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A new bioassay for determining the susceptibility of onion (*Allium cepa*) bulbs to onion thrips, *Thrips tabaci* (Thysanoptera: Thripidae)

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Abstract A series of experiments was conducted to develop a bioassay for determining the susceptibility of *Allium* plants to adult female onion thrips. Onion thrips (*Thrips tabaci* (Thysanoptera: Thripidae)) are the main insect pest on onions in New Zealand. This research aimed to develop better methods for determining the susceptibility of *Allium* species leaves and onion bulbs to onion thrips. Discs, 10 mm diam., cut from leek (*Allium porrum*) and onion (*Allium cepa*) leaves or onion bulbs, were put singly into small plastic Petri dishes with 1-day-old adult female thrips, and kept at 25°C in 16 h light : 8 h dark. After 3 days the discs were stained in acid fuchsin and the eggs counted using a stereo microscope with transmitted light. Adult thrips survived equally well on leek leaves and onion bulb scale, but laid more eggs per day on onion leaves than on leek leaves and least on onion bulbs. Thrips laid fewer eggs per day when there was more than one thrips per dish. Changing discs daily or leaving them for 3 days had no effect on the numbers of eggs laid by thrips each day. Four cultivars of onions were grown with 50, 100, 150, and 200 kg nitrogen (N) fertiliser per ha. The susceptibility of bulbs to onion thrips feeding and damage from the highest and lowest N treatments was compared. Analysis of the proportion of discs with more than one egg showed that cultivar 'Kiwigold' (early brown) was more susceptible than 'Meteor' (early red), and 'M&R Regular' (main crop brown) was more susceptible than 'Red Star' (main crop red) to onion thrips. The proportion of discs with more than three eggs was higher for brown onions in the high N treatment than in the low N treatment, suggesting that brown onions from the high N treatment were more susceptible. After 5 months in storage, red onions were softer and had more sprouts than brown onions, and their innermost skins and the outermost scales had more thrips damage. This apparent increase in susceptibility of red onions may be related to changes in the physiology of the outer scale as it shrinks to become a skin. The bioassays confirmed that both genetic (cultivar) and agronomic (N fertiliser) factors affect the susceptibility of onion bulbs to onion thrips.

Keywords plant resistance; onion thrips; *Thrips tabaci*; bioassays

INTRODUCTION

Onion thrips (*Thrips tabaci* Lindeman (Thysanoptera: Thripidae)) are the main plant-damaging herbivores of onions (*Allium cepa* L.) in New Zealand. Uncontrolled infestations can reach more than 300 insects per plant (N. A. Martin unpubl. data), causing loss of green leaf tissue and yield (Edelson et al. 1989). Onion thrips feed on exposed live scales on onion bulbs, and enter the bulbs through the necks where they feed and breed on live bulb scales (N. A. Martin unpubl. data). Feeding damage in bulbs lowers bulb quality and value for export, and has been an important issue for New Zealand onion exporters since 1997 (Wood 2001).

Research on resistance in onion plants to onion thrips has a long history, from Jones et al. (1934) to Bocak (1995). Two forms of resistance have been identified. The first is the growth form of the plant. Cultivars with open growth and leaves that are circular in cross-section are more resistant than plants with upright leaves that are flatter in cross-section at their base (Jones et al. 1934; Coudriet et al. 1979). More recent research suggests that there is an association between the waxes on leaves and

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resistance to onion thrips in garlic and onions. Plants with glossy leaves and less wax are more resistant to onion thrips than are plants with high levels of wax on the leaf surface (Molenaar 1984; Bocak 1995; Oliveira et al. 1996).

Two factors affect the susceptibility of onion bulbs to onion thrips: bulb structure, which affects the access of thrips to live fleshy scales; and the biochemical quality of the fleshy scales, which affects the ability of thrips to feed and breed. The structural aspects include the presence of splits in the onion skins, which expose live flesh to thrips, and the openness of bulb necks, which allow thrips access to the fleshy scales. Intact skins and tight bulb necks are desirable characters for a high quality onion, but are not adequately achieved to prevent onion thrips causing a problem of bulb quality.

Recent research in New Zealand has not found any strong correlations between numbers of thrips on plants before harvest and on bulbs in onion stores (Wood 2001). No research on differences in susceptibility of onion bulbs to onion thrips has been reported. There are reports that bulbs of some cultivars, e.g., red onions, are more susceptible to onion thrips (Callaghan pers. comm.) and that agronomic factors such as fertiliser could alter the susceptibility of bulbs to onion thrips. These field observations are supported by laboratory observations that where onion thrips have access to fleshy bulb scales, the ability of onion thrips to develop and breed is variable (Martin pers. comm.).

This paper describes the development of a bioassay for determining the susceptibility of bulbs of two cultivars of red onion and two cultivars of brown onion grown with four rates of nitrogen (N) fertiliser to onion thrips feeding and damage. Because the newly eclosed female contains no fully developed eggs and appears to need to feed to develop eggs, the number of eggs laid in a given time on onion bulb tissue was used as a key indicator of nutritional quality of the substrate and hence bulb susceptibility to onion thrips feeding and damage.

MATERIALS AND METHODS

Onion thrips for the bioassays

Thrips were collected from onions in Pukekohe, South Auckland, New Zealand, in February 2000. The rearing method was developed by A. Loomans (pers. comm.). About 100 adult female thrips were added to screw-top glass Agee jars (500 ml capacity) containing tubular segments of leek (*Allium porrum*) leaves and a paper tissue. The jars were covered by paper tissues that were each held in place by a metal lid and screw band. Humidity in the jars was controlled by altering the size of a hole in the metal lid or not using a metal lid. The jars were held at 25°C in 16 h light : 8 h dark. New leek leaf segments were added every 2–3 days and rotting pieces removed. Several days before adult eclosion, all leek material with adult and larval thrips was removed from each jar so that only the pupal stages were present in and under the tissue paper.

Thrips age and oviposition in leek leaves, red onions bulbs, and brown onion bulbs

Discs, 10 mm diam., were cut from leek leaves (white sheath tissue of the fourth layer from the outside) and the second fleshy scale of brown onions ('May & Ryan Regular Pukekohe Long Keeper' (PLK) grown at Pukekohe Research Centre) and red onions (cultivar not known). One disc and a 1-day-old adult female thrips were put on filter paper in small plastic Petri dishes with tight-fitting lids (50 mm diam. and 9 mm high). Water, 1 ml, was added to prevent desiccation, especially of the leek leaf disc. The dishes were kept at 25°C in 16 h light : 8 h dark. Every 24 h discs were replaced, dead thrips recorded and 1-day-old discs were stained in acid fuchsin (0.2% acid fuchsin in 70% ethanol and glacial acetic acid (1:1)) for 20–24 h. The disc was then placed in a clearing solution (distilled water, 99% glycerine, and 85% lactic acid (1:1:1)) for 1–2 days. The numbers of eggs per disc were counted using a stereo microscope with transmitted light. The experiment continued for 17 days. Twenty-five dishes were initially set up for each substrate type.

Number of thrips per disc

Using the same basic method, an experiment was conducted to study the effect of population density, source of substrate, presence of males, and whether the substrate was changed regularly or not. The following conditions were tested:

One female per dish, 10 mm disc of leaf, changed daily over 3 days (25 dishes);

One female per dish, 10 mm disc of PLK bulb, changed daily over 3 days (25 dishes);

Five females per dish, 10 mm disc of leaf, changed daily over 3 days (5 dishes);

Five females per dish, 10 mm disc of PLK bulb, changed daily over 3 days (5 dishes);

Five females per dish, 10 mm disc of leaf, unchanged over 3 days (5 dishes);

Five females per dish, 10 mm disc of PLK bulb, unchanged over 3 days (5 dishes);

Five male and five females per dish, 10 mm disc of leaf, unchanged over 3 days (5 dishes);

Five male and five females per dish, 10 mm disc of PLK bulb, unchanged over 3 days (5 dishes).

The trial was repeated once.

Oviposition by thrips on onion leaves and onion bulbs

One female thrips was added to a dish with one 10 mm disc of either a red or PLK onion leaf or bulb tissue, or leek leaf. There were 10 dishes per treatment and an additional 10 dishes with five female thrips per leek leaf disc. The discs were changed after days 1 and 2. After processing, eggs were counted. The experiment was repeated with five (instead of one) female thrips in the onion bulb dishes.

Cultivar-N fertiliser field trial

Four cultivars were sown, two early onions, 'Kiwigold' (brown) and 'Meteor' (red), and two main crop onions, 'May & Ryan Regular' (PLK, brown) and 'Red Star' (red), in adjacent blocks of four beds (1.6 m wide, 60 m long). Each bed was divided into four plots (15 m long), giving 16 plots per cultivar. Plots were allocated to four N rates (50, 100, 150, and 200 kg/ha) and there were four replicates in a Latin square design. The same Latin square was used for each cultivar. N (urea) was applied at the flag leaf stage, 2–3rd true leaf, 6–8 true leaf, and 10 true leaves. All cultivars were sown on 20 July 2003 at Pukekohe Research Centre, South Auckland and the N treatments were applied on 29 August, 8 October, 27 November, and 22 December. For the bioassays reported in this paper bulbs were used from only the 50 and 200 kg/ha N treatments. Bulb quality after 5 months of storage was assessed from all N treatments.

The plants received normal fungicide and insecticide applications as per commercial practice. Bulbs were harvested from the central rows of the plots. The bulbs for the bioassays were harvested on 3 February 2004 (early crop) and 2 March 2004 (main crop). Bulbs from all plots were harvested on 10 March 2004, kept in brown paper bags and stored in a well ventilated, dry room at ambient temperature. Bulbs were not treated with a sprouting inhibitor.

Bioassay of bulbs from the field trial

One-day-old female onion thrips were left to feed and lay eggs in a disc of onion bulb tissue for 3 days using the methods described above. The discs were stained and the number of eggs laid counted. In each bioassay we used onion bulbs from two N treatments, 50 kg/ha and 200 kg/ha, and only bulbs from two plots per treatment. We also compared the consistency of data from each bulb by testing each half of the bulb on two consecutive days so that up to 20 discs per onion were assessed in each bioassay. After the second set of discs was taken, the rest of each bulb was frozen so that it was available for chemical analysis. Bioassays on early crop onions were conducted between 4 and 26 February 2004 and on main crop onions between 3 and 26 March 2004.

Onion bulb quality after storage

In August 2004, after 5 months of storage, the physical properties of and damage caused by thrips on up to 10 bulbs per plot were examined of the four cultivars from the four N treatments. The following features of each bulb were recorded: number of skins, number of intact skins, extent of thrips damage on the innermost skin (proportion of skin affected estimated to the nearest 5%), extent of thrips damage on the outermost fleshy scale (proportion of scale affected estimated to the nearest 5%), presence of live thrips (larvae and adults recorded separately), external sprouting (score of 1 <50 mm, 2 = 50–150 mm, 3 = >150 mm), internal sprouting (scores of 1 (least), 2 and 3 (leaves reaching neck)), firmness of bulb (two measurements per bulb using an Imada penetrometer, pressure (kg of force) when the top of the cone tip was level with the surface of bulb). Thrips feeding damage to the sprouting green leaves was not assessed.

Data analysis

All data analysis was performed using Genstat (Version 7, 2004, VSN International Ltd, Hemel Hempstead, United Kingdom).

In the initial trial, daily mortality rates on leeks, red or PLK onions were compared using logistic regression, with the number alive at the start of the day as the numerator.

In the "number of thrips per dish" trial, the number of eggs per thrips was log-transformed to stabilise variance and an Analysis of Variance (weighted by the number of female thrips per dish) performed. A similar approach was taken with the onion bulbs and leaves trial, except that because the data were unbalanced, a mixed effects model was fitted using Genstat's REML procedure.

The bioassay data from the field trial was analysed separately for the early and main crop onions. The

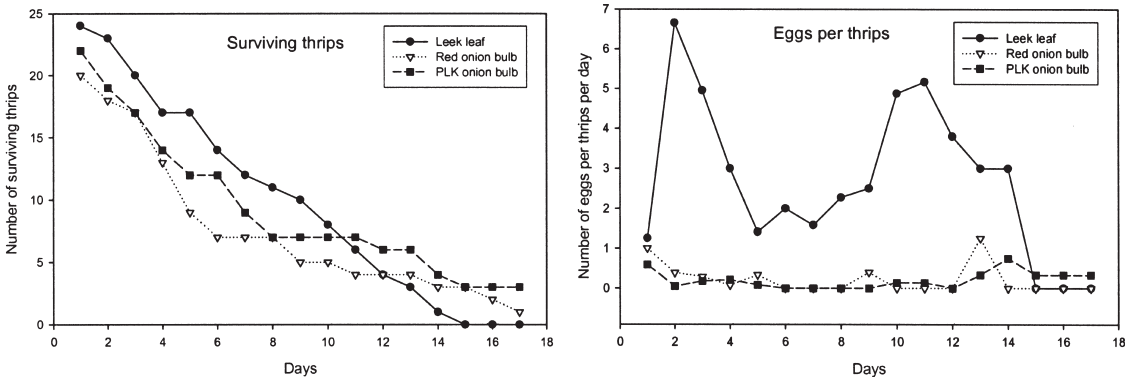

Fig. 1 Numbers of live thrips (*Thrips tabaci*) out of 25 over 17 days and numbers of eggs per day per live thrips when 1-day-old female thrips were reared on leek (*Allium porrum*) leaves or onion (*Allium cepa*) bulb scales.

proportions of discs with no eggs, more than one egg, and more than three eggs were compared using logistic regression.

For the storage trial, the effects of N were tested on each cultivar using ANOVA. Comparisons between cultivars were made using mixed models, fitted using Genstat's REML procedure. Some measures were log-transformed to stabilise the variance.

RESULTS

Thrips age and oviposition on leek leaves, red onion bulbs, and brown onion bulbs

Mortality of the adult female thrips was similar on leek leaves and brown and red onion bulb tissue, but the thrips laid more eggs per day on discs of leek leaves than onion bulb tissue ($P < 0.001$, based on a randomisation test) (Fig. 1). A high number of eggs was laid during the first 3 days (Fig. 1) so subsequent experiments were run for 3 days.

Number of thrips per disc

More eggs were laid per thrips on leek leaf discs than onion bulb disc (F ratio = 59.2, 1, 7 d.f., $P < 0.001$). The number of eggs laid per female thrips was significantly higher with 1 female per dish than with five, and lower still if there were males present (F ratio = 8.3, 3, 7 d.f., $P = 0.010$). The pattern is similar for leeks and PLK (Interaction F ratio = 2.6, 3, 7 d.f., $P = 0.133$). The pattern over time varied significantly depending on plant material and population (F ratio for Day main effect = 103.9, 2, 231 d.f., $P < 0.001$; F ratio for Treatment*Plant*Day interaction = 26.0, 7, 231 d.f., $P < 0.001$). Single thrips on leeks lay more eggs on days 2 and 3; multiple thrips on leeks lay more eggs on day 2 than day 1, and yet more on day 3; single thrips on onion bulbs lay similar numbers over the 3 days; multiple thrips on onions lay more eggs on day 2 than days 1 or 3 (Table 1).

Oviposition of thrips on onion leaves and onion bulbs

Onion thrips laid more eggs on onion leaves than leek leaves or onion bulbs (Wald statistic = 476.8, 4 d.f., $P < 0.001$), with fewest on onion bulb tissue discs (Table 2). Fewer eggs were laid per thrips per day when five thrips were in a dish than one thrips per dish (Wald statistic = 94.2, 1 d.f., $P = 0.005$). The population density effect was more marked on onion bulbs than leeks (interaction Wald statistic = 18.8, 2 d.f., $P < 0.001$).

There are significance differences over the 3 days of the experiment, but these depend on the plant material and density (Wald statistic for Day effect = 51.6, 2 d.f., $P < 0.001$; Wald statistic for Material-by-Density-by-Day interaction = 31.3, 14 d.f., $P = 0.005$); numbers of eggs laid per day are fairly constant on bulbs; on leeks they are higher on days 2 and 3 than day 1; whereas onion leaves show a similar, but less marked, pattern.

Bioassay of bulbs from the cultivar-N fertiliser field trial

Brown onions, 'Kiwigold' and 'M&R Regular', are more susceptible to onion thrips than the red onions, 'Meteor' and 'Red Star' (Table 3). High N (200 kg/ha) treatments resulted in more eggs being laid in bulbs than in bulbs from the low N (50 kg/ha) treatment.

When comparing the proportion of discs with no eggs, 'Kiwigold' (52%) was more susceptible than 'Meteor' (72%) (Deviance ratio = 17.8, 1 d.f., $P < 0.001$), and 'M&R Regular' (50%) was more susceptible than 'Red Star' (60%) (Deviance ratio = 4.9, 1 d.f., $P = 0.031$). In the early crop onions, the high N (200 kg/ha) onions were more susceptible than the low N treated bulbs (58% and 68%, respectively; Deviance ratio = 4.5, 1 d.f., $P = 0.037$). There were no significant cultivar-by-N rate interactions in either crop.

The proportion of discs with more than one egg also differed between cultivars. There were also considerable differences in susceptibility of bulbs between early crop onions fertilised with different amounts of N. 'Kiwigold' was again more susceptible than 'Meteor' (Deviance ratio = 12.7, 1 df , $P < 0.001$), and 'M&R Regular' was more susceptible than 'Red Star' (Deviance ratio = 5.6, 1 d.f., $P = 0.021$) (Table 4). For the early onions, the bulbs from the high N were more susceptible than low N (Deviance ratio = 4.6, 1 d.f., $P = 0.037$). 'Kiwigold'

Table 1 Number of eggs laid per female thrips (*Thrips tabaci*) per day on leek (*Allium porrum*) leaf or onion (*Allium cepa*) ('Pukekohe Long Keeper' (PLK)) bulb discs when 1 female, 5 female, or 5 female and 5 male thrips were present. Discs were either changed daily or left for 3 days.

		Discs changed daily		Disc not changed	
Plant	Day	1 thrips/dish	5 thrips/dish	5 thrips	5 female + 5 male
Leek	1	0.82	0.18		
	2	2.53	1.42		
	3	2.77	2.23		
	Av.*	1.79	0.82	1.38	0.81
PLK	1	0.70	0.15		
	2	0.76	0.39		
	3	0.65	0.14		
	Av. *	0.70	0.20	0.20	0.05

Least Significant Ratio
Between Averages 313% (two means are significantly different if the larger is more than 313% of the smaller)
Between treatments on daily basis 316%
Within treatments on daily basis 135%

*Calculated on log scale; corresponds to geometric mean.

Table 2 Mean number of eggs laid per thrips (*Thrips tabaci*) per day in discs of onion (*Allium cepa*) (red or 'Pukekohe Long Keeper' (PLK)) leaves or bulb tissue or leek (*Allium porrum*) leaves.

	Day	Red, leaves	PLK, leaves	Red, bulb	PLK, bulb	Leek
1 thrips per dish	1	3.37	1.74	0.66	0.50	0.94
	2	5.65	6.48	0.74	0.57	2.23
	3	4.89	6.01	0.66	0.71	2.98
	Mean	4.53	4.08	0.68	0.59	1.84
5 thrips per dish	1			0.12	0.14	0.71
	2			0.16	0.12	1.33
	3			0.19	0.19	1.23
	Mean			0.15	0.15	1.05

Least Significant Ratio between means
166% for 1 thrips per dish versus 1 thrips per dish
135% for 5 thrips per dish versus 5 thrips per dish
151% for 1 thrips per dish versus 5 thrips per dish
Least Significant Ratio within treatments
182% for onion leaves
225% for 1 thrips per dish onion bulbs
151% for 5 thrips per dish onion bulbs
182% for 1 thrips per dish leeks
132% for 5 thrips per dish leeks

was more susceptible than 'Meteor' in both low and high N treatments (interaction Deviance ratio = 0.7, 1 d.f., $P = 0.404$) (Table 4).

The comparison of the proportion of discs with more than three eggs also shows differences between the cultivars and between N treatments. 'Kiwigold' was more susceptible than 'Meteor' (Deviance ratio = 17.5, 1 d.f., $P < 0.001$) and 'M&R Regular' more susceptible than 'Red Star' (Deviance ratio = 5.1, 1 d.f., $P = 0.028$). Higher N levels tend to make onions more susceptible (Deviance ratio = 4.4, $P = 0.040$ for early crop; deviance ratio = 4.9, $P = 0.030$ for main crop), although there is a suggestion that this varies between cultivars in the early crop (interaction deviance ratio = 2.6, 1 d.f., $P = 0.110$) (Table 5).

Onion bulb quality after storage

In general, N had no effect on the number of skins or intact skins, with the exception of 'Meteor', where higher levels of N produced fewer total skins (F ratio = 12.5, 3, 6 d.f., $P = 0.005$). The two early crop cultivars had fewer skins than the main crop onions (Wald statistic = 8.9, 3 d.f., $P < 0.001$) (Table 6). The number of intact skins differed significantly between

Table 3 Mean number of eggs found in discs of onion (*Allium cepa*) bulb flesh after 3 days of feeding by one adult female thrips (*Thrips tabaci*) on early crop cultivars ('Kiwigold' (brown) and 'Meteor' (red)), and main crop cultivars ('M&R Regular' (brown) and 'Red Star' (red)). The two nitrogen (N) treatments were 50 kg per ha and 200 kg per ha.

	Early crop				Main crop			
Cultivar:	Kiwigold		Meteor		M&R Regular		Red Star	
N treatment (kg/ha)	50	200	50	200	50	200	50	200
Mean number of eggs	0.85	1.45	0.45	0.58	1.12	1.91	0.84	1.02

Table 4 Percentage of onion (*Allium cepa*) bulb discs with more than one egg.

	Early crop				Main crop			
Cultivar:	Kiwigold		Meteor		M&R Regular		Red Star	
Nitrogen treatment (kg/ha)	50	200	50	200	50	200	50	200
Percentage of discs	21	34	12	15	32	37	23	25
95% confidence limits	14, 30	26, 45	7, 20	10, 24	24, 42	28, 47	16, 32	18, 35

Table 5 Percentage of onion (*Allium cepa*) bulb discs with more than three eggs.

	Early crop				Main crop			
Cultivar:	Kiwigold		Meteor		M&R Regular		Red Star	
Nitrogen treatment (kg/ha)	50	200	50	200	50	200	50	200
Percentage of discs	6	14	3	2	9	19	6	9
95% confidence limits	3, 11	10, 21	1, 7	1, 6	5, 16	13, 28	3, 12	5, 16

Table 6 Mean number of skins (total and intact) in four cultivars of onion (*Allium cepa*) bulbs after 5 months of storage.

	Early crop		Main crop		
Cultivar:	Kiwigold	Meteor	M&R Regular	Red Star	
Colour:	Brown	Red	Brown	Red	LSD or LSR*
No. skins	3.5	3.7	4.2	4.1	0.33
No. intact*	0.20	0.24	0.65	0.36	162%*

*Back transformed means, use LSR (least significant ratio) to compare means.

Table 7 Thrips (*Thrips tabaci*) damage to innermost skin and onion (*Allium cepa*) bulb firmness after 5 months of storage.

	Early crop		Main crop		
Cultivar:	Kiwigold	Meteor	M&R Regular	Red Star	
Colour:	Brown	Red	Brown	Red	LSD or LSR*
Proportion of innermost skin with thrips damage*	4.3%	24.4%	5.1%	29.9%	196%*
Proportion of outermost scale with thrips damage	9.7%	13.5%	7.6%	16.1%	5.50
Relative size of external sprouts†	0.156	2.681	0.006	1.313	0.288
Onion firmness (kg of force)	56.9	35.2	56.1	42.2	4.63

*Back transformed means, use LSR (least significant ratio) to compare means.
†External sprouts were scored for size: 1 <50 mm, 2 = 50–150 mm, 3 = >150 mm.

cultivars (Wald statistic = 9.9, 3 d.f., $P < 0.001$), with 'M&R Regular' having the highest number, and the early cultivars having significantly fewer than the main crop cultivars (Table 6).

The N treatments had no significant effect on the proportion of damage to either the innermost skin or outermost scale. The red cultivars had more thrips damage to both innermost skin and outer scale than the two brown cultivars (for inner skin Wald statistic = 3.9, 3d.f., $P = 0.009$; for outer scale, Wald statistic = 18.5, 3 d.f., $P < 0.001$; Table 7). The two red cultivars had a higher proportion of bulbs with external sprouts ('Meteor', 0.99; 'Red Star', 0.63) and larger sprouts than the brown onions ('Kiwigold', 0.06; 'M&R Regular', 0.01) (Table 7). The red onions were also softer than the brown onions (Wald statistic = 42.2, 3 d.f., $P < 0.001$, Table 7).

DISCUSSION

Onion thrips lay most eggs within the first 3–4 days of adulthood on favoured and non-favoured substrates (Fig. 1). When confined to a small arena with a small disc of plant tissue, the presence of more than one thrips in a dish resulted in fewer eggs being laid per adult female (Table 1). Leaving the discs of plant tissue for 3 days or changing the discs daily did not affect egg laying (Table 1; unpubl. data). Although onion leaves were a more favoured substrate than leek leaves (Table 2), they tended to dry out more quickly so leek leaves appear to be more suitable for use in the bioassays. For this reason, leek leaves were used as a standard. There were no consistent differences between the age of the leek leaf and whether green of white leaf tissue was used (unpubl. data), but for these bioassays the white tissue on the fourth leaf from the outside was used. Similarly the onion bulb discs were always taken from the same layer (second fleshy scale from the outside). Using this information, we designed a bioassay to compare the susceptibility of onion bulbs to onion thrips.

Biometric analysis was used to compare the mean number of eggs laid per thrips and the proportion of discs with different numbers of eggs. The latter variable was a useful method for discriminating between tissue susceptibility in these onion disc bioassays.

The genetic variability of onion thrips collected from host plants is determined to some extent by the host plants (Brunner et al. 2004). The thrips used

for these bioassays were collected from onions and male thrips were initially common in the culture. The response of thrips in bioassays is variable and the vigour of the 1-day-old females may be affected by variations in humidity in the rearing jars. Variability in response within a treatment in a bioassay could be because of variability in the insect or plant.

The bioassay demonstrated that genetic and agronomic factors affect the susceptibility of onion bulbs to thrips. This means that it is possible to reduce the risk of thrips damage to onion bulbs by selecting cultivars with high resistance and by growing onions that are less susceptible to thrips. However, changes in the onions during storage also appear to be important. In our trials, red onions were more resistant than brown onions, but after 5 months in storage red onions had more thrips damage. The softening and shrinking of the red onions provided thrips with access to onion scales on which they could feed. It is also possible that when the outermost scale shrinks in the process of becoming a dry skin, nutrients within the scale are mobilised, making the tissue more favourable for thrips feeding and breeding. To test this idea it would be useful to compare the susceptibility of the outer two scales to onion thrips over time.

If bulb scale becomes more susceptible to onion thrips during shrinkage, the timing of lifting and harvesting of bulbs may be critical in managing insect damage. Bulbs with an intact, well-formed outer skin, preventing thrips from accessing the thin outer scale that will shrink to form a skin during the first weeks of storage, will be less susceptible to thrips.

This bioassay is potentially very suitable for use by plant breeders when selecting for thrips-resistant bulbs, because it is possible to assay the outer scales of a bulb and then give the bulb to the plant breeder to grow and produce flowers. The bioassay indicated that there is considerable variation between bulbs of open pollinated, brown onion cultivars.

The bioassay and method for rearing the thrips are labour intensive, making these bioassays relatively expensive. The identification of the particular chemicals involved in resistance to onion thrips would be useful. Chemical analysis of 'Kiwigold' and 'M&R Regular' onion bulbs for chemicals associated with pungency, carbohydrates, total N, and total sulfur showed that there were no effects of N treatments on pungency or total N (John McCallum, Crop & Food Research, Lincoln pers. comm.). Bulbs of 'Kiwigold' had a lower percentage of fructans with increasing N applications and a higher percentage of sulfur per bulb dry weight with increased N (John McCallum, Crop & Food Research, Lincoln pers. comm.). There was no similar relationship in 'M&R Regular'.

Until a chemical assay can be developed to determine the susceptibility of onion bulbs to onion thrips, the bioassay using egg laying by 1-day-old females described here may assist with the identification of genetic and agronomic factors that increase the resistance of onion bulbs to thrips.

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