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Suppression of green peach aphid (*Myzus persicae*) (Sulz.), citrus mealybug (*Planococcus citri*) (Risso), and two spotted spider mite (*Tetranychus urticae*) (Koch.) attacks on tomatoes and cucumbers by aqueous extracts from vermicomposts

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ABSTRACT

Vermicomposts are produced through interactions between earthworms and microorganisms in the breakdown of organic wastes. Aqueous extracts were prepared in commercial brewing equipment (Growing Solutions Inc.) from vermicomposts processed from pre-consumer food waste. The ratio of vermicompost to water was 1 to 5 v:v to produce a 20% aqueous solution. The effects of soil drenches at dilutions of 20%, 10%, and 5% vermicompost extracts, were compared with those of deionized water, in the suppression of green peach aphids, mealybugs, and two spotted spider mites attacking tomatoes and cucumbers, in greenhouse cage experiments.

Tomatoes and cucumber seedlings were germinated and grown for four weeks in 25 cm diam. pots containing a soil-less growth medium Metro-Mix 360 and thinned to 4 plants per pot. They were then put under cages (40 cm × 40 cm × 40 cm) with a 0.2 mm mesh, with one pot containing 4 plants in each treatment cage. Plants were treated with soil drenches of 5%, 10%, or 20% vermicompost extracts or a deionized water control to field capacity, at germination and at weekly intervals thereafter. In each experiment, either 100 green peach aphids, mealybugs, or two spotted spider mites were released into each cage (25 pests per test plant), on leaves of the same plant species. Each vermicompost extract treatment and the deionized water control were replicated 4 times per pest cage experiment laid out in a randomized complete block design. Numbers of pests were counted and damage was rated (0, none to 5, total) on days 1, 3, 5, 7, 9, 11, 13 and 14 after pest release into the cages.

All of the vermicompost extracts suppressed pest establishment on the plants, and their rates of reproduction for all three species of pests, significantly. They also caused some of the pests on the plants receiving the higher extract application rates to die after 14 days of treatment. The higher the rate of extract application the greater was the suppression of the pests. We concluded that the most likely cause for the unacceptability of the plants to pests and decreased reproduction and mortality, was the uptake of soluble phenolic materials from the vermicompost extracts into the plant tissues. These compounds are known to make plants unattractive to pests and to affect pest rates of reproduction and survival.

1. Introduction

Vermicomposts are finely-divided, fully-stabilized organic materials supporting large microbial numbers and activity. They are produced in a mesophilic process through interactions between earthworms and microorganisms in breaking down organic wastes. Solid vermicomposts increase plant germination, growth, flowering and fruiting of a wide range of crops through hormonal effects, independent of nutrients (Edwards, 2004). Low vermicompost application rates in the field, or substitutions of vermicomposts into plant growth media in the greenhouse, have been shown to suppress numbers of plant parasitic nematodes (Arancon et al., 2002), plant pathogens (Chaoui et al., 2002), and pest arthropods (Arancon et al., 2006; Edwards et al., 2007; Yardim et al., 2006).

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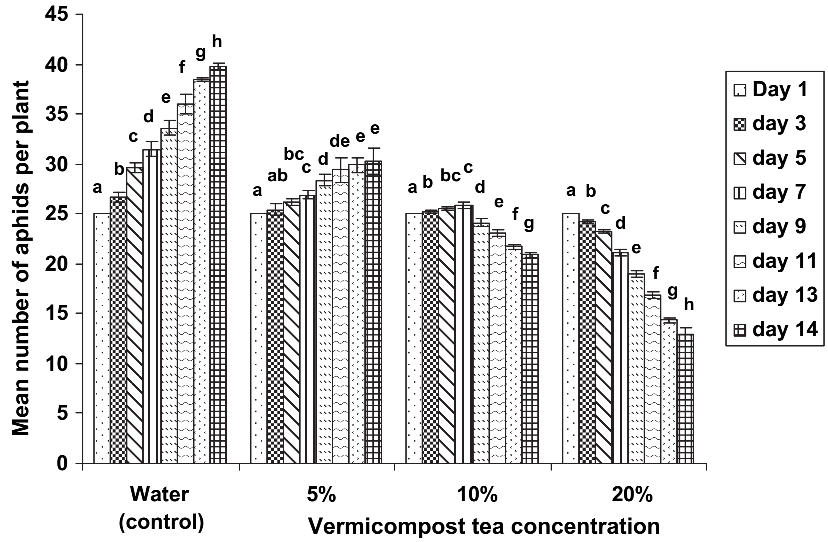

Fig. 1. Changes in green peach aphid (*Myzus persicae*) numbers on tomatoes treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

Various forms of organic matter applied to soils, may help to decrease numbers of arthropod pests and the resultant crop damage (Patriquin et al., 1995). In preliminary research in our laboratory, solid vermicomposts suppressed numbers and damage by arthropod pests, such as aphids and cabbage white caterpillars (Arancon and Edwards, 2004; Arancon et al., 2005a,b). Other workers have reported that vermicomposts suppressed attacks by jassids, aphids and spider mites (Rao et al., 2001; Rao, 2002) and psyllids (Biradar et al., 1998). More recent research in our laboratory has demonstrated significant suppression of plant parasitic nematodes, arthropod pests and plant diseases by vermicompost aqueous extracts (Edwards et al., 2007). Vermicompost extracts are much easier to handle and apply to crops than solid vermicomposts, which are bulky and heavy and need soil incorporation.

The greenhouse experiments that are reported in this paper describe the effects of aqueous extracts produced from food waste-based vermicomposts, on numbers and damage by green peach aphids (*Myzus persicae*), citrus mealybugs (*Pseudococcus citri*), and two spotted spider mites (*Tetranychus urticae*) infesting tomatoes and cucumbers. These vermicompost aqueous extracts were applied to the plants as soil drenches to field capacity at germination and thereafter at weekly intervals.

2. Materials and methods

2.1. Production of greenhouse test plants

Cucumbers (*Cucumis sativa*) and tomatoes (*Lycopersicon esculentum*) were sown in the greenhouse and grown in a soil-less bedding plant medium, Metro-Mix 360 (MM360). MM360 is a preparation from vermiculite, Canadian sphagnum peat moss, bark, ash, sand, and has a starter nutrient fertilizer in its formulation (Scotts, Marysville, OH). The commercial pre-consumer food waste vermicomposts, processed from supermarket food wastes

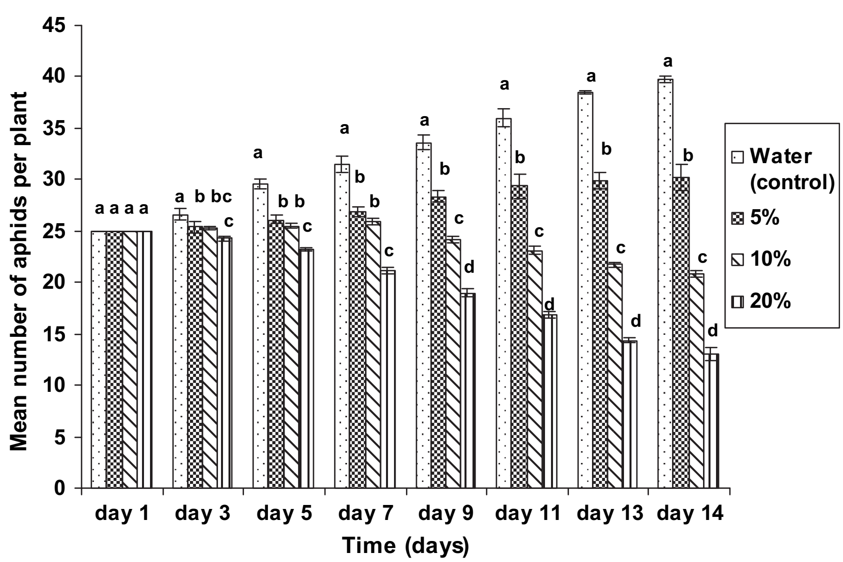

Fig. 2. Changes in green peach aphid (*Myzus persicae*) numbers over time on tomatoes treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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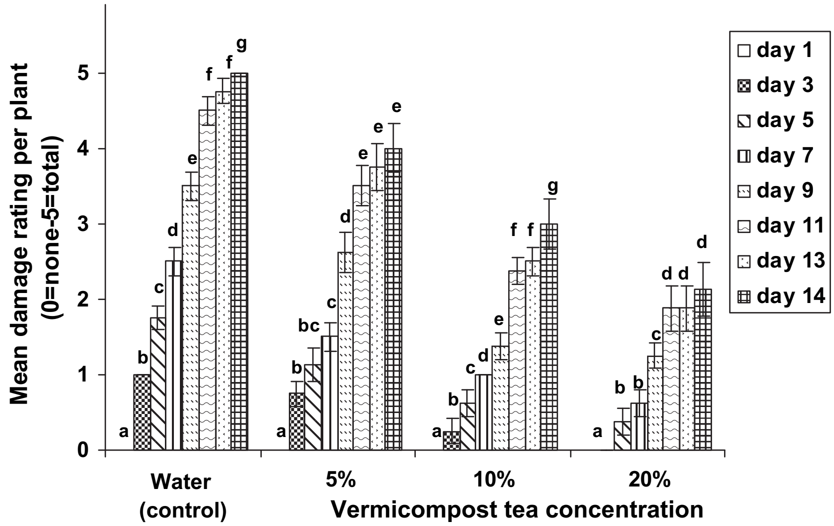

Fig. 3. Damage ratings (0–5) of green peach aphids (*Myzus persicae*) on tomatoes treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

that we used in our experiments, were produced in a fully automated continuous-flow vermicomposting reactor system designed by Edwards and his colleagues in the U.K. (Edwards and Arancon, 2004) by Oregon Soil Corporation, Portland, Oregon and contained 1.3% N, 2.7% P, and 9.2% K and trace elements.

For all experiments, 8 tomato or cucumber seeds were sown into each 25 cm diameter plant pot, containing Metro-Mix 360, and placed in a greenhouse to germinate. After plant emergence was complete, all pots were thinned to 4 seedlings per pot. Plants were watered with Peter's Nutrient Solution three times weekly which supplied all needed nutrients throughout their growth period. Peter's Nutrient Solution is a water-soluble fertilizer, recommended for continuous liquid feed programs of bedding plants, and contains 7.77% NH_4–N, 12.23% NO_3–N, 10% P_2O_5, 20% K_2O, 0.15% Mg, 0.02% B, 0.01% Cu, 0.1% Fe, 0.056% Mn, 0.01% Mo, and 0.0162% Zn. The plants were grown in the greenhouse for 4 weeks before they were caged and infested with the test arthropod pests for a test period of two weeks.

2.2. Treatments

The treatments consisted of a range of 3 concentrations of aqueous vermicompost extracts. The food waste vermicompost extract concentrations prepared from a 20% aqueous extract were diluted to 5% and 10% (v:v), and together with a 20% extract their effects were compared with those of a deionized water control. The aqueous extracts were prepared as a 20% solution using 7.5 l of food waste vermicompost in 30 l of water in commercial compost extract brewing equipment ('Growing Solutions[10TM] Compost Tea Brewing Equipment', WA, U.S.). They were aerated during production over a period of 24 h.

The 3 concentrations of aqueous vermicompost extracts (5%, 10% and 20%) and a deionized water control were applied to plants as soil drenches to approximately field capacity moisture content at sowing, and at weekly intervals thereafter. From prior tests the amount of aqueous vermicompost extract applied on each treatment date was 200 ml. The tomatoes or cucumbers were exposed

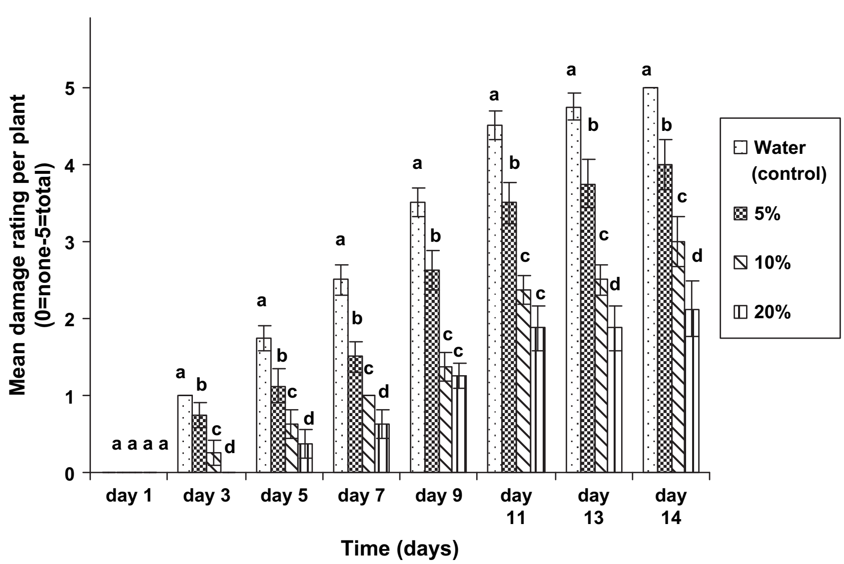

Fig. 4. Damage ratings (0–5) of green peach aphids (*Myzus persicae*) over time on tomatoes treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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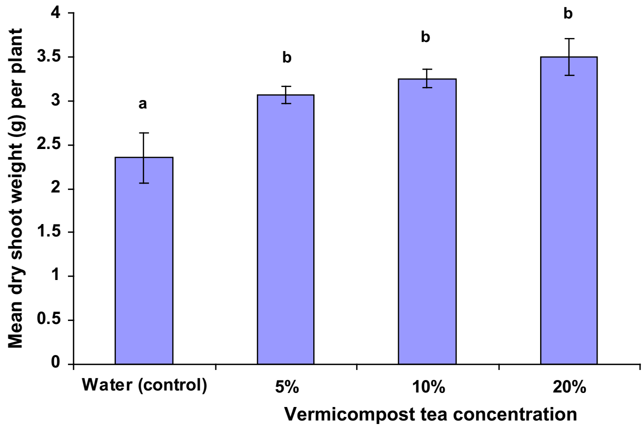

Fig. 5. Effects of soil applications of vermicompost aqueous extracts on tomato dry shoot weights when attacked by green peach aphids (*Myzus persicae*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

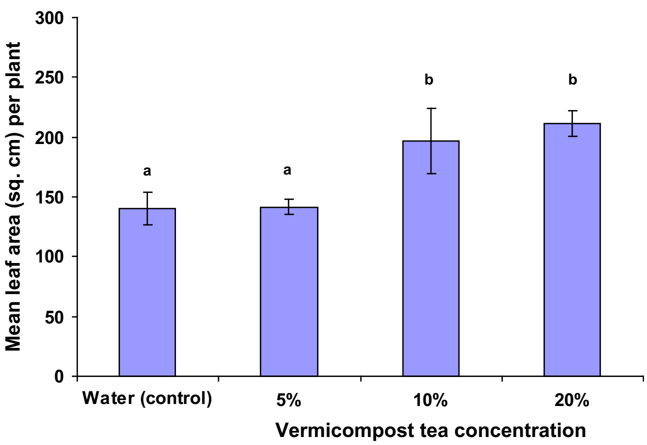

Fig. 6. Effects of soil applications of vermicompost aqueous extracts on tomato leaf areas when attacked by green peach aphids (*Myzus persicae*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

to test infestations by 3 species of arthropod pests (green peach aphids, citrus mealybugs, or two spotted spider mites), for 14 days in cages. Plants were harvested for assessment of the mean above ground and root dry weights and leaf areas per plant after 6 weeks. Shoots were oven-dried at 60 °C for 24 h before weighing to measure shoot dry weights. On the same date mean leaf areas were measured using a Licor Model 3100 leaf area meter.

2.3. Pest infestations

Each experimental treatment, involved growing seedlings of either tomatoes or cucumbers in pots with 4 seedling plants per pot per treatment, confined in a single mesh cage (40 cm × 40 cm × 40 cm) covered with a 0.2 mm aperture nylon mesh. Each cage treatment was replicated 4 times. Prior to infestation, the seedlings were raised in an insect-free greenhouse environment for four weeks. For experiments on two spotted spider mites, citrus mealybugs and green peach aphids, plants in cages were placed on capillary mats for ease and uniformity of watering without removing the cage, either with Peter's Nutrient Solution, providing all the required nutrients, or watering with only water for irrigation, according to the experimental protocol designated.

For all experiments, pots each containing 4 plants, were placed in individual cages for each treatment, which was a soil drench to field capacity with either 5%, 10%, or 20% vermicompost aqueous extracts or a deionized water control. Pests were released into cages on leaves of the same plant species placed on the surface of the growing medium in the plant pots from which they moved on to the plants within 2 h. One hundred green peach aphids (*M. persicae*), citrus mealybugs (*Planococcus citri*) or two spotted spider mites (*T. urticae*) were released into each individual experimental cage on the first day of the experiment when plants were four weeks old.

The numbers of insects or mites on the tomatoes and cucumbers were counted on days 1, 3, 5, 7, 9, 11, 13 and 14 after infestation. On the same days, assessments of damage to the plants, on a rating scale of 0 (none) to 5 (total) were made based on areas of leaf damaged. A damage rating of 3 should equate to damage to 60% of the total foliage. These ratings were very reliable and repeatable after appropriate training for the technicians making the assessments. Only damage ratings could be made for the spider mite

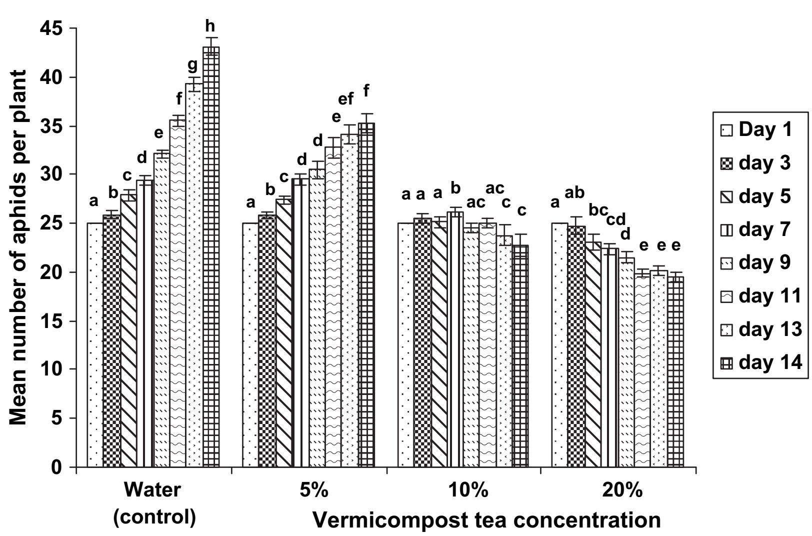

Fig. 7. Changes in green peach aphid (*Myzus persicae*) numbers on cucumbers treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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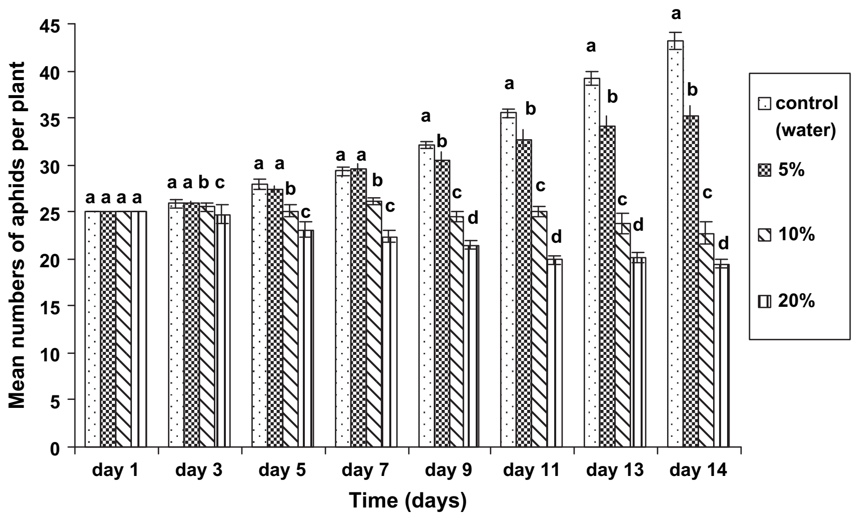

Fig. 8. Changes in green peach aphid (*Myzus persicae*) numbers in time on cucumbers treated with a range of concentrations of food waste vermicompost aqueous extract (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \le 0.05$).

experiments since the pests were too small to count on the plant foliage.

The experiments were in a completed randomized layout in the greenhouse. GLM procedures (SAS ver. 9.1.3, 2002–2003) were used to analyze results. Repeated measurements ANOVA were made for damage and number ratings on tomatoes and cucumbers. The GLM procedure for between subject effects included time and treatments rates in the model. For the univariate analysis for within subject effects, the GLM procedure was used with both time and time and treatment rates included in the model. Differences between means were separated using least significant differences (LSD) at $P \le 0.05$ and 0.01, as indicated in the captions to the figures.

3. Results

3.1. Green peach aphid experiments

In the experiment on suppression of green peach aphids on tomatoes, numbers of aphids were suppressed significantly ($P \le 0.05$) by all three vermicomposts aqueous solution concentrations, with greater suppression by 20% extract than 10% extract than 5% extract ($P \le 0.05$). All of the aphids introduced into the cages settled on the tomato plants (25 per plant). In the deionized control, aphids increased in numbers significantly ($P \le 0.05$) to 40 per plant over 14 days (Figs. 1 and 2). In the treatment receiving 5% vermicompost extract they also increased in numbers, but in the 10% extract treatment cages they continued to increase significantly ($P \le 0.05$) up to day 7, then began to decrease in numbers significantly ($P \le 0.05$). In the 20% extract treatment they decreased progressively in numbers from day 1 to day 14. A similar pattern occurred in terms of green peach aphid damage ratings where damage leveled off to a rating of 2.0 in response to 20% extract applications (Figs. 3 and 4). In terms of damage ratings, the tomatoes receiving the water (control) reached a damage rating of 5.0 (5.0 equals total damage) compared with a rating of 4.0 for plants receiving 5% vermicompost extract, 3.0 for those receiving 10% extract and less than 2.0 for plants receiving 20% extract ($P \le 0.05$). When tomato shoot dry weights were measured (Fig. 5), only the 20% vermicompost extract produced significant increases ($P \le 0.05$), although both the 10% and 20% extract applications increased tomato leaf areas (Fig. 6).

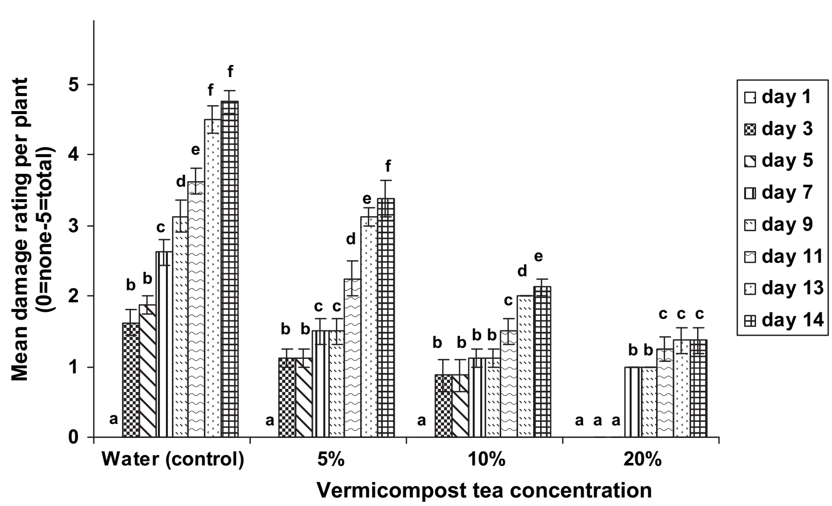

Fig. 9. Damage ratings (0–5) of green peach aphids (*Myzus persicae*) on cucumbers treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \le 0.05$).

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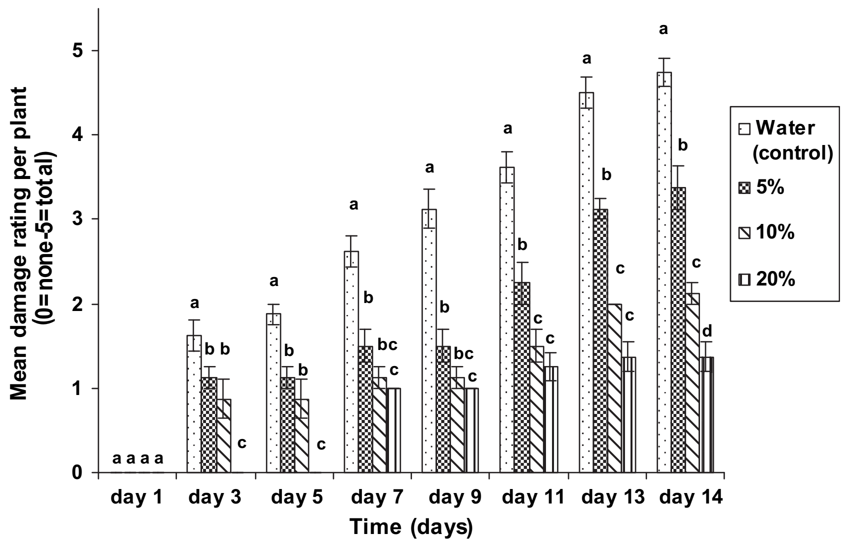

Fig. 10. Damage ratings (0–5) of green peach aphids (*Myzus persicae*) over time on cucumbers treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

The responses of the cucumbers to aphid infestations followed a similar pattern, in terms of numbers of aphids, except that control plants reached a total of 43 aphids per plant after 14 days (Figs. 7 and 8). Aphid numbers increased significantly ($P \leq 0.05$) in response to the 5% vermicompost extract treatment but decreased for the whole exposure period in response to the 10% and 20% vermicompost extract treatments. The damage ratings (Figs. 9 and 10) were higher than those on tomatoes, with the plants in the water control suffering very severe damage to a rating of nearly 5.0 after 14 days. Damage ratings were 3.3 in response to 5% extracts, 2.1 for 10% extracts, and 1.4 for 20% extract treatments ($P \leq 0.05$). Shoot dry weights increased significantly ($P \leq 0.05$) in response to 10% and 20% extracts (Fig. 11) and so did leaf areas (Fig. 12).

3.2. Citrus mealybug experiments

In the experiments on the effects of vermicompost extracts on citrus mealybug (*P. citri*) numbers on tomatoes were quite similar to those of green peach aphids in response to the same vermicompost extract concentrations. However, numbers of mealybugs increased significantly ($P \leq 0.05$) from 25 per plant on day 1 to more than 29 per plant on day 14 in the deionized water control (Figs. 13 and 14). Mealybug numbers increased significantly ($P \leq 0.05$) when 5% extracts were applied and decreased significantly ($P \leq 0.05$) in response to 10% and 20% extract applications. However, damage ratings (Figs. 15 and 16) increased significantly ($P \leq 0.05$) from 0.5 to 2.5 over 14 days on the deionized water controls and much less in the 5% extract treatment (rating of 2.0), 10% extract treatment (rating of 1.5) and 20% extract treatments (rating of 1.35) ($P \leq 0.05$). There were significant ($P \leq 0.05$) increases in dry shoot weights of tomatoes (Fig. 17) and mean leaf areas (Fig. 18) in response to all concentrations of vermicompost extract treatments.

The responses of cucumbers infested by mealybugs were similar but numbers increased significantly ($P \leq 0.05$) from 25 to 33 per plant in the water control, rather less in the 5% extract treatment, not at all in the 10% extract treatment, and decreased significantly ($P \leq 0.05$) in response to the 20% extract treatment (Figs. 19 and 20). The damage ratings decreased significantly ($P \leq 0.05$) from 2.5 per plant in the water control to 1.9 per plant in response to the 5% extract treatment, 1.75 per plant in the 10% extract treatment, and 1.5 per plant in the 20% extract treatment (Figs. 21 and 22). There were significant differences ($P \leq 0.05$) in cucumber dry shoot

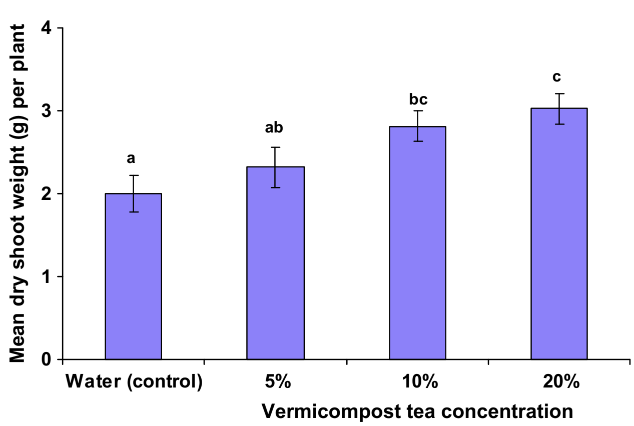

Fig. 11. Effects of food waste vermicompost aqueous extracts on cucumber shoot dry weights when attacked by green peach aphids (*Myzus persicae*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

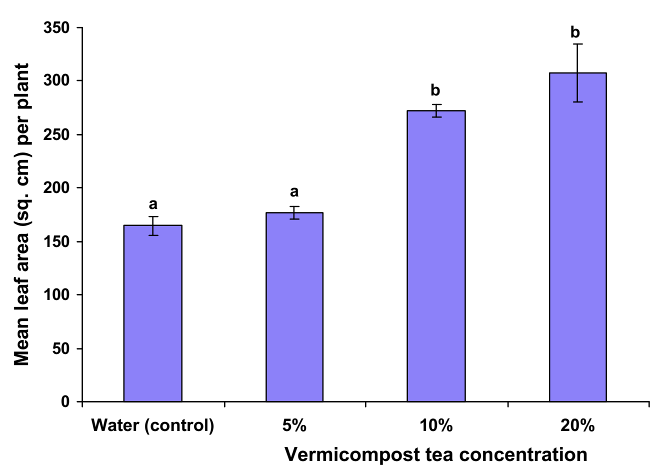

Fig. 12. Effects of food waste vermicompost aqueous extracts on cucumber mean leaf areas when attacked by green peach aphids (*Myzus persicae*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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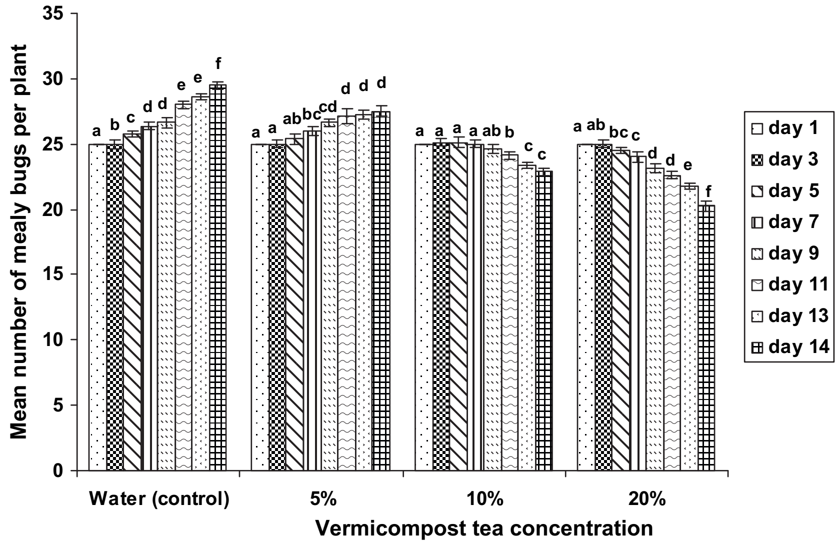

Fig. 13. Effects of food waste vermicompost aqueous extracts on citrus mealybug (*Planococcus citri*) numbers on tomatoes (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

weights (Fig. 23) and leaf areas (Fig. 24) in response to 10% and 20% extract treatments but not in response to the 5% extract treatment ($P \leq 0.05$).

3.3. Two spotted spider mite experiments

The two spotted spider mites were too small for their numbers to be counted on the leaves, but the damage that they caused was severe. Two spotted spider mite damage ratings on tomatoes between treatments increased from a rating of 1.0 on day 3 to a rating of 4.5 (out of a total of 5.0) on day 14 in the deionized water controls (Figs. 25 and 26). By comparison, damage ratings increased significantly ($P \leq 0.05$) from 0.5 to 2.5 in response to 5% extract treatments, from 0.5 to 2.0 in response to 10% extract treatments, and from 0.3 to 1.5 in response to 20% extract applications after 14 days.

Tomato dry shoot weights increased significantly ($P \leq 0.05$) in response to both the 10% and 20% extract applications but not to the 5% extract treatment (Fig. 27). Tomato leaf areas increased significantly ($P \leq 0.05$) in response to all of the extract application rates (Fig. 28).

For cucumbers infested by two spotted spider mites, damage ratings increased from 1.0 on day 3 to 5.0 (out of a total of 5.0) on day 14, in the deionized water control treatment. By comparison there were significantly lower increases ($P \leq 0.05$) from 0.5 to 2.9 in response to the 5% extract treatment, from 0.5 to 2.8 in response to the 10% extract treatment, and from 0.3 to 1.85 in response to the 20% extract treatment, after 14 days (Figs. 29 and 30). In terms of dry shoot weights only the 20% extract treatment increased shoot dry weights significantly ($P \leq 0.05$) but all three extract treatments (Fig. 31) increased the leaf areas of cucumbers infested with two spotted spider mites significantly ($P \leq 0.05$) (Fig. 32).

4. Discussion

We focused on tomatoes and cucumbers in these experiments because they are valuable greenhouse crops which are very susceptible to a range of foliar pests that are expensive to control.

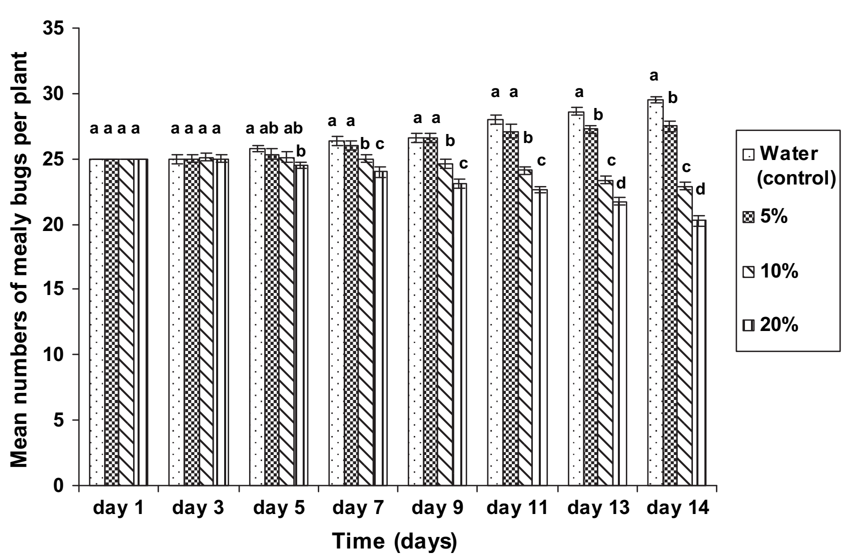

Fig. 14. Effects of food waste vermicompost aqueous extracts on citrus mealybug (*Planococcus citri*) numbers on tomatoes over time (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

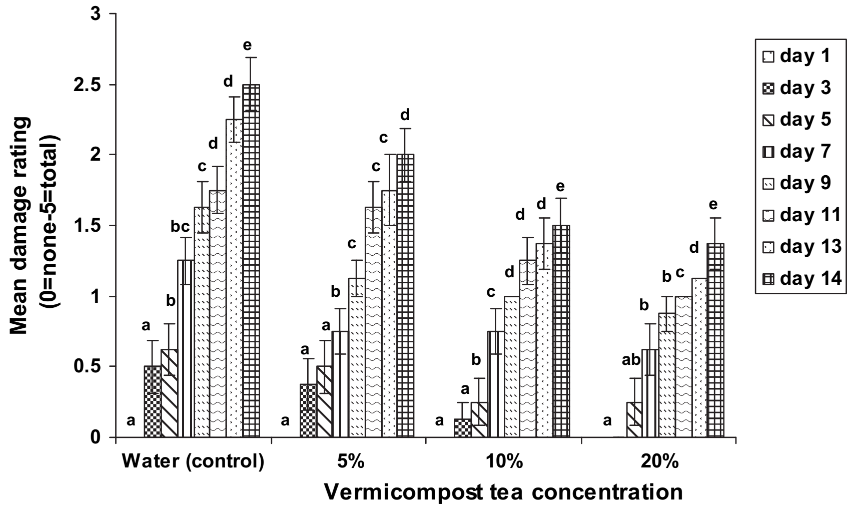

Fig. 15. Damage ratings (0–5) of citrus mealybugs (*Planococcus citri*) on tomatoes treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

The pests that we tested in our vermicompost aqueous extract experiments to assess the effects of the extracts on pest suppression were, green peach aphids, citrus mealybugs, and two spotted spider mites, which are all important pests of these crops, and the degree of suppression of these pests by the aqueous extracts was dramatic. The availability of such innovative organic control measures as aqueous vermicompost extracts would be particularly welcome to organic growers who are prohibited from using inorganic pesticides on their crops. Vermicomposting is a process that can be carried out at a range of scales using relatively simple to high technologies (Edwards and Arancon, 2004) and a variety of relatively inexpensive equipment for vermicompost extract preparation is available commercially.

Yardim et al. (2006) reported suppression of the chewing pests cucumber beetles and tomato hornworms by vermicomposts. There are a few reports in the scientific literature of the suppression of sucking pests by solid vermicomposts. Biradar et al. (1998) reported significant suppressive effects of vermicomposts on psyllid attacks, Rao et al. (2001) and Rao (2002) reported suppression of jassids, aphids and spider mites on groundnuts by vermicomposts. Arancon et al. (2006) reported suppression of aphids, mealybug, and spider mite attacks by solid vermicomposts.

The data presented in the research reported in this paper are the first detailed reports in the scientific literature, of the suppression of important sucking pests such as aphids, mealybugs and spider mites by aqueous extracts from vermicomposts. The overall effects of the aqueous vermicompost solutions on both numbers and damage by all three of these pests were dramatic, significant and consistent on two crops. Clearly, weekly applications of these aqueous extracts to tomatoes and cucumbers as soil drenches had three major effects. Firstly, since all three species of pests tested in the experimental cages had a free choice to infest the test plants, it seems that the application of all application rates of the aqueous extracts made both tomatoes and cucumber plants much less attractive to all three species of pests. The highest application rate of 20% aqueous extract stopped virtually all pest infestations and the 10% extract had major impacts on the extent of infestation. In a number of the experiments even the 5% extracts made the plants relatively unattractive to the pests.

The weekly soil drenches of vermicompost extract to the soil in which the plants grew must also have interfered with the reproduction patterns of the green peach aphids, citrus mealybugs and two spotted spider mites, since the increased rates of application of aqueous extracts decreased the rates of reproduction of the pests,

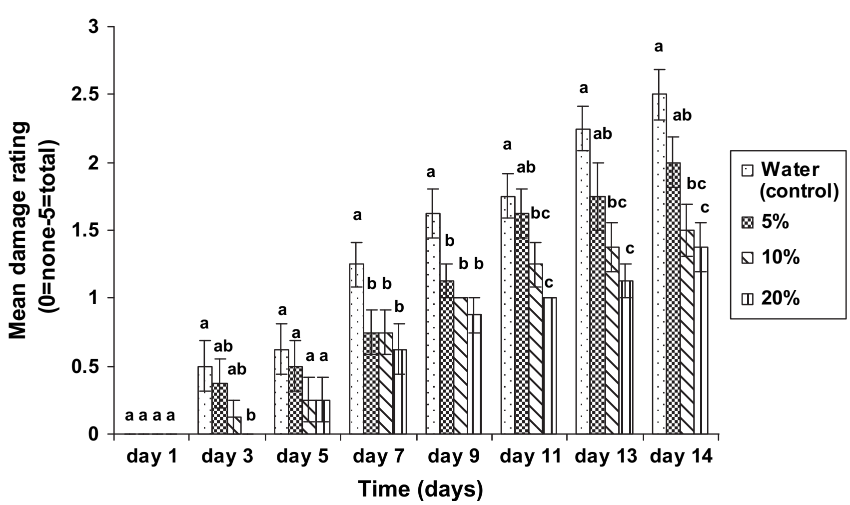

Fig. 16. Damage ratings (0–5) of citrus mealybugs (*Planococcus citri*) over time on tomatoes treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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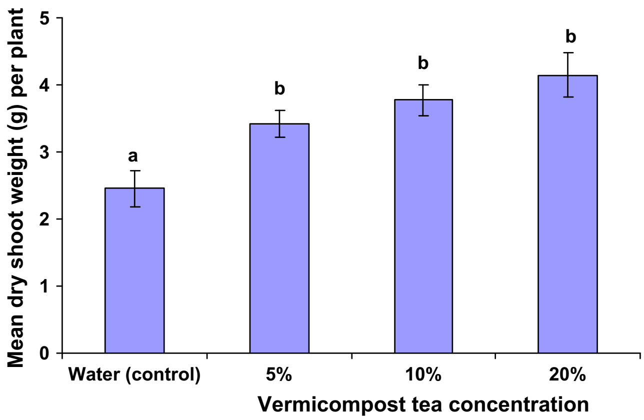

Fig. 17. Effects of food waste vermicompost aqueous extracts on tomato dry shoot weights attacked by citrus mealybugs (*Planococcus citri*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

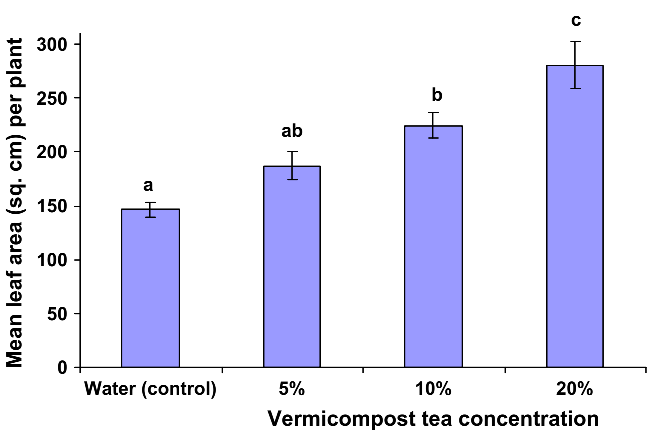

Fig. 18. Effects of food waste vermicompost aqueous extracts on tomato mean leaf areas attacked by citrus mealybugs (*Planococcus citri*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

because numbers of all three species leveled off or decreased particularly in response to the higher application rates of extracts. Finally, there was consistent evidence that the higher application rates of vermicompost extracts caused the pests to either leave the plants or die, since overall numbers of the pests on the crops decreased significantly with time in response to these higher application rates.

These results raise the question of possible mechanisms of how these vermicompost extract soil drenches may affect the response of the pests when taken up into the plants. There are many reports in the literature of organic nutrient sources decreasing numbers of pest arthropods (Culliney and Pimentel, 1986; Eigenbrode and Pimentel, 1988; Yardim and Edwards, 2003; Patriquin et al., 1995; Morales et al., 2001; Phelan, 2004). There have also been suggestions of these effects being due to the uptake into plants of phenols from organic manures (Ravi et al., 2006). However, although such mechanisms may account for the suppression of pest attacks by solid vermicomposts, they are unlikely to account for similar suppression by liquid extracts from vermicomposts applied to the soil in which the crops grow. Materials that can pass readily from the solid vermicomposts into the aqueous extracts include soluble nutrients, free enzymes, a wide variety of microorganisms, and water-soluble phenols.

Vermicomposts have much greater microbial diversity and activity than conventional thermophilic composts, because organic wastes that have been fragmented by earthworms have a much greater surface area and can support considerably greater microbial activity. By comparison, microbial activity tends to be suppressed by the high temperatures reached during thermophilic composting.

To identify the mechanism of pest suppression further, it is important to discuss which of the materials passing into the extracts could be responsible for the pest suppression, since the response must depend on uptake of these materials into the tomato and cucumber plants from the soil drenches. It could not be caused by uptake of soluble nutrients since all of the experimental treatments were supplied regularly with all the nutrients that they needed from Peter's Nutrient Solution, which was applied to the experimental plants three times a week. Possibly, some free enzymes in the aqueous extract could influence the pest suppression, but this is very unlikely on the scales and consistencies of suppression demonstrated in these experiments. For instance, the

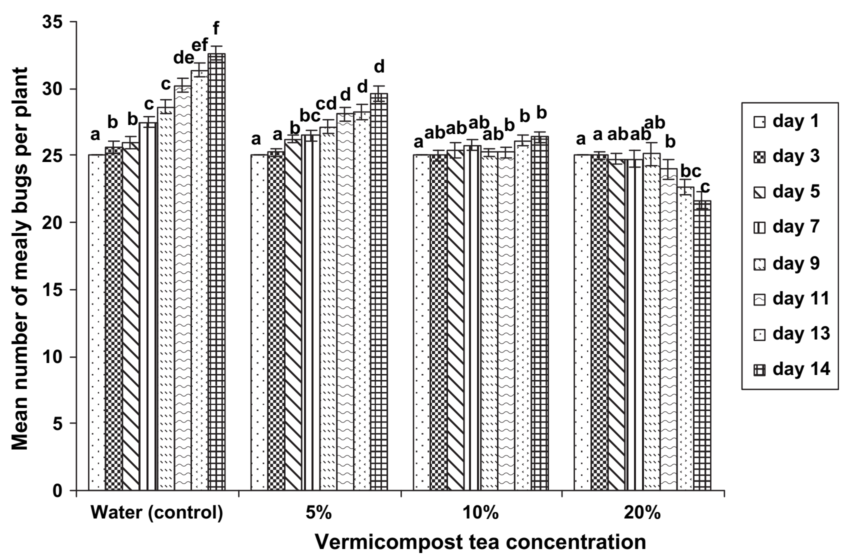

Fig. 19. Effects of food waste vermicompost aqueous extracts on citrus mealybug (*Planococcus citri*) numbers on cucumbers (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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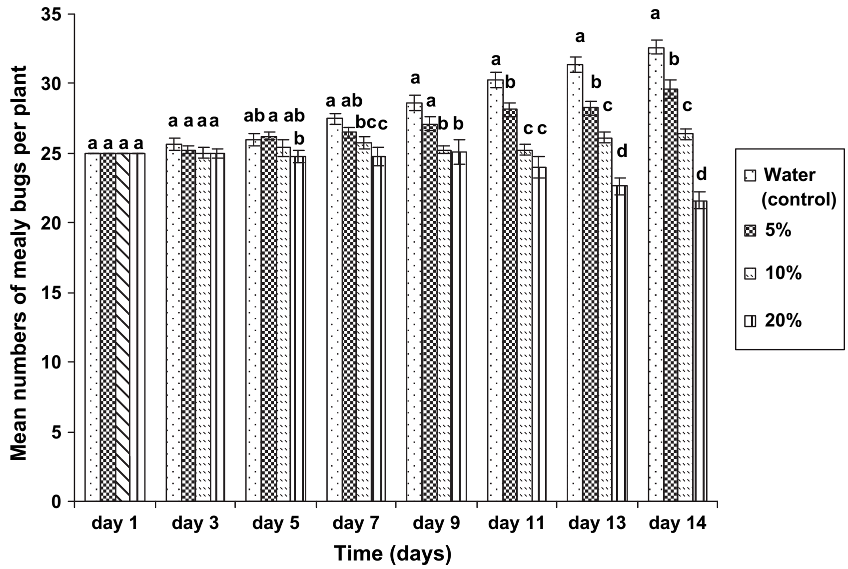

Fig. 20. Effects of food waste vermicompost aqueous extracts on citrus mealybug (*Planococcus citri*) numbers over time on cucumbers (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

enzyme chitinase has been reported to be present in some vermicomposts (Hahn, 2001) and it is feasible that this could affect arthropod pest molting, but there seem to be no reports in the literature of this enzyme having any effects on pests, although there is evidence it may have some influences on plant pathogens. We reviewed possible mechanisms by which microorganisms could be taken up into the tissues of plants and influence arthropod pest feeding but could not find any relevant reports.

The other possible mechanism by which vermicomposts and similar organic materials may suppress attacks by arthropod pests on the foliage and fruits of crop plants, could be to change the pests' feeding responses, due to soluble phenolic substances in the soil drenches that were taken up into plants from vermicomposts. It is well known that soluble phenolic substances are distasteful to secondary invertebrate decomposers in soil systems and can inhibit the breakdown of dead and decaying plant materials (Edwards and Heath, 1963; Heath and Edwards, 1964). An endogenous phenol oxidase enzyme has been extracted from an earthworm, *Lumbricus rubellus*, that is sometimes used in vermicomposting, and this compound can bioactivate organic compounds to form phenols, such as *p*-nitrophenol (Park et al., 1996). Polychlorinated phenols and their metabolites have been reported from a range of soils containing earthworms (Knuutinen et al., 1990). Vinken et al. (2005) reported that monomeric phenols could be absorbed by humic acids in the gut of earthworms.

Phenolics have been identified as common insect antifeedants (Koul, 2008). Stevenson et al. (1993) reported inhibition of the development of *Spodoptera litura* caterpillars by a phenolic compound present in wild groundnuts. Summers and Felton (1994) proposed that lepidoptera larval feeding was decreased by oxidative stress caused by phenolic compounds in plants. Haukioja et al. (2002) reported that phenolics in plant tissues decreased the rates of consumption of tissues by a geometrid caterpillar *Epirrita autumnata*. Phenols deterred feeding by southern armyworms,

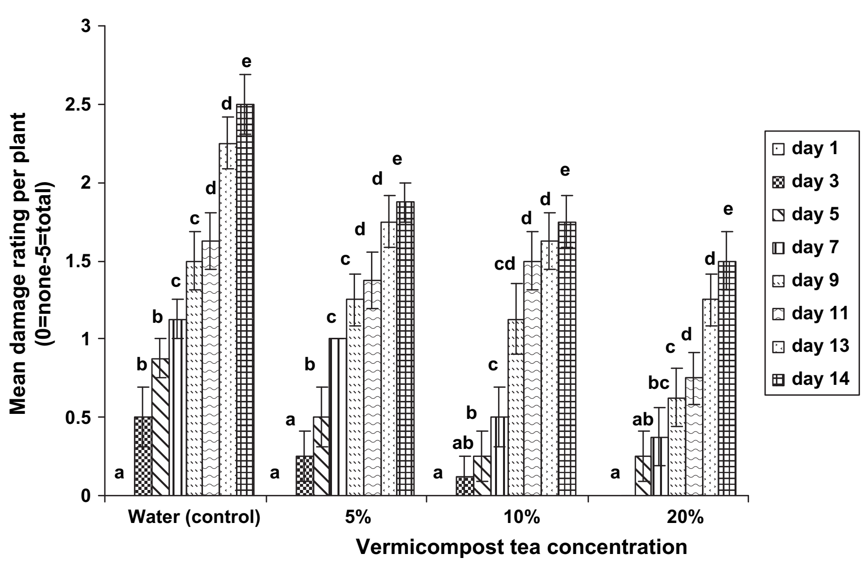

Fig. 21. Damage ratings (0–5) of citrus mealybugs (*Planococcus citri*) on cucumbers treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

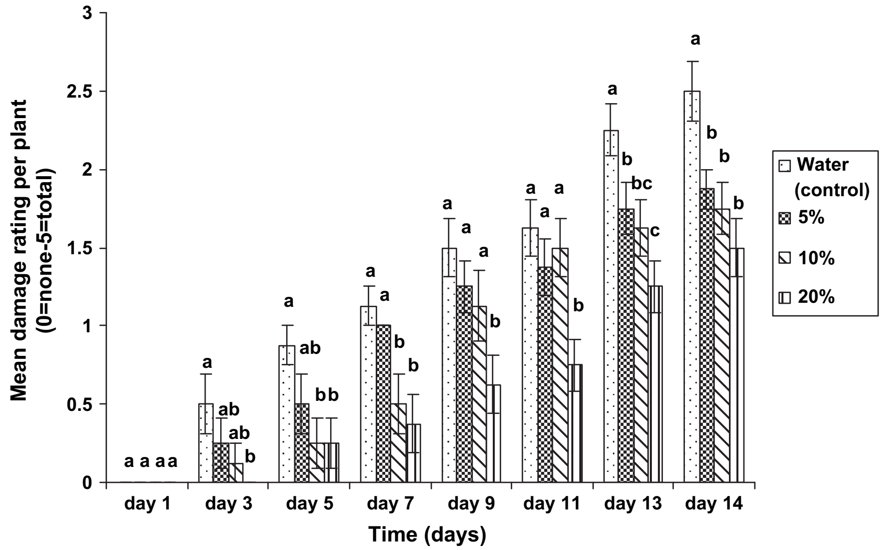

Fig. 22. Damage ratings (0–5) of citrus mealybugs (*Planococcus citri*) over time on cucumbers treated with a range of concentrations of food waste vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

Spodoptera eridania (Lindroth and Peterson, 1988). Kurowska et al. (1990) reviewed the effects of 46 phenols as insect repellents and feeding deterrents and concluded that many can have significant effects in this way on pest attacks. Bhonwong et al. (2009) reported that polyphenol oxidases in tomatoes could produce resistance to cotton bollworm (*Helicoverpa armigera*) and beet armyworm (*Spodoptera exigua*). They concluded that there was a clear feeding deterrent effect of these chemicals to the pests. Tomato phenol oxidase in tomato plants slowed down feeding and rates of growth of the common cutworm, *S. litura* F. (Mahanil et al., 2008). Plant phenolics affected the rates of development and survival of the autumn moth, *E. autumnata* (Hawida et al., 2007). These diverse results all point to the probability that water-soluble phenols, extracted from the vermicompost during aquatic extraction, taken up into plants from soil receiving drenches of vermicompost aqueous extracts, could be the most likely mechanisms by which vermicompost aqueous extracts can suppress pest attacks. A similar mechanism could account for the suppression of arthropod pests by solid vermicomposts (Arancon and Edwards, 2004; Arancon et al., 2005a,b).

Chrzanowski (2008) reported that phenolic acids in blackcurrant and sour cherry leaves slowed the reproduction and general fecundity of grain aphids (*Sitobian avenae*). Eleftherianos et al. (2006) reported that changes in the levels of total phenols in maize and barley plants decreased the fecundity of the cereal aphids *Rophalosiphum padi* and *S. avenae*. Galls induced by *Pemphigus populi* aphids on *Populus nigra* were suppressed by high levels of phenols in the plant tissues (El-Akkad and Zalat, 2000).

We hypothesize that the decreases in insect pest numbers and damage to plants grown with aqueous vermicompost extracts in our greenhouse experiments, could be attributed to the presence of water-soluble phenolic compounds in plants grown with vermicomposts and vermicompost aqueous extracts which make the plants less attractive to pests and interfere with their reproduction.

Although these conclusions are based on circumstantial evidence the breadth and weight of evidence makes it extremely likely that

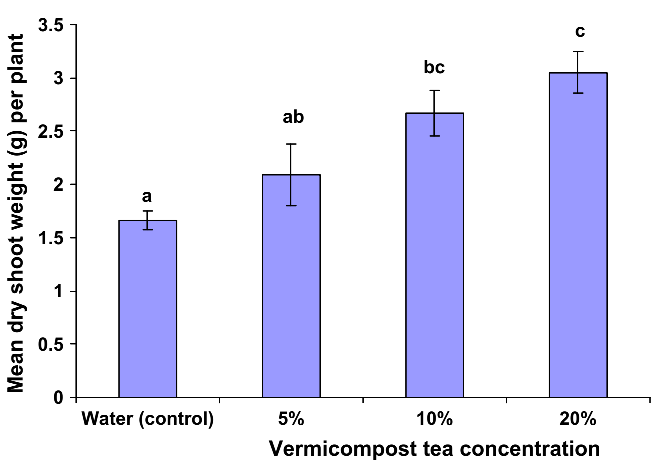

Fig. 23. Effects of food waste vermicompost aqueous extracts on mean dry shoot weights of cucumber plants attacked by citrus mealybugs (*Planococcus citri*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

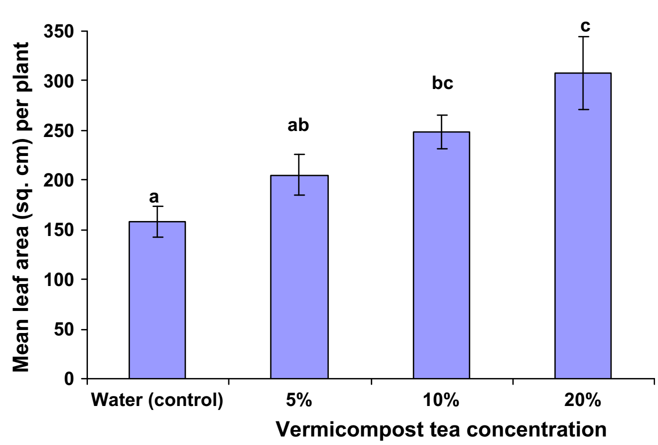

Fig. 24. Effects of food waste vermicompost aqueous extracts on mean leaf areas of cucumber plants attacked by citrus mealybugs (*Planococcus citri*) (mean ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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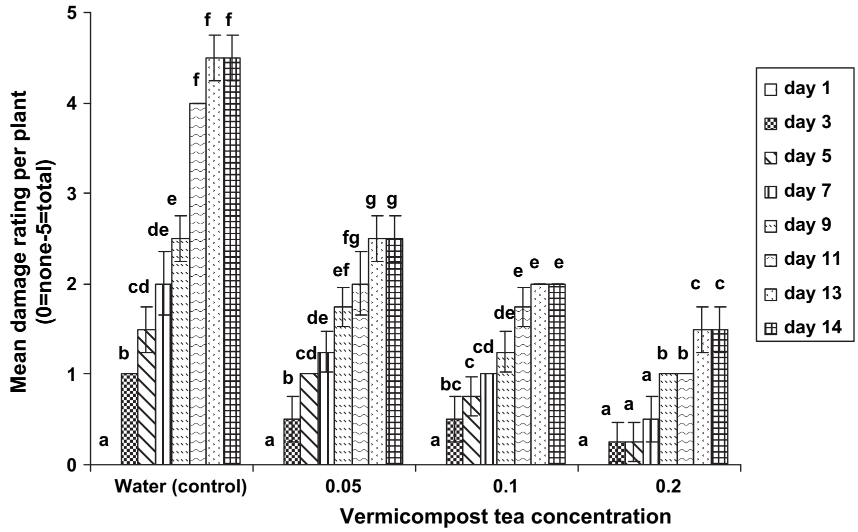

Fig. 25. Damage ratings (0–5) of two spotted spider mites (*Tetranychus urticae*) on tomatoes treated with a range of soil-applied vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

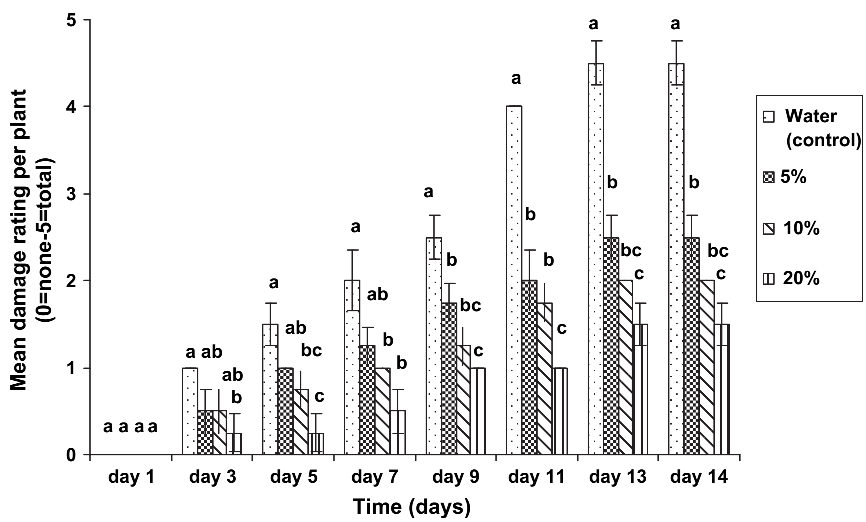

Fig. 26. Damage ratings (0–5) of two spotted spider mites (*Tetranychus urticae*) over time on tomatoes treated with a range of soil-applied vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

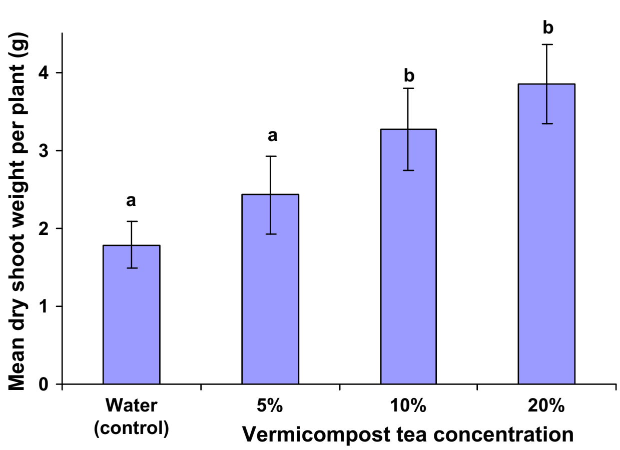

Fig. 27. Effects of a range of soil-applied vermicompost aqueous extracts on mean shoot dry weights of tomato plants attacked by two spotted spider mites (*Tetranychus urticae*) (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

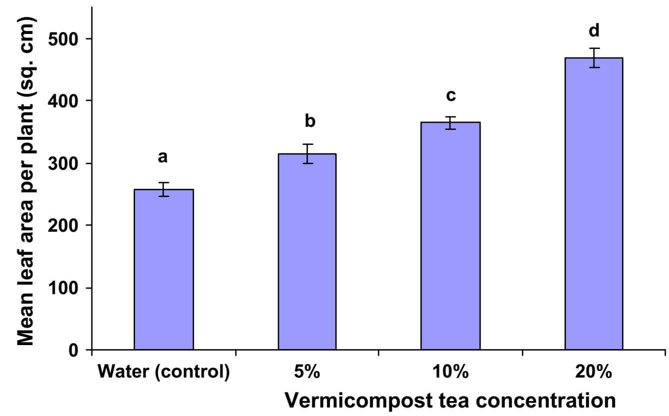

Fig. 28. Effects of a range of soil-applied vermicompost aqueous extracts on leaf areas of tomato plants attacked by two spotted spider mites (*Tetranychus urticae*) (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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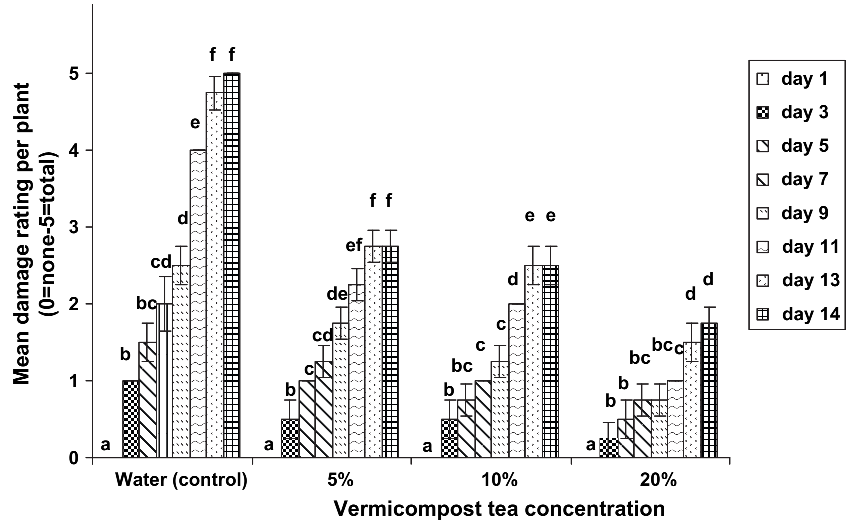

Fig. 29. Damage ratings (0–5) of two spotted spider mites (*Tetranychus urticae*) on cucumbers treated with a range of soil-applied vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

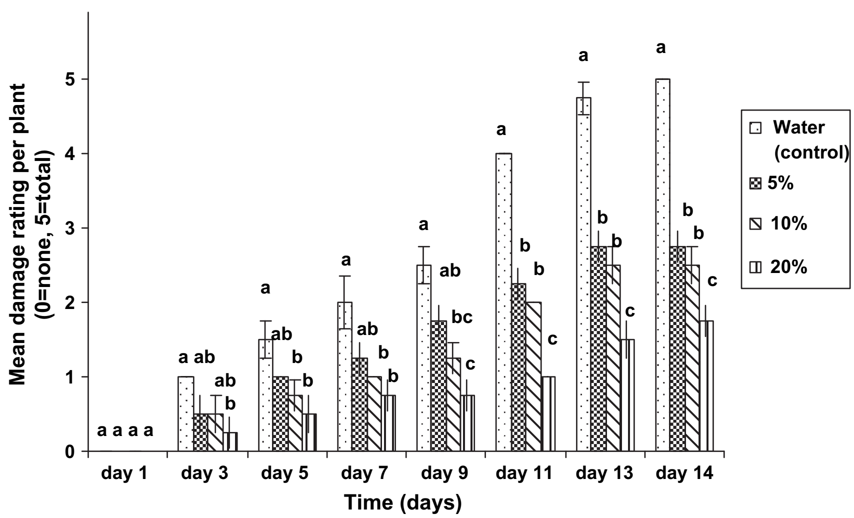

Fig. 30. Damage ratings (0–5) of two spotted spider mites (*Tetranychus urticae*) over time on cucumbers treated with a range of soil-applied vermicompost aqueous extracts (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

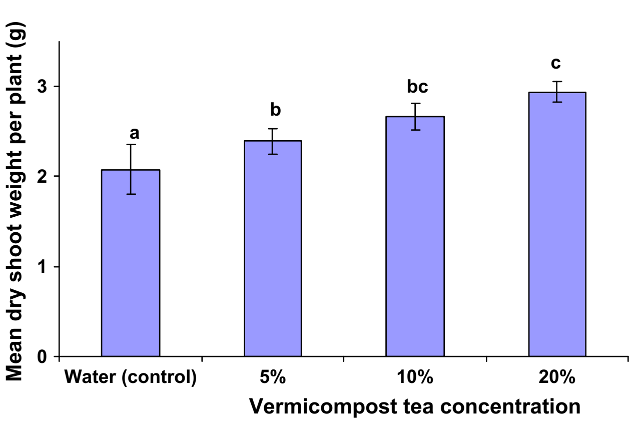

Fig. 31. Effects of a range of soil-applied vermicompost aqueous extracts on mean dry shoot weights of cucumber plants attacked by two spotted spider mites (*Tetranychus urticae*) (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

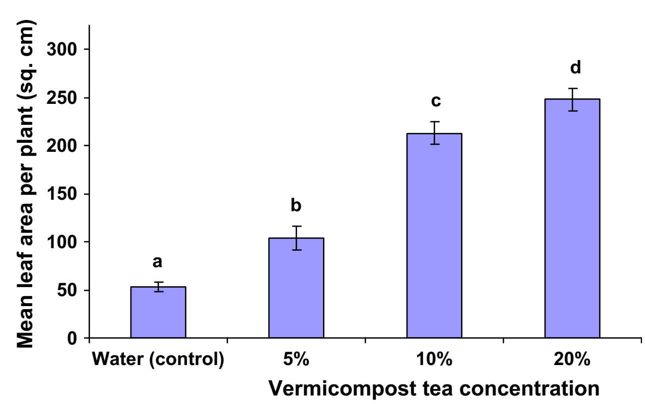

Fig. 32. Effects of a range of soil-applied vermicompost aqueous extracts on mean leaf areas of cucumber plants attacked by two spotted spider mites (*Tetranychus urticae*) (means ± S.E.). Means followed by the same letters are not significantly different for each treatment concentration ($P \leq 0.05$).

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water-soluble phenols, passing from vermicomposts into aqueous extracts and thence into plants, may be the main mechanism by which vermicompost aqueous extracts influence the suppressions of pest feeding, reproduction and mortality by aphids, mealybugs and spider mites reported in this paper.

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