Available online at www.sciencedirect.com
SCIENCE DIRECT®
Crop Protection 22 (2003) 1033–1038
Crop Protection
www.elsevier.com/locate/cropro

Barriers, repellents and antifeedants for slug and snail control

I. Schüder[a,*], G. Port[a], J. Bennison[b]

[a] University of Newcastle upon Tyne, School of Biology, Ridley Building, Newcastle upon Tyne, NE1 7RU, UK
[b] ADAS Boxworth, Cambridge, CB3 8NN, UK

Received 31 March 2003; received in revised form 30 April 2003; accepted 15 May 2003

Abstract

Laboratory bioassays were carried out to evaluate the efficacy of various products with potential for slug and snail control in horticulture and agriculture. The products tested were cinnamamide, copper ammonium carbonate, garlic, aluminium and copper foil, a mulch, ureaformaldehyde and the proprietary products SnailBan® and Tex-R® matting. The trials were carried out using the slug *Deroceras panormitanum* (Lessona and Pollonera, 1882) (*D. caruanae*) and the snail *Oxyloma pfeifferi* (Rossmässler, 1835), which are the most abundant slug and snail pest species found damaging hardy ornamental plants in commercial nurseries in the UK.

The tested products had irritant, antifeedant, physical barrier, chemical repellent, or molluscicidal effects or showed a combination of more than one effect. Garlic, ureaformaldehyde and cinnamamide were the three best products for controlling molluscs. In 7 day bioassay trials these products had mortality rates between 20% and 95% which was significantly higher than on the untreated compost. In comparison to the untreated compost they also gave significant reductions in damage, between 41% and 100%, depending on species and application technique. Further investigations are needed to evaluate their efficacy under field conditions, the behavioural response of the slugs and snails, the most cost-effective concentrations and the best application techniques, and to understand the mode of action of the products.

Some of the products will only be applicable in horticulture due to their cost or the practicalities of their use. However, most of the products also may have potential for use in agriculture as the slug tested, *D. panormitanum*, is closely related to *D. reticulatum*, the main slug pest species in agriculture.

Keywords: *Deroceras panormitanum*; *Oxyloma pfeifferi*; Pest control; Horticulture; Molluscicide

1. Introduction

Slugs and snails are common pests in UK horticulture and agriculture. Growers and farmers often experience difficulty controlling these pests with conventional bait pellets containing molluscicides such as methiocarb and metaldehyde. For example, in wet conditions the efficacy of these pellets can be very low (Hata et al., 1997) leading to unsatisfactory control levels. Furthermore, poison baits can be toxic to other non-target soil invertebrates, as well as birds and mammals such as shrews and field mice (Martin, 1993; Purvis, 1996).

The development of effective alternatives to conventional molluscicides, particularly those which could be used in an integrated control strategy, would reduce plant losses, improve plant quality and offer a sustainable strategy for controlling slug and snail pests with reduced molluscicide input. The development of alternative snail and slug control methods compatible with Integrated Pest Management (IPM) strategies used to control other pests will help satisfy increasing market demands for ornamental plants and edible crops grown with environmentally responsible production methods.

Investigations carried out by ADAS in 2000 (unpublished) established two mollusc species as the main pests in horticultural nurseries producing hardy ornamental plants in the UK: the snail *Oxyloma pfeifferi* and the slug *Deroceras panormitanum*. As part of a programme of research to establish IPM strategies for these pests a range of potential barriers, repellents and antifeedants were studied and the results are reported here.

*Corresponding author. Tel.: +44-191-222-5952; fax: +44-191-222-5229.
E-mail address: ingo.schueder@ncl.ac.uk (I. Schüder).

0261-2194/03/$ - see front matter
doi:10.1016/S0261-2194(03)00120-0

2. Methods

Slugs (*D. panormitanum)* and snails (*O. pfeifferi)* were collected from field sites and from ornamental plant nurseries, respectively. The potential repellent, barrier or antifeedant effects of 10 products were investigated (Table 1), using replicated laboratory bioassays. SnailBan® is an incinerated kaolin mineral and is available as a snail barrier on the amateur gardening market. Mypex® is a plastic woven matting and is widely used in the horticulture industry to cover benches and other production areas. Tex-R® is a textile non-woven matting with a copper-salt formulation bound to a latex matrix. This matting is widely used in landscaping to suppress plant root growth. All bioassays were carried out under identical laboratory conditions (15°C and 16:8 h light:dark).

Two different approaches of applying products were used in laboratory experiments testing the effect of materials as a horizontal barrier (tested with slugs and snails) or a vertical barrier (tested with slugs only). In addition to the barrier effect, mortality and leaf damage were recorded, providing data on the repellent, irritant or antifeedant effects of the products.

2.1. Barrier against horizontal movement

The slugs and snails were starved for 48 h prior to the experiment. Experiments were carried out in circular plastic dishes, 16 cm in diameter and filled with 2 cm of damp compost. A 3 cm-wide strip in the middle of each dish was treated with one of the products (30 ml solution or application of foil or mineral). A 4 cm^2 piece of Chinese cabbage was offered in one semicircle and two slugs or one snail were placed in the other. Slugs weighing 150–400 mg and snails weighing 50–120 mg were used. Pieces of cardboard (9 cm^2) were provided as shelters. There were 20 replicate dishes per treatment. Leaf damage (cm^2 eaten), position of the animals in the dish and mortality were recorded every 24 h for 2 days (with the slugs) and for 7 days (with the snails).

2.2. Barrier against vertical movement

Slugs were starved for 24 h prior to the experiment. One slug was buried in each of 20 individual transparent plastic beakers (300 ml, 6 cm diameter) under a 2 cm layer of damp compost. The treatments were applied to the surface of the compost as a solid disc (metal foils and mattings), 6 mm-deep layer of material (minerals and mulch) or 8 ml solution, respectively. The position of the slugs and the damage caused to a 4 cm^2 piece of Chinese cabbage leaf (area eaten) on the surface were recorded every 24 h for 7 days.

2.3. Statistical analysis

Binomial data were analysed with a G-Test. Multiple comparisons of the control with all treatments were then carried out based on the angular transformed proportions (according to Zar, 1999).

Continuous data was tested for normality. Non-parametric data was analysed with a Kruskal–Wallis-Test and consequently with a post hoc procedure of multiple comparisons of the untreated compost with all treatments (Wilcoxon and Wilcox, 1964) as cited in Zar (1999).

3. Results

3.1. Barrier against horizontal movement—*D. panormitanum*

A significant barrier effect against horizontal movement of *D. panormitanum* was observed with three products ($N = 20$, G-Test: $P < 0.001$, Table 2). Garlic and ureaformaldehyde had a strong effect in repelling the slugs, with 65% and 72.5% barrier efficacy,

Table 1
Products used in bioassays and their abbreviations in tables

Product	Type of product	Concentration	Abbreviation
Untreated	Compost	n.a.	UNT
Aluminium	Metal foil	n.a.	AL
Cinnamamide	Solution	1%	CIN
Copper	Metal foil	n.a.	CU
Croptex-Fungex®	Copper ammonium carbonate solution	0.6%	CF
Garlic	Solution	2.5% and 5% (horiz. and vert. barrier)	GA
Mulch	Chipboard waste	1 cm depth	MU
Mypex®	Horticultural matting	n.a.	MYP
SnailBan®	Mineral	1 cm depth	SB
Tex-R®	Horticultural matting	n.a.	TEX
Ureaformaldehyde	Solution	6%	UF

Table 2
Barrier efficacy of treatments against horizontal movement, mortality of and damage (±SE) by *D. panormitanum* after 48 h. Treatment abbreviations as in Table 1

Treatment	Barrier efficacy[a] (%)	Mortality rate (%)	Damage	
			Accum. (cm^2)	Reduced[b] (%)
UNT	0	3	6.6±0.4	x
AL	0	8	6.5±0.3	1
CIN	10	15	5.2±0.4***	41
CU	25***	5	3.9±0.6***	60
CF	0	3	2.7±0.5	21
GA	65***	0	0.3±0.1***	95
MU	13	13	3.9±0.6***	41
MYP	0	0	5.5±0.4	17
SB	0	0	6.9±0.3	−5
TEX	0	15	2.8±0.3***	58
UF	73***	3	0.4±0.3***	94

[a] Barrier efficacy: no damage occurred and no slug observed crossing the barrier before the end of the experiment;
*** significantly higher than with the untreated compost, $P<0.001$.
[b] Damage reduced: in comparison with the untreated compost;
*** indicates that accumulated damage over 7 days was significantly lower than with the untreated compost, $P<0.001$.

respectively. None of the products had a mortality rate significantly higher than the untreated compost ($N=20$ dishes G-Test: $P>0.05$, Table 2).

Overall, leaf damage was significantly reduced in six treatments: cinnamamide, mulch, Tex-R matting, copper foil, ureaformaldehyde and garlic ($N=20$, Kruskal–Wallis-Test: $P<0.001$, Table 2). For the two best products, garlic and ureaformaldehyde, the reduction in damage was more than 90%.

3.2. Barrier against horizontal movement—*O. pfeifferi*

Several products showed a high barrier efficacy against horizontal movement of *O. pfeifferi* ($N=20$, G-Test: $P<0.001$, Table 3). The two products causing greatest repellency were ureaformaldehyde and copper foil with 90% and 80% barrier efficacy, respectively. Mortality rates of *O. pfeifferi* were higher than those of *D. panormitanum*. Of those rates significantly higher than the untreated compost, garlic caused the greatest mortality with 30% ($N=20$, G-Test: $P<0.05$, Table 3). All products reduced snail damage significantly in comparison with the untreated compost, ranging from a 46% reduction of damage with Mypex and aluminium to nearly 100% with ureaformaldehyde ($N=20$, Kruskal–Wallis-Test: $P<0.001$, Table 3).

3.3. Barrier against vertical movement—*D. panormitanum*

All products except copper foil had significant effects as barriers against vertical movements and prevented buried slugs coming to the surface ($N=20$, G-Test: $P<0.001$, Table 4). With a 5% solution of garlic concentrate 95% of all slugs were killed before they could penetrate the treated soil and come to the surface. Another four products had a significantly higher mortality rate than the untreated compost, but with mortality between 15% and 35% this was not as dramatic as with garlic concentrate ($N=20$, G-Test: $P<0.001$, Table 3).

As a consequence of killing the slugs in the soil or at least stopping them coming to the surface, all products significantly reduced damage ($N=20$, Kruskal–Wallis-Test: $P<0.001$, Table 4). The success varied between 61% reduction of damage with Tex-R® matting and 100% reduction with garlic and ureaformaldehyde.

Table 3
Barrier efficacy of treatments against horizontal movement, mortality of and damage (±SE) by *O. pfeifferi* after 7 days. Treatment abbreviations as in Table 1

Treatment	Barrier efficacy (%)	Mortality rate (%)	Damage	
			Accum. (cm^2)	Reduced (%)
UNT	0	0	5.5±0.5	x
AL	0	5	2.9±0.3***	46
CIN	35***	20*	1.1±0.3***	90
CU	80***	5	0.5±0.2***	95
CF	30***	0	0.2±0.1***	80
GA	25***	30*	0.7±0.2***	88
MU	55***	10	1.7±0.5***	70
MYP	0	5	3.0±0.4***	46
SB	35***	15*	1.5±0.4***	72
TEX	5	5	1.9±0.4***	66
UF	90***	20*	0.0±0.0***	99

*** Significantly different from the untreated compost, $P<0.001$.
* Mortality significantly higher than with untreated compost, $P<0.05$.

Table 4
Barrier efficacy of treatments against vertical movement, mortality of and damage (±SE) by *D. panormitanum* after 7 days. Treatment abbreviations as in Table 1

Treatment	Barrier efficacy (%)	Mortality rate (%)	Damage	
			Accum. (cm^2)	Reduced (%)
UNT	0	0	13.6±1.3	x
AL	45***	5	5.1±1.3***	63
CIN	45***	35***	4.2±1.0***	84
CU	15	5	2.2±0.6***	77
CF	40***	15***	3.1±0.7***	69
GA	100***	95***	0.0±0.0***	100
MU	40***	35***	1.4±0.6***	89
MYP	55***	0	2.3±0.9***	83
SB	75***	10	1.1±0.6***	92
TEX	35***	10	5.3±1.1***	61
UF	65***	25***	0.0±0.0***	100

*** Significantly different from untreated compost, $P<0.001$.

4. Discussion

4.1. Products

Cinnamamide, garlic concentrates and various copper-based products were known to have activity against slugs and snails.

Cinnamamide is known to have an antifeedant effect when used as a seed coating (Watkins et al., 1996). This antifeedant effect is confirmed in the experiments reported here. However, the repellent barrier effect on slugs and snails and the increase in mortality rate are new observations.

Previous suggestions for application of copper-based products included solid copper sulphate (Miles et al., 1931) copper sulphate mixed with aluminium sulphate and borax (Glen et al., 1986), or copper hydroxide (Liao and Wang, 1999), copper glass (Chandiwana et al., 1987) and copper foil.

Ryder and Bowen (1977) showed that the foot of the slug is the site of copper uptake. This is an important penetration route for highly soluble copper-salts, which can be expected to cause some internal damage and irritant effects. For example, Marigomez et al. (1986) showed the histological effects of diets rich in heavy metals on *Arion ater*. However, for other copper products (solid copper sheet and Tex-R® matting, impregnated with a copper formulation), the copper is not easily dissolved and ready for uptake into the body. Thus other mechanisms must play a predominant role in their efficacy. Slugs were observed producing large amounts of mucus when the animals came into contact with the copper surfaces. This irritation can cause significant dehydration. Both slugs and snails were observed to quickly withdraw their tentacles when encountering copper sheet or Tex-R® matting. We conclude that these two products are very powerful physico-chemical barriers. In this context the observation of Sullivan and Cheng (1976) that the aquatic snail *Biomphalaria glabrata* is more likely to die when exposed to external rather than to internal copper poisoning supports the observation that successful control with copper-based products need not include ingestion or pedal uptake. Singh and Singh (1993) and Singh and Singh (1995) showed that garlic extracts have an effective repellent effect on snails and proved that the active ingredient is allicin. In the trials presented in this paper garlic was one of the two best performing products, giving mortality rates of up to 100%.

No data have previously been published on the antifeedant, repellent, irritant or molluscicidal effects of mulch, SnailBan®, ureaformaldehyde and chipboard waste-based mulch on slugs and snails. Nair et al. (1982) found that chipboard waste contains up to 2% nitrogen, mainly as ureaformaldehyde, and suggested the use of the waste as a slow releasing nitrogen fertiliser. Ureaformaldehyde is already used in horticulture (Brown, 1972) usually as pellets, and has advantages over other nitrogen fertilisers, as it is cheaper and less toxic (Allen, 1982). The application of a pure solution of the chemical seems to be cleaner, easier and cheaper than the application of a mulch. This is further supported by the fact that customer acceptance of mulch on the surface of plant containers is doubtful (Richardson, personal communication). Both ureaformaldehyde and mulch would need registration as pesticides if sold for slug and snail control.

'Snail-Ban'® has been until recently available on the amateur market in the UK, for use as an "environmentally friendly" physical barrier to deter slugs and snails. When dry, the product was claimed to prevent slugs and snails moving across the material by absorbing their mucus, and when wet, the product acts as an irritant. With 75% barrier efficacy 'Snail-Ban'® showed the second best result as a physical vertical barrier. However, it did not show any effects in the horizontal barrier bioassays with slugs.

Some of the products will only be applicable in horticulture due to their cost or the practicalities of their use. Examples of those products are copper foil and copper impregnated mattings. However, some of the products, such as cinnamamide, garlic and ureaformaldehyde have potential for use in agriculture as the slug tested, *D. panormitanum*, is closely related to *D. reticulatum*, the main slug pest species in agriculture.

4.2. Barrier against horizontal movement

The design of the barrier experiments was very challenging for the products with only a 3 cm-wide barrier strip. However, this situation is realistic for products that are best placed on the surface of compost in pots (all solutions, mulches and minerals), because pot diameters can be as small as 4 cm. The products performed less efficiently when applied against slugs than against snails. This could be explained by the shorter duration of the trial and the body size: barrier width ratio, which was in the slugs' favour. Once the slugs had crossed the barrier there was no or little reduction in their activity. Thus, if it were commercially acceptable and practicable, the treatments should be applied to the entire pot surface or bench surface. The mattings should be considered for full-area treatment in greenhouses or polythene tunnels, to stop slugs and snails migrating into the production area or from one pot to another.

4.3. Barrier against vertical movement

The observed barrier effects against vertical movement of slugs could be either physical or chemical. Some

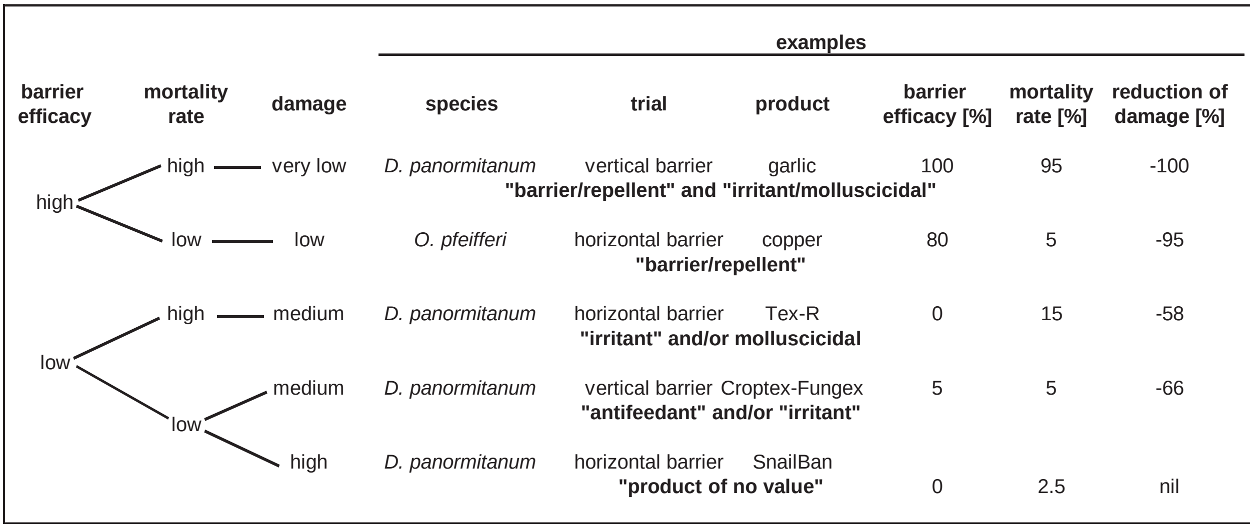

Fig. 1. Different products have a different combination of properties, which makes them more or less useful for a specific application against slug and snail pests.

of the products, which did not perform very well in other trials, did very well in this trial, especially 'SnailBan'® minerals. Some products such as copper foil or copper-impregnated mattings still acted as a barrier against horizontal movement after the slugs had overcome the vertical barrier. This was because the slugs moved up the beaker wall to the surface, so they still had to cross the surface to reach the leaf in the centre of the beaker. The barrier to vertical movement would only be effective against animals which were already in the container at the time of treatment. The barrier to horizontal movement is likely to be mainly a chemical effect and would also affect animals that moved onto the pot after the treatment had been applied. An ideal product would be effective, both as a vertical barrier (physical or repellent) and as a horizontal barrier (repellent or irritant), or at least as an antifeedant.

4.4. Product properties

It is useful to differentiate between the effects of the treatments, such as the irritant, repellent and antifeedant effects, and to understand their mechanisms.

While the reduction of the damage was significantly different from the untreated compost with most products, the actual barrier effect was often quite low. This emphasises the fact that most of the products have more than a simple repellent or physical barrier effect, i.e. they also work as antifeedants or as irritants, which weaken the animal or at least make the animals less hungry. How a combination of different properties of a product can influence the final impact of a treatment is illustrated in Fig. 1. In addition to the non-lethal effects, treatments such as cinnamamide, copper ammonium carbonate, garlic and ureaformaldehyde also showed molluscicidal properties.

5. Conclusions

The width of a barrier treatment has to be in appropriate proportion to the body size of the predominant slug or snail, to prevent their access to plants. Covering the entire growing surface of a greenhouse or polythene tunnel such as floor, bench or standing area with repellent mattings such as Tex-R® may be more effective than treating individual pots.

All barrier treatments tested significantly reduced leaf damage by *D. panormitanum* and/or *O. pfeifferi*, when compared with the untreated compost. However, some of the products may not be acceptable to customers. Others are currently too expensive. Some are not very practical in their application.

Garlic, ureaformaldehyde and cinnamamide gave the highest reduction of damage, barrier efficacy and mortality rates in experiments carried out in the laboratory. Tex-R® matting, Croptex-Fungex®, garlic and ureaformaldehyde are likely to have most immediate commercial potential, due to current availability, practicability and cost.

Future work is needed on the most commercially promising products, to determine the optimal timing, width, depth or position and concentrations for application, their durability and the factors affecting their efficacy. Investigations should also include the effect of the products in suppressing egg laying and egg development together with behavioural studies to clarify the mode of action of the products, primarily the repellent effect.

Acknowledgements

This work was funded by the Horticultural Development Council (HDC) and the Department for Environment, Food & Rural Affairs (Defra). We thank Paul Sopp from Fargro Ltd. and Muree Groom from Ecospray Ltd. for giving us basic information about their products and for supplying us with horticultural mattings and garlic concentrate respectively and for technical product information. Thanks also to John Richardson of Johnsons of Whixley Ltd. for practical advice on consumer demands and to Heather Maher and Alan Craig for their support in collecting slugs and snails.

References

Allen, S.E., 1982. Slow-release Nitrogen Fertilizers. Nitrogen in Crop Production. American Society of Agronomy, Madison, Wisconsin, USA, pp. 195–206.

Brown, W.L., 1972. Fertilization and growing media for ornamentals in containers. La. Agr. 16, 12–13, 15.

Chandiwana, S.K., Ndamba, J., Makura, O., Taylor, P., 1987. Field evaluation of controlled release copper glass as a molluscicide in snail control. Trans. Roy. Soc. Trop. Med. Hyg. 81, 952–955.

Glen, D.M., Milsom, N.F., Wiltshire, C.W., 1986. Evaluation of a mixture containing copper sulphate, aluminium sulphate and borax for control of slug damage to potatoes. Ann. Appl. Biol. 108, 26–27.

Hata, T.Y., Hara, Arnold, H., Hu, B.K.S., 1997. Molluscicides and mechanical barriers against slugs, Vaginula plebeia Fischer and Veronicella cubensis (Pfeiffer) (Stylommatophora: Veronicellidae). Crop Protect. 16, 501–506.

Liao, C.T., Wang, W.J., 1999. The repellent and toxic effect of copper on slug, Parmarion martensi (Simroth) (Pulmonata: Helicarionidae). Plant Protect. Bull. 41, 35–42.

Marigomez, J.A., Angulo, E., Saez, V., 1986. Feeding and growth responses to copper, zinc, mercury and lead in the terrestrial gastropod Arion ater (Linne). J. Mollusc. Stud. 52, 68–78.

Martin, T.J., 1993. The ecobiological effects of arable cropping including the non-target effects of pesticides with special reference to methiocarb pellets (Draza, Mesurol) used for slug control. Pflanzenschutz-Nachr. Bayer. 46, 49–102.

Miles, H.W, Wood, J., Thomas, I., 1931. On the ecology and control of slugs. Ann. Appl. Biol. 18, 370–400.

Nair, N.M., Unnikrishnan, K.G., Unnikrishnan, M., Nair, C.S.B., 1982. Ureaform as slow release nitrogenous fertiliser. Waste wood fiber as a soil amendment. Fertil. News. 27, 19–21, 31.

Purvis, G., 1996. The hazard posed by methiocarb slug pellets to carabid beetles: understanding population effects in the field. BCPC Monograph No. 66 'Slug & Snail Pests In Agriculture', pp. 189–196.

Ryder, T.A., Bowen, I.D., 1977. The slug foot as a site of uptake of copper molluscicide. J. Invertebr. Pathol. 30, 381–386.

Singh, D.K., Singh, A., 1993. Allium sativum (Garlic), a potent new Molluscicide. Biol. Agric. Hortic. 9, 121–124.

Singh, V.K., Singh, D.K., 1995. Characterization of allicin as a molluscicidal agent in Allium sativum (Garlic). Biol. Agric. Hortic. 12, 119–131.

Sullivan, J.T., Cheng, T.C., 1976. Comparitive Mortality Studies on Biomphalaria glabrata (Mollusca: Pulmonata) exposed to copper internally and externally. J. Invertebr. Pathol. 28, 255–257.

Watkins, R.W., Mosson, H.J., Gurney, J.E., Cowan, D.P., Edwards, J.P., 1996. Cinnamic acid derivatives: Novel repellent seed dressings for the protection of wheat seed against damage by the field slug, Deroceras reticulatum. Crop Prot. 15, 77–83.

Wilcoxon, F., Wilcox, R.A., 1964. Some rapid approximate statistical procedures. Lederie Laboratories, Americ. Cyanamid Corp., Pearl River, New York.

Zar, J.H., 1999. Biostatistical Analysis, 4th Edition. Prentice-Hall International Inc., Englewood Cliffs, NJ.