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(54) **CIS-JASMONE AS SEMIOCHEMICAL**

CIS-JASMON ALS SEMIO-CHEMIKALIE

CIS JASMONE COMME SUBSTANCE SEMIOCHIMIQUE

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## Description

**[0001]** This invention relates to a new use of a material as a semiochemical, for example a plant stress signal, and to a method of changing the physiology of plants comprising the exposure of plants to this material.

**[0002]** Methyl salicylate has been reported as repelling the black bean aphid, *Aphis fabae*, and cereal aphids including the grain aphid, *Sitobion avenae*, and also inhibiting attraction to their host plants. See *J. Chem. Ecol.* **20**, 2565-2574 (1994) (Pettersson *et al.*) and *J. Chem. Ecol.* **20**, 2847-2855 (1994) (Hardie *et al.*). It was suggested that this repellency arose from the relationship of methyl salicylate with salicylic acid and inducible plant defence mechanisms, with the metabolite methyl salicylate acting as a volatile and thereby external signal; the presence of methyl salicylate signalled that chemical defence was induced, and the otherwise attractive host plants were thus perceived as unsuitable hosts by the aphid pests.

**[0003]** More recently, it has been shown that methyl salicylate also acts as an airborne signal mediating plant pathogen resistance. See *Nature* **385**, 718-721 (1997) (Shulaev *et al.*). Methyl salicylate was initially identified by Pettersson *et al.* as an aphid semiochemical (for example a behaviour-controlling chemical or a signal otherwise influencing the physiology of the organism) by gas chromatography (GC) coupled directly to a single cell recording (SCR) from the olfactory organs on the antenna. Subsequently, more than thirty species of insects, both plant-feeders and their natural enemies, from four orders have been found to possess highly specific and sensitive olfactory receptors for this compound.

**[0004]** WO-A-91/19512 (Washington State University Research Foundation) discloses a method of inducing plant defence mechanisms using jasmonic acid or its esters, or substituted derivatives thereof. The compound induces the production of plant defence proteins, such as proteinase inhibitors, and can promote insect, pathogen or viral resistance in plants by inducing the expression of plant defence genes. Plants may be contacted with the compound by direct application to plant tissue or by airborne transmission of the compound. The expression of plant defence proteins is useful in protecting the plants from the effects of insect attack, but does not prevent the insects in question from attacking the plants. The plants, together with any adjacent plants, will continue to be attacked by predators. The effect moreover is generally short-lived and disappears after removal of the stimulus.

**[0005]** Jasmonic acid and methyl jasmonate, along with a number of other materials, are also discussed by Karban and Baldwin in *Induced Responses to Herbivory* 12-46 (The University of Chicago Press, Chicago, 1997).

**[0006]** Another material, *cis*-jasmane, is well known as a volatile component of plants and its release can be induced by damage, for example during feeding on cotton by lepidopterous larvae. See *J. Chem. Ecol.*, **21**, 1217-1227 (1995) (Loughrin *et al.*). It is a fragrant material and has often been used for this desirable property. US-A-4788164 (Che *et al.*/Hoechst Celanese Corporation) discloses a sustained release composition including a fragrance or an insect repellent. One example (example IV) uses a solution containing jasmane to impart the odour of jasmine.

**[0007]** US 5665344 (Pair *et al.*/The United States of America as represented by the Secretary of Agriculture) indicates that compositions of *cis*-jasmane were found to attract adult Lepidoptera. The *cis*-jasmane may be used alone or in combination with one or more other volatiles of the Japanese honeysuckle flower, particularly linalool and/or phenylacetaldehyde. By attracting the adult Lepidoptera to attracticidal baits and/or field traps, the attractants are said to be useful for the control and monitoring of these agricultural pests. The *cis*-jasmane may be combined with an insect toxicant or pesticide to kill these pests.

**[0008]** WO 98 00023 A discloses a method of protecting a plant against a pathogen comprising a compound which induces the expression of a plant defensin gene by stimulating the jasmonate pathway. As inducers are described jasmonic acid, jasmonate and jasmonate like compounds.

**[0009]** Chemical Abstracts, vol.124, no.3; 15 January 1996, abstract no. 23889, & *J.Agric.Food Chem.*, vol. 44, no. 1, 1996, pages 206-209 describes a mixture released from a flower (Japanese honeysuckle) which is able to attract Lepidoptera. The mixture contains 27 compounds.

**[0010]** Chemical Abstracts, vol.99, no.21, 21 November 1983; abstract no 172845 & *J.Agric.Food Chem.*, vol.31, no.6, 1983, pages 1167-1170 describes the mixture released from Acacias (*acacia berlandieri* and *acacia rigidula*) which attracts a fly *Cochliomyia hominivorax*.

**[0011]** Chemical Abstracts, vol.114, no.5, 4 February 1991; abstract no. 39576, & *J.Chem.Ecol.*, vol.16, no.9, 1990, pages 2647-2666 studies the olfactory sensitivity of two sympatric species of rice leaf folders to plant volatiles including *cis*-jasmane, for which the insects are sensitive. The compound is considered as a potential attractant.

**[0012]** Chemical Abstracts, vol. 126, no.4, 27 January 1997; abstract no. 45169 & *J.Chem.Ecol.*, vol.22, no.10, 1996, pages 1735-1766 describes the olfactory sensitivity of moths to plant volatiles including *cis*-jasmane, for which an important signal is shown, and which is described as a potential attractant.

**[0013]** Chemical Abstracts, vol. 127, no.1, 5 January 1998; abstract no. 366208, *Helv.Chim.Acta*, vol.80, no.3, 1997, pages 838-850 discloses the biosynthesis of *cis*-jasmane from jasmonic acid and methyl-1,2-didehydrojasmonate in plants.

**[0014]** Chemical Abstracts, vol.113, no.15, 8 October 1990; abstract no. 129467, & *Shokubutso No Kagaku Choset-*

su, vol.24, no.2, 1989, pages 147-150 states that *cis*-jasmone is inactive to induce potato tuber formation.

**[0015]** Chemical Abstracts, vol. 122, no.7, 13 February 1995; abstract no. 76939 & Proc.Natl.Acad.Sci.USA., vol. 91, no.25, 1994, pages 11836-11840 describes the emission of volatile compounds from cotton plants attacked by herbivorous insects, including *cis*-jasmone.

**[0016]** Biological Abstracts, I, vol.96, Philadelphia, PA, US; abstract no. 467116 & Nature biotechnology, vol14, no. 9, 1996, pages 1129-1132 describes the production of paclitaxel and baccatin induced by *cis*-jasmone in cell suspension culture.

**[0017]** Database Chemabs [Online] Chemical Abstracts Service, accession no. 129;64289 CA & Environ Entomol., vol.27, no.2, 1998, pages 395-400 discloses the attraction of beetles by *cis*-jasmone compositions.

**[0018]** Pesticide Science, vol.55, no.3, March 1999 (1999-03), pages 225-235 relates to semiochemical compounds.

**[0019]** We have now discovered that *cis*-jasmone also has direct signalling roles with plant-feeding aphids, in attraction of aphid predators and parasitoids, and as an airborne signal inducing production of volatile plant components, including the monoterpene (*E*)- $\beta$ -ocimene, that stimulate foraging by parasitoids. This signalling role is qualitatively different from that of the biosynthetically related methyl jasmonate and gives a long-lasting effect after removal of the stimulus. In contrast to what the prior art suggests, it may be used to attract insects which are beneficial to the plants concerned or to repel undesirable insects.

**[0020]** Thus according to the present invention there is provided the use of *cis*-jasmone as a semiochemical that changes the physiology of plants.

**[0021]** A semiochemical may be regarded as a chemical signal causing a behavioural change or some other physiological change but without generally being directly involved in that process.

**[0022]** The invention may involve the use of *cis*-jasmone as a plant stress signal or otherwise, and is particularly applicable when *cis*-jasmone is used on plants so as to cause insect repellency or attractancy.

**[0023]** The terms "beneficial" and "undesirable", when used in connection with insects, indicate either their desirability to man or, when the *cis*-jasmone is used on plants, their desirability to the plant concerned. However, when the *cis*-jasmone is used on plants to change the physiology of those plants, the invention is not restricted to the ability of the compound to attract beneficial insects or repel undesirable insects.

**[0024]** *cis*-Jasmone may be used as a repellent of plant-feeding insects, such as plant-feeding aphids. It is however particularly useful as an attractant of beneficial insects, including insect predators and insect parasitoids, especially predators or parasitoids of plant-feeding aphids. It may also, by signifying a plant under stress, encourage some herbivores to attack the apparently weakened plant.

**[0025]** *cis*-Jasmone may be used to induce the production of volatile plant semiochemicals, such as (*E*)- $\beta$ -ocimene, (*E,E*)- $\alpha$ -farnesene, (-)- $\beta$ -caryophyllene and (*E*)-4,8-dimethyl-1,3,7--nonatriene. We have found that (*E*)- $\beta$ -ocimene is particularly prevalent following exposure of plants to *cis*-jasmone, especially when it is used to induce the production of volatile semiochemicals from bean plants.

**[0026]** In a further aspect of the invention, we provide a method of changing the physiology of plants comprising the exposure of the plants to *cis*-jasmone.

**[0027]** The *cis*-jasmone may be applied direct to plant tissue by foliar application, but preferably plants are exposed to air containing *cis*-jasmone. The *cis*-jasmone is used at a concentration of 10-1000  $\mu$ g per litre of air, but particularly favourable results are obtained when the *cis*-jasmone is used at a concentration of 50-200  $\mu$ g per litre of air, more particularly 75-125  $\mu$ g per litre of air and especially in the region of 100  $\mu$ g per litre of air. This might be achieved by putting the *cis*-jasmone in an encapsulated form for aerial release.

**[0028]** The *cis*-jasmone may lead to the repelling or attraction of insects to the plants, for example the repelling of plant-feeding insects such as aphids. It is particularly useful when it leads to the attraction of insect predators or insect parasitoids, especially predators or parasitoids of plant-feeding aphids. This signal would be of immense value for the many areas in which it would be preferable to regulate gene expression, i.e. switch genes on, for the various requirements of crop protection, nutrition or yield timing. Attention may be drawn to the book, *Induced Responses to Herbivory* (The University of Chicago Press, Chicago, 1997) by Karban and Baldwin, where the need for plant-defence inducing signals such as that forming the subject of the present invention is emphasized. Using a signal will result in plant energetics not being wasted. Problems with pest resistance would be obviated by useful genes only expressing their products when required.

**[0029]** Thus, the invention includes the use of *cis*-jasmone as a semiochemical that changes the physiology of plants, wherein the *cis*-jasmone is used to effect gene expression.

**[0030]** In order that the invention may be better understood, it will now be described with reference to the following drawings in which—

Fig. 1 shows back transformed mean numbers of cereal aphids per 60 tillers of winter wheat, *Triticum aestivum*, following treatment with *cis*-jasmone on 5 May and 11 June 1999, with an asterisk (\*) denoting significant difference between treatments;

Fig. 2 shows levels of (*E*)- $\beta$ -ocimene produced by bean plants, *Vicia faba* (Fabaceae), during 48 hour entrainments following 24 hour exposure to *cis*-jasmonate (100  $\mu$ g/l in air);

Fig. 3 shows, for comparison with the above *cis*-jasmonate example, levels of (*E*)- $\beta$ -ocimene produced by *V. faba* during 48 hour entrainments following 24 hour exposure to methyl jasmonate (100  $\mu$ g/l in air); and

Fig 4. shows differential expression of a gene-specific sequence (D251) in *Vicia faba* plants. Total RNA was isolated from stem or leaf tissue of plants exposed to air, methyl jasmonate or *cis*-jasmonate. 10  $\mu$ g RNA per sample was loaded and separated on a formaldehyde gel (Panel A). The samples were then transferred to a nylon membrane and probed with the D251 sequence (Panel B). Lane 1 = air treatment (control); lane 2 = *cis*-jasmonate treatment; lane 3 = methyl jasmonate treatment. In the case of RNA isolated from leaf tissue, only *cis*-jasmonate treatment results in upregulation.

**[0031]** Not forming part of the invention claimed here, *cis*-Jasmonate was also investigated for behavioural activity with the alate forms of the lettuce aphid *Nasonovia ribis-nigri* (Homoptera: Aphididae) in a 4-way olfactometer, and was found to be significantly repellent (the mean number of entries into the treated arm was  $2.0 \pm 0.58$ , whereas the mean number of entries into the control arms was  $4.3 \pm 0.58$ ; the mean time spent in the treated arm  $0.5 \pm 0.16$  minutes, whereas the mean time spent in the control arms was  $2.1 \pm 0.36$  minutes;  $P < 0.05$ ). Repellency was also demonstrated in preliminary field trials with summer morphs of the hop aphid, *Phorodon humuli*, where catches in water traps with visual (yellow) attractancy were reduced by 40% ( $P < 0.04$ ) through a slow release of *cis*-jasmonate (2.05  $\mu$ g/day/trap).

**[0032]** Field-trapping experiments were also conducted using *cis*-jasmonate against pollen beetles. Attractive yellow bowl traps, at 1 m height and 10 m spacing, were placed in a Latin square design (one row of the Latin square = one replicate; traps are re-randomized to the next row of the square when a mean of 10 beetles are caught per trap). Catches in an unbaited bowl were compared with those bowls baited with *cis*-jasmonate released at two different rates. Analysis was by ANOVA, on transformed total catch data. The transformation used was  $x = \log_{10}(y + 1)$ , where  $x$  and  $y$  are the transformed and untransformed data, respectively. Transformed means were compared using the LSD (least standard difference) test and transformed back to give the results as set out in Table 1.

TABLE 1.

Field-trapping experiments using <i>cis</i> -jasmonate against pollen beetles.			
	Back-transformed mean catch per replicate		
	Experiment A	Experiment B	Analysis A
unbaited trap	48.3 <sup>a</sup>	333.1 <sup>a</sup>	127.3 <sup>a</sup>
<i>cis</i> -jasmonate 2.2 mg/day	38.2 <sup>ab</sup> (21%)	130.7 <sup>bc</sup> (60%)	70.9 <sup>b</sup> (44%)
<i>cis</i> -jasmonate 25 mg/day	31.4 <sup>b</sup> (35%)	84.6 <sup>c</sup> (75%)	51.7 <sup>c</sup> (59%)

The means in the same column, followed by different letters, are significantly different.  $P < 0.05$ . Numbers in brackets are the per cent reduction in trap catch compared with the unbaited trap.

**[0033]** Fig. 1 shows the comparison of mean numbers of cereal aphids on *cis*-jasmonate treated and untreated plots in field studies on five sampling dates. The data have been transformed back from the logs to ease presentation. Aphid numbers were consistently lower in the *cis*-jasmonate plots and differed significantly from the control on the last two sample dates. The predominant aphid species was *Metopolophium dirhodum*, the rose-grain aphid. *S. avenae* and *Rhopalosiphum padi* were also present, but numbers were very low. Numbers of parasitized aphids were also low and no significant difference was observed between treatments.

**[0034]** Since semiochemicals acting as repellents or inhibitors of host attractancy for herbivorous insects are often involved in predation or parasitism, the activity of *cis*-jasmonate was also investigated at higher trophic levels. Thus, the seven-spot ladybird, *Coccinella septempunctata* (Coleoptera : Coccinellidae), an important aphid predator, was shown to be attracted to a source of the compound in the olfactometer (the mean number of observations in the treated arm was  $4.1 \pm 1.55$ , whereas the mean number of observations in the control arms  $2.4 \pm 0.69$ ;  $P < 0.005$ ). Responses of the aphid parasitoid *Aphidius ervi* (Hymenoptera : Braconidae), which preferentially attacks aphids colonizing plants in the Fabaceae, were also investigated in a wind tunnel and demonstrated that *cis*-jasmonate was attractive in a single choice test (Table 2). These experiments indicate a behavioural role for *cis*-jasmonate in influencing interactions between plants, herbivorous insects and their predators and parasitoids.

TABLE 2.

Responses of <i>A. ervi</i> in the wind tunnel to synthetic compounds (10 µg) on filter paper (single choice test).		
Stimulus	No. parasitoids tested	% showing oriented flight
<i>cis</i> -jasmone	64	53.1 <sup>a</sup>
( <i>E,E</i> )- $\alpha$ -farnesene	70	60.9 <sup>a</sup>
( <i>E</i> )- $\beta$ -ocimene	61	48.8 <sup>a</sup>
hexane control	45	26.7 <sup>b</sup>

ANOVA analysis  $F = 16.19$ ,  $P = < 0.01$ . Values followed by a different letter are significantly different at  $P = < 0.05$  (Tukey multiple comparison test).

**[0035]** Returning to the claimed invention, a possible role for the compound as an airborne plant signal was investigated using the broad bean, *V. faba* (cv The Sutton). Plants were kept for 24 hours in clean air or in air incorporating *cis*-jasmone at 100 µg/l; subsequently, samples of volatiles released by the plants were obtained by entrainment over 4 periods of 48 hours, i.e. up to 192 hours after the end of the treatment. The *cis*-jasmone itself was undetectable after 48 hours. However, levels of (*E*)- $\beta$ -ocimene released by the plants exposed to *cis*-jasmone increased significantly over the 192 hour entrainment period and, in all 4 samples, were 2½-3 times higher than those from the control plants (Fig. 2). There was also, from some replicates, enhancement of (*E,E*)- $\alpha$ -farnesene, (-)- $\beta$ -caryophyllene and (*E*)-4,8-dimethyl-1,3,7-nonatriene. These compounds have all been implicated in herbivorous insect-induced production and increased parasitoid foraging. The nonatriene can also be produced innately by plants imitating damage for defence against herbivores and which are thus attractive to parasitoids. (*E*)- $\beta$ -Ocimene and (*E,E*)- $\alpha$ -farnesene were investigated with *A. ervi* in the wind tunnel and both compounds proved to be attractive in the single choice test (Table 2). This activity, and the elevated levels of these compounds produced by *V. faba* after treatment with *cis*-jasmone, suggested that there might be increased foraging and attraction of *A. ervi* to the treated plants compared with the controls. Indeed, in the single choice test, *V. faba* plants taken 48 hours after treatment, when *cis*-jasmone levels were undetectable, were significantly more attractive to *A. ervi* in the wind tunnel than untreated plants (Table 3a). Furthermore, a wind tunnel experiment in which *A. ervi* were offered a choice of treated or untreated plants demonstrated that over 3 times as many parasitoids oriented towards the *cis*-jasmone treated plant compared to the control (Table 3b).

TABLE 3.

Responses of <i>A. ervi</i> in the wind tunnel to <i>V. faba</i> plants 48 hr after exposure to <i>cis</i> -jasmone (100 µg/l in air).		
(a) Single choice test		
Plant treated with	No. parasitoids tested	% showing oriented flight
<i>cis</i> -jasmone	50	44
hexane control	50	20
$\chi^2 = 6.62$ (contingency test using Pearson on Genstat). $P = < 0.01$ .		
(b) Dual choice test (treated plant versus control plant)		
No. parasitoids tested	% oriented to	
	treated plant	control plant
50	32	10
$\chi^2 = 5.762$ ( $\chi^2$ test). $P = < 0.05$		

**[0036]** For comparison with *cis*-jasmone we also investigated the activity of methyl jasmonate with *V. faba* under the same conditions as for *cis*-jasmone. In this system, exposure to methyl jasmonate did not significantly increase the levels of (*E*)- $\beta$ -ocimene released (Fig. 3). This demonstrates that *cis*-jasmone, as an airborne signal, has properties different to those of methyl jasmonate. *cis*-Jasmone is closely related to jasmonic acid, being the product of further catabolization, i.e.  $\beta$ -oxidation, dehydration and decarboxylation, although the exact route is not yet reported. The results show that, rather than *cis*-jasmone being considered as merely another lipoxygenase-derived volatile and a sink for jasmonic acid, it should be viewed as a potentially important airborne plant signal relating to other aspects of plant signalling. It should also be noted that *cis*-jasmone is more volatile than methyl jasmonate and, as such, could

make a more effective signal compound. We have demonstrated that, far from being biologically inactive, *cis*-jasmone has activity at all three trophic levels investigated in this study.

**[0037]** We have therefore identified a compound capable of inducing production of these types of compounds as an airborne signal, namely *cis*-jasmone, an extremely benign compound having, to human beings, a pleasant aroma.

## METHODS

### *Electrophysiology.*

**[0038]** Electroantennogram (BAG) recordings from alate *N. ribis-nigri* were made using Ag-AgCl glass electrodes filled with saline solution, as reported in *J. Exp. Biol.* **51**, 71-97 (1969) (Maddrell) but without the glucose. The insect was anaesthetized by chilling and the head was excised and mounted on the indifferent electrode. The tip of the recording electrode was removed so that its inside diameter was just wide enough to accept the terminal process of the antenna. The signals were passed through a high impedance amplifier (UN-03b, Syntech) and displayed on an oscilloscope.

### *Coupled Gas Chromatography (GC)-Electrophysiology.*

**[0039]** The coupled GC-electrophysiology system, in which the effluent from the capillary column GC is delivered simultaneously to the antennal preparation and the GC detector, has been described previously. See Wadhams in *Chromatography and Isolation of Insect Hormones and Pheromones* (eds. McCaffery *et al.*) 289-298 (Plenum Press, New York, 1990). Separation of the air entrainment sample was achieved on an AI 93 GC equipped with a cold on-column injector and a flame ionization detector (FID). The column (30 m x 0.53 mm ID, HP-1) was maintained at 40 °C for 2 min and then programmed at 10 °C/min to 250 °C. The carrier gas was hydrogen. The outputs from the BAG amplifier and the FID were monitored simultaneously on a chart recorder.

### *Olfactometry: aphids.*

**[0040]** Behavioural assays were done in a Perspex™ olfactometer similar to that described in *J. Entomol. Scand.* **1**, 63-73 (1970) (Pettersson), with a weak airstream directed towards the centre from each of 4 side arms. The test compound (1 µg) in hexane (10 µl) was placed on filter paper (Whatman No. 1) at the end of one of the side arms, with hexane alone used as a control in the other arms. One alate virginopara of *N. ribis-nigri* was placed in the centre of the arena and its movements observed over 10 min. The apparatus, maintained at 24 °C, was lit from above by fluorescent tubing and was rotated 90° every 2.5 min to avoid any directional bias. The experiment was replicated 6 times and results analysed by Student's *t*-test.

### *Olfactometry: ladybirds.*

**[0041]** Apparatus and methodology were similar to that employed for aphids (above). The test compound was applied in 0.5 µl microcaps (Drummond Sci. Co.) at the end of one of the side arms and each arm was supplied with moist filter paper to minimize differences in relative humidity. Individual *C. septempunctata* were introduced into the centre of the arena and their positions noted every 2 min for 20 min. The experiment was replicated 8 times and results analysed as above.

### *Wind tunnel studies.*

**[0042]** Naive female *A. ervi* were flown in a wind tunnel, as described in *J. Chem. Ecol.* **16**, 381-396 (1996) (Poppy *et al.*). The parasitoids were released 25 cm downwind (single choice tests) or 40 cm downwind (dual choice test) of the target, which was either a plant or a synthetic compound (10 µg in 10 µl hexane) placed on a 2 x 1 cm strip of filter paper (Whatman No. 1) surrounded by a ring of green crepe paper. The proportions of parasitoids responding with an oriented flight to the synthetic chemicals were calculated each day on 3 separate days. These values were then subjected to a logit transformation to normalize the data before being analysed by ANOVA followed by Tukey *post-hoc* tests. The number of parasitoids orienting upwind to the single plant target were recorded and subjected to a  $\chi^2$  contingency test (Pearson method on Genstat—see Genstat 5 Committee. *Genstat 5 Reference Manual, Release 3* (Clarendon Press, Oxford, 1993)) to determine whether an orienting response was linked to the type of plant treatment. The numbers orienting to each plant in the dual choice test were analysed by a  $\chi^2$  to determine whether one plant was more attractive than the other.

*Field Studies.*

[0043] Plots (6 m x 6 m) of winter wheat, *Triticum aestivum* (cv Consort), were arranged in a 5 x 5 quasi-complete Latin square design. The five *cis*-jasmonate treated plots were sprayed on 5 May and 11 June 1999, using a hand-held hydraulic device, at a rate of 50 g active ingredient/ha in 200 l/ha of aqueous Ethylan BV (0.1%). Control plots were untreated. Cereal aphids and parasitized aphids were counted on 8 occasions between early May and mid-July. At each count, five tillers were inspected at 12 separate sites on two diagonal transects totalling 60 tillers per plot. Transformed data ( $y = \log(y+1)$ ) were subjected to ANOVA and the sums of squares of the treatments were partitioned to test for significant differences.

*Induction studies.*

[0044] Bean plants, *V. faba* (cv The Sutton) were grown under standard glasshouse conditions until the 2-4 leaf stage when they were rinsed free of soil and transplanted into baked glass jars containing washed sand, with 3 plants per jar. These were left for 1-2 days to acclimatize. Plants to be treated (three jars of three plants each) were sealed in a 25 l glass tank for 24 hours with either *cis*-jasmonate or methyl jasmonate (2.5 mg) applied to a piece of filter paper (Whatman No. 1) placed on the floor of the tank. Treated or untreated plants were then placed in 10 l glass entrainment vessels and the volatiles from each collected over 48 hour periods for 192 hours. See Blight in *Chromatography and Isolation of Insect Hormones and Pheromones* (eds. McCaffery *et al.*) 289-298 (Plenum, New York, 1990). Volatiles were eluted from glass tubes containing Porapak Q (50 mg), using freshly distilled diethyl ether (500  $\mu$ l), and then concentrated to 100  $\mu$ l for analysis by GC and GC-MS.

*Analysis.*

[0045] GC analysis was carried out using a Hewlett Packard 5890 GC equipped with a temperature programmable on-column injector and FID. This was fitted with HP-1 (50 m x 0.32 mm ID) and SPB-35 (30 m x 0.32 mm ID) columns with hydrogen as the carrier gas. The oven was maintained at 40 °C for 1 min then programmed at 10 °C/min to 250 °C. GC-MS analysis was carried out using a Hewlett Packard 5890 GC connected to a VG Autospec mass spectrometer (Fisons Instruments). Ionization was by electron impact at 70 eV, 230 °C. The GC was maintained at 30 °C for 5 min then programmed at 5 °C/min to 180 °C. Detection limits for *cis*-jasmonate in the entrainment samples were 40 pg/hour for GC and 400 pg/hour for GC-MS. Compounds identified by GC/GC-MS were confirmed by co-injection of authentic samples on HP-1 (non-polar) and SPB-35 (polar) columns. Authentic samples were obtained from commercial sources, except for (*E*)- $\beta$ -ocimene, (*E,E*)- $\alpha$ -farnesene and (*E*)-4,8-dimethyl-1,3,7-nonatriene which were synthesized by standard methods, as follows.

(*E,E*)- $\alpha$ -Farnesene and (*E*)- $\beta$ -ocimene.

[0046] (*E,E*)- $\alpha$ -Farnesene and (*E*)- $\beta$ -ocimene were synthesized from 3-methyl-2,5-dihydrothiophene-1,1-dioxide. See *J. Chem Soc. Chem. Comm.*, 1984, 1323 (Chou *et al.*). Sulphur dioxide elimination was achieved using excess lithium aluminium hydride following a modified protocol based on that in *Tetrahedron Lett.*, 1977, **11**, 947 (Gaoni).

[0047] To a stirred suspension of lithium aluminium hydride (1 equiv. by weight) in refluxing dry diethyl ether (10 mmol/ml) was added dropwise via syringe a solution of the dihydrothiophene-1,1-dioxide (1 equiv.) in dry diethyl ether (1 ml). After refluxing for 1 hour, the cooled (0 °C) mixture was treated with 15% NaOH (1 ml), water (3 ml), and the mixture filtered through Celite™. Evaporation of the filtrate under reduced pressure followed by column chromatography over Florisil™ (100% hexane) yielded the product as a colourless oil.

4,8-Dimethyl-1,3,7-nonatriene.

[0048] 4,8-Dimethyl-1,3,7-nonatriene was synthesized in two steps from geraniol.

[0049] Geraniol (7.0 g, 0.045 mol, 1 equiv.), manganese (IV) dioxide (100.0 g) and dichloromethane (500 ml) were stirred together at ambient temperature overnight. The mixture was filtered through Celite™, and the filtrate concentrated *in vacuo* to yield geraniol (5.42 g, 80%). A cooled (-15°C), stirred suspension of methyltriphenylphosphonium iodide (16.0 g, 0.039 mol, 1.1 equiv.) in tetrahydrofuran (50 ml) and diethyl ether (50 ml) was treated with *n*-butyllithium (2.5 M; 16 ml, 0.039 mol, 1.1 equiv.). After 0.25 hours, geraniol (5.42 g, 0.036 mol, 1 equiv.) was added and the mixture allowed to stir at ambient temperature for 1 hour. The mixture was partitioned between diethyl ether (200 ml), water (200 ml) and petroleum ether b.p. 40-60 °C (200 ml), and the organic layer dried (MgSO<sub>4</sub>) and concentrated *in vacuo* to yield a crude oil which was subjected to column chromatography over Florisil™ (100% hexane) to give the nonatriene as a colourless oil (3.42 g, 64%).



## DIFFERENTIAL DISPLAY

**[0050]** In order to determine if *cis*-jasmonate was capable of inducing alterations in plant gene expression, the sensitive technique of differential display was carried out on RNA extracted from plants which had been exposed to air, methyl jasmonate or *cis*-jasmonate. A number of the resulting PCR products were observed to show alterations in their abundance in the presence of *cis*-jasmonate. To confirm this observation, bands of interest were recovered by excision from the dried gel and re-amplified with the appropriate pair of oligonucleotide primers. The resulting PCR products were cloned and sequenced to confirm the homogeneous nature of the amplified product. These sequences were then used to probe RNA isolated from control or treated *V. faba* plants. As can be seen from Fig. 4, one particular sequence (D251) was shown to be upregulated in leaf tissue only in the presence of *cis*-jasmonate. Interestingly, when this same (cloned) sequence was used to probe RNA isolated from *V. faba* stem tissues, it was upregulated to a similar level in plants that had been treated with either *cis*-jasmonate or methyl jasmonate. It is important to note that the nature of the differential display technique generates short gene-specific probes, containing mainly 3' untranslated regions of transcribed sequences, and therefore the functional part of the differentially expressed gene is unknown.

**[0051]** Thus, using differential display and confirmatory northern blotting, we have shown that methyl jasmonate and *cis*-jasmonate have apparently distinct effects on plant gene expression. In this study, the differentially displayed PCR product D251 was cloned and used to probe northern blots from leaf or stem tissues of *V. faba* plants treated with air, methyl jasmonate or *cis*-jasmonate. This clearly showed (Fig. 4) that whilst the D251 sequence was upregulated by treatment with vapours of both compounds in stem tissue, only *cis*-jasmonate brought about an increase in the steady-state transcript level of this sequence in leaf tissue. Thus, the two compounds have distinct effect on plant gene expression and the response to these signalling compounds may be tissue-specific.

## Claims

1. Use of *cis*-jasmonate as a semiochemical that changes the physiology of a plant to which the *cis*-jasmonate is applied.
2. Use as claimed in Claim 1, wherein the *cis*-jasmonate is used to change the physiology of the plant by inducing the expression of one or more genes of the plant.
3. Use as claimed in claim 2, wherein *cis*-jasmonate is used as a plant stress signal to induce expression of one or more plant stress-related genes.
4. Use as claimed in claim 1, 2 or 3, wherein *cis*-jasmonate is used on plants so as to cause insect repellency or attractancy.
5. Use as claimed in claim 4, wherein *cis*-jasmonate is used as a repellent of plant-feeding insects.
6. Use as claimed in claim 5, wherein the insects are plant-feeding aphids.
7. Use as claimed in claim 4, claim 5 or claim 6, wherein *cis*-jasmonate is used as an attractant of insect predators or insect parasitoids.
8. Use as claimed in claim 7, wherein the insect predators or insect parasitoids are predators or parasitoids of plant-feeding aphids.
9. Use as claimed in any preceding claim, wherein *cis*-jasmonate is used to induce the production of volatile plant semiochemicals.
10. Use as claimed in claim 9, wherein the volatile plant semiochemicals comprise one or more compounds selected from (*E*)- $\beta$ -ocimene, (*E,E*)- $\alpha$ -farnesene, (-)- $\beta$ -caryophyllene and (*E*)-4,8-dimethyl-1,3,7-nonatriene.
11. Use as claimed in claim 10, wherein the volatile plant semiochemicals comprise (*E*)- $\beta$ -ocimene.
12. Use as claimed in any one of claims 9 to 11, wherein the *cis*-jasmonate is used to induce the production of volatile semiochemicals from bean plants.
13. A method of changing the physiology of plants by inducing the expression of one or more genes of a plant to which

the *cis*-jasmon is applied comprising the exposure of the plants to *cis*-jasmon.

14. A method as claimed in claim 13 in which the plants are exposed to air containing *cis*-jasmon.

5 15. A method as claimed in claim 14 in which the *cis*-jasmon is used at a concentration of 100-1000µg per litre of air.

16. A method as claimed in claim 15 in which the *cis*-jasmon is used at a concentration of 100µg per litre of air.

10 17. A method as claimed in any one of claims 13 to 16, wherein *cis*-jasmon is used on plants to lead to the repelling or attraction of insects.

18. A method as claimed in claim 17, wherein *cis*-jasmon is used to lead to the repelling of plant-feeding insects.

15 19. A method as claimed in claim 18, wherein the insects are plant-feeding aphids.

20. A method as claimed in claim 17, wherein *cis*-jasmon is used on plants to lead to the attraction of insect predators or insect parasitoids.

20 21. A method as claimed in claim 20, wherein the insect predators or insect parasitoids are predators or parasitoids of plant-feeding aphids.

22. A method as claimed in any one of claims 13 to 21, wherein the production of volatile plant semiochemicals is induced.

25 23. A method as claimed in claim 19, wherein the volatile plant semiochemicals comprise one or more compounds selected from (*E*)-β-ocimene, (*E,E*)-α-farnesene, (-)-β-caryophyllene and (*E*)-4,8-dimethyl-1,3,7-nonatriene.

24. A method as claimed in claim 23, wherein the volatile plant semiochemicals comprises (*E*)-β-ocimene.

30 25. A method as claimed in any one of claims 22 to 24, wherein bean plants are exposed to *cis*-jasmon.

### Patentansprüche

35 1. Verwendung von *cis*-Jasmon als eine Semiochemikalie, welche die Physiologie einer Pflanze verändert, auf die das *cis*-Jasmon appliziert wird.

40 2. Verwendung nach Anspruch 1, worin das *cis*-Jasmon zur Veränderung der Physiologie der Pflanze durch Induktion der Expression von einem oder mehreren Gen(en) der Pflanze verwendet wird.

3. Verwendung nach Anspruch 2, worin *cis*-Jasmon als ein Pflanzenstresssignal zur Induktion der Expression von einem oder mehreren Pflanzenstress-bezogenen Gen(en) verwendet wird.

45 4. Verwendung nach Anspruch 1, 2 oder 3, worin *cis*-Jasmon an Pflanzen verwendet wird, um auf diese Weise das Abwehren oder Anlocken von Insekten zu veranlassen.

5. Verwendung nach Anspruch 4, worin *cis*-Jasmon als ein Repellent gegen Pflanzen fressende Insekten verwendet wird.

50 6. Verwendung nach Anspruch 5, worin die Insekten Pflanzen fressende Blattläuse sind.

7. Verwendung nach Anspruch 4, 5 oder 6, worin *cis*-Jasmon als ein Attraktant für Insektenräuber oder Insektenparasitoide verwendet wird.

55 8. Verwendung nach Anspruch 7, worin die Insektenräuber oder Insektenparasitoide Räuber oder Parasitoide Pflanzen fressender Blattläuse sind.

9. Verwendung nach einem der vorangehenden Ansprüche, worin *cis*-Jasmon zur Induktion der Produktion flüchtiger

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Pflanzen-Semiochemikalien verwendet wird.

- 5 10. Verwendung nach Anspruch 9, worin die flüchtigen Pflanzen-Semiochemikalien eine oder mehrere Verbindung(en) umfassen, die aus (*E*)- $\beta$ -Ocimen, (*E,E*)- $\alpha$ -Farnesen, (-)- $\beta$ -Caryophyllen und (*E*)-4,8-Dimethyl-1,3,7-nonatrien ausgewählt sind.
11. Verwendung nach Anspruch 10, worin die flüchtigen Pflanzen-Semiochemikalien (*E*)- $\beta$ -Ocimen umfassen.
- 10 12. Verwendung nach einem der Ansprüche 9 bis 11, worin das *cis*-Jasmon zur Induktion der Produktion von flüchtigen Semiochemikalien von Bohnenpflanzen verwendet wird.
13. Verfahren zur Veränderung der Physiologie von Pflanzen durch Induktion der Expression von einem oder mehreren Gen(en) einer Pflanze, auf die das *cis*-Jasmon appliziert wird, umfassend die Exposition der Pflanzen gegenüber *cis*-Jasmon.
- 15 14. Verfahren nach Anspruch 13, worin die Pflanzen der Luft, enthaltend *cis*-Jasmon, ausgesetzt werden.
15. Verfahren nach Anspruch 14, worin das *cis*-Jasmon in einer Konzentration von 100 - 1000  $\mu$ g pro Liter Luft verwendet wird.
- 20 16. Verfahren nach Anspruch 15, worin das *cis*-Jasmon bei einer Konzentration von 100  $\mu$ g pro Liter Luft verwendet wird.
17. Verfahren nach einem der Ansprüche 13 bis 16, worin *cis*-Jasmon an Pflanzen verwendet wird, um zum Abwehren oder Anlocken von Insekten zu führen.
- 25 18. Verfahren nach Anspruch 17, worin *cis*-Jasmon verwendet wird, um zum Abwehren von Pflanzen fressenden Insekten zu führen.
- 30 19. Verfahren nach Anspruch 18, worin die Insekten Pflanzen fressende Blattläuse sind.
20. Verfahren nach Anspruch 17, worin *cis*-Jasmon an Pflanzen verwendet wird, um zum Anlocken von Insektenräubern oder Insektenparasitoiden zu führen.
- 35 21. Verfahren nach Anspruch 20, worin die Insektenräuber oder Insektenparasitoide Räuber oder Parasitoide von Pflanzen fressenden Blattläusen darstellen.
22. Verfahren nach einem der Ansprüche 13 bis 21, worin die Produktion flüchtiger Pflanzen-Semiochemikalien induziert wird.
- 40 23. Verfahren nach Anspruch 19, worin die flüchtigen Pflanzen-Semiochemikalien eine oder mehrere Verbindung(en), die aus (*E*)- $\beta$ -Ocimen, (*E,E*)- $\alpha$ -Farnesen, (-)- $\beta$ -Caryophyllen und (*E*)-4,8-Dimethyl-1,3,7-nonatrien ausgewählt sind, umfassen.
- 45 24. Verfahren nach Anspruch 23, worin die flüchtigen Pflanzen-Semiochemikalien (*E*)- $\beta$ -Ocimen umfassen.
25. Verfahren nach einem der Ansprüche 22 bis 24, worin Bohnenpflanzen dem *cis*-Jasmon ausgesetzt werden.

### 50 **Revendications**

1. Utilisation de *cis*-jasmone comme une substance sémi chimique qui change la physiologie d'une plante à laquelle la *cis*-jasmone est appliquée.
- 55 2. Utilisation suivant la revendication 1, dans laquelle la *cis*-jasmone est utilisée pour changer la physiologie de la plante en induisant l'expression d'un ou de plusieurs gènes de la plante.
3. Utilisation suivant la revendication 2, dans laquelle la *cis*-jasmone est utilisée comme un signal de stress de la

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plante pour induire l'expression d'un ou de plusieurs gènes liés au stress de la plante.

- 5 4. Utilisation suivant la revendication 1, 2 ou 3, dans laquelle la *cis*-jasmane est utilisée sur des plantes de manière à entraîner une répulsion ou une attraction sur des insectes.
- 5 5. Utilisation suivant la revendication 4, dans laquelle la *cis*-jasmane est utilisée comme un répulsif d'insectes se nourrissant de plantes.
- 10 6. Utilisation suivant la revendication 5, dans laquelle les insectes sont des pucerons se nourrissant de plantes.
- 10 7. Utilisation suivant la revendication 4, la revendication 5 ou la revendication 6, dans laquelle la *cis*-jasmane est utilisée comme un attractif pour des prédateurs d'insectes ou des parasitoïdes d'insectes.
- 15 8. Utilisation suivant la revendication 7, dans laquelle les prédateurs d'insectes ou les parasitoïdes d'insectes sont des prédateurs ou des parasitoïdes de pucerons se nourrissant de plantes.
- 15 9. Utilisation suivant l'une quelconque des revendications précédentes, dans laquelle la *cis*-jasmane est utilisée pour induire la production de substances sémiologiques volatiles de plantes.
- 20 10. Utilisation suivant la revendication 9, dans laquelle les substances sémiologiques volatiles de plantes comprennent un ou plusieurs composés choisis parmi le (E)- $\beta$ -ocimène, le (E,E)- $\alpha$ -farnésène, le (-)- $\beta$ -caryophyllène et le (E)-4,8-diméthyl-1,3,7-nonatriène.
- 25 11. Utilisation suivant la revendication 10, dans laquelle les substances sémiologiques volatiles de plantes comprennent le (E)- $\beta$ -ocimène.
- 25 12. Utilisation suivant l'une quelconque des revendications 9 à 11, dans laquelle la *cis*-jasmane est utilisée pour induire la production de substances sémiologiques volatiles de plantes de haricot.
- 30 13. Procédé pour le changement de la physiologie de plantes en induisant l'expression d'un ou de plusieurs gènes d'une plante à laquelle la *cis*-jasmane est appliquée comprenant l'exposition des plantes à la *cis*-jasmane.
- 30 14. Procédé suivant la revendication 13, dans lequel les plantes sont exposées à l'air contenant de la *cis*-jasmane.
- 35 15. Procédé suivant la revendication 14, dans lequel la *cis*-jasmane est utilisée à une concentration de 100-1000  $\mu$ g par litre d'air.
- 35 16. Procédé suivant la revendication 15, dans lequel la *cis*-jasmane est utilisée à une concentration de 100  $\mu$ g par litre d'air.
- 40 17. Procédé suivant l'une quelconque des revendications 13 à 16, dans lequel la *cis*-jasmane est utilisée sur des plantes pour conduire à la répulsion ou à l'attraction d'insectes.
- 40 18. Procédé suivant la revendication 17, dans lequel la *cis*-jasmane est utilisée pour conduire à la répulsion d'insectes se nourrissant de plantes.
- 45 19. Procédé suivant la revendication 18, dans lequel les insectes sont des pucerons se nourrissant de plantes.
- 45 20. Procédé suivant la revendication 17, dans lequel la *cis*-jasmane est utilisée sur des plantes pour conduire à l'attraction de prédateurs d'insectes ou de parasitoïdes d'insectes.
- 50 21. Procédé suivant la revendication 20, dans lequel les prédateurs d'insectes ou les parasitoïdes d'insectes sont des prédateurs ou des parasitoïdes de pucerons se nourrissant de plantes.
- 55 22. Procédé suivant l'une quelconque des revendications 13 à 21, dans lequel la production de substances sémiologiques volatiles de plantes est induite.
- 55 23. Procédé suivant la revendication 19, dans lequel les substances sémiologiques volatiles de plantes comprennent

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un ou plusieurs composés choisis parmi le (E)- $\beta$ -ocimène, le (E,E)- $\alpha$ -farnésène, le (-)- $\beta$ -caryophyllène et le (E)-4,8-diméthyl-1,3,7-nonatriène.

5      **24.** Procédé suivant la revendication 23, dans lequel les substances sémi-chimiques volatiles de plantes comprennent le (E)- $\beta$ -ocimène.

10      **25.** Procédé suivant l'une quelconque des revendications 22 à 24, dans lequel des plantes de haricot sont exposées à la *cis*-jasmone.

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Fig.1.

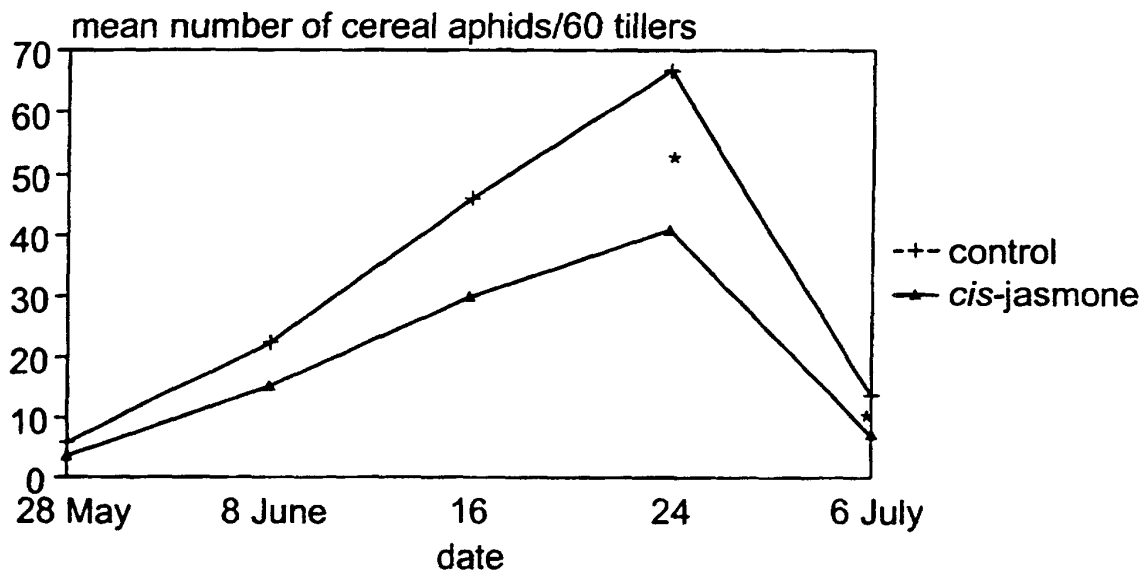


Fig.2.

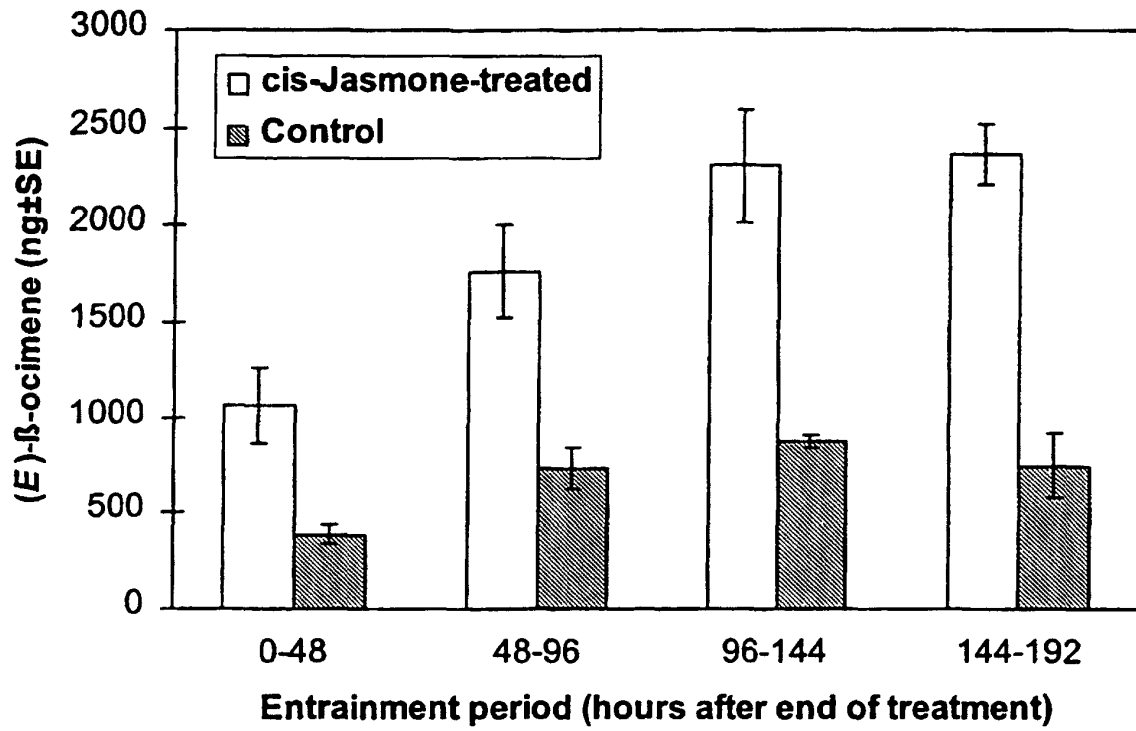


Fig.3.

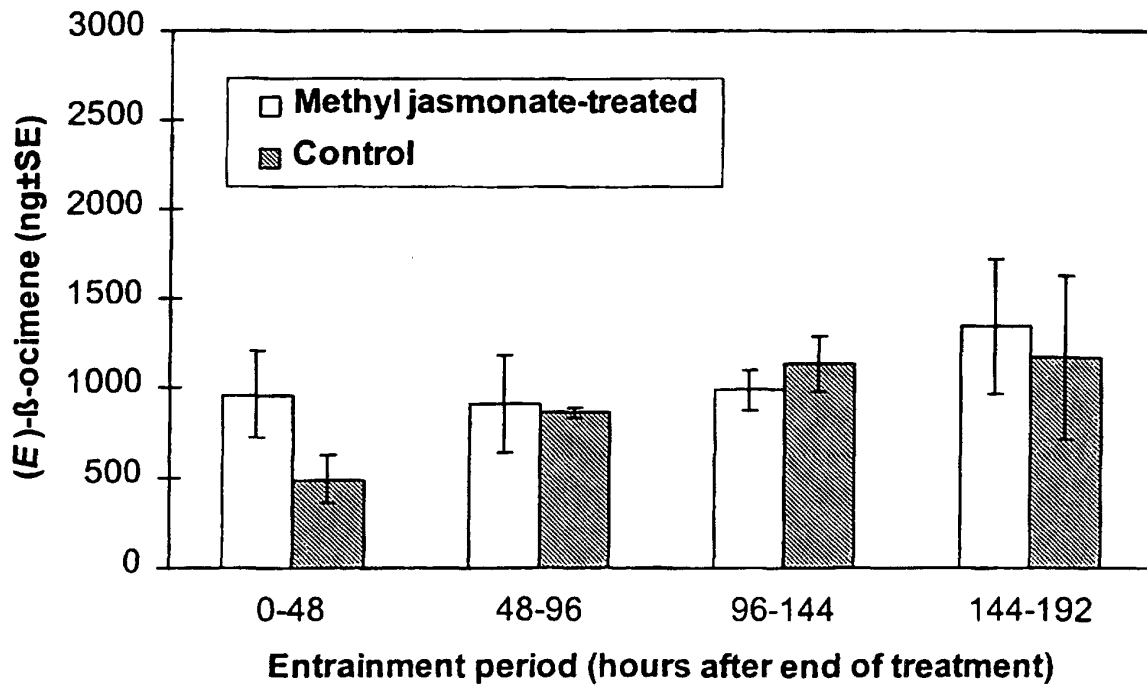


Fig.4.

