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# Evaluation of Efficacy of Three Essential Oils against *Odontotermes feae* (Isoptera: Termitidae)

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**Abstract** efficacy of essential oils from three locally available plants of Assam, India namely *Citrus grandis*, *Citrus paradisi* and *Cassia fistula* were evaluated against the worker group of termite *Odontotermes feae* Wasmann. Different doses of essential oil were applied by using contact residual toxicity method and LC50 values were recorded after 2h, 4h, and 6h of post treatment. The result revealed highest toxicity of *C. grandis* with LC50 value 272.36 ppm at 6 h followed by *C. paradisi* and *Cassia fistula* with LC50 value 1313.57 ppm and 5537.06 ppm respectively. In all the essential oil treated group of termite the glutathione-S-transferase enzyme activity was found to decrease. Total carbohydrate and protein content was found to significantly decrease in response to LC50 dose of *C. grandis* and *C. paradisi.* From the present finding, it can be inferred that the plant essential oil considered for present investigation possess termiticidal properties.

***Keywords:*** *Citrus grandis, Citrus paradisi, Cassia fistula, Odontotermes; essential oil, GST*

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## 1. Introduction

Termites, "the silent destroyer", are the social insects comprising around 2700 species worldwide. In India 269 confirmed species of termites are reported [1]. This group of social insects received economic importance as they destroy various wooden materials, agricultural products, stored materials, household furniture etc. while feeding on cellulosic products of these materials for getting nourishment. Termites generally remain conceal and their presence is often detected while their damages are quite severe [2]. They generally form a tunnel of soil to protect them from the sunlight when infest the wooden materials. Though from ecological point of view, termites are beneficial for their role in nutrient recycling, soil aeration etc. but their extensive destructive activities compelled human beings to treat them as pest. So, different control measures have been tried against termite from time immemorial.

Use of synthetic pesticides in the soil and the wooden material is a common practice to prevent the attack of the termite. But these bear various side effects like effect on non-target organisms, environmental pollution, mammalian toxicity etc. Therefore it is relevant to develop alternative control measures to manage the pest successfully that may eliminate negative effects of synthetic chemicals. In this regard, nowadays natural products are getting more importance globally as these are environment friendly and comparatively less toxic to mammals and other non-target organisms. These include plant-based products such as plant extract, essential oil etc.

Plant essential oils have been suggested as alternative sources for insect control as they are target specific, biodegradable, and have lower environmental persistence [3,4]. Essential oils are natural volatile substances found in a variety of aromatic plants [5]. It comprises of plant secondary metabolites which is stored in different parts including flower, fruit, bark, leaves, seeds, peel etc. in aromatic plants. These are highly volatile and lipophilic in nature. Many plant essential oils have already been studied for assessing their toxicity, developmental disturbance, repellency, and feeding deterrent activities against many insect species. These attributes of essential oils are due to the presence of complex mixtures of monoterpenoids and related phenols and other higher terpenoid compounds [6].

In the present investigation, the efficacy of essential oils derived from three different plants namely *Citrus grandis*, *Citrus paradisi* and *Cassia fistula* were evaluated against the worker group of termite *Odontotermes feae*. This species of termite is one of the most common termite species in India causing severe damages to buildings, dead woods, stem of live plants etc [7,8]. The selected plants are locally available in Assam and the efficacies of the essential oils derived from these aromatic plants are not found to be tested against the termite but reported to possess insecticidal activities against some other insect pests. Therefore in the present study attempt was made to assess the efficacy of these essential oils against *O. feae* in terms of its mortality rate, their effect on total protein and carbohydrate contents and their effects on one of the most important detoxifying enzyme i.e. Glutathione-S-transferase activities.

## 2. Materials and Methods

### 2.1. Collection of Plant Materials

The fruits of *Citrus grandis* and *Citrus paradisi* and the seeds of *Cassia fistula* are collected from Nalbari district, Assam, India.

### 2.2. Extraction of Essential Oil

Essential oils of *Citrus grandis* and *Citrus paradisi* were extracted from the peel of fruits and essential oil of *Cassia fistula* was extracted from seeds of cereal of the plants by hydro-distillation method using Clevenger apparatus. Essential oils were collected after 6 hours and stored in clean glass vials after removing water traces with the help of micropipette and anhydrous sodium sulphate [9] and stored at 4°C for further study.

### 2.3. Collection of Termite

Worker termites were collected from the infested woods of Gauhati University campus, Guwahati, Assam

### 2.4. Identification of Termite

Collected termites were identified with the help of the taxonomic key described by Saha et al. [10].

### 2.5. Bioassay of Individual Essential Oil against Worker Termite

The bioassay of the selected essential oils was done against the worker termite by following filter paper impregnation method described by Gupta et al. [11] with little modifications. Filter papers (Whatman No 1) were placed in the petri plates and the solutions of the essential oils prepared in acetone were applied on it. A series of concentrations viz. 10, 50, 100, 500, 1000, 5000 ppm solutions were prepared and 2ml of each solution were applied on filter paper. Filter paper without treating any solvent and filter paper treated with solvent only were used as the negative and positive control respectively. Both the treated and control filter paper were allowed to dry for 10 minutes for evaporation of solvent. Then 10 worker termites were released on each plate. The dishes were kept in the dark place and a few drops of water were periodically sprayed onto the filter paper in the dishes to maintain sufficient moisture for the termites. The whole experiment was performed in triplicate and the mean mortality rate was recorded after specific time intervals for 6 h. LC50 were calculated at 2 hour, 4 hour and 6 hour exposure period.

### 2.6. Effect of Essential Oil on the GST Activity of the Termite

The effects of three different essential oils on the GST activity of the termites were studied by following the method described by Farahnak et al.[12].The effect of the 1000 ppm concentration of each oil on the GST activity of termite at 24h of exposure period was measured spectrophotometrically using 1-chloro-2, 4- dinitrobenzene (CDNB) (100 mM) as substrate. Six larvae were homogenized in 5ml PBS buffer (pH=7.4) and centrifuged at 10,000g for 10 min at -4°C. 100µl of supernatant was mixed with 900µl of cocktail buffer (980µl PBS+ 10µl of 100mM GSH + 10µl of 100mM CDNB). The absorbance was read at 340 nm.

### 2.7. Effect of Essential oil on the Protein Content of the Termite

After applying LC50dose of 6hour the live three termites from each treatment were sacrificed at 24 hours and tissue homogenates was prepared with phosphate buffer and centrifuged at 10000 rpm for 10 minutes. The supernatant was combined with phosphate buffer from which 1ml sample was mixed with 1 ml 20% TCA. After half an hour, the sample was centrifuged and pellet was dissolved in 5 ml NaOH (0.1N). After dissolving, the protein content was estimated using the Lowry method [13]. BSA was used as standard. The experiment was repeated for three times.

### 2.8. Effect of Essential Oil on the Carbohydrate Content of the Termite

Carbohydrate was estimated according to the Anthrone method described by Piriet al. [14] after applying LC50dose of 6hour. The insects were homogenized in 62.5 µl of sodium sulphate solution (2% $Na_2SO_4$) and mixed with 468.75 µl of chloroform/methanol (1:2). The homogenate was centrifuged at 10000 rpm for 10 minutes and 150 µl of the supernatant was transferred into an eppendrof and 100 µl of distilled water and 500 µl of anthrone reagent (0.05% in sulphuric acid) were added to each tube and heated in a 90°C water bath for 10 minutes. Distilled water was used for the blank. The absorbance was recorded at 630 nm. Glucose was used as the standard. Three replicas were set for the same treatment.

### 2.9. Statistical Analysis

The LC50 doses were calculated by probit analysis using SPSS and MINITAB software. The tukey test was done with the help of SPSS software (version16).

## 3. Results

### 3.1. Antitermitic Activity

Acute toxicity of the selected three essential oils on worker termites is shown in Table 2. The result revealed that the rate of mortality of termite was dependent on the concentration and exposure period of each essential oil. Essential oil extracted from the peel of *Citrus grandis* showed highest efficacy against the worker group of termite with LC50 values 931ppm, 341ppm and 272ppm respectively at 2h, 4h and 6h of exposure period. The oil of this plant initiated rapid lethal effects on termites in comparison to the other two plants (Figure 1-Figure 3). Next to *Citrus grandis*, the oil of *Citrus paradisi* was found to be more responsive (LC50 value 1313ppm at 6h) than the essential oil of *Cassia fistula* (LC50 value 5537 ppm at 6h) against the selected pest.

**Table 1. List of the plants selected for bioassay against *O. feae***

| Essential oil | Family | Parts used |
|---|---|---|
| *Citrus grandis* | Rutaceae | Peel |
| *Citrus paradishi* | Rutaceae | Peel |
| *Cassia fistula* | Fabaceae | Seed |

**Table 2. LC50 value of *C.grandis, C.paradisi* and *Cassia fistula* oil against O. feae**

| Essential oil | Time | LC50 value | 95% confidence level | | Regression Equation | Chi-square value |
|---|---|---|---|---|---|---|
| | | | Lower limit | Upper limit | | |
| *Citrus grandis* | 2 Hour | 931.72ppm | 0.677 | 1.272 | Y=1.36147+1.22539x | 11.616 |
| | 4 Hour | 341.92ppm | 0.852 | 1.453 | Y=1.31145+1.45567x | 15.376 |
| | 6 Hour | 272.36ppm | 0.909 | 1.519 | Y=1.35316+1.49759x | 18.216 |
| *Citrus paradisi* | 2 Hour | 5360.73ppm | 0.719 | 1.711 | Y=0.559121+1.19085x | 9.860 |
| | 4 Hour | 1716.89ppm | 0.860 | 1.647 | Y=0.776624+1.30563x | 13.730 |
| | 6 Hour | 1313.57ppm | 0.838 | 1.561 | Y=0.954681+1.29722x | 13.630 |
| *Cassia fistula* | 2 hour | - | - | - | - | - |
| | 4 Hour | 6647.99ppm | 0.450 | 1.181 | Y=0.722830+1.11889x | 14.089 |
| | 6 Hour | 5537.06ppm | 0.556 | 1.217 | Y=1.95984+0.812437x | 11.305 |

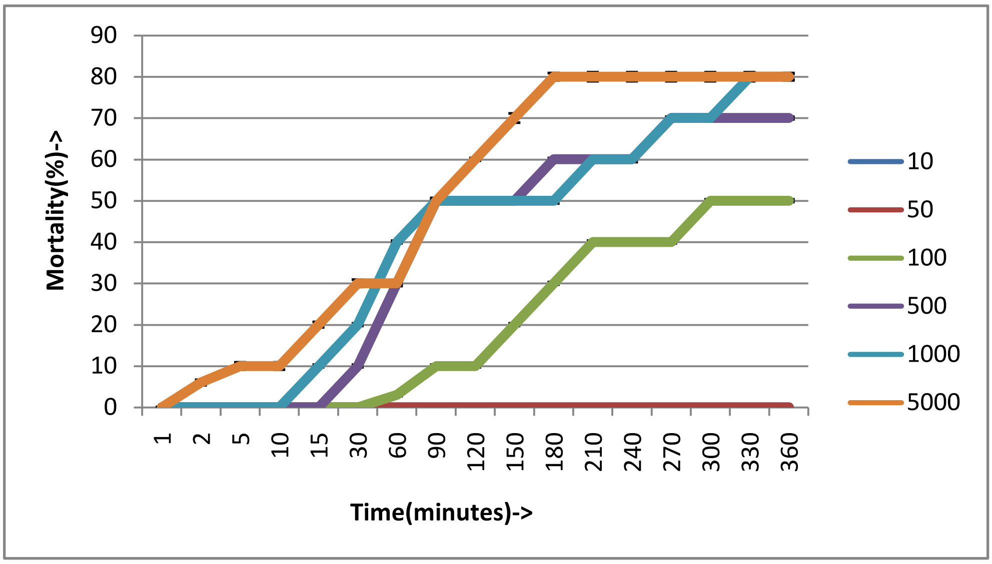


**Figure 1.** Relation between the mortality rate (%) of worker termite and concentration of *Citrus grandis* oil with time

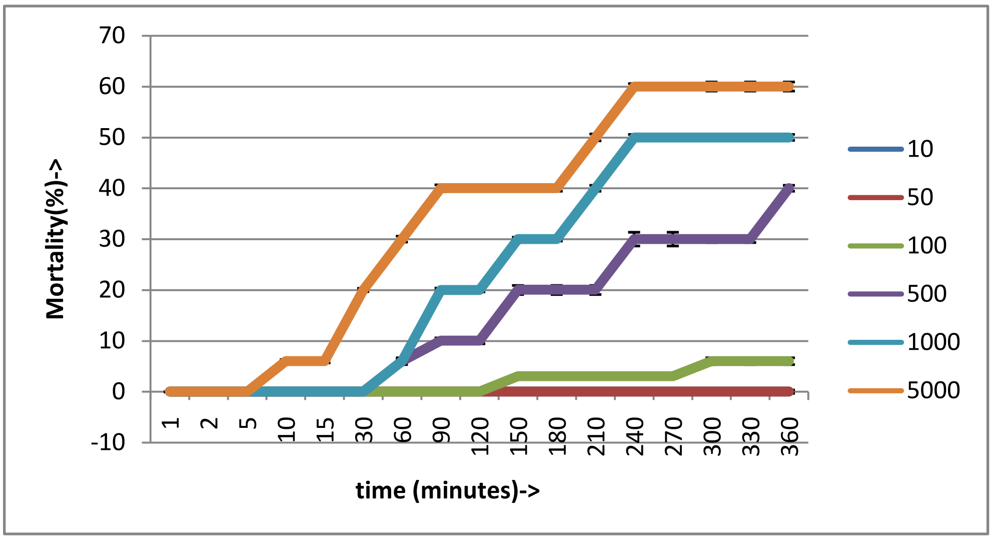


**Figure 2.** Relation between mortality rate (%) of the worker termite and the concentration of *Citrus paradisi* oil with time

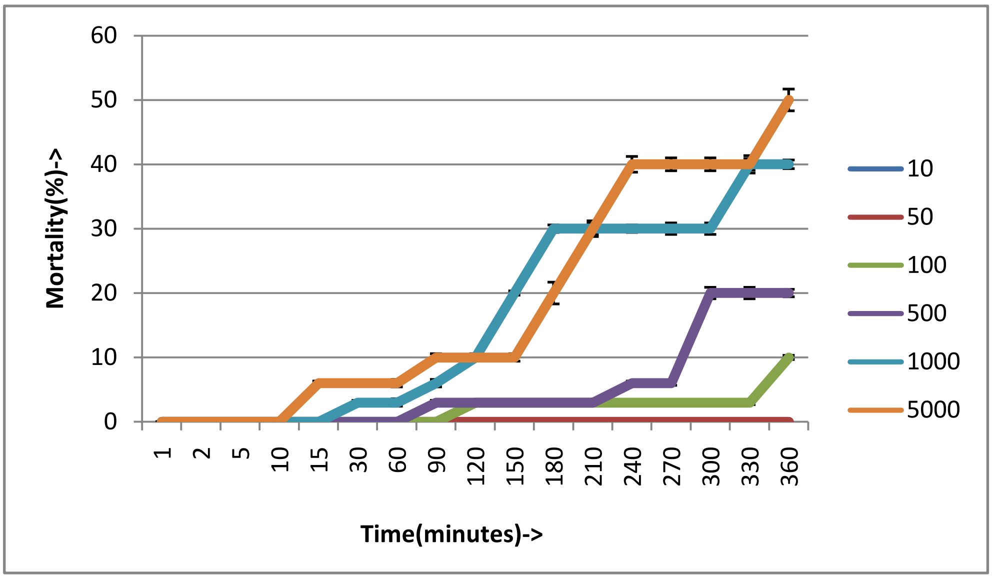


**Figure 3.** Relation between mortality rate (%) of worker termite and concentration of *Cassia fistula* oil with time

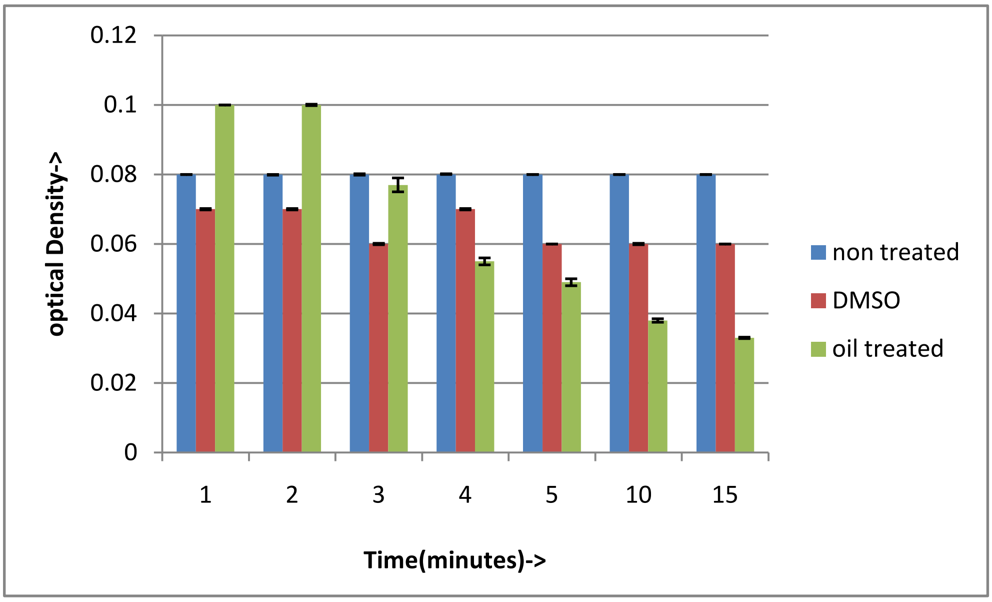


**Figure 4.** Effect of *Citrus grandis* oil on the GST activity of the worker termite

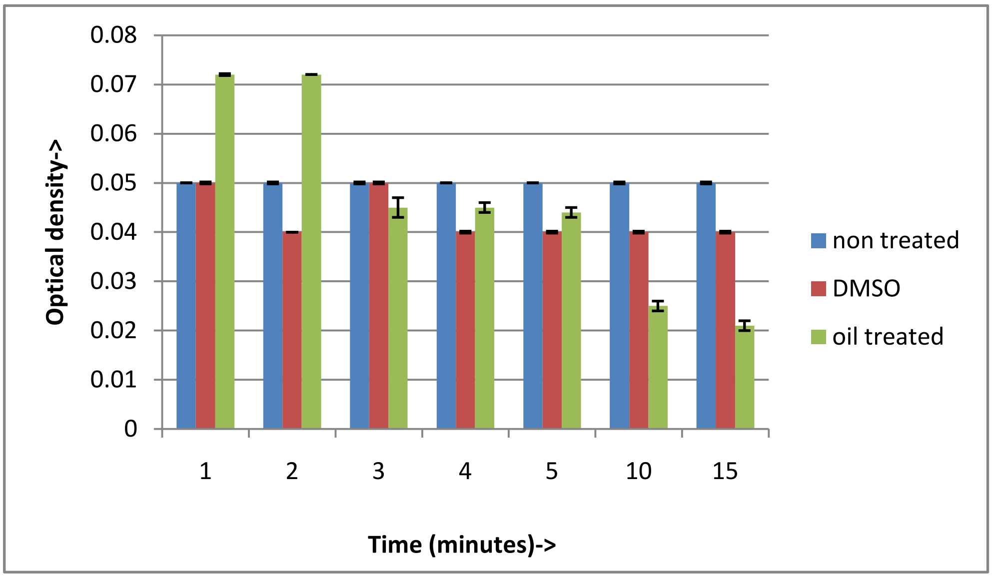


**Figure 5.** Effect of *Citrus paradisi* oil on the GST activity of the worker termite

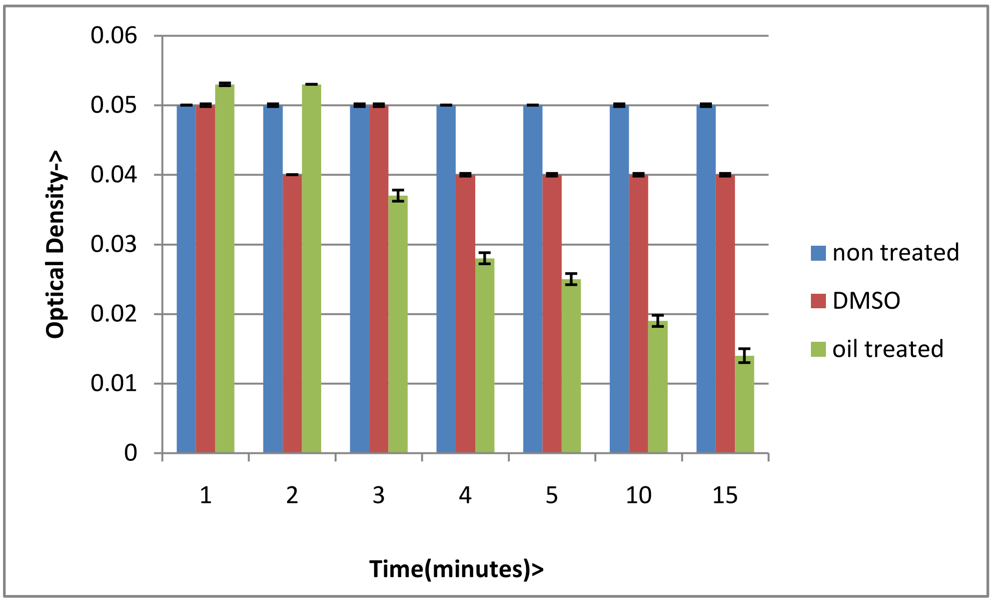


**Figure 6.** Effect of *Cassia fistula* oil on the GST activity of the worker termite

## 3.2. Effect on GST Activity

While studying the effect of selected essential oils on GST enzyme activities it was observed that the enzyme activity was found to decrease till 15 minutes after treatment of the selected essential oil at sublethal dose in comparison to positive control (Figure 4, Figure 5 & Figure 6). No changes of enzyme activities were recorded in non treated control group. Highest depletion of enzyme activity was recorded in the *Cassia fistula* treated group of termites.

## 3.3. Total Carbohydrate Content

Treatment of the worker termite with LC50 dose of each essential oil showed significant decrease of carbohydrate content in all the cases. The lowest carbohydrate content was found in *Citrus grandis* oil- treated termite. The carbohydrate content of each treated and control group are listed in Table 3. *Citrus grandis* essential oil treated group of termite showed significant variation of total carbohydrate content from other all treated group of termites. However no significant difference was observed between the *Citrus paradisi* and *Cassia fistula* treated group as shown in Table 4.

**Table 3. The carbohydrate content in treated and control group of termite**

| Sl. No | Treatment | Carbohydrate content (mg/g) |
|---|---|---|
| 1 | *Citrus grandis* | 36.5 |
| | *Positive control* | 93.3 |
| | *Negative control* | 125 |
| 2 | *Citrus paradisi* | 79.33 |
| | *Positive control* | 84.66 |
| | *Negative control* | 125 |
| 3 | *Cassia fistula* | 80.16 |
| | *Positive control* | 83 |
| | *Negative control* | 125 |

**Table 4. Result of Tukey test of the carbohydrate content of termite with different essential oils**

| (I) treated | (J) treated | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| negaive control | positive control *Cg* | 31.66667* | 1.98746 | .000 | 24.8026 | 38.5307 |
| | positive control *Cp* | 40.33333* | 1.98746 | .000 | 33.4693 | 47.1974 |
| | positive control *Cf* | 42.00000* | 1.98746 | .000 | 35.1360 | 48.8640 |
| | *Cg* | 88.50000* | 1.98746 | .000 | 81.6360 | 95.3640 |
| | *Cp* | 45.66667* | 1.98746 | .000 | 38.8026 | 52.5307 |
| | *Cf* | 44.25000* | 2.22205 | .000 | 36.5758 | 51.9242 |
| positive control *Cg* | negaive control | -31.66667* | 1.98746 | .000 | -38.5307 | -24.8026 |
| | positive control *Cp* | 8.66667* | 1.98746 | .010 | 1.8026 | 15.5307 |
| | positive control *Cf* | 10.33333* | 1.98746 | .002 | 3.4693 | 17.1974 |
| | *Cg* | 56.83333* | 1.98746 | .000 | 49.9693 | 63.6974 |
| | *Cp* | 14.00000* | 1.98746 | .000 | 7.1360 | 20.8640 |
| | *Cf* | 12.58333* | 2.22205 | .001 | 4.9091 | 20.2576 |

| (I) treated | (J) treated | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| positive control *Cp* | negaive control | -40.33333* | 1.98746 | .000 | -47.1974 | -33.4693 |
| | positive control *Cg* | -8.66667* | 1.98746 | .010 | -15.5307 | -1.8026 |
| | *positive control Cf* | 1.66667 | 1.98746 | .976 | -5.1974 | 8.5307 |
| | *Cg* | 48.16667* | 1.98746 | .000 | 41.3026 | 55.0307 |
| | *Cp* | 5.33333 | 1.98746 | .178 | -1.5307 | 12.1974 |
| | *Cf* | 3.91667 | 2.22205 | .591 | -3.7576 | 11.5909 |
| positive control *Cf* | negaive control | -42.00000* | 1.98746 | .000 | -48.8640 | -35.1360 |
| | positive control *Cg* | -10.33333* | 1.98746 | .002 | -17.1974 | -3.4693 |
| | positive control *Cp* | -1.66667 | 1.98746 | .976 | -8.5307 | 5.1974 |
| | *Cg* | 46.50000* | 1.98746 | .000 | 39.6360 | 53.3640 |
| | *Cp* | 3.66667 | 1.98746 | .544 | -3.1974 | 10.5307 |
| | *Cf* | 2.25000 | 2.22205 | .942 | -5.4242 | 9.9242 |
| *Cg* | negative control | -88.50000* | 1.98746 | .000 | -95.3640 | -81.6360 |
| | positive control *Cg* | -56.83333* | 1.98746 | .000 | -63.6974 | -49.9693 |
| | positive control *Cp* | -48.16667* | 1.98746 | .000 | -55.0307 | -41.3026 |
| | positive control*Cf* | -46.50000* | 1.98746 | .000 | -53.3640 | -39.6360 |
| | *Cp* | -42.83333* | 1.98746 | .000 | -49.6974 | -35.9693 |
| | *Cf* | -44.25000* | 2.22205 | .000 | -51.9242 | -36.5758 |
| *Cp* | negaive control | -45.66667* | 1.98746 | .000 | -52.5307 | -38.8026 |
| | positive control *Cg* | -14.00000* | 1.98746 | .000 | -20.8640 | -7.1360 |
| | positive control *Cp* | -5.33333 | 1.98746 | .178 | -12.1974 | 1.5307 |
| | positive control *Cf* | -3.66667 | 1.98746 | .544 | -10.5307 | 3.1974 |
| | *Cg* | 42.83333* | 1.98746 | .000 | 35.9693 | 49.6974 |
| | *Cf* | -1.41667 | 2.22205 | .994 | -9.0909 | 6.2576 |
| *Cf* | negative control | -44.25000* | 2.22205 | .000 | -51.9242 | -36.5758 |
| | positive control *Cg* | -12.58333* | 2.22205 | .001 | -20.2576 | -4.9091 |
| | positive control *Cp* | -3.91667 | 2.22205 | .591 | -11.5909 | 3.7576 |
| | positive control *Cf* | -2.25000 | 2.22205 | .942 | -9.9242 | 5.4242 |
| | *Cg* | 44.25000* | 2.22205 | .000 | 36.5758 | 51.9242 |
| | *Cp* | 1.41667 | 2.22205 | .994 | -6.2576 | 9.0909 |

*. The mean difference is significant at the 0.05 level.
Cg=*Citrus grandis*, Cp= *Citrus paradisi*, Cf=*Cassia fistula*.

### 3.4. Total Protein Content

The protein content of the worker termite was found to decrease after treatment with LC50 dose of the three essential oils as compared to the positive and negative control (Table 5). The worker termites treated with the oil of *C. grandis* showed less protein content than the application of other two essential oils. The total protein content was significantly different between the control group and all treated groups of the target insect. However, the protein content of *Citrus grandis* essential oil treated individuals was not significantly differed from the protein content of *Citrus paradisi* treated individuals (Table 6).

**Table 5. The protein content in treated and control group of termite.**

| Sl. No | Treatment | Protein content (mg/g) |
|---|---|---|
| 1 | *Citrus grandis* | 46.83 |
| | *Positive control* | 164 |
| | *Negative control* | 193.16 |
| 2 | *Citrus paradisi* | 59.33 |
| | *Positive control* | 164 |
| | *Negative control* | 193.16 |
| 3 | *Cassia fistula* | 117.16 |
| | *Positive control* | 163.99 |
| | *Negative control* | 193.16 |

**Table 6. Result of Tukey test of the protein content of Termite with different essential oils**

| (I) treated | (J) treated | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| negative control | positive control *Cg* | 29.16667* | 7.16086 | .015 | 4.7153 | 53.6180 |
| | positive control *Cp* | 29.16667* | 7.16086 | .015 | 4.7153 | 53.6180 |
| | positive control *Cf* | 29.17000* | 7.16086 | .015 | 4.7186 | 53.6214 |
| | *Cg* | 146.33333* | 7.16086 | .000 | 121.8820 | 170.7847 |
| | *Cp* | 133.83333* | 7.16086 | .000 | 109.3820 | 158.2847 |
| | *Cf* | 87.83333* | 7.16086 | .000 | 63.3820 | 112.2847 |
| positive control *Cg* | negative control | -29.16667* | 7.16086 | .015 | -53.6180 | -4.7153 |
| | positive control *Cp* | .00000 | 7.16086 | 1.000 | -24.4514 | 24.4514 |
| | positive control *Cf* | .00333 | 7.16086 | 1.000 | -24.4480 | 24.4547 |
| | *Cg* | 117.16667* | 7.16086 | .000 | 92.7153 | 141.6180 |
| | *Cp* | 104.66667* | 7.16086 | .000 | 80.2153 | 129.1180 |
| | *Cf* | 58.66667* | 7.16086 | .000 | 34.2153 | 83.1180 |
| positive control *Cp* | negative control | -29.16667* | 7.16086 | .015 | -53.6180 | -4.7153 |
| | positive control *Cg* | .00000 | 7.16086 | 1.000 | -24.4514 | 24.4514 |
| | positive control *Cf* | .00333 | 7.16086 | 1.000 | -24.4480 | 24.4547 |
| | *Cg* | 117.16667* | 7.16086 | .000 | 92.7153 | 141.6180 |
| | *Cp* | 104.66667* | 7.16086 | .000 | 80.2153 | 129.1180 |
| | *Cf* | 58.66667* | 7.16086 | .000 | 34.2153 | 83.1180 |
| positive control of *Cf* | negative control | -29.17000* | 7.16086 | .015 | -53.6214 | -4.7186 |
| | positive control Cg | -.00333 | 7.16086 | 1.000 | -24.4547 | 24.4480 |
| | positive control*Cp* | -.00333 | 7.16086 | 1.000 | -24.4547 | 24.4480 |
| | *C. g.* | 117.16333* | 7.16086 | .000 | 92.7120 | 141.6147 |
| | *C. p.* | 104.66333* | 7.16086 | .000 | 80.2120 | 129.1147 |
| | *C. f.* | 58.66333* | 7.16086 | .000 | 34.2120 | 83.1147 |
| *Cg* | negative control | -146.33333* | 7.16086 | .000 | -170.7847 | -121.8820 |
| | positive control *Cg* | -117.16667* | 7.16086 | .000 | -141.6180 | -92.7153 |
| | positive control *Cp* | -117.16667* | 7.16086 | .000 | -141.6180 | -92.7153 |
| | positive control *Cf* | -117.16333* | 7.16086 | .000 | -141.6147 | -92.7120 |
| | *Cp* | -12.50000 | 7.16086 | .600 | -36.9514 | 11.9514 |
| | *Cf* | -58.50000* | 7.16086 | .000 | -82.9514 | -34.0486 |
| *Cp* | negative control | -133.83333* | 7.16086 | .000 | -158.2847 | -109.3820 |
| | positive control *Cg* | -104.66667* | 7.16086 | .000 | -129.1180 | -80.2153 |
| | positive control *Cp* | -104.66667* | 7.16086 | .000 | -129.1180 | -80.2153 |
| | positive control *Cf* | -104.66333* | 7.16086 | .000 | -129.1147 | -80.2120 |
| | *Cf* | 12.50000 | 7.16086 | .600 | -11.9514 | 36.9514 |
| | *Cf* | -46.00000* | 7.16086 | .000 | -70.4514 | -21.5486 |
| *Cf* | negative control | -87.83333* | 7.16086 | .000 | -112.2847 | -63.3820 |
| | positive control *Cg* | -58.66667* | 7.16086 | .000 | -83.1180 | -34.2153 |
| | positive control *Cp* | -58.66667* | 7.16086 | .000 | -83.1180 | -34.2153 |
| | positive control *Cf* | -58.66333* | 7.16086 | .000 | -83.1147 | -34.2120 |
| | *Cg* | 58.50000* | 7.16086 | .000 | 34.0486 | 82.9514 |
| | *Cp* | 46.00000* | 7.16086 | .000 | 21.5486 | 70.4514 |

*. The mean difference is significant at the 0.05 level.
*Cg=Citrus grandis, Cp= Citrus paradishi, Cf=Cassia fistula.*

## 4. Discussion

Considering the damages caused by termites and the cost incurred thereafter, different plant essential oils have been tried to control different termite species worldwide besides other control measures. Some of the essential oils have reported to possess potential toxic effects against them [11,15]. However, many of the plants essential oil has not yet been tested against termites. In the present investigation, essential oils of three plants viz. *Citrus grandis*, *Citrus paradisi* and *Cassia fistula* which were not found to be studied against termite were assessed for their termiticidal activities against worker caste of *Odototermes feae*. The results showed promising termiticidal activities of these three essential oil of which highest efficacy was obtained for the essential oil of *C. grandis* and the lowest activities was observed for the essential oil of *Cassia fistula*. Earlier efficacies of these selected essential oils were found to be reported against a wide group of insects like mosquitoes, beetle, aphids etc. [16,17,18] but not against termites. Yazdgerdian et al. [15] studied contact and residual toxicity of eleven different essential oils including *Citrus aurentium* and *Citrus sinensis* against beech aphid and rice weevil. Zia et al. [19] studied the toxic effects of four different plant species of the genus *Citrus* L. against three species of beetle. The flower-extract or seed extracts and oils of leave of *Cassia fistula* were also reported as anti-microbial as well as mosquitocidal agents [20,21]. The findings of the present studies also showed potential termiticidal effect of the selected essential oil against *O. feae*.

Generally, the efficacy of an essential oil depends upon its chemical composition and the ratio of the constituents present in the mixture. Various compounds present in essential oils such as alcohols, aldehydes, terpene, terpinoid, phenol etc. jointly or individually contribute to the insecticidal activities of essential oils. It has been reported that the constituent compounds of some plant essential oils like diallyltrisulphide, diallyldisulphide, eugenol etc. were responsible for antitermitic activities [22]. Usually the toxicity of the essential oils is due to the presence of the major constituent compounds. Earlier GC-MS analysis of the essential oil extracted from the peel of *C. paradisi* showed limonene and áterpinol as major compound [23]. Similarly, eugenol, E-phytol, limonene and camphor were found to present as major compounds in the essential oil of *Cassia fistula* [19]. These major compounds might be responsible for the antitermitic activities of the plant essential oil against *O. feae*. However, other minor compounds present in the oil also might play important role as they could inhibit or enhance the effect of other major compounds present in essential oils.

Investigation of mode of action of these oils may give useful information for the control of termite. There are many reports where inhibition of GST activity by plant products has been recorded [1]. GSTs are multifunctional detoxifying enzymes that catalyze the conjugation of reduced glutathione and play an essential role in detoxification of xenobiotic compounds. Plant-derived natural products were also reported as an activator of GST activity in insects [24]. In the present study, effect of these three essential oils on inhibition of GST activity was observed after 24 hour of treatment at sublethal concentration and it has been found that the enzyme activity was decreased up to 15 minutes in case of all three essential oil. So, it seems to be relevant that the decline of the detoxification ability might be one of the reasons for their insecticidal activities. However at 1-2 minutes of incubation period the enzyme level was observed higher in treated termites than non- treated control group.

The main source of the energy in the animal body is the carbohydrate. In the present study, all the three oils showed significant depletion of the total carbohydrate content of the worker termite. The reduction of carbohydrate may be linked with the antifeedent activities and high metabolic rate under the stress produced by the xenobiotic compounds. The changes in energy reserves such as carbohydrates, lipids, proteins, and glycogen may be related with the susceptibility of the insect to insecticide and its function alterations [14].

Proteins are important biomolecules associated with the various metabolic processes. The results of the present study also showed significant reduction of the protein content after treatment with the plant oils. The decrease of the protein content might be due to the use of the proteins as energy source or their breakdown to various amino acids under stress [25]. So, protein depletion in tissues might interfere with various physiological mechanisms that impact on the life span of the treated insects.

Our results indicate that these three plant essential oils may be useful as termiticidal agent to be used in termite management programme in future. However further study is necessary for exploring the persistence of these materials in field along with their effects on other organisms.

## 5. Conclusion

Essential oil from the selected plants could be an alternative measure for the control of termites as they showed potential effects which are generally free from health hazards, environmental pollution. Further studies are required to identify the active compounds responsible for their effectiveness, to reveal the mode of action of the selected plant essential oils on the target species and last but not the least, to highlight the field trials.

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## Conflict of Interest

The authors have no competing interest.

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