Synergistic activity of lemongrass and sesame oils on spinosad: A new approach to control the peach fruit fly; *Bactrocera zonata* (Saunders, 1841), referring to their effect on the adult biological and protein aspects

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**Abstract:** The peach fruit fly *Bactrocera zonata* (Diptera: Tephritidae), is considered a major destructive pest for fruits and some vegetables. Toxicity of Spinosad mixtures with each lemongrass (*Cymbopogon citratus* Stapf) and sesame (*Sesamum indicum* L.) oils were evaluated against *Bactrocera zonata* (Saunders, 1841) adults in a lab by feeding method. The study proved that mixing LC₂₅ of spinosad with LC₂₅ of the plant oils showed a high percentage of mortalities than using each compound individually. The mixture of spinosad with each lemongrass and sesame oil strongly affected the longevity of males (39.66 and 35.66 days) and females (54.33 and 53.33 days), respectively. Also treating insects with the tested mixtures adversely affected the egg numbers (28.7, 21.3), hatchability (46.66 and 33.33) of the deposited eggs, percentage of pupation (29.0 and 42.0), and percentage of adult emergence (20.33 and 36.66). Fractionation of proteins by SDS-PAGE showed that some protein bands were missed or expressed under stress of the spinosad, lemon grass, sesame oil and their mixtures.

**Keywords:** the peach fruit fly, bioinsecticides, plant oils, mortality, co-toxicity factor

**Introduction**

Family Tephritidae (fruit flies), is among the largest families of Diptera. Currently, it is generally acknowledged that there are probably 1500 fruit fly species related to fruits; more than 250 species of which are of economic significance (Lizhi *et al.* 2013). These tephritid fruit pests are found in almost all fruit-growing areas of the world, where they can cause serious damage to fruits, sometimes resulting in almost total crop failure. In Africa, most species that attack commercially grown fruit crops belong to *Ceratitis* and *Dacus* as well as some *Bactrocera* species (Grove & Beer 2014). *Bactrocera zonata* (Saunders, 1841) is a polyphagous pest that attacks a wide range of plant families. It was found in Egypt by late 1990. It is considered a very important economic pest as it causes severe damage to fruits and vegetables as well (Koohkanzadeh *et al.* 2019).

Spinosad is a product obtained from the fermentation of the soil bacterium *Saccharopolyspora spinosa* which had been known for its insecticidal activity (Manrakhan *et al.* 2013). It proved high effect on tephritids with low toxicity against mammals and has low effects on beneficial insects (Urbaneja *et al.* 2009).

Nowadays, it's recommended to save the environment by decreasing the hazardous use of chemical insecticides and going to new alternatives such as plant oils. Essential oils are unstable, natural, and complex compounds characterized by a strong odor and are formed by aromatic plants as secondary metabolites (Pramod & Sharangouda 2021). *Cymbopogon*
*citratus* (Stapf.) (lemongrass) represents one of the most sourced plants in the world because of its distribution and application. The active ingredients found in the essential oil of lemongrass are limonene, citral, geraniol, myrcene, citronellol, geranyl acetate, neral and nerol. Even though myrcene and limonene are aromatic compounds, citral and geraniol show antimicrobial and insecticidal activity (Kuete 2017). Sesame (*Sesamum indicum* L.) oil is well known as an effective antioxidant and its synergistic effect has been reported on pesticides against *Spodoptera littoralis* (Boisduval) (Abdel-Hafez & Abdel-Aziz 2010). It's composed of the following fatty acids: linoleic acid (41% of total), oleic acid (39%), palmitic acid (8%), stearic acid (5%), and others in small amounts (Ming–Shun et al. 2019).

Synergism is a special case of joint reaction where one of the compounds can increase the potency of the other compound of the mixture; and their combined effect is more than using every compound individually (Pop 2014).

In the present study, the synergistic effect of both lemongrass and sesame oils when mixed with spinosad was investigated. Either the lemongrass essential oil or sesame oil was mixed with spinosad in different ratios to assess their toxicological and biological effects against the *B. zonata* adults by feeding method. Adult internal protein profiles were estimated for all control and treated samples with spinosad, lemongrass, sesame oil and their mixture to observe if there were biochemical changes that had been happened.

**Materials and Methods**

**Mass rearing of insects**

Adults of *B. zonata* were reared according to standard laboratory procedures maintained by the Plant Protection Research Institute Laboratory. The peach fruit fly colonies were maintained at a constant temperature of 25±2°C and relative humidity (RH) of 65±5%. Adults were provided with a mixture of sugar and protein hydrolysate at a ratio of 1:3 in Petri dishes. Water was added to a small plastic bottle. The cage was supplied with plastic fruits that had many small pores (as an oviposition receptacle). Eggs were collected twice per week and deposited on a larval artificial diet. The trays of the diet were then placed in a large wooden box with sand at the bottom to allow the jumping larvae to pupate (Shehata et al. 2006).

**Used bioinsecticides**

A commercial spinosad (Conserve 0.024% BC, Dao Agro Science - England*) as well as plant oils such as lemongrass (*C. citratus*) oil and sesame (*S. indicum*) oil (National Research Centre) was used in this study.

**Application and assessment of insecticide – oil mixtures against adult insects**

Spinosad was mixed with plant oils in different concentrations to determine which of these concentrations have antagonistic, additive or synergistic activity against the peach fruit fly. The most potent obtained mixtures were tested in serial dilutions to evaluate their toxicity against adults of the peach fruit fly. Ten pairs of newly emerged adults were transferred to a small iron cage covered with muslin. The compounds were mixed with sugar solution (5%). Two ml of solutions were placed on a plastic cover then left for dryness. The plastic covers were put in the treatment cages for feeding insects. Three replicates for each concentration against three replicates with sugar solution only as a control was used. Mortality was observed 24 h after treatment.
**Biological aspect studies**

After 24 h from treating adult insects with LC$_{50}$ dose of each potent mixture adults were transferred to another small treatment cages using an aspirator. Five pairs of adults (5 males and 5 females) were confined in each cage in three replicates for each treatment. Oviposition periods, fecundity, fertility, longevity of males and females, and percentage of pupal formation and adult emergence were estimated.

**Protein electrophoresis**

Insects treated with LC$_{50}$ dose of spinosad, lemongrass and sesame oils and their mixtures were prepared for protein profile determination. SDS-PAGE was performed in 12% polyacrylamide slab gel according to the method of Laemmli (1970). For protein electrophoresis samples of *B. zonata* were homogenized in saline solution (75%) using a glass homogenizer for 3 min. Then the insoluble material was removed by centrifugation at 1500 g for 10 min at 4°C. The supernatant of each sample was kept at -20°C until used for protein analysis. 20µl of protein extract was added to an equal volume of buffer solution, then 25ml of each sample of proteins was loaded in the poly acrylamide gel. After electrophoresis, the gel was immersed in Coomassie Brilliant Blue (staining solution) for 18 h. and then distained for visualization of bands. The gel was analyzed using Gel-Pro Analyzer, Ver. 3.1 software.

**Statistical analysis**

Abbott’s formula was used for comparing and correcting mortalities in the treatments (Abbott 1925). Probit analysis was used to calculate LC values and the slope of regression lines for the tested toxicants (Finney 1971). All tested biological parameters were statistically analyzed by SAS version 9.1. (SAS Institute 2002).

The co-toxicity factor was calculated using equation suggested by Mansour et al. (1966):

\[ \text{Co-toxicity factor} = \frac{(\text{observed mortality %}) - (\text{expected mortality %})}{(\text{expected mortality %})} \times 100 \]

This factor is used to assess whether an antagonistic, additive or synergistic relation exists among components within a mixture compared with the individual components. Values lower than –20 show an antagonistic relationship, values between –20 and 20 shows an additive reaction, values more than 20 show a synergistic action. Values less than –15 but more than –20 or more than 15 but less than 20 indicate trends of antagonistic and synergistic activity.

**Results**

**Combined action studies of spinosad–plant oil mixtures on *B. zonata* adults**

The combination between different values of lethal concentrations of spinosad with lemongrass and sesame oils revealed a potential action (Table 1). Mixing LC$_{20}$ spinosad + LC$_{30}$ lemongrass oil showed additive co-toxicity factor. Mixing of LC$_{25}$ spinosad + LC$_{25}$ lemongrass oil and LC$_{25}$ sesame oil caused 100% mortality for the tested insects at both sexes and they were the most effective mixtures from which toxicological, biological and biochemical studies were made.

As shown in Fig. 1 mixing LC$_{25}$ of spinosad with LC$_{25}$ of lemongrass oil or LC$_{25}$ of sesame oil, caused a statistically significant increase in mortality of males or females of peach fruit flies, which reached 100% compared to LC$_{25}$ of spinosad, lemongrass, and sesame oil alone (13.33, 36.67%), (3.33, 13.33%) and (6.67, 3.33%), for males and females of peach fruit flies, respectively.
Table 1. The joint action of spinosad and plant oils against adults of *Bactrocera zonata* (Saunders).

| Mixture of spinosad and plant oils | Observed mortality | Co - toxicity factor |
|-----------------------------------|--------------------|---------------------|
|                                   | Male   | Female  | Male   | Female  |
| LC10 spinosad + LC40 lemongrass   | 21     | 26      | +73.3(p) | +40(p) |
| LC20 spinosad + LC30 lemongrass   | 14     | 20      | +33.3(p) | -6.7(d) |
| LC25 spinosad + LC25 lemongrass   | 30     | 30      | +100(p)  | +100(p) |
| LC30 spinosad + LC20 lemongrass   | 26     | 30      | +100(p)  | +73.3(p) |
| LC40 spinosad + LC10 lemongrass   | 29     | 30      | +100(p)  | +93.3(p) |
| LC10 spinosad + LC40 sesame       | 21     | 27      | +80(p)   | +40(p) |
| LC20 spinosad + LC30 sesame       | 23     | 26      | +73.3(p) | +53.3(p) |
| LC25 spinosad + LC25 sesame       | 30     | 30      | +100(p)  | +100(p) |
| LC30 spinosad + LC20 sesame       | 27     | 28      | +86.7(p) | +80(p)  |
| LC40 spinosad + LC10 sesame       | 30     | 29      | +93.3(p) | +100(p) |

Expected mortality = 50%  (p) = potentiation  (d) = additive effect

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**Lethal effect of spinosad–plant oil mixtures on *B. zonata* adults**

The lethal effect of the tested compounds against males and females of *B. zonata*, when mixed with the sugary solution, was evaluated. For males of peach fruit flies, LC50 values for mixture solution of LC25 spinosad + LC25 lemongrass oil and LC25 spinosad + LC25 Sesame oil given in Table 2 were 0.15 and 0.15%; while that recorded for females were 0.07 and 0.06%, respectively. Mixing the spinosad with lemongrass and sesame oils showed steep toxicity lines, recording 2.5 and 3.97 for males of the peach fruit fly and 3.078 and 6.65 for a females, respectively.
Table 2. Lethal values and parameters of mortality regression line for adults of *Bactrocera zonata* (Saunders) exposed to mixtures of spinosad and plant oils.

| Mixture                        | Stage | LC₂₅ | LC₅₀ | LC₉₀ | Confid. limits(s) LC₂₅ | Confid. limits(s) LC₅₀ | Confid. limits(s) LC₉₀ | Slope ± SD | Chi Square |
|--------------------------------|-------|------|------|------|------------------------|------------------------|------------------------|------------|------------|
|                                |       | Lower| Upper| Lower| Lower Upper Lower Upper| Lower Upper Lower Upper|                       |            |            |
| LC₂₅ spinosad + LC₂₅ lemongrass oil | Male  | 0.083| 0.15 | 0.50 | 0.038 0.093 0.109 0.18 | 0.44 1.145            | 2.5 ±0.31               | 12.89      |            |
|                                | Female| 0.039| 0.07 | 0.169| 0.034 0.044 0.060 0.07 | 0.149 0.20            | 3.078 ±0.24             | 6.47       |            |
| LC₂₅ spinosad + LC₂₅ sesame oil  | Male  | 0.10 | 0.15 | 0.32 | 0.091 0.115 0.14 0.16  | 0.29 0.37             | 3.97 ±0.34             | 5.06       |            |
|                                | Female| 0.062| 0.08 | 0.12 | 0.057 0.067 0.075 0.082| 0.11 0.13             | 6.65 ±0.54             |            | 6.019      |

Sub-lethal effects of the tested compounds on certain biological aspects of *B. zonata*

A significant decrease in the longevity of males and females of the peach fruit fly was recorded after treatment with LC₅₀ for the mixtures of spinosad and plant oils against control (Table 3). Treatment significantly affect pre- or post-oviposition periods compared to the untreated group. Regarding oviposition periods recorded for the mixtures (30 and 28.66 days, respectively) there were significant decreases in those periods compared with the untreated group (87.33 days).

Table 3. Influence of spinosad and plant oils mixtures on selected biological aspects of *Bactrocera zonata* (Saunders).

| Mixture                        | Longevity (days) | Mean of oviposition periods (days) | Mean No. of eggs / female (± SE) | Hatchability (%) ± SE | Mean No. of pupation (%) ± SE | Adult emergence (%) ± SE |
|--------------------------------|------------------|-----------------------------------|----------------------------------|-----------------------|-------------------------------|--------------------------|
|                                | Male ± SE        | Female ± SE                       | pre-oviposition period ± SE      | oviposition period ± SE| post-oviposition period ± SE  |                          |
| Control                        | 90 ± 0.58a       | 108.67 ± 1.33a                    | 14.3 ± 0.33b                     | 87.33 ± 0.33a         | 7 ± 0.0b                      | 411 ± 0.9 a              | 98 ± 0.33a               | 96.67 ± 3.3a             |
| LC₂₅ lemongrass oil + LC₂₅ spinosad | 39.66 ± 2.6b     | 54.33 ± 1.45b                    | 17 ± 1.2a                       | 30 ± 0.0b             | 7.33 ± 0.33a                  | 28.7 ± 0.7 b             | 46.66 ± 0.88b            | 29 ± 0.57c               | 20.33 ± 0.33c           |
| LC₂₅ sesame oil + LC₂₅ spinosad  | 35.66 ± 2.18c    | 53.33 ± 1.85b                    | 17.3 ± 2.3a                     | 28.66 ± 0.88c         | 6.33 ± 0.33ac                 | 21.3 ± 0.3 c             | 33.33 ± 0.88c            | 42 ± 1.5b               | 36.66 ± 1.2b            |

Significant decreases in total number of eggs laid by females, with spinosad-lemongrass oil and spinosad - sesame oil mixtures were also investigated (28.7 and 21.3 eggs, respectively) as compared to control individuals (411 eggs). A combination between spinosad and sesame oil or lemon grass oil significantly affected the number of eggs. For
the hatchability of laid eggs, significant decrement took place after being treated by different tested compounds. The formed larvae hardly succeeded to pupate after treating insects with spinosad and lemongrass oil as well as spinosad and sesame oil (29 and 42%, respectively) as compared to control (98%). Percentage of adult emergence greatly decreased when spinosad with lemongrass oil or with sesame oil was used.

**Fractional protein patterns of adult tissues after treatment with Spinosad, lemongrass, sesame oil and their mixture**

Protein SDS-PADG revealed that the tissues of adult male peach fruit flies (control and treated samples) were separated into 59 different bands according to their relative frequency (Rf) values. Figure (2) illustrated the total number of bands in untreated and treated samples with spinosad, sesame oil, lemongrass oil and their spinosad mixtures A, B, C, D, E, F & G was 9, 13, 10, 9, 10 & 10, respectively.

Band no. 39 with M.w 32.01 Kda. was common for A, E & F samples. Bands no. 4, 11, 14, 24, 30, 39, 46, 51 & 59 with M.w 84.96, 69.47, 67.54, 40.78, 38.42, 32.01, 27.67, 22.83 & 14.25 were characteristic for control sample (A). While no. 6, 7, 13, 16, 22, 27, 28, 34, 40, 47, 52, 53 & 58 with M.w. 83.78, 71.77, 68.68, 66.04, 44.68, 40.16, 39.03, 35.83, 31.45, 27.16, 22.39, 20.86 & 15.40 Kda. were characteristic for males treated with spinosad (B). Bands 3, 5, 8, 9, 15, 18, 20, 21, 23, 25, 29, 32, 37, 38, 42, 44, 48, 56 & 57 were characteristic for samples treated with the mixtures of oils and spinosad. All bands are characteristic except band no.26 with M.w.40.58 Kda. was shared between E &F .In A sample band no. 14 with M.w 67.54 has the highest concentration with percentage amount to 26.2. Bands no. 13, 15, 18, 19 & 17 with M.w 68.68, 66.48, 65.69, 64.02 & 64.45 have the greatest density reached to 26.2, 30.3, 51, 37.5, 37.3 & 33.3; respectively.

Changes for treated and untreated females of peach fruit flies as a result of treating with LC$_{50}$ of spinosad, plant oils and their mixture were investigated according to their SDS-PAGE pattern. Forty seven bands were recognized as shown in figure (3). Ten bands were observed in females of control sample (A) with M.w ranged between 90.83 Kda. to 17.29 Kda Bands no. 2, 10, 18, 22, 27, 31, 33, 39 & 46 with M.w .ranged from 104.51 to 17.68 Kda were characteristic for samples treated with spinosad (B). Bands no. 6, 11, 17, 28, 35 & 43 and no. 1, 5, 9, 16, 26, 36 & 44 with M.w ranged from 87.61 to 19.12 Kda and 120.32 to 19.06 Kda; respectively, are characteristic for female samples treated with plant oils (C & D). On the other hand, bands no. 3, 7, 14, 19, 23, 30, 38, 41 & 44 and no. 5, 8, 16, 21, 25, 30, 37, 42 & 45 with M.w between 90.07 to 18.88 Kda. were characteristic for (E & F). Bands no. 4, 11, 30 &
44 are shared between A & F, B & C, E & F and D & E; respectively.

Fig. 3. SDS-PAGE protein pattern of control and treated female tissues of *Bactrocera zonata* (Saunders) with spinosad, lemongrass and sesame oils and their mixtures.

**Discussion**

Fruit flies are a great group of pests belonging to Diptera. Family Tephritidae belong to the largest families of flies and are part of the most destructive agricultural pests in the world, attacking a wide variety of fruits and vegetables (Sanja *et al.* 2019).

From data obtained in the present study the amount of insecticides used to control the peach fruit fly can be reduced with increasing its efficiency by mixing with natural plant oils as attempt to keep on the environment from hazardous excess of using chemical pesticides and in the same time the aim of controlling the *B. zonata* can be reached.

Synergistic activity of mixing LC25 spinosad + LC25 lemongrass oil and LC25 spinosad + LC25 sesame oil were investigated against males and females of peach fruit fly. The potential, additive or antagonistic effects of mixing plant oils with spinosad were tested against newly emerged adult males and females of this species.

In the present study the lethal doses (LC25, LC50 and LC90) of the insecticide-plant oil mixtures were compared with results obtained previously (Elsayed *et al.* 2022). Very little doses of insecticides or plant oils were used when mixing 1:1 ratio at the level of LC25 than using spinosad or plant oils alone. Also, the effect of the sub lethal dose (LC50) of the newly tested mixtures on some biological aspects and change in protein patterns in treated adult insects had been studied.

Plant oils mixed with insecticides were tested by Abd El-Razik & Zayed (2014). The Authors showed that the combination between spinosad and sesame oil (90:10) proved a high synergistic effect recording a co-toxicity coefficient of 503.40, while using corn sunflower oil mixed with spinosad revealed antagonistic effect at all ratios of mixing.

Treatment of the peach fruit flies with spinosad mixed with plant oils led to a decrease in longevity for both sexes. Also, they negatively affected the oviposition periods. Used compounds had different effects on the number of eggs laid by females and on the fertility of the deposited eggs. The percentage of pupation and adult emergence significantly decreased. The impact of LC50 dose for the mixtures on some biological aspects was compared with that obtained by Elsayed *et al.* (2022). The tested mixtures had a potent impact on the tested biological activities than using spinosad, lemongrass or sesame oils separately.

Adverse effects on fecundity and fertility were observed by Medina *et al.* (2003) when 10 days old adults of *Chrysoperla carnea* (Stephens) were treated by spinosad; only 38.2% of the eggs were hatched. Data was consistent with those obtained by Soonwera & Sinthusiri (2014) who proved that *Cymbopogon citratus* (lemongrass oil) and *Syzygium aromaticum* (clove oil) have
larvicidal, pupicidal, adulticidal, oviposition deterrent and ovicidal activities against housefly (*Musca domestica* L.). Similar findings were obtained by Mohamed *et al.* (2020). They used different volatile oils against the greater wax moth (*Galleria mellonella* L.) that caused a lower percentage of pupation and adult emergence (Marei *et al.* 2009), also remarked that sesame oil has a latent effect on larvae of *S. littoralis* up to certain limits.

Recent findings showed that after fractionation of protein by SDS-electrophoresis there were some protein bands that were missing or expressed under stress of the tested compounds and their mixtures. These observations were in agreement with Mikhail & Amin (2013) when they studied the protein profile for *C. olbiceps* larvae after exposure to thyme, ginger, cloves, jojoba and cinnamon; they observed the appearance of a new protein band might be due to an increase of protein synthesis while the disappearance of other could be attributed to their breakdown as a result of the toxicity of oils. Also, sub-lethal effect of spinosad on protein content was observed by Piri *et al.* (2014). They found that the total amount of protein is reduced after treatment with LC$_{30}$ and LC$_{40}$ of spinosad. Treatment with spinosad also decreased the total protein in the whole body of the late 2$^{nd}$ instar larvae of *Culex pipiens* L. (Moselhy *et al.* 2015). The total number of protein bands were increased when *Tenebrio molitor* L. larvae were exposed to deodar oil (Buneri *et al.* 2017). Rodriguez–Ortega *et al.* (2003) mentioned in their explanation that the exposure of an organism to xenobiotics can modify the synthesis of certain metabolites (proteins) and disturb the functionality of the organism.

**Conclusion**

In conclusion; it is necessary to avoid pesticides hazards with their negative effects on mammalian health. Also, it is important to overcome the appearance of new pest resistance to pesticides. This study attempted to reduce the recommended dose of spinosad used in the control of the peach fruit fly and worked to induce its insecticidal efficiency by using natural plant oils. This new trend would lower the dangerous effects of pesticides on the environment and living organisms, and finally, reduce the economic cost of using insecticides only.

**References**

Abbott WS. 1925. A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology*, 18(2): 265- 267. doi.org/10.1093/jee/18.2.265.

Abd El-Hafez HF, Abdel-Aziz MA. 2010. Synergistic effects of some plant extracts to biorational product, spinosad against the cotton leaf worm, *Spodoptera littoralis* (Biosd.) (Lepidoptera: Noctuidae). *Egyptian Journal of Biological Pest Control*, 20: 27-32.

Abd El-Razik MAA, Zayed GMM. 2014. Effectiveness of three plant oils in binary mixtures with pyridalyl, abamectin, spinosad and malathion against *Callosobruchus maculates* adults. *American Journal of Biochemistry and Molecular Biology*, 4(2): 76-85. doi.org/10.3923/ajbmb.76-85.

Buneri ID, Yousuf M, Attaullah M, Afridi S, Anjum SI, Rana H, Ahmad N, Amin M, Tahir M, Ansari MJ. 2017. A comparative toxic effect of Cedrus deod oil on larval protein contents and its behavioral effect on larvae of mealworm beetle (*Tenebrio molitor*) (Coleoptera: Tenebrionidae). *Saudi Journal of Biological Sciences*, 26: 281-285. doi.org/10.1016/j.sjbs.2017.06.005

Elsayed DAE, El Shafei AM, Mosallam AMZ, Negm AAKH, Maamoun SAM. 2022. Toxicity and biological effects of certain pesticides and natural oils on the peach fruit fly, *Bactrocera zonata* (Saunders, 1841) (Diptera: Tephritidae). *Polish Journal of Entomology*, 91(1): 1–10. doi:10.5604/01.3001.0015.7350
Finney DJ. 1971. Probit analysis a statistical treatment of the sigmoid response curve. Cambridge Univ. Press, Cambridge, 333 pp. https://doi.org/10.1002/jps.2600600940

Grove T, Beer MSD. 2014. Monitoring fruit flies in Litchi orchards in south Africa and determining the presence of alien invasive Bactrocera species. Acta Horticulturae 1029, 425–432. https://doi.org/10.17660/ActaHortic.2014.1029.54

Koohkanzadeh M, Pramual P, Fekrat L. 2019. Genetic analysis of populations of the peach fruit fly, Bactrocera zonata (Diptera: Tephritidae), in Iran. Neotropical Entomology, 48: 594–603.

Kuete V. 2017. Medicinal spices and vegetables from Africa, Therapeutic potential against metabolic inflammatory infectious and systemic diseases. Academic Press Elsevier, San Diego, USA, 670 pp.

Laemmli UK. 1970. Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature, 227, 680-685. https://doi.org/10.1038/227680a0

Lizhi H, Jiang F, Ma XL, Fang Y, Sun ZZ, Qin YJ, Wang QL. 2013. Review on prevention and control techniques of Tephritidae invasion. Plant Quarantine, 27: 1–10.

Manrakhan A, Kotze C, Daneel JH, Stephen PR, Beck RR. 2013. Investigating a replacement for Malathion in bait sprays for fruit fly control in South African citrus orchards. Crop Protection, 43: 45–53. doi.org/10.1016/j.cropro.2012.09.010

Mansour NA, Elderfawi ME, Toppozada A, Zeid M. 1966. Toxicological studies on the Egyptian cotton leafworm, Prodenialitura, VI. Potentiation and antagonism of organophosphorus and carbamate insecticides. Journal of Economic Entomology, 59: 307–311. https://doi.org/10.1093/jee/57.4.591

Marei SS, Amr EM, Salem NY. 2009. Effect of some plant oils on biological, physiological and biochemical aspects of Spodoptera littoralis. Research Journal of Agriculture and Biological Sciences, 5: 103-107.

Medina P, Flor B, Estal PD, Vinuela E. 2003. Effects of three modern insecticides, pyriproxyfen, spinosad and tebufenozide on survival and reproduction of Chrysoperla carnea adults. Annals of Applied Biology, 142: 55- 61. doi.org/10.1111/j.1744-7348.2003.tb00229.x

Mikhaeil AA, Amin MM. 2013. Laboratory Assessment for the efficacy of some botanical oils to prevent animal wound myiasis by flesh fly Chrysomya albiceps (Diptera: Calliphoridae). Journal of Radiation Research and Applied Sciences, 1: 53 – 67.

Ming-Shun W, Levent BBA, Marjette YUB, Chien-Lun H, Kathlia AC, Ling-Ling Y, Po-Wei T. 2019. Anti-Inflammatory and anticancer properties of bioactive compounds from Sesamum indicum L. A Review. Molecules, 24: 1-28. doi.org/10.3390%2Fmolecules24244426

Mohamed HF, EL-Naggar SEM, Ibrahim AA, Elbarky NM, Salama MSM. 2020. Effect of volatile oils and / or gamma irradiation on the 4 th instar larvae of Galleria mellonella. Journal of Nuclear Technology in Applied Science, 8: 15-28. https://dx.doi.org/10.21608/jntas.2020.19151.1007

Moselhy WA, Abdelbaset BZ, Mostafa AA, Hanaa I, Mahmoud HI, Hamed S. 2015. Spinosad as an alternative larvicide for mosquito Culex pipiens. Control, 4: 646-657.

Piri F, Sahragard A, Ghadmamyari M. 2014. Sublethal effects of spinosad on some biochemical and biological parameters of Glyphodes pyloalis Walker (Lepidoptera: Pyralidae). Plant Protection Science, 50(3): 135–144. https://doi.org/10.17221/50/2013-pps

Pope C. 2014. Chemical Interactions. In: Wexler P. (Eds.). Encyclopedia of Toxicology. 3th Edition. Elsevier BV, Amsterdam, The Netherlands, pp. 793–794.
Pramod T, Sharangouda JP. 2021. Essential oils production methods, chemical constituents, biosynthesisis and their application in infectious diseases. In:, Lingayya H, Sharangouda JP, Pramod T (Eds). Bioactive molecules against infectious diseases: Current Concepts & Updates. Innovationinfoebooks, Cambridge, United kingdom, pp 162-178.
Rodriguez-Ortega MJ, Grovisk BE, Rodriguez-Ariz A, Goksoyr A, Lopez-Barea J. 2003. Changes in protein expression profiles in bivalve mollusks (Chamaelea gallina) exposed to four model environmental pollutants. Proteomics, 3: 1535-1543. doi.org/10.1002/pmic.200300491
Sanja R, Hrnčić S, Perović T. 2019. Overview of fruit flies important for fruit production on the Montenegro seacoast. Journal of Biotechnology, Agronomy and Society and Environment, 23: 46-56.
SAS Institute. 2002. SAS, version. 9.1.2. SAS Institute, Cary, NC.
Shehata NF, Younes MWF, Mahmoud YA. 2006. Anatomical effects of gamma irradiation on the peach fruit fly, Bactrocera zonata (Saund.) male gonads. Journal of Applied Sciences Research, 2: 510-513. https://doi.org/10.15242/jrras.2016.05.004
Soonwera M, Sinthusiri J. 2014. Thai essential oils as botanical insecticide against house fly (Musca domestica). International Conference on Agriculture, Ecological and Medical Sciences, Bali, pp. 67-69. https://doi.org/10.15242/iicbe.c 0214046.
Urbaneja A, Chueca P, Montón H, Pascual-Ruiz S, Dembilio O, Vanaclocha P, Abad-Moyano R, Pina T ,Castañera P. 2009. Chemical alternatives to malathion for controlling Ceratitis capitata (Diptera: Tephritidae), and their side effects on natural enemies in Spanish citrus orchards. Journal Economic Entomology, 102: 144-151. doi.org/10.1603/029.102.0121

Received: 22.02.2022
Accepted: 3.06.2022
Published online: 30.06.2022