Use of Controlled Atmospheres to Enhance Essential Oil Fumigant Toxicity against Western Flower Thrips, *Frankliniella occidentalis*

Ernst J Woltering[1], Alida F Janmaat[1,3] and Willem Jan de Kogel[2]
[1] Agrotechnological Research Institute (ATO), Wageningen University & Research Center, PO Box 17, 6700 AA Wageningen, The Netherlands. E.J.Woltering@ato.wag-ur.nl
[2] Plant Research International (PRI), Wageningen University & Research Center, PO Box 16, 6700 AA Wageningen, The Netherlands
[3] Current address: University of British Columbia, Dept. Zoology, 6270 University Boulevard, Vancouver, B.C. Canada V6T 1Z4

Abstract

The fumigant toxicity of selected essential oils was assessed against the Western Flower Thrips, *Frankliniella occidentalis.* Adult females and larvae were exposed to combinations of essential oil doses and increased carbon dioxide and decreased oxygen levels. Application of such combinations were found to significantly increase the fumigant toxicity against thrips. An increase in exposure time also led to an increase in mortalities in both essential oil alone and combined treatments. These results indicate that by combining applications of the essential oils with e.g. moderately increased carbon dioxide levels (2 to 10%), it may be possible to achieve toxicity levels similar to those of standard chemical fumigants.

INTRODUCTION

Fresh produce and flowers are being transported all over the world due to considerable advances in postharvest storage techniques and the ever widening global economy. This escalating commodity movement has inadvertently led to an increase in the transfer of a number of exotic pest organisms. Strict quarantine treatments are enforced at a number of ports of call to limit the introduction of hitchhiking pests. The primary quarantine treatment method currently used is fumigation with methyl bromide (Yokoyama, 1994). Methyl bromide has been identified as a contributor to ozone depletion which has led to the formation of an international agreement under the United Nations Environment Programme Montreal Protocol to phase out methyl bromide use.Therefore, there is an urgent need to find an alternative to methyl bromide.

Research into the use of volatile essential oils or other natural compounds has provided a promising alternative, however, no such compounds tested have proven to be equally effective as methyl bromide. Essential oils are composed of secondary plant chemicals that are thought to play a role in plant defense against phytophagous insects, bacteria and fungi (Whittaker, 1970). Monoterpenoids comprise the majority of the essential oil components and they have been widely assayed for insecticidal properties (Rice and Coats, 1994; Regnault-Roger and Hamraoui, 1995; Shaaya et al., 1991, 1997).

Studies of essential oil toxicity have largely focused on the identification of suitable components under standard air conditions. However, it is possible that the result of toxicity studies will vary with the fumigation condition. Studies of traditional fumigants have identified that altering fumigation conditions such as temperature, CO_2 levels and atmospheric pressure leads to changes in toxicity. Enhanced CO_2 levels (30-40%) increased the action of phosphine and methyl bromide against stored product pests in many studies (Kashi and Bond, 1975; Desmarchelier et al., 1984; Rajendran, 1990). Therefore, it seems likely that altering fumigation conditions will also lead to changes in essential oil toxicity.

In the present study, the interaction between decreased levels of oxygen and increased levels of CO_2 and some essential oils on Western Flower Thrips (*Frankliniella occidentalis* Pergande) mortality was examined. *F. occidentalis* was chosen as the test organism due to its significance as a quarantine pest in the export of cutflowers.

Proc. 8th Int. CA Conference
Eds. J. Oosterhaven & H.W. Peppelenbos
Acta Hort 600, ISHS 2003

MATERIALS AND METHODS

F. occidentalis were maintained on flowering yellow chrysanthemums (variety Sunny Casa) in an isolated greenhouse kept at 25^oC and 70% RH at Plant Research International (Wageningen, the Netherlands). The thrips fumigation treatment was done in a 300 mL glass jar containing a small petri dishe (d=3.5 cm) with water-agar and a bean leaf disc. Fifteen female insects were placed on the bean leaf disc. Cut "First Red" roses were treated with essential oils in 70L stainless steal containers, eqiupped with a small fan to ensure proper distribution of the oil vapor.

Appropriate amounts of esential oils were applied through a rubber septum to a filter paper in the jar or container. The atmosphere in the fumigation containers was adjusted to the appropriate O_2 and CO_2 levels by adding volumes of N_2 and CO_2 through the rubber septum by syringe. Fumigation jars were flushed with air for one hour following fumigation. The fumigation jars were then inspected immediately for the presence of live or dead thrips.

RESULTS AND DISCUSSION

LD_{50} values were determined for different essential oils after 3h of treatment. Roughly, sensitivity of thrips life stages and 'First Red' roses showed a positive relation. Oils that were toxic to thrips were also highly toxic to rose flowers, indicating that use of such oils is not a viable concept (Table 1). When such oils or mixtures of oils were applied together with an increased carbon dioxide or decreased oxygen concentration, a marked increase in mortality was observed. Although the applied high carbon dioxide and low oxygen levels alone did not cause significant mortality, it markedly enhanced the toxic properties of essential oils (Table 2). This indicated that combined treatments of essential oils and modified atmosphere may be a way to achieve high insect mortality while avoiding damage to the produce.

In the horticultural industry the use of increased carbon dioxide levels is more practical than decreased levels of oxygen. Therefore, the effect of carbon dioxide together with some other oils was tested. A marked synergism was again observed using different oils and a moderate level (10%) of carbon dioxide (Figure 1). This shows that the putative toxicity of essential oils against thrips is very dependent on the other environmental conditions and oils with little or no toxicity under standard conditions (e.g. limonene, cypress oil) may be very toxic under conditions of increased carbon dioxide.

A more detailed study was carried out using p-cymene and different fumigation times and carbon dioxide levels on adult female mortality. Fumigation with p-cymene alone over a 24-hour period resulted in 57±22% adult female thrip mortality at the highest dose tested (10 μl = ~2500 μg/L) (Figure 2). Addition of 10% CO_2 significantly increased the mortality of adult female thrips exposed to p-cymene resulting in 99±3% mortality after 24h at the highest dose tested. The LD_{50} of p-cymene applied in combination with 10% CO_2 after a 24 h fumigation period was 4.0 μl (3.5-4.5 μl) as compared to 11.6 μl (8.9-16.8 μl) when applied alone. CO_2 at 10% alone did not significantly increase thrips mortality without p-cymene.

Increases in exposure time from 2 h to 24 h and from 24 h to 48 h also resulted in a significant increase in thrip mortality. The mean difference in mortality caused by an increase in exposure time from 2 to 24h or 24 to 48h was 11.9% as compared to a difference of 44% caused by the addition of 10% CO_2 to the p-cymene treatment. In preliminary experiments, mortality was assessed 1 hr and 24 h following fumigation. There was an overall increase in thrips mortality between the two observation periods of 8.4±1.0%. The change in thrip mortality over the post-fumigation 24 h period was not significantly affected by the 10% CO_2 treatment, exposure period or p-cymene dose.

Lower dosages of CO_2 were also found to significantly increase thrips mortality when applied in combination with the essential oils. CO_2 treatments of 2.5 and 5% were found to significantly increase thrip mortality when applied in combination with p-cymene (Figure 3). Both treatments resulted in 100% thrips mortality when applied in combination with p-cymene. Addition of 2.5 and 5% CO_2 to control jars did not increase thrips mortality as compared to control mortality.

Addition of carbon dioxide (2-10 %) to essential oil treatments generally led to an increase in the mortality of *F. occidentalis* adult females. 100% mortality was attained by exposure to combined treatments for 24 and 48 h. At CO_2 levels as low as 1% insects are known to increase spiracle opening and this may facilitate the diffusion of fumigants into the tracheae (Wigglesworth, 1972). The success of combined CO_2 and p-cymene treatments at low CO_2 levels is directly applicable to practical situations. These results indicate that combined controlled atmosphere and essential oil treatments are an effective and promising alternative to traditional fumigants.

ACKNOWLEDGEMENTS

We would like to acknowledge the technical support received from Mariska Nijenhuis-de Vries, Agrotechnological Research Institute and Gerrie Wiegers, Plant Research International.

Literature Cited

Desmarchelier, J.M., Wohlgemuth, R., & Ripp, B.E. (1984). Response of several species of insects to mixtures of phosphine and carbon dioxide. Amsterdam, Elsvier. Proceedings of an international symposium on "Practical aspects of controlled atmosphere and fumigation in grain storages", pp 75-81.

Kashi, D.P. & Bond, E.J. (1975). The toxic action of phosphine: role of carbon dioxide on the toxicity of phosphine to *Sitophilus granarius* (L.) and *Tribolium confusum* DuVal. *J Stored Prod Res*, 11, 9-15.

Rajendran, S. (1990). The toxicity of phosphine, methyl bromide, 1,1,1-trichloroethane and carbon dioxide. *Pestic Sci*, 29, 75-84.

Regnault-Roger, C. & Hamraoui, A. (1995). Fumigant toxic activity and reproductive inhibition induced by monoterpenes on Acanthoscelides obtectus (Say)(Coleoptera: Tenebrionidae). *J Stored Prod Res*, 31, 291-9.

Rice, P.J. & Coats, J.R. (1994). Insecticidal properties of several monoterpenoids to the house fly (Diptera: Muscidae), Red Flour Beetle (Coleoptera: Tenebrionidae) and Southern Corn Rootworm (Coleoptera: Tenebrionidae). *J Econ Ent*, 87, 1172-9.

Shaaya, E., Kostjukovski, M., Eilberg, J., & Sukprakarn, C. (1997). Plant oils as fumigants and contact insecticides for the control of stored-product insects. *J Stored Prod Res*, 33, 7-15.

Shaaya, E., Ravid, U., Paster, N., Juven, B., Zisman, U., & Pissarev, V. (1991). Fumigant toxicity of essential oils against four major stored-product insects. *J Chem Eco*, 17, 499-504.

Whittaker, R.H. (1970). The biochemical ecology of higher plants. In *Chemical Ecology*, ed. E. Sondheimer and J. B. Simeone, Academic, New York, pp. 43-70.

Wigglesworth, V.B. (1972). *The principles of insect physiology.*, Chapman and Hall, London, 1972.

Yokoyama, V.Y. (1994). Fumigation. In *Quarantine Treatments for Pests of Plant Food.*, ed. J.L. Sharp and G.J. Hallman, Westview Press, Boulder, pp. 67.

Tables

Table 1. Thrips mortality (LD50 values in µg/L) and concentration resulting in significant damage to leaves or flowers in 'First Red' roses following treatment with essential oils for 3h at 20°C.

Compound	Larvae LD50 (µg/L)	Female adult LD50 (µg/L)	Rose damage (µg/L)
1.8-cineol	2100	900	~3000
p-cymene	2700	1700	~3000
linalool	220	180	250
(+)-carvon	95	70	50

Table 2. Effect of natural oils combined with different oxygen and carbon dioxide levels on thrips larvae mortality after a 3h treatment at 20°C. A sub-optimal dose of the essential oil mixture (cymene/linalool) was applied.

Condition	Thrips larvae mortality (%)	
	No oil added	Sub-optimal oil dose
Air	0	13
10 % oxygen	2	7
2 % oxygen	0	27
0.2 % oxygen	10	**58**
2 % carbon dioxide	2	22
10 % carbon dioxide	0	34
30 % carbon dioxide	0	**40**
60 % carbon dioxide	4	**41**

Figures

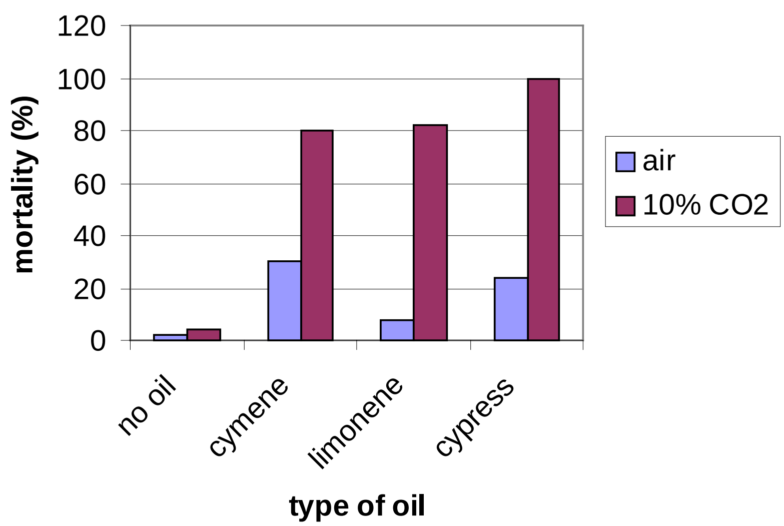

Fig. 1. Effect of combined treatments of essential oils and 10% carbon dioxide on adult female thrips mortality after 24 h of treatment at 20°C. 10 µl of oil was applied to 300 mL glass jars yielding oil gaseous concentrations of 2- 3000 µg/L.

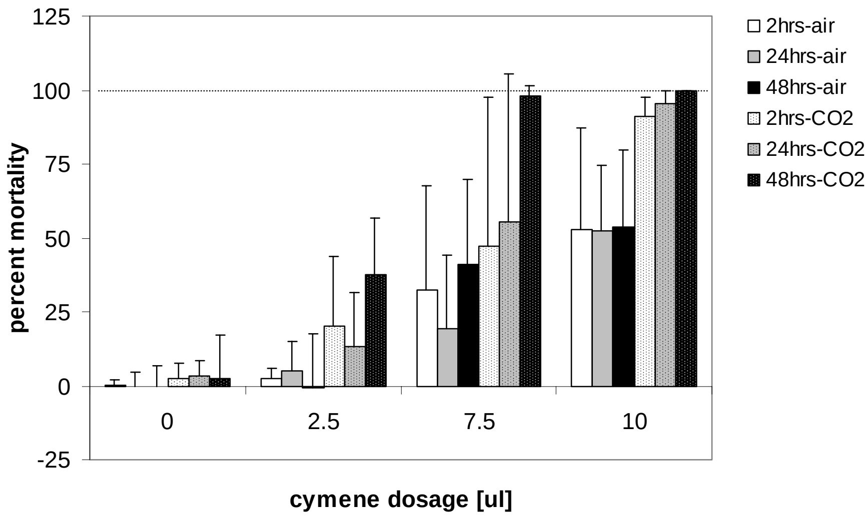

Fig. 2. Interaction between cymene dose (0 – 10 µl applied to 300 mL jar), exposure time (2, 24 and 48 h) and carbon dioxide (0 and 10%) on adult female thrips mortality at 20°C.

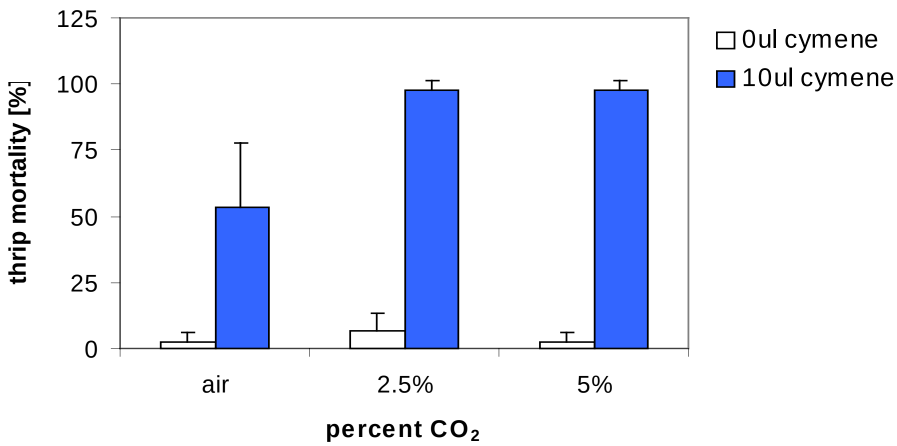

Fig. 3. Effect of carbon dioxide on adult thrips mortality when treated with p-cymene (10 µl cymene added to 300 mL jar) for 24 h at 20 °C.