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Manangement and control of onion thrips in export onions during harvesting, storage and shipping

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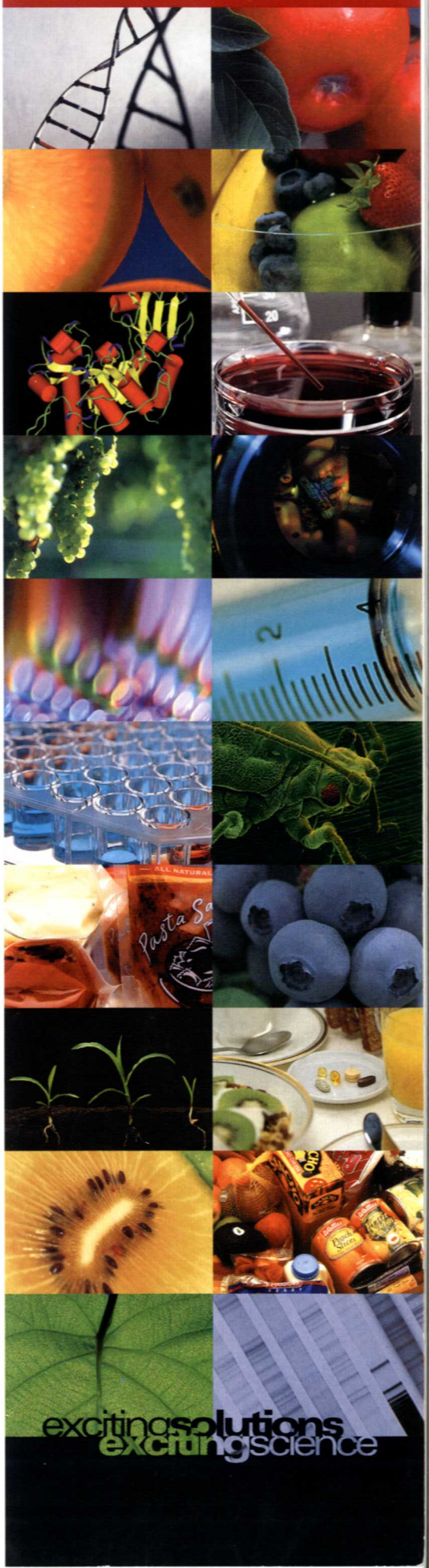

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EXECUTIVE SUMMARY

Management and control of onion thrips in export onions during harvesting, storage and shipping

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HortResearch was contracted by the Onion Exporters Association of New Zealand Ltd to undertake a series of commercial-scale field trials to determine the effect of different harvesting practices on the incidence of onion thrips (*Thrips tabaci*) and black mould (*Aspergillus niger*) both in the field and after storage. The research was carried out as part of a comprehensive study by HortResearch and The New Zealand Institute for Crop and Food Research Ltd (Crop and Food) on the management and control of onion thrips in export onions.

Complementary research on the dynamics of thrips populations in small field plots, survival and damage caused by thrips in bulbs, and disinfestation methods for export onions has been carried out by Crop and Food. Those results are reported separately.

The commercial-scale trials were located on the properties of cooperating growers. Observations were made on onions in two fields, one an early (January) harvested block, the second on a mid-season (March) harvested block. On each property, a range of different topping and harvesting practices was applied. Observations on thrips and black mould incidence were made prior to topping, immediately after topping, between topping and harvesting (removal of onions from the field) and on several occasions during commercial shed storage. Samples of onions were also held under conditions of high temperature and humidity, and conditions simulating a shipping voyage to Europe. The incidence of thrips and black mould was assessed at different times under the different storage conditions and at the end of the simulated shipping voyage.

The principal findings were:

Thrips

- Due to the large variability in thrips distribution and numbers throughout the field sites, and the low replication of treatments (only duplicate plots of each treatment), in most cases it was not possible to demonstrate statistically significant treatment effects either in the field or during storage.
- Onions lifted in the green stage and hand-clipped had the highest infestation of thrips at harvest in the early-season and mid-season crops.
- Onions from the early-season crop, lifted at the green stage and machine topped generally had the lowest infestations of thrips on bulbs both at harvest and in ambient temperature storage. This pattern was not apparent in the mid-season crop where the machine topping onions were left with longer tops providing a source of thrips for later assessments.
- No live thrips were found on bulbs prior to topping in the early-season crop but within one day of topping live thrips had moved onto the bulbs.
- The numbers of thrips in bulbs post-topping was not a reliable indicator of the numbers of thrips in bulbs at harvest.
- At harvest, i.e. when bulbs were removed from the field to storage, up to one third of all thrips found were in the bulb as opposed to in the sheath.
- Onion thrips are able to pupate in the bulb.
- Onion thrips are able to reproduce and increase in numbers in ambient temperature storage.

- There was no indication of an increase in thrips numbers in high-temperature/high relative humidity storage.
- Mortality of onion thrips was higher in high-temperature/high-humidity storage than in ambient temperature storage.
- Onions with windows and split skins were more likely to be infested with thrips.

Black mould

- The recovery of black mould spores from onion plants and bulbs in the field was extremely variable both within and between plots in both the commercial scale trials and the small plot trial.
- The incidence of black mould after storage was also extremely variable in bulbs from all trial sites.
- There was no detectable effect of field handling method on the incidence of black mould on bulbs either before or after storage in any of the trials.
- A high level of bulb infestation in the field occurred from time to time but this was not necessarily reflected in a high mould incidence after storage.
- There was a tendency for a higher proportion of mature bulbs (100% dry at lifting) to have high rates of spore infestation in the mid-season crop than in the early-season crop. It was not possible to determine what factors may have been responsible for that difference.
- The incidence of black mould in storage was significantly increased by prolonged storage under conditions of high temperature and relative humidity. The severity of mould increases with increased time of exposure to these conditions. An increase in black mould incidence could be expected under conditions experienced durig shipping to Europe.
- The lack of a correlation between infestation in the field and incidence of mould in storage suggests that swab assessments of bulbs before storage will not give a reliable indication of predisposition to later mould development.
- Onions with split skins are more likely to develop black mould.

RECOMMENDATIONS

- Lifting at the green stage and hand-clipping onions should not be the preferred topping technique for export onions.
- Crops may be sampled at harvest and categorised as either high or low risk for severe thrips infestation in storage.
- Bulbs with a high risk of severe thrips infestation at harvest should be shipped as soon as possible as thrips numbers can increase in ambient temperature on-shore storage but are unlikely to increase during the higher temperatures experienced during shipping.
- Onions with split skins should be graded out of export lines.
- Audit trails for export onions should be established so that "problem consignments" can be traced back to individual blocks.
- The effect of removal of hand-clipped tops from the field on subsequent numbers of thrips in onion bulbs should be investigated.
- The relationship between numbers of thrips at harvest and the numbers of thrips after ambient temperature storage should be further investigated to establish risk thresholds for thrips infestations in stored and export onions.
- Future work on black mould should focus on monitoring of conditions within bulk stored onions in different kinds of storage facilities to identify commercial storage conditions conducive to black mould.

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BACKGROUND

Onions represent the largest horticultural export crop after apples and kiwifruit. Over 80% of national production is exported with an annual value ranging from $51M to $97M, depending on the buoyancy of the export market in any particular year. The bulk of production is in the Pukekohe district with increasing areas being planted in the Waikato. Waikato production is almost entirely a result of Pukekohe growers relocating their growing operations either to avoid onion white rot or to expand their production areas. Onions are the mainstay of the vegetable industry in Pukekohe. Without onions many of the other vegetable growing enterprises in the district would be uneconomic. Europe is the major market for New Zealand onions.

A high incidence of onion thrips (*Thrips tabaci*) and black mould (caused by the fungus *Aspergillus niger*) in onion consignments arriving in the European markets has caused major problems for exporters in recent years. The feeding activity of onion thrips scores the bulb surface making the onion visually unattractive and causes skin separation, a major cause of rejection by European packers. Shipments containing thrips not only lower the market value quality of the product on arrival but also contravene quarantine regulations of importing countries. Product value can be further downgraded by a high incidence of black mould in the bulbs. In some importing countries (e.g. Germany) black mould is regarded as a human health hazard. There is anecdotal evidence of a linkage between high populations of thrips and a high incidence of black mould.

New Zealand's dominant export market position (against its chief competitor Tasmania) depends on continuing to meet the importer's perceptions and expectations of reliably high quality of bulbs from New Zealand. The confidence of importers has been severely tested in recent seasons because of quality lapses almost entirely due to infestation by thrips and black mould.

High populations of thrips in the field late in the season have been an increasing problem for producers over the past 5 years. Control of thrips accounts for the greatest use of insecticides on onions. Investigations by the onion industry showed that there was widespread resistance by thrips to the insecticides being used. It was concluded that continued undisciplined use of insecticides would ultimately result in the development of resistance to all insecticides available with catastrophic results for onion growers. In an initiative led by the Onion Exporters Association of New Zealand Ltd and supported by the Technology for Business Growth programme of the Foundation for Research, Science and Technology, thrips population thresholds for insecticide application have been established and a strategy of block applications of different insecticides adopted by the majority of growers.

There have been numerous commercial examples of high populations of thrips, both in storage and on export outturn, in onions that had low insect populations in the field prior to harvest. Previous research (Tomkins *et al.* 2000) has confirmed that thrips populations could continue to develop and damage onions in storage and transit despite good field control. The results of that work also indicated that the method of topping, the length of tops left on onions and the period and manner in which the onions dry in the field could have an effect on the subsequent development of the thrips numbers in the bulbs.

It was decided by the onion industry that, in order to ensure product quality, it was necessary to identify those handling practices that would minimise postharvest infestations of thrips. A two-year research programme was planned and was successful in gaining financial support from the Sustainable Farming Fund of the Foundation for Research, Science and Technology.

Much has yet to be learned about the dynamics of thrips populations at harvest time. However, it is known that, due to the mobility of the adult insects, any attempt to evaluate the effects of different handling practices on mature onion has to be done on a reasonably large scale to avoid the effects of insect migration between treatments. For that reason the research protocols involved the application of a range of handling practices to large-scale plots in commercial fields.

The objectives of the first year of the study were:

- To determine the effect of timing and method of topping applied under commercial conditions on the incidence of onion thrips on onion bulbs at harvest and in storage.
- To determine the incidence of black mould in the field and in stored bulbs after the same commercial topping practices.
- To determine the effects of differences in field-handling practices on the incidence of black mould on onions grown under small plot conditions.

The results of the first year of trials are reported here.

METHODS

The effects of several field-handling practices on thrips populations and black mould incidence was determined in two commercial onion crops. Once bulbs were harvested, the effects of several storage regimes (including a simulated shipping regime) on thrips incidence and survival were compared. In addition, the incidence of black mould was monitored on onions in replicated small-plot trials established as part of the Crop and Food component of the overall research programme.

COMMERCIAL-SCALE TRIALS

The fields were chosen to provide two different crop maturity times ("early-season" and "mid-season"). A proposed trial on a third "late-season" crop did not proceed due to the unavailability of a suitable site. The resources intended for that trial were redirected to a more detailed study of thrips populations in bulbs stored for an extended period and also during a simulated shipping trial. Both commercial fields were in the Pukekohe region. Each field was divided into 12 plots, comprising six treatments each replicated twice. The six treatments employed a selection of commercial field-handling practices. They were:

1. Lifted green, unclipped
2. Lifted green, hand-clipped
3. Machine-topped, lifted green
4. Lifted 50% dry, unclipped
5. Machine-topped, lifted 50% dry
6. Lifted 100% dry

Plot sizes were designed to be large enough to allow the use of commercial harvesting and handling equipment. A similar trial layout was used in both trials although plot sizes differed between the sites. The plot layout and dimensions of plots in both trial sites are shown in Appendix 1.

Effect of field-handling practices on incidence of onion thrips and black mould

Onion plants or bulbs for thrips assessments were collected from each plot at five different times during the field-handling process (Table 1). On each occasion a total of 50 plants or bulbs were collected from the field by taking 10 plant or bulbs at random from the central five beds of each plot, approximately midway along the plot. Field sampling plans are shown in Appendix 2. All onions were placed into insect-proof (terylene) bags and stored at 12°C until assessed. All assessments were carried out within three days of collection from the field. Each onion was dissected and individually assessed for: thrips numbers (living and dead); life stage; location on the onion (leaf, sheath (neck), scale, base); presence of "windows" and "split skin". If the top layer of skin was not completely intact, the onion was recorded as having a "window". An onion was recorded as having "split skin" if there was a split in the skin extending more than three layers into the onion. The presence of black mould was also recorded on bulbs used for thrips assessments. Those data are additional to that obtained for onions collected specifically for black mould assessment.

Assessments for the presence of black mould spores on plants and bulbs in the field were made at the same time as onion plants were collected for the pre-topping, post-topping, and harvest assessments of thrips infestations. Swabs were taken from the neck and upper bulb region of each plant in the field to determine the presence of black mould spores. Swabs were prepared by dipping the tip of a standard medical swab into molten Potato Dextrose Agar containing the antibiotics Ampicillin and Rifampicin to inhibit bacterial growth. Swabs were incubated at 35°C[1] for approximately 7 days, then examined for the presence of *A. niger*. Fifty onions were assessed from each plot, comprising five samples of ten onions selected in the same manner as, but additional to, the plants and bulbs sampled for thrips assessments.

Table 1: Collection dates for assessment of onion thrips and black mould incidence between topping and harvest.

Sampling time	Early-season crop			Mid-season crop		
	Green	50% dry	100%dry	Green	50% dry	100%dry
1-2 days prior to topping treatment	05-Jan-01	12-Jan-01	30-Jan-01	12-Jan-01	30-Jan-01	05-Mar-01
1-2 days after topping treatment	12-Jan-01	16-Jan-01	- [1]	16-Jan-01	02-Feb-01	- [1]
7 days post- treatment	15-Jan-01	22-Jan-01	07-Feb-01	22-Jan-01	09-Feb-01	12-Mar-01
At harvest [2]	30-Jan-01	09-Feb-01	05-Mar-01	27-Feb-01	12-Mar-01	19-Mar-01

Top 8 15 31 15 2 5
DAT der 22 25 33

[1] 100% dry plots were not topped therefore no post-treatment samples were collected

Effect of storage regime on incidence of onion thrips and black mould

The changes in thrips and black mould incidence were monitored once onions were removed from the field and stored in bins kept in ambient temperature conditions. Samples for thrips assessments were taken from storage bins by selecting 10 onions at random from each of the four corners and the centre of the storage bin. The storage times and storage conditions are shown in Table 2. The effect of both ambient temperature storage (for 15, 30 and 60 days) and high temperature (HT)/high relative humidity (HRH) (30°C />90% relative humidity) storage (for 30 days only) on thrips incidence were investigated. Also, the effect of a combination of ambient temperature and HT/HRH storage was assessed, where samples of onions were collected from bins stored at ambient temperature for 30 days and transferred to HT/HRH for an additional 30 days. Onions were assessed for thrips and black mould as described above for the evaluation of field-handling practices.

[1] *A. niger* is a high temperature fungus. At 35°C, *A. niger* will grow well but most other microorganisms are inhibited allowing very easy identification of the target fungus.

[2] In this report, the term "harvest" refers to the operation of removing the cured or onions from the field to storage

Table 2: Dates that bulbs were harvested or removed from storage for assessment of onion thrips infestation.

Sampling time	Early-season crop			Mid-season crop		
	Green	50% dry	100%dry	Green	50% dry	100%dry
At harvest	30-Jan-01	09-Feb-01	05-Mar-01	27-Feb-01	12-Mar-01	19-Mar-01
15 days ambient storage	19-Feb-01	26-Feb-01	19-Mar-01	14-Mar-01	27-Mar-01	03-Apr-01
30 days ambient storage	05-Mar-01	13-Mar-01	29-Mar-01	29-Mar-01	11-Apr-01	18-Apr-01
30 days HT/HRH storage	05-Mar-01	13-Mar-01	29-Mar-01	29-Mar-01	11-Apr-01	18-Apr-01
30d ambient + 30d HT/HRH storage	04-Apr-01	12-Apr-01	03-May-01	27-Apr-01	11-May-01	18-May-01
60 days ambient storage	04-Apr-01	12-Apr-01	03-May-01	27-Apr-01	11-May-01	18-May-01

To determine the effect of storage regime on the incidence of black mould, two samples of 100 onions were collected from each plot immediately prior to the planned harvest and placed into standard mesh onion bags. The samples were stored under conditions of HT/HRH for 30 and 60 days at which times the onions were dissected and examined for the presence of black mould. The incidence of black mould was also assessed in samples of onions (n=100 per plot) that had been stored in bins held at ambient temperature for 60 days. Assessment dates are shown in Table 3.

Table 3: Dates that onions harvested or removed from storage for assessment of black mould incidence.

Sampling time	Growth stage Early-season crop			Growth stage Mid-season crop		
	Green	50% dry	100%dry	Green	50% dry	100%dry
At harvest	30-Jan-01	09-Feb-01	05-Mar-01	27-Feb-01	12-Mar-01	19-Mar-01
30 days HT/HRH storage	02-Mar-01	07-Mar-01	12-Mar-01	07-Mar-01	11-Apr-01	18-Apr-01
60 days HT/HRH storage	02-Apr-01	06-Apr-01	11-Apr-01	06-Apr-01	11-May-01	18-May-01
60 days ambient storage[1]	04-Apr-01	12-Apr-01	03-May-01	27-Apr-01	11-May-01	18-May-01

[1] The date onions were removed from 60 days storage at ambient temperature is later than the date onions were removed from 60 days storage at HT/HRH storage because of delays between planned harvest and the actual harvest dates and placement of onions into ambient temperature storage.

Effects of simulated shipping conditions on the incidence of onion thrips and black mould.

A trial to examine effects of a simulated shipping voyage on thrips populations and black mould commenced on 21 March 2001, after the last-harvested treatment (from the mid-season field) had been in ambient temperature storage for 2 days. Fifty onions were collected from each bin of stored onions from each plot to be assessed for thrips assessments (incidence and distribution) after simulated shipping. A further 100 onions from each bin were collected to be assessed for black mould. Samples were taken from stored onions of both of the field trials described above. The temperature and humidity conditions for the simulated shipping voyage are shown in Table 4. The trial was carried out in a constant temperature room with a capability for adjustment of temperature and relative humidity. Adjustments were made by hand on the due date.

Table 4: Temperature and Relative Humidity profiles for simulated shipping conditions

Day	Temperature (°C)	Relative Humidity
0	18-20	75
1-5	20-22	75-85
6-10	22-25	90-95
11-15	25-30	90-95
16-20	30-35	90-95
21-25	35-27	95-75
26-30	27-20	75-70
31-35	20-15	70

At the conclusion of the simulated shipping period, onions were stored at 12°C and assessed within three days. Onions collected for evaluation for thrips incidence were individually examined for thrips numbers, life stage and location on the onion. The presence of windows, split skin, and black mould on onion bulbs was also recorded. Onions collected for black mould monitoring were only assessed for presence of black mould alone.

SMALL PLOT TRIAL

Effect of field-handling practices on incidence of black mould

The small plot trial was located at the Pukekohe Research Station and formed part of the Crop and Food component of the overall programme. The thrips control spray programme at the trial area had been manipulated to provide plots with both high and low populations of thrips. Five field-handling practices were applied to plots, with four replicates for each practice. The layout of the small plot trial is shown in Appendix 3. The treatments were:

1. Lifted green, unclipped
2. Lifted green, hand-clipped
3. Lifted 50% dry, unclipped
4. Lifted 50% dry, hand-clipped
5. Control (neither lifted nor clipped)

Onions were assessed for black mould on three occasions covering the topping and harvesting period, and a further assessment was carried out after 30 days storage at HT/HRH. Dates of collection of onions from the small plot trials are shown in Table 5.

Table 5: Dates onions from small-plot trial collected for assessment of black mould incidence pre harvest and after storage.

Sampling time	Growth stage		
	Green	Control	50% dry
Pre treatment	25-Jan-01	25-Jan-01	05-Feb-01
Post treatment	31-Jan-01	31-Jan-01	09-Feb-01
At harvest	26-Feb-01	26-Feb-01	26-Feb-01
30 days HT/HRH	28-Mar-01	28-Mar-01	28-Mar-01

The incidence of black mould was evaluated by taking swabs from onions in the field immediately prior to topping, after topping and at harvest. Swabs were processed as described for trials with commercial-scale crops. In addition, 30 onions were taken from each plot at harvest, and placed into HT/HRH storage for 30 days. Onions were then examined for the presence of black mould as described for trials with commercial-scale crops.

STATISTICAL ANALYSES

The effects of topping treatments on the number of thrips per 50 onions and the percentage thrips infestation of onions were analysed using ANOVA. All percentages were angular transformed prior to analysis but untransformed percentages are presented in the Tables. Differences between treatments were tested for significance using Fisher's Least Significant Difference (LSD). Results that are not significantly different ($P>0.05$) are indicated by "ns" in the tables. All analysis was carried out using the statistics software SAS (SAS Institute 1985). The data derived from black mould assessments were analysed using the ANOVA function in EXCEL. Where significant treatment effects were indicated, treatments were compared using paired t-tests using MINITAB.

RESULTS AND DISCUSSION

ONION THRIPS

Effect of field-handling practices on incidence of thrips at harvest

Early-season crop. The mean numbers and percentages of live thrips and total thrips (dead and alive) in the early-season crop are shown in Table 6. There were no significant differences either in number of thrips per plant, or in the percentage of infested plants between treatment plots prior to topping despite the 3 week interval between the assessment of green plots and 100% dry plots. When onion plants were assessed 7 days after topping, plots that were lifted when 50% dry and unclipped had significantly higher numbers of thrips than all other treatments. However, the numbers had declined by harvest. Onions that were lifted green and hand-clipped had significantly higher numbers of live thrips per 50 plants and a significantly higher percentage of plants infested with live thrips at harvest. There were no significant differences between the other treatments either in numbers of thrips per 50 plants or percentage of plants infested at harvest.

Mid-season crop. The mean numbers and percentages of live thrips and total thrips (dead and alive) in the mid-season crop are shown in Table 7. The pre-topping assessments (at different stages of crop maturity) indicates that there was a change in thrips numbers in the trial site during the course of the trial. There was a significant increase in thrips numbers in the plots as the plants matured from green tops to 50% dry. The numbers of thrips then declined as the plants approached 100% dry.

There were very low thrips numbers in all green bulbs immediately after lifting and topping. In contrast, onions that had been machine topped at 50% dry had significantly higher thrips numbers immediately after topping than all other treatments. In this particular trial site, the necks of onions that had been machine topped were quite long (15-20 cm) with considerable leaf still present. The high thrips numbers found on those bulbs after topping are a reflection of the long necks and the high pre-topping thrips numbers in those plots. No treatment effects were apparent when bulbs were assessed seven days after topping.

At harvest, bulbs that had been lifted when green and hand-clipped, and bulbs that were harvested untopped at 100% dry, had significantly more thrips per 50 plants and a higher percentage of infested plants than all other treatments. However, there were fewer live thrips in the bulbs harvested at 100% dry when compared with those that had been hand-clipped when green.

Table 6: Effect of field handling practice on the mean number of thrips per 50 fruit (total and live) and mean percentage of onion plants infested with thrips (total and live) between topping and to harvest. Results from early-season crop.

Treatment	Pre-top	At topping	7 days after topping	At harvest
Total number of thrips (dead + alive) /50 onions				
Green, unclipped	20 a[1]	-	17 b	14 a
Green, hand-clipped	23 a	7 a	4 b	43 a
Green, machine topped	24 a	8 a	15 b	6 a
50% dry, unclipped	31 a	-	52 a	12 a
50% dry, machine topped	30 a	12 a	19 b	21 a
100% dry, unclipped	22 a	-	22 b	17 a
Number of live thrips/50 onions				
Green, unclipped	8 a	-	8 b	4 b
Green, hand-clipped	3 a	3 a	1 b	32 a
Green, machine topped	3 a	3 a	7 b	2 b
50% dry, unclipped	6 a	-	39 a	2 b
50% dry, machine topped	14 a	4 a	9 b	10 b
100% dry, unclipped	9 a	-	12 b	4 b
% onions infested with total thrips (dead+alive)				
Green, unclipped	24 a	-	23 ab	17 a
Green, hand-clipped	23 a	11 a	6 c	41 a
Green, machine topped	33 a	11 a	19 b	10 a
50% dry, unclipped	35 a	-	40 a	17 a
50% dry, machine topped	31 a	18 a	21 b	23 a
100% dry, unclipped	20	-	20	22 a
% onions infested with live thrips				
Green, unclipped	8 a	-	12 ab	5 b
Green, hand-clipped	3 a	4 a	2 c	31 a
Green, machine topped	5 a	4 a	9 bc	3 b
50% dry, unclipped	12 a	-	26 a	2 b
50% dry, machine topped	14 a	5 a	11 b	12 ab
100% dry, unclipped	7 a	-	9 bc	7 b

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

Table 7: Effect of field-handling practice on the mean number of thrips per 50 fruit (total and live) and mean percentage of onion plants infested with thrips (total and live) between topping and to harvest. Results from mid-season crop.

Treatment	Pre-top	At topping	7 days after topping	At harvest
Total number of thrips (dead + alive) /50 onions				
Green, unclipped	59 b[1]		89 a	3 b
Green, hand-clipped	46 b	9 b	27 a	20 a
Green, machine topped	46 b	43 b	46 a	4 b
50% dry, unclipped	172 a	-	72 a	4 b
50% dry, machine topped	230 a	97 a	24 a	5 b
100% dry, unclipped	9 b	-	11 a	20 a
Number of live thrips/50 onions				
Green, unclipped	8 b		53 a	1 b
Green, hand-clipped	6 b	3 b	21 a	9 a
Green, machine topped	8 b	14 b	23 a	2 b
50% dry, unclipped	120 a	-	53 a	1 b
50% dry, machine topped	169 a	70 a	14 a	0 b
100% dry, unclipped	4 b	-	2 a	2 b
% onions infested with total thrips (dead+alive)				
Green, unclipped	54 ab		62 a	6 b
Green, hand-clipped	48 ab	14 a	25 b	23 a
Green, machine topped	44 ab	46 a	42 b	7 b
50% dry, unclipped	71 ab	-	35 b	6 b
50% dry, machine topped	76 a	54 a	26 b	7 b
100% dry, unclipped	10 c	-	10 c	15 a
% onions infested with live thrips				
Green, unclipped	13 b		39 a	2 a
Green, hand-clipped	11 b	5 a	19 ab	13 a
Green, machine topped	12 b	21 a	30 ab	3 a
50% dry, unclipped	56 a	-	27 ab	2 a
50% dry, machine topped	70 a	50 a	16 bc	0 a
100% dry, unclipped	4 b	-	3 c	3 a

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

Effect of field-handling practices on location, life stages and mortality of thrips

The location of the thrips on the onion plants (i.e. whether on leaves, sheath or bulb) and the life-stages identified at each field sampling time are shown in Tables 8 and 9. The Tables are derived from the pooled data for all treatments and replicates, and provide an indication of when the thrips move into the bulb and whether they are able to pupate and reproduce (indicated by the presence of larvae and pupae).

Very few thrips were found in the onion bulbs prior to topping. The majority of thrips found on onion plants in the field up until harvest were found in the sheath. This reflects the tendency of this species to hide in enclosed spaces, a behaviour known as "thigmotaxis" (Salas 1994). There was a progressive increase in the proportion of thrips found in the bulbs between topping and harvest in both early-season and mid-season crops. Between 4 - 8% live thrips were found in the bulbs seven days after topping and this increased to 34 - 68% at harvest.

Although there was an apparent migration of thrips into bulbs during field-curing, there was a higher rate of mortality in the bulbs (69% and 75% for the early-season and mid-season crops respectively) than in the sheaths (47% and 59% for the early-season and mid-season crops respectively).

The majority of the thrips found at all sampling times were adults. However, larvae and pupae were also present.

Table 8: Total numbers of thrips, their distribution in different plant parts and the proportion of different life stages on onions from the early-season crop.

	Pre-top	7 days after topping	At harvest
Total thrips (dead + alive)			
Total number	297	254	224
Location			
% at leaves	30	15	1
% at sheath	69	75	68
% at bulb	1	10	31
Lifestage			
% at adult stage	87	80	85
% at pupal stage	4	7	5
% at larval stage	9	13	9
Live thrips			
Total number	81	148	105
Location			
% at leaves	23	20	-
% at sheath	77	76	64
% at bulb	0	4	36
Lifestage			
% at adult stage	72	70	79
% at pupal stage	9	9	9
% at larval stage	20	21	12

Table 9: : Total numbers of thrips, their distribution in different plant parts and the proportion of different life stages on onions from the mid-season crop.

	Pre-top	7 days after topping	At harvest
Total thrips (dead + alive)			
Total number	1127	538	116
Location			
% at leaves	13	9	-
% at sheath	84	84	32
% at bulb	2	8	68
Lifestage			
% at adult stage	82	74	77
% at pupal stage	5	13	5
% at larval stage	13	12	18
Live thrips			
Total number	630	330	28
Location			
% at leaves	12	11	-
% at sheath	86	84	64
% at bulb	1	5	36
Lifestage			
% at adult stage	73	64	71
% at pupal stage	5	18	11
% at larval stage	22	18	18

Effect of storage regime on the incidence of thrips

Early-season crop. The numbers of thrips found on onions, and the proportion of onions infested, after storage for different times and under different conditions are shown in Tables 10 and 11 respectively. There were significantly higher numbers of live thrips and a significantly higher proportion of infested bulbs at harvest in plots of the early-season crop that were lifted and hand-clipped when green than in plots of all other treatments. Onions from the green, hand-clipped plots continued to have the highest total numbers (dead + alive) of thrips throughout the different storage times and regimes. Infestation (total thrips numbers) of green hand-clipped onions stored under ambient temperature conditions ranged from 63% to 78%. Onions that had been machine-topped when green, or when 50% dry had low thrips numbers, both at harvest and throughout storage with only 3-35% of onions being infested. Number of thrips on onions lifted when 100% dry tended to be high after 30 and 60 days ambient temperature storage. However, values were not significantly different from other treatments.

Mid-season crop. The numbers of thrips found on onions, and the proportion of onions infested, after storage for different times and under different conditions are shown in Tables 12 and 13 respectively. Bulbs from the mid-season crop had consistently lower total numbers (dead + alive) of thrips at the different assessment times and regimes compared with those from the early-season crop. Onions from plots treated with the field-handling practices that resulted in the most thrips at harvest (green hand-clipped and 100% dry unclipped) also tended to have the most thrips after 15 and 30 days ambient temperature storage.

Table 10: Numbers of thrips per 50 plants at harvest and after storage for different times and under different conditions. Early-season crop

Treatment	At harvest (no storage)	15 days ambient storage	30 days ambient storage	60 days ambient storage	30 days HT/HRH storage	30 days ambient + 30 days HT/HRH storage	Simulated shipping regime
Total number of thrips (dead + alive)							
Green, unclipped	14 a	25 b	42 b	104 abc	7 b	25 c	54 b
Green, hand-clipped	43 a	320 a	381 a	190 a	61 a	205 a	211 a
Green, machine topped	6 a	30 b	31 b	31 c	2 b	16 c	5 b
50% dry, unclipped	12 a	14 b	25 b	42 bc	4 b	20 c	21 b
50% dry, machine topped	21 a	16 b	25 b	11 c	12 b	30 bc	14 b
100% dry, unclipped	17 a	29 b	182 b	152 ab	17 b	78 a	25 b
Number of live thrips							
Green, unclipped	4 b	16 b	21 a	68 a	1 b	2 a	1 a
Green, hand-clipped	32 a	200 a	84 a	18 bc	12 a	2 a	6 a
Green, machine topped	2 b	19 b	8 a	5 c	1 b	3 a	0 a
50% dry, unclipped	2 b	8 b	13 a	17 bc	0 b	2 a	0 a
50% dry, machine topped	10 b	11 b	14 a	0 c	3 b	0 a	0 a
100% dry, unclipped	4 b	16 b	71 a	34 b	3 b	7 a	1 a

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

Table 11: Percentage of bulbs infested by thrips at harvest and after storage for different times and under different conditions. Early-season crop

Treatment	At harvest (no storage)	15 days ambient storage	30 days ambient storage	60 days ambient storage	30 days HT/HRH storage	30 days ambient + 30 days HT/HRH storage	Shipping regime
Percentage of bulbs with thrips (dead + alive)							
Green, unclipped	17 a	21 b	33 bc	48 ab	6 bc	26 a	33 b
Green, hand-clipped	41 a	78 a	77 a	63 a	39 a	62 a	58 a
Green, machine topped	10 a	20 b	24 c	17 cd	3 c	9 a	6 d
50% dry, unclipped	17 a	12 b	24 c	35 bc	6 bc	18 a	21 bc
50% dry, machine topped	23 a	15 b	19 c	10 d	11 bc	35 a	11 cd
100% dry, unclipped	22 a	31 b	67 ab	53 ab	17 b	38 a	21 bc
Percentage of bulbs with live thrips							
Green, unclipped	5 b	19 b	18 ab	43 a	2 b	4 a[1]	1 a
Green, hand-clipped	31 a	72 a	52 a	21 ab	18 a	3 a	2 a
Green, machine topped	3 b	16 b	6 b	4c d	1 b	4 a	0 a
50% dry, unclipped	2 b	11 b	10 b	18 bc	0 b	3 a	0 a
50% dry, machine topped	12 ab	10 b	13 b	0 d	2 b	0 a	0 a
100% dry, unclipped	7 b	18 b	49 a	29 ab	5 ab	9 a	1 a

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

Table 12: Numbers of thrips per 50 plants at harvest and after storage for different times and under different conditions. Mid-season crop

Treatment	At harvest	15 days ambient storage	30 days ambient storage	60 days ambient storage	30 days HT/HRH storage	30 days ambient + 30 days HT/HRH storage	Shipping regime
Total number of thrips (dead + alive)							
Green, unclipped	3 b	9 a	16 c	8 a	3 a	1 a	2 a
Green, hand-clipped	20 a	94 a	56 b	47 a	36 a	48 a	34 a
Green, machine topped	4 b	10 a	19 bc	21 a	1 a	1 a	3 a
50% dry, unclipped	4 b	7 a	7 c	9 a	9 a	5 a	1 a
50% dry, machine topped	5 b	5 a	8 c	45 a	2 a	72 a	5 a
100% dry, unclipped	20 a	83 a	108 a	45 a	9 a	35 a	3 a
Number of live thrips							
Green, unclipped	1 b	1 b	2 c	0 a	0	1 a	0 a
Green, hand-clipped	9 a	13 b	11 b	1 a	0	1 a	1 a
Green, machine topped	2 b	3 b	7 bc	12 a	0	0 a	1 a
50% dry, unclipped	1 b	3 b	2 c	1 a	0	0 a	0 a
50% dry, machine topped	0 b	3 b	5 bc	35 a	0	12 a	0 a
100% dry, unclipped	2 b	32 a	19 a	2 a	0	1 a	0 a

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

Table 13: : Percentage of bulbs infested by thrips at harvest and after storage for different times and under different conditions. Mid-season field

Treatment	At harvest	15 days ambient storage	30 days ambient storage	60 days ambient storage	30 days HT/HRH storage	30 days ambient + 30 days HT/HRH storage	Shipping regime
Percentage of bulbs with thrips (dead + alive)							
Green, unclipped	6 b	8 b	11 c	5 a	4 a	1 b	3 a
Green, hand-clipped	23 a	36 a	31 a	22 a	18 a	26 a	22 a
Green, machine topped	7 b	13 ab	16 bc	21 a	1 a	1 b	5 a
50% dry, unclipped	6 b	7 b	8 c	7 a	11 a	4 b	2 a
50% dry, machine topped	7 b	6 b	10 c	16 a	3 a	22 a	6 a
100% dry, unclipped	15	36 a	29 ab	22 a	12 a	22 a	3 a
Percentage of bulbs with live thrips							
Green, unclipped	2 a	2 a	1 a	0 a	0	1 a	0 a
Green, hand-clipped	13 a	14 a	9 a	2 a	0	1 a	1 a
Green, machine topped	3 a	5 a	9 a	12 a	0	0 a	1 a
50% dry, unclipped	2 a	4 a	3 a	1 a	0	0 a	0 a
50% dry, machine topped	0 a	6 a	7 a	16 a	0	8 a	0 a
100% dry, unclipped	3 a	16 a	8 a	3 a	0	2 a	0 a

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

Effect of storage regime on location and life stage of thrips

The location of the thrips on the bulbs (i.e. whether on leaves, sheath or bulb) and the life-stages identified at each sampling time for onions stored for diferent times and under different conditions are shown in Tables 14 and 15, for the early-season and mid-season crops respectively,

Thrips were found in both bulbs and sheaths after storage. There was no evidence that storage regime affected the location of thrips during storage. Most of the live thrips found in the field and after ambient temperature storage were adults (64-89%). The tendency to find a higher proportion of adults in the onion thrips population is due to the fact that onion thrips spend the longest proportion of their lives as adults (22 days as adults at 32°C compared to 2 days as pupae and 3 days as larvae) (Salas 1994). Overall, onions (from both trials) that had been stored under ambient temperature conditions had higher total thrips numbers than onions stored under conditions HT/HRH. There was a higher proportion of live thrips found as pupae after the HT/HRH storage (both regimes) than the proportion found as pupae in the field. The pupal stage is barely mobile, moving only when disturbed, and does not tend to feed (Salas 1994). The decrease in the proportion of adults (the most mobile phase), together with the low total recovery (both dead and alive) from bulbs in the HT/HRH storage regimes suggests that, in the early-season crop, the adult thrips may have left the onions in search of more favourable conditions. Unfortunately, because of the low numbers of live thrips recovered from onions from the mid-season crop (both after the 30 day HT/HRH storage, and after the simulated shipping trial), the migration of adult thrips out of the stored onions could not be confirmed.

Table 14: Total numbers of thrips, their distribution in different plant parts and the proportion of different life stages on bulbs after storage. Early-season crop.

	At harvest	15 days ambient storage	30 days ambient storage	60 days ambient storage	30 days HT storage	30 days ambient + 30 days HT/ HRH storage	Shipping regime
	Total thrips (dead + alive)						
Total number	224	902	1431	1269	234	762	669
Location							
% at leaves	1	-	-	-	-	-	-
% at sheath	68	58	29	40	29	34	65
% at bulb	31	42	71	60	71	66	35
Lifestage							
% at adult stage	85	85	90	92	82	88	89
% at pupal stage	5	6	6	7	11	11	11
% at larval stage	9	10	4	1	6	1	0
	Live thrips						
Total number	105	538	417	281	29	30	13
Location							
% at leaves		-	-	-	-	-	-
% at sheath	64	58	35	46	23	53	92
% at bulb	36	42	65	54	77	47	8
Lifestage							
% at adult stage	79	79	80	87	44	33	0
% at pupal stage	9	6	13	10	26	67	100
% at larval stage	12	15	7	3	31	3	0

Table 15: Total numbers of thrips, their distribution in different plant parts and the proportion of different life stages on bulbs after storage. Mid-season crop.

	At harvest	15 days ambient storage	30 days ambient storage	60 days ambient storage	30 days HT/ HRH storage	30 days ambient + 30 days HT/ HRH storage	Shipping regime
	Total thrips (dead + alive)						
Total number	116	486	437	421	117	342	96
Location							
% at leaves	-	-	-	-	-	-	-
% at sheath	32	38	42	28	19	28	44
% at bulb	68	62	58	72	81	75	56
Lifestage							
% at adult stage	77	89	90	89	98	62	95
% at pupal stage	5	8	9	10	2	32	4
% at larval stage	18	3	1	1	0	1	1
	Live thrips						
Total number	28	107	87	101	0	27	2
Location							
% at leaves	-	-	-	-	-	-	-
% at sheath	64	30	56	41	0	15	0
% at bulb	36	70	44	59	0	85	100
Lifestage							
% at adult stage	71	83	89	87	0	26	100
% at pupal stage	11	12	9	11	0	74	0
% at larval stage	18	5	2	2	0	0	0

Effect of storage regime on thrips mortality

The average numbers of thrips per 50 onions and the % mortality of thrips on onions under the different storage regimes (results from all field-handling practices combined) for both trials are shown in Table 16.

In the early-season crop, the numbers of live thrips per 50 onions increased dramatically during the first 15 days in ambient temperature storage then gradually declined up to 60 days. After 60 days ambient temperature storage the number of live thrips per 50 onions was still higher than at harvest. There was high mortality of thrips after 30 HT/HRH, the 30 day ambient temperature + 30 days HT/HRH, and the simulated shipping storage regimes. Low total thrips numbers (dead + alive) combined with high mortality rates resulted in low numbers of live thrips being present on onions after the various HT/HRH storage regimes.

In the mid-season crop there was a similar increase in the number of live thrips per 50 onions between during the first 15 days storage at ambient temperature. However, the increase was not as large as seen on onions from the early-season crop. As with onions from the early-season crop, the recovery of live thrips after the HT/HRH storage regimes was low and the percent mortality was high.

Both trials confirmed that onion thrips can reproduce and increase in numbers in onions in ambient temperature storage. However, onion thrips are apparently unable to reproduce successfully (or even to survive) under conditions of HT/HRH.

Table 16: Number of thrips and percent mortality on onions after different storage regimes

Storage regime	Total thrips (dead+alive) /50 onions	No. live thrips/50 onions	% mortality
Early-season crop			
At harvest	19 c[1]	9 d	53 d
15 days ambient	76 b	45 a	40 d
30 days ambient	119 a	35 b	71 c
60 days ambient	106 a	24 c	78 bc
30 days HT/HRH	20 c	4 d	84 b
30 days ambient + 30 d HT/HRH	64 b	3 d	96 a
Shipping regime	56 b	1 d	99 a
Mid-season crop			
At harvest	10 a	3 ab	76 d
15 days ambient	41 a	9 a	78 d
30 days ambient	37 a	7 a	81 d
60 days ambient	36 a	9 a	77 d
30 days HT/HRH	10 a	0 b	100 a
30 days ambient + 30 d HT/HRH	29 a	3 ab	93 c
Shipping regime	8 a	0 b	98 b

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

Effect of skin defects on incidence of thrips and black mould

The percentage of onion bulbs from each field-handling practice treatment that had skin defects (windows in the skin and split skin) is shown in Table 17. A slightly lower percentage of onions with windows was recorded in onions from the early-season crop that were lifted when green and unclipped compared to onions treated with other topping regimes. Split skins were more common on onions from the early-season crop that had been lifted when 100% dry. This trend was not as evident in onions from the mid-season crop although onions from the lifted green plots tended to have a lower percentage with split skins.

Table 17: Mean percentage of onions from each field-handling practice treatment with skin defects.

Topping treatment	Mean % of onions with windows	Mean of % onions with split skins
Early-season crop		
Lifted green, unclipped	87 b[1]	2 b
Lifted green, hand-clipped	95 a	1 b
Lifted green, machine topped	95 a	1 b
Lifted 50% dry, unclipped	96 a	3 b
Lifted 50% dry, machine topped	94 a	2 b
Lifted 100% dry, unclipped	93 a	13 a
Mid-season crop		
Lifted green, unclipped	93 a	1 bc
Lifted green, hand-clipped	90 a	0 c
Lifted green, machine topped	94 a	1 bc
Lifted 50% dry, unclipped	89 a	3 ab
Lifted 50% dry, machine topped	91 a	8 a
Lifted 100% dry, unclipped	96 a	8 a

[1]Values within a cell followed by the same letter are not significantly different (P>0.05)

The percentage of onions with skin defects and the relationship between these defects and the incidence of thrips and black mould are shown in Table 18. Skin defects and incidence of black mould were routinely recorded as bulbs were examined for thrips. These onions thus represent additional data to those collected specifically for black mould assessments.

Table 18: The percentage of bulbs with skin defects and the relationship between skin defects and incidence of thrips and black mould

	Early-season crop	Mid-season crop
Window in skins		
% bulbs with window	93	92
Of bulbs with window, % with thrips	19	9
Of bulbs with no window, % with thrips	7	5
Of bulbs with window, % with black mould	5	4
Of bulbs with no window, % with black mould	9	6
Split skins		
% bulbs with split skins	4	3
Of bulbs with split, % with thrips	40	42
Of bulbs with no split, % with thrips	18	8
Of bulbs with split, % with black mould	16	5
Of bulbs with no split, % with black mould	5	4

The key relationships between skin defects and the incidence of thrips and black mould were:

- Onions from the early-season crop with windows had higher thrips infestation (19% infested) than onions without windows (7% infested).
- Onions from the early-season crop with split skins were more likely to develop black mould (16% infected) than onions without split skins (5% infected).
- Onions from both sites with split skins were more likely to be infested with thrips (40-42% infested) than onions without split skins (8-18% infested).

Conclusions

The design of the commercial scale trials needed to be big enough to implement different commercial topping treatments and to allow sufficient buffering between treatment plots to reduce the effects of insect migration after treatment. This limited the trial design to only 2 replicates of the 6 topping treatments. As a result of a high degree of variability in thrips numbers throughout the field sites, and the low replication (duplicate plots only) few significant treatment effects could be detected either between field-handling methods or between storage regimes. However, those differences that were detected will be of commercial significance. Principal conclusions are:

1. Onions lifted at the green stage and hand-clipped had the highest infestation of thrips at harvest in both the early-season and mid-season crops.
2. Onions from the early-season crop, lifted at the green stage and machine-topped generally had the lowest infestation of thrips at harvest and in ambient temperature storage.
3. This pattern was not apparent at the mid-season crop where the machine topping onions were left with longer tops that were able to sustain thrips populations after topping.
4. No live thrips were found on bulbs of onions prior to topping in the early-season crop. Within 1 day of topping live thrips had moved onto the bulbs.
5. At harvest, up to one third of all thrips found were in the bulb in the sheath.
6. Onion thrips are able to pupate in the bulb and are able to reproduce and increase in numbers in ambient temperature storage.
7. There was no indication of an increase of thrips numbers in high-temperature/high-humidity storage.
8. Mortality of onion thrips was higher in HT/HRH storage than in ambient temperature storage.
9. Onions with window and split skins are more likely to be infested with thrips and onions with split skins are more likely to develop black mould.

BLACK MOULD

Commercial field trials

The incidence of black mould detected in onions in the field by swab tests, and incidence of mould on onion samples held in storage are shown in Tables 19 and 20 for the early and mid-season trials respectively. There were duplicate plots of each treatment in each field. The individual results from each pair of plots for each treatment are shown in the table (rather than the more commonly used average) to demonstrate the extreme variability of the results even between plots of the same treatment.

Swab tests of onions at different times in the field are a measure of the occurrence of black mould spores on the surface of the onion prior to storage. Incidence of mould after storage at HT/HRH, or after simulated shipping conditions, is a measure of how the disease may be expected to develop in storage or shipping.

Early-season crop

The incidence of black mould overall was relatively low varying from 0-42% in swab tests and 0-42% in bulb infections across the whole trial. There was no consistency between the paired plots of the same treatment either in swab tests or bulb infections.

Effect of topping regime. Because of the low rates of infestation of bulbs both in the field and in storage, and the extreme variability of results across all plots and treatments, no statistically significant differences could be detected between treatments, either in swab tests or in bulb infection. Any differences observed between data in the tables could just as likely have been the result of chance e.g. natural variations in distribution of the fungus in the field. In some plots e.g. plots 5 and 9, there was a relatively high proportion of bulbs in the field carrying mould spores. This did not consistently correlate with high proportion of bulbs showing mould after storage.

Effect of field-sampling time. When results were averaged across all treatments for each field sampling time (each swab timing) it was found that there was a significant difference in incidence of mould spores on bulbs between the pre-lift and post-lifting sampling. Significantly more bulbs were carrying mould spores after lifting. This is attriubuted to the disturbance of lifting which would result in bulbs becoming contaminated with spores and other debris. In this particular trial, there was no significant difference in spore contamination of bulbs between lifting and harvesting.

Effect of storage regime. Storage of onions under conditions of high temperature and humidity increased the proportion of bulbs with black mould. The incidence of black mould increased with increasing time at high temperature and high relative humidity with maximum numbers of bulbs affected after 60 days. Numbers of diseased bulbs at 30 days at HT/HRH and after simulated shipping were higher than when bulbs were stored at ambient temperature for 60 days. However because of high variability of mould incidence throught out the data, the differences were not statistically significant.

Mid-season crop.

Effect of topping regime. The only trend evident in the data is for a higher incidence of bulbs carrying spores in the latest harvested treatment (100% dry machine topped). Although high variability within the total data set prevented the demonstration of any statistically significant treatment effect, it may be reasonably expected that onions left in the field for an extended period before harvest may be carrying higher spore loads of the mould fungus. However, the high incidence of spores on those bulbs was not reflected in a high incidence of mould in storage, even after 60 days at high temperature and humidity.

Effect of field-sampling time. When averaged across all treatments, there was a greater proportion of bulbs infested with spores at harvest time (after a curing period in the field) than before or after lifting. The difference was statistically significant. There was no difference in numbers of infested bulbs before and after lifting.

Effect of storage regime. As in the early-season crop, there was an increase in the proportion of mould-affected bulbs with increasing storage timeHT/HRH. Only the difference between the proportion of mould-affected bulbs after 60 days ambient temperature storage and that at 60 days at HT/HRH was statistically significant.

Table 19: Percentage of onion bulbs with black mould spores in the field and percentage of onions with black mould after storage. Early-season crop, Pukekohe 2001.

		Percentage of swabs with black mould (n=50 per plot)			Percentage of bulbs with black mould after storage (n=100 per plot)			
Plot	Treatment	Pre-lift	Post-lift	Harvest	30d HT/HRH	60d HT/HRH	60d ambient	Shipping
1	Lifted green unclipped	4	12	28	0	5	0	5
2	Lifted green unclipped	0	2	0	0	5	0	2
3	Lifted green hand-clipped	0	24	10	25	21	0	11
4	Lifted green hand-clipped	0	2	8	5	3	0	2
5	Green machine topped	0	42	26	2	10	1	6
6	Green machine topped	4	24	4	0	1	0	0
7	50% dry unclipped	2	14	2	0	1	0	2
8	50% dry unclipped	4	8	6	0	0	0	0
9	50% dry machine topped	8	40	26	5	3	1	3
10	50% dry machine topped	2	12	10	4	7	0	0
11	100% dry machine topped	4	-	4	7	15	2	15
12	100% dry machine topped	2	-	4	2	11	1	3
	Mean	2.5%	18.0%	10.7%	4.2%	6.8%	0.4%	4.1%
		a	b	ab	ab	a	b	ab

Means accompanied by the same letter are not significantly different (P > 0.05)

Table 20: Percentage of onion bulbs with black mould spores in the field and percentage of onions with black mould after storage. Mid-season crop. Pukekohe 2001.

		Percentage of bulbs with black mould spores (n=50 per plot)			Percentage of bulbs with black mould after storage (n=100 per plot)			
Plot	Treatment	Pre-lift	Post-top	Harvest	30d HT/HRH	60d HT/HRH	60d ambient	Shipping
1	Lifted green unclipped	4	0	4	2	12	1	1
2	Lifted green unclipped	14	0	30	6	23	2	3
3	Lifted green hand-clipped	4	8	16	13	11	4	6
4	Lifted green hand-clipped	18	0	52	18	27	4	12
5	Green machine topped	0	0	6	0	0	1	1
6	Green machine topped	2	0	6	8	15	1	7
7	50% dry unclipped	0	0	54	1	4	1	0
8	50% dry unclipped	14	8	58	0	4	0	5
9	50% dry machine topped	14	20	40	1	13	0	2
10	50% dry machine topped	0	8	40	0	0	0	1
11	100% dry machine topped	30	42	64	6	5	0	2
12	100% dry machine topped	40	36	88	2	12	1	4
	Mean	11.7%	10.2%	38.2%	4.8%	10.5%	1.3%	3.7%
		a	a	b	ab	a	b	b

Means accompanied by the same letter are not significantly different ($P < 0.05$)

Small Plot trial

The percentage of swabs with black mould at different handling times and percentage of bulbs with black mould after 30 days at HT/HRH are shown in Table 21.

Table 21: Percentage of onion bulbs with black mould spores in the field and percentage of onions with black mould after storage in a crop harvested mid-season. Small plot trial. Pukekohe Research Station 2001.

Treatment	Replicate	Pre-lift (%)	Post-lift (%)	Harvest (%)	Bulbs with BM (%)
(n=30 for all tests)					
Control (Not lifted not topped)	1	3.3	13.3	10.0	13.3
Control (Not lifted not topped)	2	6.7	3.3	3.3	10.0
Control (Not lifted not topped)	3	10.0	0.0	0.0	0.0
Control (Not lifted not topped)	4	13.3	0.0	0.0	0.0
Lifted 50% dry and topped	1	3.3	16.7	0.0	23.3
Lifted 50% dry and topped	2	6.7	3.3	6.7	0.0
Lifted 50% dry and topped	3	10.0	10.0	3.3	0.0
Lifted 50% dry and topped	4	13.3	0.0	3.3	6.7
Lifted 50% dry, not topped	1	3.3	13.3	0.0	36.7
Lifted 50% dry, not topped	2	6.7	10.0	0.0	13.3
Lifted 50% dry, not topped	3	10.0	0.0	3.3	0.0
Lifted 50% dry, not topped	4	13.3	0.0	6.7	10.0
Lifted green and topped	1	3.3	3.3	26.7	3.3
Lifted green and topped	2	6.7	3.3	3.3	13.3
Lifted green and topped	3	10.0	3.3	3.3	0.0
Lifted green and topped	4	13.3	0.0	6.7	0.0
Lifted green, not topped	1	3.3	6.7	23.3	13.3
Lifted green, not topped	2	6.7	0.0	3.3	16.7
Lifted green, not topped	3	10.0	3.3	3.3	3.3
Lifted green, not topped	4	13.3	0.0	0.0	6.7
	Mean	8.3	4.5	5.3	8.5

As in the commercial trials the results both for recovery of spores (as positive swab tests) and as mould-affected bulbs after storage were very variable. Swab recoveries varied from 0% to approximately 27%. Bulb infection varied from 0% to approximately 27%. There was no relationship between either handling method and incidence of mould spores on bulbs or between incidence of mould spores on bulbs and incidence of mould in storage.

Conclusions

1. The design of the trials (with very low replication of treatments) was inadequate to provide a valid test of the effect of harvest regime on the incidence of prestorage bulb infestation, or the incidence of mould in storage. There was inadequate replication of treatments to overcome the extreme variability found both in the field and in storage. Nevertheless, if there was going to be a "commercially significant" effect of any particular harvest regime on the incidence of mould in stored bulbs it could have been expected to show up in these trials. The results suggests it is unlikely that field-handling methods over harvest have a large influence on the incidence of black mould in stored onions.

2 In some crops there may be a tendency for an increase in spore contamination of bulbs after field-curing but this may not necessarily translate into a mould problem after storage at high temperature and humidity.

3. Storage of onions at high temperatures and humidities can promote the development of black mould. The effect increases with increased storage time at those conditions. Thus,an increase in incidence of black mould can be expected during prolonged shed storage under hot ambient temperature conditions and also during shipping.

4. Overall, there was a higher incidence of spore-infested onions in the mid-season harvested crop than in the early-season crop. Because only one field was monitored for each harvest time it is not known whether the differences are due to the timing of the harvest, to differences between the localities, or to other factors such as management practices, previous cropping regimes etc.

5. The variability of incidence of mould spores throughout commercial fields, and the lack of correlation between infestation in the field and incidence of mould in storage suggests that swabbing before storage will not give a reliable indication of a predisposition to later mould development.

RECOMMENDATIONS

In order to obtain a better understanding of factors contributing to high numbers of thrips and rates of black mould in storage emphasis should be given to:

- Lifting at the green stage and hand-clipping onions should not be the preferred topping technique for export onions.
- Crops may be sampled at harvest and categorised as either high or low risk for severe thrips infestation in storage.
- Bulbs with a high risk of severe thrips infestation at harvest should be shipped as soon as possible as thrips numbers can increase in ambient temperature on-shore storage but are unlikely to increase during the higher temperatures experienced during shipping.
- Onions with split skins should be graded out of export lines.
- Audit trails for export onions should be established so that "problem consignments" can be traced back to individual blocks.
- The effect of removal of hand-clipped tops from the field on subsequent numbers of thrips in onion bulbs should be investigated.
- The relationship between numbers of thrips at harvest and the numbers of thrips after ambient temperature storage should be further investigated to establish risk thresholds for thrips infestations in stored and export onions.
- Future work on black mould should focus on monitoring of conditions within bulk stored onions in different kinds of storage facilities to identify commercial storage conditions conducive to black mould.

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The authors, and the onion industry, are indebted to Wallace Fulton and Howe Young for their cooperation, patience and support in allowing the field trials to be conducted on their properties. We are well aware of the inconvience caused to growers by participating in trials of this scale. We would like to thank Natalie Page, Doug Fielding and Kirsten Anderson for their excellent technical assistance. Thanks also to Richard Wood, John Thacker and Pam Strange for their assistance in planning and co-ordinating the field operations.

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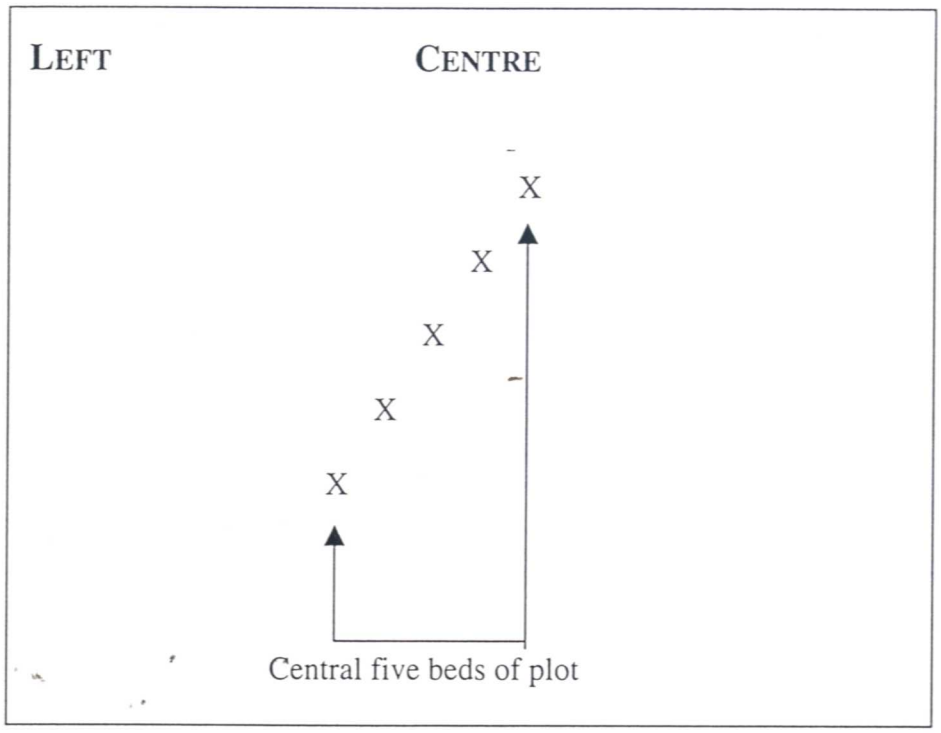
Appendix 1. Plot layout for commercial trial sites

Plot 3 Lifted green Hand-clipped Rep 1	Plot 6 Lifted green Machine topped Rep 1	Plot 9 Lifted 100% dry Rep2	Plot 12 Lifted green Unclipped Rep2
Plot 2 Lifted green Unclipped Rep 1	Plot 5 Machine topped Lifted 50% dry Rep 1	Plot 8 Lifted 50% dry Unclipped Rep 2	Plot 11 Lifted green Hand-clipped Rep2
Plot 1 Lifted 50% dry Unclipped Rep 1	Plot 4 Lifted 100% dry Rep1	Plot 7 Lifted green Machine topped Rep 2	Plot 10 Machine topped Lifted 50% dry Rep 2

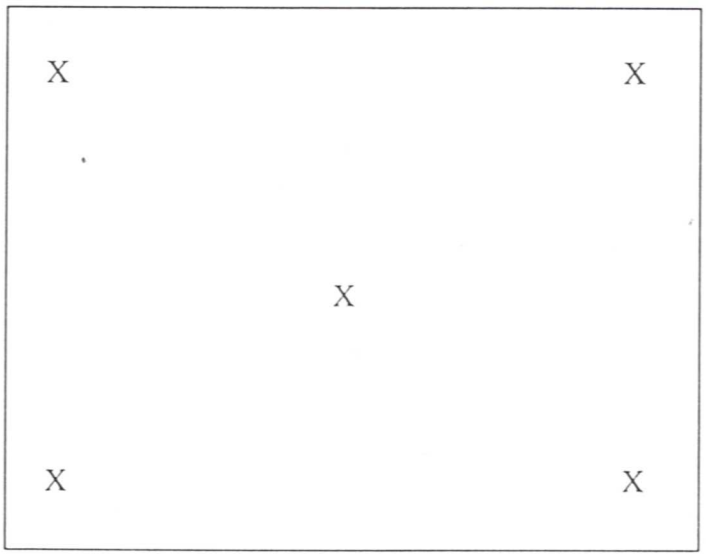
Left **Onion field** Right

Early-season crop: Plots 22 beds wide by approximately 50m long
Mid-season crop: Plots 11 beds wide by approximately 50m long

Appendix 2. Field and bin sampling plans



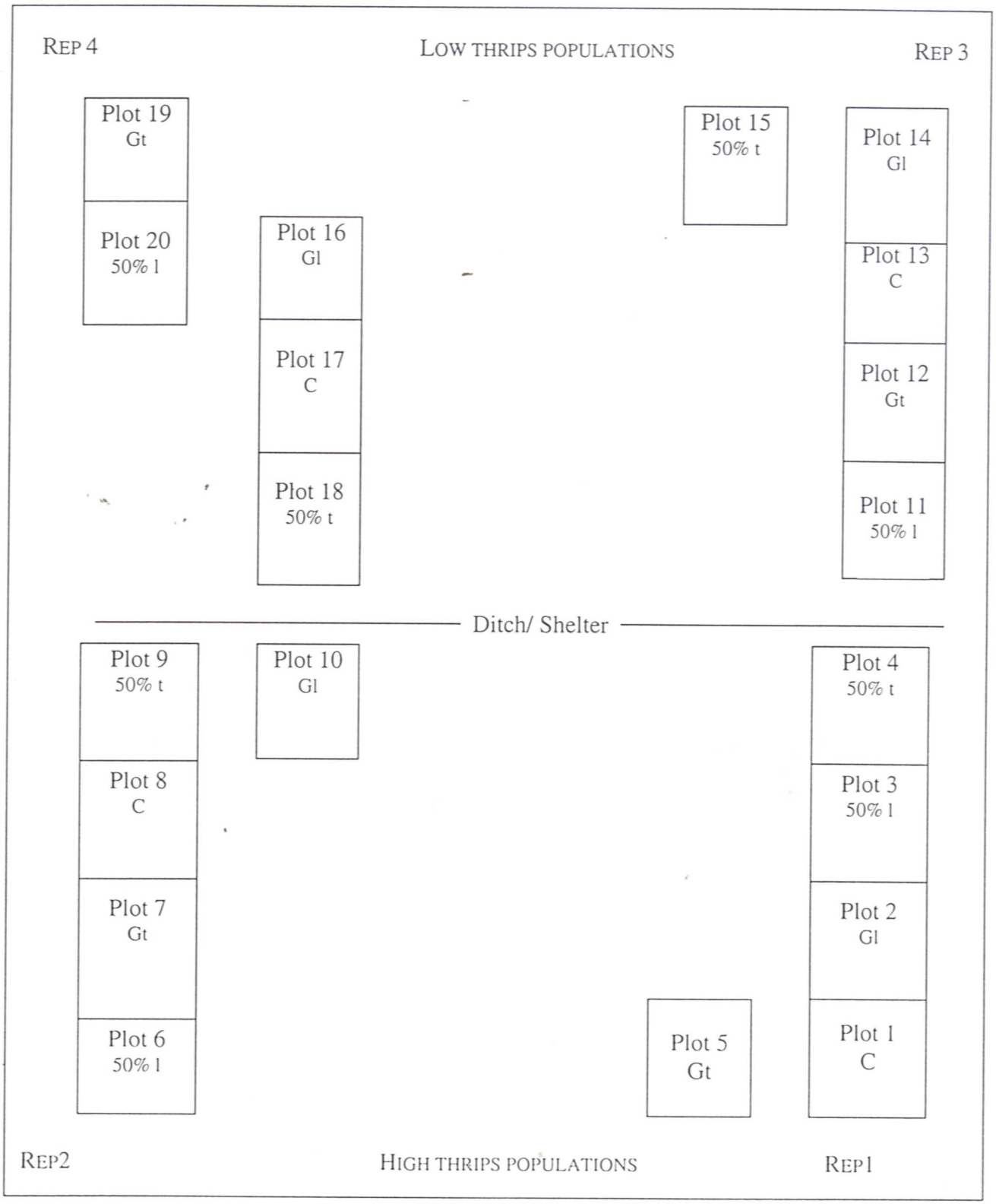
Individual onion plot



Onion storage bin

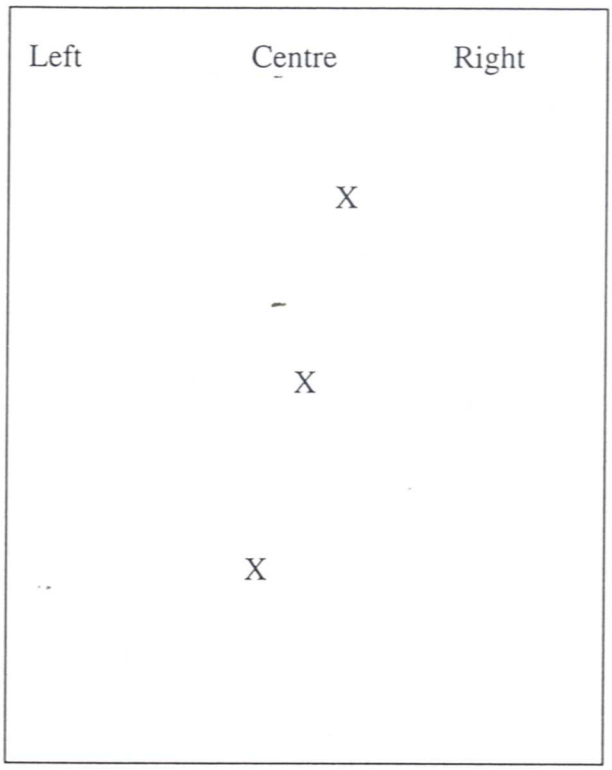
Where X Sample of 10 onions

Appendix 3. Plot layout for small plot trial



WHERE	50% T	LIFTED 50% DRY AND HAND-CLIPPED
	50% l	Lifted 50% dry and not clipped
	Gl	Lifted green and not clipped
	Gt	Lifted green and hand-clipped
	C	Control (Not lifted or clipped)

Appendix 4. Sampling plan for small plot trial



Individual plot

Where X A sample of 10 onions