of method and temperature of shipping of onions.

5.1 Thrips

Despite the presence of unsprayed populations of onion thrips on the plants at top-down, the numbers of thrips on bulbs after shipping were low. The low numbers of thrips and the lack of effect of time of lifting, time of topping and field curing conditions is consistent with previous small plot trials at the Pukekohe Research Centre.

The reduction of thrips populations and the numbers of damaged and infested bulbs by refrigerated shipping is consistent with information on the biology of the insect, and confirms the benefits of keeping onions as cool as practical after removing from the field. This includes removing field heat as quickly as possible, keeping onion stores cool and preventing bins at the top of stacks from becoming hotter than the rest.

6 Recommendations

Our general recommendations based on this experiment and on previous research follow.

- Allow onion tops to mature before harvesting.
- Ideally, onion plants should be lifted when fine weather is forecast during the field-curing period.

- Avoid overhead irrigation when the crop is approaching maturity
- The crop should be lifted when onions are at 70-90% top-down.
- It is preferable to lift onion bulbs before all the tops have fallen to encourage drying off without excessive skin loss.
- If onions are lifted too early (before 50% top-down), the foliage will take longer to dry during field-curing, especially if wet weather persists during this time.
- Tops should be allowed to desiccate as much as possible after lifting and before topping.
- Avoid damaging bulbs. Careful handling of onions during harvest, topping, grading and transport will avoid cuts and bruises, reducing entry points for pathogens.
- Store onions only after they have been properly dried.
- Store bulbs in cool temperatures (<20°C) and at relative humidity around 70 to 75% with good ventilation to prevent condensation forming on bulbs.
- Onions that are likely to have postharvest soft rot problems are best shipped in refrigerated conditions. Such onions include those that were field cured in wet conditions – especially if they were topped "green", or are a soft rot susceptible type (e.g. a mild/sweet red).
- Minimising bulb temperatures at all stages following removal from the field, during storage and shipping, will minimise thrips infestation and thrips damage to bulbs.

7 References

Bleasdale, J.K.A.; Thompson, R. 1966: Onion skin colour and keeping quality. *Annual Report on the National Vegetable Research Station, Wellesbourne, UK, for 1965*: 47-49.

Currah, L.; Proctor, F.J. 1990: Onions in tropical regions. Natural resources bulletin No. 35. xiii + 232 p.

Hale, C.N.; Fullerton; R.A.; Wright, P.J. 1992: Onion soft rot. *Commercial Grower 47*: 21-22.

Hoyle, B.J. 1947: Storage breakdown of onions affected by stage of maturity and length of topping. *Proceedings of the American Society for Horticultural Science 50*: 353-360.

Hoyle, B.J. 1948: Onion curing - a comparison of storage losses from artificial, field and non-cured onions. *Proceedings of the American Society for Horticultural Science 52*: 407-414.

Maude, R.B. 1983: Onions. *In*: Dennis, C. *ed*. Post-harvest pathology of fruits and vegetables. London, Academic Press. Pp. 73-101.

Rickard, P.C.; Wickens, R. 1977: The effect of time of harvesting of spring-sown onions on their yield, keeping ability, and skin quality. *Experimental Horticulture 29*: 45-51.

Sanguansri, P.; Sutherland, J. 1991: Artificial curing of onions for Victoria. *Onions Australia 8*: 31.

Steel, R.G.D.; Torrie, J.H. 1980: Principles and procedures of statistics. New York, McGraw-Hill Book Company.

Snowdon, A.L. 1991: Bulbs. Pp. 240-241 in: A colour atlas of post-harvest diseases and disorders of fruits and vegetables. Volume 2. Vegetables. London, Wolfe Scientific Ltd.

Thompson, A.K.; Booth, R.H.; Proctor, F.J. 1972: Onion storage in the tropics. *Tropical Science 14*: 19-34.

Tucker, W.G.; Drew, R.L.K. 1982: Post harvest studies on autumn-drilled onion bulbs. The effect of harvest date, conditioning treatments and field drying on skin quality and on storage performance. *Journal of Horticultural Science 57*: 339-348.

Vaughan, E.K.; Cropsey, M.G.; Hoffman, E.N. 1964. Effects of field-curing practices, artificial drying, and other factors in the control of neck rot in stored onions. *Oregon Agricultural Experiment Station Bulletin No. 77*. 21 p.

Wright, P.J.; Triggs, C.M. 2003: Effects of moisture, leaf removal, and artificial inoculation with soft-rotting bacteria at five different stages of foliage-drying on the incidence of bacterial soft rot of onion (*Allium cepa*) bulbs in storage. For publication in *New Zealand Journal of Crop and Horticultural Science*.

Wright, P.J.; Grant, D.G.; Triggs, C.M. 2001: Effects of onion (*Allium cepa*) plant maturity and method of topping on bulb quality and incidence of rots in storage. *New Zealand Journal of Crop and Horticultural Science 29*: 85-91.

Wright, P.J.; Grant, D.G. 1997: Effects of cultural practices at harvest on quality characteristics of onion bulbs and incidence of rots in storage. *New Zealand Journal of Crop and Horticultural Science 25*: 353-358.

Wright, P.J.; Hale, C.N.; Fullerton, R.A. 1993: Effect of husbandry practices and water applications during field curing on the incidence of bacterial soft rot of onions in store. *New Zealand Journal of Crop and Horticultural Science 21*:161-164.

Wright, P.J. 1993: Effects of nitrogen fertilizer, plant maturity at lifting, and water over field-curing on the incidence of bacterial soft rot of onions in store. *New Zealand Journal of Crop and Horticultural Science 21*: 377-381.