Effect of silver and silica nanoparticles on the larvae of pink stem borer
*Sesamia cretica* Lederer, 1857 (Lepidoptera: Noctuidae)
and maize plants *Zea mays* Linneaus, 1753

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Abstract: This study was aimed to evaluate the toxicological and biological effects of three nanoparticles (silver, hydrophilic and hydrophobic silica) at four concentrations (100, 200, 400 and 800 ppm) against 1st instar larvae of *Sesamia cretica* Lederer, 1857 and its effects on some maize characters. Each concentration and control was repeated 4 times (10 larvae/replicate). Larvae were fed on treated stem maize and mortality rate was recorded. After treatment with LC₅₀ values, the survival larvae were collected and the larval duration, pupal duration, pupal weight, pupation percentage and adult longevity were recorded. Seedling maize plants were sprayed with three concentrations (50, 100 and 200 ppm) at 4 categories (every 1, 3, 7 and 14 days) to detect the effect of nanoparticles on leaf area, extended height and leaf chlorophyll content. Results showed that hydrophilic silica nanoparticle was the most effective, followed by silver nanoparticle then hydrophobic silica nanoparticle with LC₅₀ 121.19, 405.71 and 416.82 ppm, respectively. All nanoparticles led to increase in larval durations, reduction of egg number per female and decrease of eggs hatchability rate. All nanoparticles caused positive effect on leaf area, extended height and chlorophyll content. These nanoparticles may be recommended to control *S. cretica* with positive effects on plant characters.

Keywords: Stem borer, corn, botanical characteristic, nanotechnology, larval mortality, biological aspects

Introduction

Maize (*Zea mays* Linneaus, 1753) is an important economic cereal crop. In developing countries, maize grain-flour is essential for making bread. Green maize plants, silage and maize grains represent a significant source for livestock fodder worldwide. Moreover, several food industries stand on processing maize grains and their byproducts (Orhun 2013).

In Egypt, maize plantations are usually subject to a variety of insect pests. The most economically serious of these pests are a group of insects, commonly and collectively known as “Corn Borers”. A corn borer that represents a real threat to maize plantations, particularly at the early stages of plant growth, is the “pink stem borer” *Sesamia cretica* Lederer, 1857 (Lepidoptera: Noctuidae) which is a key pest that destroys corn plantation especially in eastern Mediterranean countries, as well as in Africa and Asia (Onukogu 1984, Moyal *et al.* 2002). In Egypt, maize plantation are severely attacked by *S. cretica* especially those sown early from late March to mid-May (Metwally *et al.* 2015).

Stem borers affect maize yields through reducing the photosynthetic area of green leaves as well as the death of the growing points surrounded by whale leaves and early leaf senescence, reduced translocation, lodging and direct damage to ears. Secondary losses may also occur due to bacterial infections via entry points created by stem borers within plant tissue (Ndiritu 1999). To reduce dependency on chemical insecticides for the control of stem borers seeking for other alternatives becomes a significant requirement. Among such alternatives, nanotechnology seemed to be one of the
promising recent approaches for stem borer control. Nanoparticles represent a new generation of environmental remediation technologies that could provide a cost-effective solution to some of the most challenging environmental clean-up problems and help to produce new pesticides, insecticides and insect repellants (Cicek & Nadaroglu 2015). Among the most important nanoparticles used for the control of insect pests is silver and silica nanoparticles. Literatures refer to the toxic effects of silica and silver nanoparticles on insect pests specially the lepidopterous insects as Spodoptera littoralis (Boisdruval, 1833), Spodoptera litura (Fabricius, 1775), Tuta absoluta (Meyrick, 1917) and Helicoverpa armigera (Hübner, 1808). Nanoparticles may lead to a negative impact on the insect's biological and physiological properties that led to a reduction in insect’s populations. (Chakravarthy et al. 2012, Elbendary & El-Helaly 2013, Devi et al. 2014, Yasur & Usha Rani 2015, El-Helaly et al. 2016, Ayoub et al. 2017, Abd El Naby 2019, Ahmed et al. 2019).

Nanoparticles proved an effective role in controlling stored grain pests as Sitophilus oryzae (Linnaeus, 1763), Corcyra cephalonica (Stainton, 1866), Tribolium castaneum (Herbst, 1797) and Callosobruchus maculates (Fabricius, 1775) (Rouhani et al. 2012, Abduz Zahir et al. 2012, Vani & Brindhaa 2013, El-Samahy et al. 2014, Abd-El-Salam et al. 2015, Osman et al. 2015).

Applications of the nanoparticles in agriculture may play an important role in the global food security by helping to develop improved plant varieties with high productivity (Parisi et al. 2015). The unique properties of silver and silica nanoparticles allow them to cope with agricultural damage that may occur through climate change and/or abiotic stress and thus may be used in horticultural practices as a potential plant growth regulator (Tripathi et al. 2012, Byczyńska 2017). The effects of nanoparticles can be investigated at different levels in plants. These effects can vary according to size, shape and concentration of the nanoparticles as well as age and species of plants (Rico et al. 2011). Nano silica is considered the most widely used nano structural preparation in the field of agricultural insect’s pest control. In addition to its role in increasing the productive efficiency of plants in general, silica (whether in its pulk or nanoparticles forms) plays a major role in increasing plant growth, improving its ability to resist pest infestations (Siddiqui et al. 2015), as well as reducing the toxicity of mineral pollutants, salinity tolerance, drought, and frost effects (Marafon & Endres 2013). As for maize plants, silica and silica nanoparticles increase the efficiency of water use through reducing transpiration from leaves, increasing the rate of water flow in woody vessels, increase the rate of photosynthesis and in addition to increasing the leaf surface area (Suriyaprabha et al. 2012) which ultimately leads to increased grain production (Zhiming 2014). Also silver nanoparticles are regarded as one of the useful substances that can increase the growth and efficiency of maize plants by increasing leaf surface area, the percentage of germination, roots elongation in addition to raising the proportion of chlorophyll, carbohydrates and protein (Salama 2012, Almutairi & Alharbi 2015).

This study evaluates the effect of silver, hydrophilic silica and hydrophobic silica nanoparticles on the (neonate) first instar larvae of S. cretica and their effect on the various biological aspects under laboratory conditions as well as on the characteristics of maize plants related to infestation with S. cretica under field conditions.

**Materials and Methods**

**Handling insect material**

Full-grown larvae of the maize borer, S. cretica were hand-collected from maize fields and maintained on fresh maize stem cuttings at Corn Borers Research Laboratory (CBRL), Department of Economic Entomology
and Pesticides, Faculty of Agriculture, Cairo University until pupation. A stock culture of the study insect was reared and maintained for several generations under constant laboratory conditions of 27±2°C and 60±10% RH. The collected larvae were reared inside glass boxes with screen lids, fed on stem maize plants until pupal stage. Pupae were sexed by examining the ventral aspects of their terminal abdominal ends which show 3 genital pores in females and only 2 genital pores in males. Sexed pupae were then individually placed on moist cotton wool in glass tubes plugged with cotton wool until the emergence of adult moths. Every adults (4 females and 6 males) was introduced into a lantern glass cage, fitted on a plastic pot 10 cm in diameter and containing three maize seedlings (15 to 20 cm height) to serve as egg-deposition sites. Oviposition cages were covered with muslin and each supplied with a cotton piece saturated with 10% sugar solution then incubated at 25°C. Egg masses were collected daily by carefully dissecting the seedlings to gather the egg-masses laid on the inner surfaces of the leaf-sheaths. Egg masses were then kept in Petri dishes or glass tubes (2.5 × 9 cm.) tightly closed with cotton and incubated at 27–28°C and 75–80% R.H. until hatching. Newly hatched larvae were treated with LC50 values of the three tested nanoparticles (121.19, 416.82 and 405.71 ppm) for hydrophilic silica, hydrophobic silica and silver nanoparticles supplied by Nano Tech. Company, Egypt.

**Nano materials**

Three nano materials were used in this investigation, these are silver, hydrophilic silica and hydrophobic silica nanoparticles supplied by Nano Tech. Company, Egypt.

**Characterization of Nano materials**

The size, morphology and composition of the three tested nano materials were determined by a high resolution Transmission Electron Micrograph (JEOL 20100) (HR-TEM). The transmission electron microscope (TEM) images were carried out at the Faculty of Agriculture, Cairo University, Giza, Egypt. Dispersed nanoparticle samples in absolute ethanol were dropped on to coated copper grids and allowed to evaporate. Micrographs were obtained using a high-resolution transmission electron microscope (HR-TEM) (FEI TECNAI 02) with the software TECNAI G2. The HR-TEM is a JOEL JEM-M2100 operating at 200 kV equipped with a Gatan Erlangshen ES500 digital camera.

**Bioassay**

Four concentrations for each tested nanoparticle are used (100, 200, 400, and 800 ppm) against 1st instar larvae of *S. cretica* by leaf dipping technique of fresh seedling 3–4 weeks old after germination. Four replicates were devoted for each tested concentration with 10 neonate larvae for each. Small stem pieces of maize seedling (3 cm in length) were dipped into each of the different tested concentrations for 5 min. The stem pieces were placed on a paper towels until dried. Newly hatched larvae of *S. cretica* were then gently placed by fine camel-hair brush into glass vials (2.5 × 9 cm), each supplied with treated stem pieces (Osman et al. 2014). Vials encountering neonate larvae and stem pieces were closed with cotton then kept in under the above mentioned laboratory conditions. Control treatments received the same protocol using distilled water. The experiment was divided into three groups and checked after 1, 3 and 7 days for the first, second and third group, respectively after exposure and recording numbers of dead larvae. The mortality percentages were corrected according to Abbott’s formula (Abbott 1925) and the LC50 and LC90 values for all treatments were calculated.

**Biological studies**

One hundred newly-hatched larvae of *S. cretica* were treated with LC50 values of the three tested nanoparticles (121.19, 416.82 and 405.71 ppm) for hydrophilic silica, hydrophobic silica and silver nanoparticles,
respectively and control was treated with distilled water. Vials were examined after 7 days and surviving larvae were kept individually in glass jars containing untreated maize cutting and maintained at 27±2°C and 60±5% R.H. Jars were examined daily until pupation occurred to determine the larval duration. Obtained pupae were carefully weighted before their transfer individually to glass vials (4 × 10 cm) covered with muslin fitted with rubber band. All vials were kept under the previously mentioned conditions, checked daily until adult emergence and the pupal duration recorded. Newly-emerged adults, each one male and one female were transferred into new glass vials provided with cotton wool saturated with 10% honey solution and covered with muslin fitted with rubber band and examined daily. Female longevity, male longevity, number of eggs laid per female, pre oviposition period were recorded. Newly laid eggs (50 per replicate per treatment) were kept in petri dishes and incubated until hatching to record both incubation period and percentage of hatchability.

**Plant characteristics**

The study was conducted at the experimental Station of the Faculty of Agricultural, Cairo University, Giza, Egypt throughout 2019 maize growing season to evaluate the effect of three tested nanoparticles (hydrophilic silica, hydrophobic silica and silver) each at three concentrations (50, 100 and 200 ppm) on certain maize plant characteristics (leaf area, extended height and leaf chlorophyll content) which related to infestation with *S. cretica* under field conditions.

The maize variety (single cross 2031) was chosen for the field evaluation as susceptible to infestation with *S. cretica* (Metwally 2015). Seeding occurred during the 2nd week of April, 2019. An experimental area of about 200 m² was divided into 37 equal plots (5.6 m² in area for each). Treatments were distributed in a randomized complete blocks design with four replicates. Each plot was 2.8 x 2.0 meters separated by ridges and irrigation canals of suitable size. Every plot consisted of 4 rows 2 meters long and 70 cm. apart. Each plot represented concentration and each row represents a spraying period. Ten days after germination, spray treatments was started performed and three concentrations (50, 100 and 200 ppm) of nanoparticles were applied for 4 categories; every day, every 3 days, every week and every 2 weeks. The control plants were sprayed with distilled water. Plant samples were examined after 30 days from the commencement of spraying. At every sampling date a sample of 10 plants were randomly selected from each treatment and the following data were recorded:

a. Extended height (EH) in cm. to represents the maximum length of the plant with all of its leaves extended up to their tips (Metwally 2015).

b. Leaf chlorophyll content (LCh) for the 3rd bottom leaf of the plant using a chlorophyll meter.

c. Leaf area (LA) which was measured by multiplying: Leaf length by maximum width by 0.75 (Francis et al. 1969).

**Statistical analysis**

Duncan post hoc test was applied to calculate the mortality rates of larvae and evaluate significant differences for all treatment and were performed with SPSS computing program (Version 16, SPSS Inc., Chicago, IL, USA). Concentration-mortality response curve for probit analysis were conducted as described by (Finney 1952). Bioassay data were pooled and analyzed (LC₅₀ and LC₉₀ confidence limit values) according to the methods described by Noack & Reichmuth (1978). The results are displayed as mean ± standard error with a 95% confidence level.
Table 1. Corrected mortality percentage of newly hatched larvae of Sesamia cretica treated with silver, hydrophilic silica and hydrophobic silica nanoparticles. Means followed by same letters are non-significant, small letters represent significant differences between concentrations.

| Nanoparticle | Conc. | Corrected mortality percentages (mean ± SE) | F. value | P. value |
|--------------|-------|---------------------------------------------|----------|----------|
|              |       | Days after exposure                          |          |          |
|              |       | 1               | 3               | 7               |          |          |
| Silver       | 100   | 0.00 ± 0.00aA | 6.25 ± 0.48bA  | 18.75 ± 0.63cA | 437.500 | <0.001   |
|              | 200   | 6.25 ± 0.48bB | 12.50 ± 0.65bb | 31.25 ± 0.48cB | 580.357 | <0.001   |
|              | 400   | 12.50 ± 0.29aC| 12.50 ± 0.29ab | 56.25 ± 0.48bC | 4835.526| <0.001   |
|              | 800   | 12.50 ± 0.65aC| 18.75 ± 0.48bC | 62.50 ± 0.29cD | 3053.571| <0.001   |
| F. value     |       | 196.429        | 108.696         | 1 819.444       | <0.001   |<0.001   |
| P. value     |       | <0.001         | <0.001          | <0.001          |          |          |
| Hydrophilic silica | 100 | 0.00 ± 0.00aA | 25.00 ± 0.41bA | 43.75 ± 0.75cA | 1 982.143| <0.001   |
|              | 200   | 12.50 ± 1.04aB| 43.75 ± 0.75bb | 62.50 ± 0.29cB | 1 106.928| <0.001   |
|              | 400   | 12.50 ± 0.65aB| 43.75 ± 0.85bb | 75.00 ± 0.71cC | 1 780.063| <0.001   |
|              | 800   | 31.25 ± 0.48aC| 62.50 ± 0.29bC | 81.25 ± 0.63cD | 2 702.206| <0.001   |
| F. value     |       | 384.036        | 608.108         | 709.459         |          |          |
| P. value     |       | <0.001         | <0.001          | <0.001          |          |          |
| Hydrophobic silica | 100 | 0.00 ± 0.00aA | 6.25 ± 0.49bA  | 18.75 ± 0.48cA | 596.591  | <0.001   |
|              | 200   | 6.25 ± 0.48aB | 25.00 ± 0.82bB | 37.50 ± 0.65cB | 565.476  | <0.001   |
|              | 400   | 6.25 ± 0.48aB | 31.25 ± 0.48bC | 50.00 ± 0.71cC | 1 508.152| <0.001   |
|              | 800   | 12.50 ± 0.65aC| 50.00 ± 0.71bB | 62.50 ± 0.29cD | 2 031.250| <0.001   |
| F. value     |       | 119.048        | 801.282         | 1 133.475       |          |          |
| P. value     |       | <0.001         | <0.001          | <0.001          |          |          |

Table 2. Influences of different nanoparticles LC50 on some biological aspects of the greater corn borer Sesamia cretica. Means followed by same letters are non-significant.

| Biological aspects (Mean ±SE) | Nanoparticles | Hydrophilic silica | Hydrophobic silica | Control | F. value | P. value |
|------------------------------|---------------|--------------------|--------------------|---------|----------|----------|
| Larval duration              | Silver        | 44.88 ± 1.47b      | 42.56 ± 2.32b      | 43.55 ± 0.91b |         | 35.60 ± 0.65a |
|                              |               | 16.714             | <0.001             |         |          |          |
| Pupal weight                 |               | 0.10 ± 0.01b       | 0.12 ± 0.01b       | 0.12 ± 0.01b | 0.19 ± 0.01a | 44.059 |
|                              |               | <0.001             | <0.001             |         |          |          |
| Pupal duration               |               | 8.50 ± 0.42b       | 9.00 ± 0.44b       | 7.36 ± 0.41a | 7.24 ± 0.12a | 8.156  |
|                              |               | 8.156              | <0.001             |         |          |          |
| Male longevity               |               | 5.00 ± 0.45c       | 6.00 ± 0.00b       | 6.20 ± 0.37b | 8.36 ± 0.11a | 32.102 |
|                              |               | 32.102             | <0.001             |         |          |          |
| Female longevity             |               | 6.40 ± 0.245b      | 6.40 ± 0.25b       | 6.20 ± 0.20b | 7.75 ± 0.45a | 4.569  |
|                              |               | 4.569              | 0.014              |         |          |          |
| Pre-oviposition period       |               | 3.60 ± 0.245b      | 2.20 ± 0.20a       | 2.20 ± 0.20a | 2.60 ± 0.25a | 8.733  |
|                              |               | 8.733              | 0.001              |         |          |          |
| No of Eggs laid / female     |               | 43.80 ± 16.87b     | 40.00 ± 14.75b     | 41.40 ± 17.61b | 94.80 ± 13.47a | 2.845 |
|                              |               | 2.845              | 0.071              |         |          |          |
| Incubation period            | Non           | 4.40 ± 0.25b       | 5.40 ± 0.25c       | 3.60 ± 0.25a | 13.556    | 0.001  |
|                              |               | 13.556             | 0.001              |         |          |          |
| Hatchability %               | Non           | 34.40 ± 15.47b     | 39.00 ± 13.53b     | 84.80 ± 2.87a | 12.726    | <0.001 |

Results

Characterization of Nano materials

The TEM clearly shows that the size of silver nanoparticles was found to be 13±5.5 nm compared to <50 nm for hydrophilic silica nanoparticles and >50+10 nm for hydrophobic silica nanoparticles. The shape of the 3 tested nanoparticles was spherical-like shape as shown in Fig. 1.
Table 3. Effect of silver, hydrophilic silica and hydrophobic silica nanoparticles concentrations on extended-height (cm) of maize plants. Means followed by same letters are non-significant, small letters represent differences between dates of spraying and capital letters represent differences between concentrations, "n.s" refer to non-significant.

| Nanoparticle        | Conc. | Extended-height (cm) (Mean ± SE) | Frequency of spraying (Days) | F. value | P. value |
|---------------------|-------|---------------------------------|-----------------------------|----------|----------|
|                     |       | Control                         | 1   | 3     | 7     | 14    |       |
| **Silver**          | 50    | 138.2 ± 3.50a                   | 187.5 ± 2.50dA              | 186.3 ± 2.39dA | 166.8 ± 2.69cA | 154.3 ± 2.18b | 61.493 | <0.001 |
|                     | 100   | 138.2 ± 3.50a                   | 196.3 ± 2.39dAB             | 193.8 ± 2.39dA | 176.8 ± 2.69cB | 156.3 ± 2.39b  | 84.269 | <0.001 |
|                     | 200   | 138.2 ± 3.50a                   | 200.0 ± 4.08dB              | 198.3 ± 1.18dB  | 179.3 ± 3.25cB | 160.0 ± 4.08b  | 59.958 | <0.001 |
| **Hydrophilic silica** | 50    | 138.2 ± 3.50a                   | 195.7 ± 3.25c               | 193.0 ± 1.78c   | 168.7 ± 4.27b  | 140.2 ± 1.84a  | 80.058 | <0.001 |
|                     | 100   | 138.2 ± 3.50a                   | 197.2 ± 4.92c               | 195.7 ± 3.38c   | 170.0 ± 4.08b  | 142.5 ± 4.79a  | 45.206 | <0.001 |
|                     | 200   | 138.2 ± 3.50a                   | 198.0 ± 4.55c               | 198.7 ± 5.15c   | 172.5 ± 4.33b  | 146.2 ± 2.39a  | 47.448 | <0.001 |
| **Hydrophobic silica** | 50    | 138.2 ± 3.50a                   | 151.2 ± 4.27b               | 147.5 ± 3.23ab  | 147.5 ± 1.44ab | 138.7 ± 2.39a  | 3.481  | 0.034  |
|                     | 100   | 138.2 ± 3.50a                   | 155.0 ± 3.54c               | 148.7 ± 4.27bc  | 148.0 ± 1.78abc| 139.5 ± 2.10ab | 4.818  | 0.011  |
|                     | 200   | 138.2 ± 3.50a                   | 157.5 ± 4.79c               | 152.5 ± 2.50c   | 148.7 ± 1.25bc | 141.2 ± 1.25ab | 7.049  | 0.002  |

**Effect of the different nanoparticles materials on larval stage**

Nanoparticles induced a toxic effect on the 1st larval instar of *Sesamia creatica*. Toxicity increased with increase of exposure time (Table 1). For silver nanoparticles, 100 ppm concentration caused 0.00, 6.25 and 18.75% mortalities at 1, 3 and 7 days post treatment, respectively—while percentage were 6.25, 12.50 and 31.25% at 1, 3 and 7 days post treatment, respectively, for the concentration 200 ppm. Mortality increased with concentration as well, up to 12.50, 18.75 and 62.50% mortality after 1, 3 and 7 days post treatment, respectively with 800 ppm.

A similar effect occurred in hydrophobic silica nanoparticles, mortality percentages ranged (0.00% for 100 ppm) to (12.50% for 800 ppm) concentration at 1 day post treatment. While increased to 6.25, 25.00, 31.25 and 50.00% at 3 days post treatments at 100, 200, 400 and 800 ppm concentration, respectively. Also at 7 days post treatments, reached 18.75, 37.50, 50.00 and 62.50% for the concentrations, respectively.

A high toxic effect occurred when the larvae were treated with hydrophilic silica nanoparticles where one day post treatment mortality percentage received 0.00, 12.50, 62.50% and 31.25% for 100, 200, 400 and 800 ppm, respectively. 3 days post treatment,
Table 4. Effect of silver, hydrophilic silica and hydrophobic silica nanoparticles concentrations on leaf area (cm$^2$) of maize plants. Means followed by same letters are non-significant, small letters represent differences between dates of spraying and capital letters represent differences between concentrations, "n.s" refer to non-significant.

| Nanoparticle       | Conc. | Leaf area (cm$^2$) (Mean ± SE) | Frequency of spraying (Days) | F. value | P. value |
|--------------------|-------|-------------------------------|----------------------------|----------|----------|
|                    |       | Control                        | 1        | 3        | 7        | 14        |               |
| Silver             | 50    | 220.3 ± 10.55a                 | 427.8 ± 4.64d               | 413.7 ± 8.59d | 349.5 ± 7.51c | 250.9 ± 11.84b | 109.184 <0.001 |
|                    | 100   | 220.3 ± 10.55a                 | 437.4 ± 12.71c              | 431.1 ± 10.32d | 354.4 ± 9.38b | 251.3 ± 9.29a | 90.732 <0.001  |
|                    | 200   | 220.3 ± 10.55a                 | 444.3 ± 13.07d              | 436.4 ± 7.56d | 375.4 ± 12.22c | 265.1 ± 11.57b | 82.357 <0.001  |
| F. value           |       |                               | 0.584                         | 1.785                | 1.993                | 0.545                |               |
| P. value           |       |                               | n.s                           | n.s                  | n.s                  | n.s                  |               |
| Hydrophilic silica | 50    | 220.3 ± 10.55a                 | 359.2 ± 10.34c              | 335.2 ± 9.54abC      | 307.2 ± 7.75b       | 242.6 ± 8.20a      | 40.612 <0.001  |
|                    | 100   | 220.3 ± 10.55a                 | 388.2 ± 12.58c              | 386.3 ± 17.11BC      | 335.7 ± 11.23b      | 254.3 ± 6.09a      | 40.492 <0.001  |
|                    | 200   | 220.3 ± 10.55a                 | 398.9 ± 17.36c              | 387.1 ± 13.32BC      | 341.4 ± 13.54b      | 257.4 ± 2.94a      | 40.030 <0.001  |
| F. value           |       | 2.244                         | 4.736                         | 2.719                | 1.638                |                      |               |
| P. value           |       | n.s                           | 0.039                         | n.s                  | n.s                  | n.s                  |               |
| Hydrophobic silica | 50    | 220.3 ± 10.55a                 | 251.6 ± 4.80b               | 243.9 ± 3.21BA       | 230.4 ± 5.03ab      | 229.0 ± 8.75ab      | 3.196 0.044    |
|                    | 100   | 220.3 ± 10.55a                 | 262.1 ± 6.75b               | 261.8 ± 9.08BA       | 231.3 ± 6.66a       | 233.0 ± 5.11a       | 5.897 0.005    |
|                    | 200   | 220.3 ± 10.55a                 | 265.3 ± 7.22b               | 265.1 ± 4.55bB       | 233.5 ± 9.46a       | 233.1 ± 5.90a       | 6.841 0.002    |
| F. value           |       | 1.267                         | 3.421                         | 0.048                | 0.117                |                      |               |
| P. value           |       | n.s                           | 0.079                         | n.s                  | n.s                  | n.s                  |               |

mortality was 25.00, 43.75, 43.75 and 62.50% respectively for the same previous concentrations. As well as, mortality percentage increased to 43.75, 62.50, 75.00 and 81.25% after 7 days of treatments for the same previous concentrations, respectively. Differences between concentrations and days after exposure for each used nanoparticles were statistically highly significant (P<0.001).

Effect of the three nanoparticles on the first larval instar of *S. cretica* under constant laboratory conditions (27–28°C and 75–80% R.H.) is shown in Fig. 2. According to lethal concentration (LC$_{50}$), Hydrophilic silica nanoparticles was relatively more effective (LC$_{50}$=121.19) than silver nanoparticles (LC$_{50}$=405.72) followed by silica hydrophobic nanoparticles which was the least effective (LC$_{50}$=416.82).

**Effect of nanoparticles on biological aspects**

Different biological parameters were determined for the larvae of *S. cretica* when they were exposed to nanoparticles LC$_{50}$ illustrated in Table 2. There were statistically significant differences between all biological parameters in the treatments and those in the control. Silver nanoparticles prolonged the total larval duration to an average of 44.88 days followed by larvae exposed to hydrophobic silica nanoparticles recording an average of 43.55 days then the treatment of hydrophilic silica nanoparticles which recorded
Table 5. Effect of silver, hydrophilic silica and hydrophobic silica nanoparticles concentrations on leaf-chlorophyll content % of maize plants. Means followed by same letters are non-significant, small letters represent differences between dates of spraying and capital letters represent differences between concentrations, "n.s" refer to non-significant.

| Nanoparticle | Conc. | Leaf-chlorophyll content % (Mean ± SE) | Frequency of spraying (Days) | F. value | P. value |
|--------------|------|--------------------------------------|-----------------------------|----------|----------|
| Silver       | 50   | 41.4 ± 1.15a                         | 45.8 ± 1.39b                | 3.080    | 0.049    |
|              | 100  | 41.4 ± 1.15a                         | 46.0 ± 0.50b                | 12.138   | <0.001   |
|              | 200  | 41.4 ± 1.15a                         | 47.3 ± 0.45b                | 12.227   | <0.001   |
| Hydrophilic silica | 50   | 41.4 ± 1.15a                         | 45.5 ± 0.69b                | 5.098    | 0.009    |
|              | 100  | 41.4 ± 1.15a                         | 45.3 ± 0.58b                | 6.986    | 0.002    |
|              | 200  | 41.4 ± 1.15a                         | 45.3 ± 0.57bc               | 6.281    | 0.004    |
| Hydrophobic silica | 50   | 41.4 ± 1.15                          | 41.4 ± 0.67                 | 0.187    | n.s      |
|              | 100  | 41.4 ± 1.15                          | 41.6 ± 0.43                 | 0.052    | n.s      |
|              | 200  | 41.4 ± 1.15                          | 42.1 ± 0.31                 | 0.391    | n.s      |

...an average of 42.56 days compared with an average 35.60 days in the control. While average weight of pupa decreased to 0.10, 0.12 and 0.12 g in silver, hydrophobic silica and hydrophilic silica nanoparticles treatments, respectively compared to the control (0.19 g). Treatment with hydrophilic silica nanoparticles increased average of pupal duration to (9.00 days) more than silver nanoparticles (8.50 days) and hydrophobic silica (7.36 days) compared to the control (7.24 days). Decreasing in male longevity was observed in the treatments which was 6.20, 6.00 and 5.00 days at hydrophobic silica, hydrophilic silica and silver nanoparticles, respectively compared to 8.36 days at control. Likewise at female longevity means decreased to 6.20, 6.40 and 6.40 days at hydrophobic silica, hydrophilic silica and silver nanoparticles, respectively compared to 7.75 days in control. The longest pre-oviposition period was achieved in silver nanoparticles treatments (with average 3.60 days) while both of hydrophobic silica and hydrophilic silica nanoparticles treatments revealed shorter longevity (with the same average 2.20 days) than that in control (with average 2.60 days. The three tested nanoparticles decreased number of eggs laid by female to 43.80, 41.40 and 40.00 eggs for silver, hydrophobic silica and hydrophilic silica nanoparticles, respectively compared to 94.80 eggs in...
control. No hatching eggs occurred at silver nanoparticles treatments but, percentage of hatchability was 34.40 and 39.00% with incubation period, 4.40 and 5.40 days at hydrophilic silica and hydrophobic silica nanoparticles, respectively compared to 84.80% and 3.60 days for control. There are significant differences between nanoparticles and control.

**Effect of nanoparticles on certain botanical characteristics of the maize plant seedlings**

Extended height (EH), leaf area (LA) and leaf chlorophyll content (LCh) for maize seedlings sprayed with 50, 100 and 200 ppm of each silver, hydrophilic silica and hydrophobic silica nanoparticles through 4 foliar spraying categories; every 1, 3, 7 and 14 days after germination are shown in Tables 3, 4 and 5.

1. **Extended height (EH)**

Effect of nanoparticles on the extended height of maize plants was illustrated in Table 3. For silver nanoparticles, increased in concentration and spraying rate caused increasing in extended height of maize plants. Highly impact on extended height was at spraying every day with means 187.5, 196.3 and 200.0 cm in 50, 100 and 200 ppm respectively. Furthermore, the lowest plant height was recorded at spraying every 14 days with means, 154.3, 156.3 and 160.0 cm for the same concentrations respectively, compared to 138.2 cm for control. Differences between all concentrations at all spraying rates except spraying every 14 days were statistically significant and there were non-significant differences between spraying every day and 3 days in all concentrations.

With regard to hydrophilic silica nanoparticles, extended height of maize plants appeared at the same trend where increased by increasing concentration and spraying rate. High impact on extended plant height with means 195.7, 197.2 and 198.0 cm was at spraying every day for 50, 100 and 200 ppm respectively, compared to 138.2 cm for control. Differences between spraying dates were statistically significant but, there were non-significant differences between all concentrations at all spraying rates.

Also for hydrophobic silica nanoparticles, spraying every day was the most effective with increasing concentration. Means were 151.2, 155.0 and 157.5 cm for 50, 100 and 200 ppm concentrations, respectively compared to 138.2 cm for control. Differences between spraying dates were statistically significant but, there was non-significant differences between all concentrations at all spraying rates.

In general, silver nanoparticles had the highest impact on extended plant height followed by hydrophilic silica nanoparticles then hydrophobic silica nanoparticles which revealed the lowest impact.
Fig. 2. Lethal concentration of different nanoparticles for first larval instar of Sesamia cretica after 7 days post treatment.

2. Leaf area (LA)

Table 4 shows the effect of nanoparticles on leaf area. Nanoparticles have positive effect on leaf area that nearly reach double at 200 ppm of silver nanoparticles which revealed the highest impact compared to control where leaf area increased to 427.8, 437.4 and 444.3 cm at spraying every day in 50, 100 and 200 ppm, respectively compared to 220.3 cm for control. Differences between spraying dates were statistically significant but, there was non-significant differences between all concentrations at all spraying rates.

For hydrophilic silica nanoparticles, the same positive impact was observed, spraying every day had the highest effect on leaf area with means 359.2, 388.2 and 398.9 for 50, 100 and 200 ppm, respectively compared to 220.3 cm for control. While the effect gradually decreased with spacing of the spraying periods. Differences between spraying dates were statistically significant but, there was non-significant differences between concentrations at spraying rates except spraying every 3 days.

In general, silver nanoparticle was the highest impact on leaf area followed by hydrophilic silica nanoparticles then hydrophobic silica nanoparticles which had the lower impact.

3. Leaf chlorophyll content (LCh)

As shown in Table 5, the largest leaf chlorophyll content occurred in plants that spraying every day with silver nanoparticle and the effect increased by increasing concentration (45.8, 46.0 and 47.3% for concentrations 50, 100 and 200 ppm, respectively). Leaf chlorophyll content gradually decreased with increased interval between spraying periods in each concentration. Differences between spraying dates were statistically significant but, there was non-significant differences between concentrations at spraying rates except spraying every 7 days.
Effect of hydrophilic silica nanoparticles on leaf chlorophyll content varied with different spraying periods. Concentration 50 ppm achieved the highest effect on the chlorophyll content at spraying every day and every 3 days. Where means were 45.5, 45.3 and 45.3% for 50, 100 and 200 ppm concentration at spraying every day, respectively. And 45.3, 43.7 and 43.6% for 50, 100 and 200 ppm concentration at spraying every 3 days, respectively. But leaf chlorophyll content decreased to (40.9 and 41.1%) for 100 ppm and (41.0%) for 200 ppm at spraying every 7 days and every 14 days compared with control (41.4%). Differences between spraying dates were statistically significant but, there was non-significant differences between all concentrations at spraying rates.

Effect of hydrophobic silica nanoparticles on leaf chlorophyll content was statistically non-significant. The means ranged (41.4–40.3%), (41.6–41.1%) and (42.1–41.0%) for 50, 100 and 200 ppm concentrations at frequency of spraying periods compared with control (41.4%).

Discussion

Several studies confirmed the efficiency of certain nanoparticles on Lepidopterous insect pests (Chakravarthy et al. 2012, El-Samahy et al. 2014, Devi et al. 2014, Osman et al. 2015, Yasur & Usha Rani 2015, El-Helaly et al. 2016, Ahmed et al. 2019, Hashem et al. 2019). However, apparently the effect of nanoparticles on the corn borer, *S. cretica* was scarcely investigated. Hence the present study is supposed to be the first to investigate the toxic effect of silver, hydrophilic silica and hydrophobic silica nanoparticles on the first larval instar of *S. cretica* under laboratory conditions. Hydrophilic silica caused the highest mortality percentage (81.25%) after 7 days post treatment by 800 ppm with LC50=121.19 ppm. In general, toxic effect increased by increasing exposure time in agreement with El-bendary & El-Helaly (2013) and El-Helaly et al. (2016) who stated that hydrophilic silica nanoparticles caused highest mortality percentage on neonate larvae of *S. littoralis* (Boisduval, 1833) after 15 days of treatment. Toxic effect for the same insect may be different by different plant species and exposure conditions to nanoparticles, El-Bendary & El-Helaly (2013) reported that treatment with 350 ppm of hydrophilic silica nanoparticles caused 98.24% mortality at neonate larvae of *S. littoralis* (Boisduval, 1833) on tomato plants but treatment with 500 ppm caused 89.82% on squash plants which stated by El-Helaly et al. (2016). Also El-Samahy et al. (2014) indicated that reduction rate of *Tuta absoluta* (Meyrick, 1917) larvae in tomato after treatment with 300 ppm silica nanoparticles increased gradually to maximum 100% after 15 days of treatment. The toxicity of SiO2 nanoparticles is due to their binding to the insect cuticle, followed by physico-sorption of waxes and lipids, leading to insect dehydration (Benelli 2018).

Hydrophobic silica nanoparticles caused lower toxic effect (LC50=416.82 ppm) than silica hydrophilic nanoparticles with highest toxicity (LC50=121.19 ppm) and which caused 62.50% mortality for 1st larval instar after treated with 800 ppm concentration. However, Abd El Naby (2019) stated that hydrophobic silica nanoparticles caused the highest mortality 83.0% than hydrophilic silica nanoparticles 69.0% on 2nd larval instar of *S. littoralis* (Boisduval, 1833) when treated with 20 g/L after 24 h of treatment on castor leaf plant.

In the present study, silver nanoparticles caused acceptable mortality rates when applied at high concentrations (LC50=405.71 ppm) against the 1st larval instar of *S. cretica* comparing with hydrophilic silica nanoparticles but effected on long run on biological aspects. While silver nanoparticles increased larval duration and pupal duration, reduce male and female longevity than control and prevent eggs hatchability. That is possible due to mode of action of silver nanoparticles which is up and
down regulate key insect genes, reducing protein synthesis and gonadotrophin release, leading to developmental damages and reproductive failure (Benelli 2018). This result tends to agree with Yasur & Usha Rani (2015) who indicated that larval and pupal body weights of *S. litura* (Fabricius, 1775) and *Achaea janata* insects increased along with the increase of the concentrations of silver nanoparticles. Also Chakravarthy et al. (2012) stated that Nano-Ag caused maximum 56.89% mortality at 2400 ppm on the 2nd larval instar of *S. litura* (Fabricius, 1775) with LC50=1 403.14 ppm and reduced insect growth with prolonged larval period and larvae became sluggish movement and the oozing of the body contents eventually lead them to death. As that Ahmed et al. (2019) indicated that LC50 up to 1000.9 ppm for 2nd larval instar of *S. littoralis* (Boisduval, 1833) when treatment with silver nanoparticles where concentration 999 ppm caused 50% mortality. But the results disagreed with the results of Devi et al. (2014) where found that silver nanoparticles LC50 value decreased to 33.383 ppm for first larval instar of *H. armigera* (Hübner, 1808) on cotton leaves where treatment with 100 ppm caused 94.0% mortality. This differences may be due to the differences in insect species.

Both types of silica nanoparticles which used in this study effect on biological aspects of *S. cretica* where increased larval duration, pupal duration but reduced pupal weight, male longevity, female longevity, No. of eggs laid by female, incubation period and hatchability percentage. Similar observation was observed by El-Bendary & El-Helaly (2013) and El-Helaly et al. (2016) when treatment neonate larvae of *S. littoralis* (Boisduval, 1833) with hydrophilic silica nanoparticles. Also, Abd El Naby (2019) stated that treatment the 2nd larval instar of *S. littoralis* (Boisduval, 1833) with both hydrophilic silica (LC50=10.76 g/L) and hydrophobic silica nanoparticles (LC50=10.05 g/L) increased larval duration but reduced all of pupal duration, pupal weight, adult longevity, number of eggs laid by female and hatchability percentage. Osman et al. (2015) also confirmed that silica nanoparticles have a toxic effect on the 2nd larval instar of *S. littoralis* (Boisduval, 1833) where reduced the 6th larval instar weight, pupation rate pupal weight and adult emergence rate. This effect increased by increasing concentration.

Besides the negative effect of nanoparticles on the previously mentioned biological aspects of insect life, nanoparticles play an important role in the improvement of plant growth and some botanical characteristics including leaf area, stem height, chlorophyll content, germination, number of leaves and yield (Salama 2012, Lu et al. 2015, Roohizadeh et al. 2015, El-Helaly et al. 2016, Yassen et al. 2017, Amer & El- Emary 2018, Prihastanti et al. 2018). Several investigations referred to a splendid effect of nanoparticles especially on maize plants (Yuvakkumara et al. 2011, Salama 2012, Suriyaprabha et al. 2012, Suriyaprabha et al. 2014, Jafari et al. 2018, Sehnal et al. 2019).

Recent studies indicated that there was a strong relationship between maize infestations with *S. cretica* and some botanical characteristic of maize plants including the leaf angle and extended plant height and chlorophyll content. Plants with narrow leaf angle and short extended height may receive relatively less infestation with *S. cretica* in maize fields (Al-Naggar et al. 2000, Saad El-Deen 2008 and Metwally 2015). Leaf chlorophyll content is closely related to the resistance of maize plants to *S. cretica*. It is anticipated to increase of chlorophyll content in maize leaves promotes resistance to the *S. cretica* as mentioned by Metwally (2015) who stated that increasing leaf chlorophyll content may be a point to the lower infestation by *S. cretica*.

This study confirmed that foliar spraying of silver, hydrophilic silica and hydrophobic silica nanoparticles increased both the leaf area and extended height of maize plants. Effect of the frequency spraying of maize plants with nanoparticles indicated that daily spraying
induced a positive effect on the leaf area which decreased by prolong the spraying intervals. This means that spraying every day was the most effective followed by spraying every 3 days then every 7 days then every 14 days. Also leaf area increased by increasing concentration, 200 ppm was the most effective than 100 pm and 50 ppm. Similar results were observed by Suriyaprabha et al. (2012) who treated the soil with silica nanoparticles, leaf area and stem height increased by increasing concentration after 20 days from plantation. Also Berahmand et al. (2012) indicated that treatment with silver nanoparticles in the irrigation water increased maize plant height.

Effect of nanoparticles on leaf chlorophyll content was varied according to type of nanoparticles, concentration used and frequency of spraying. For silver nanoparticles, spraying every day was the most effective with increasing concentration followed by spraying every 3 days then every 7 days and spraying every 14 day was the least effective on leaf chlorophyll content. But this result is not with the same line with Salama (2012) who stated that the low concentration of silver nanoparticle lesser than 60 ppm increased leaf area and chlorophyll content of maize plants but high concentrations up to 60 ppm have inhibitory effect. This difference may be due to the method of application.

Hydrophobic silica nanoparticles increased the chlorophyll content of maize plants in concentration of 50 ppm but the effect decreased by increasing concentration and the extending of the spraying intervals. In other meaning the high concentrations of silica nanoparticles had a negative effect on chlorophyll content. Similar observation was obtained by Suriyaprabha et al. (2012) who stated that high concentration of silica nanoparticles more than 10 kg/ha of soil reduce leaf chlorophyll content of maize plants. Also Suriyaprabha et al. (2014) confirmed that foliar spraying with 15 g/L of silica nanoparticles increased leaf chlorophyll content of maize plants.

On the other hand, our results disagree with Amer & El-Emary (2018) who stated that under foliar application with high concentration 300 mg/L of silica nanoparticles, leaf chlorophyll content increased and that may be due to increased leaf area that renders better light absorption and photosynthetic activity of chlorophyll a and b.

For hydrophobic silica nanoparticles, the spraying every day increased leaf chlorophyll content gradually with increasing concentration. But frequency of spraying every 3, 7 and 14 days reduced leaf chlorophyll content at all concentrations. Although the leaf area increases with increasing concentration, the chlorophyll content decreases with increasing concentration and this can be explained by anatomical studies and the effect on absorption of elements. These previous results agreed with Suriyaprabha et al. (2012) who mentioned that despite of increasing leaf area in maize plants treated with silica nanoparticles, the leaf chlorophyll content decreased.

In general, silver nanoparticle revealed the most effective on botanical characteristics of the maize plants at all concentrations and frequency of spraying followed by hydrophilic silica nanoparticles, then hydrophobic silica nanoparticles.

Conclusion

In this study, silver, hydrophilic silica and hydrophobic silica nanoparticles have a toxic effect on the first larval instar of S. cretica under laboratory condition. Hydrophilic silica was the most effective followed by Silver then hydrophobic silica nanoparticles. All nanoparticles increased larval duration, pupal duration and incubation period for eggs but reduced pupal weight, male and female longevity, number of eggs laid per female and hatchability percentage in comparison with control. Three types of nanoparticles had a noticeable effect on botanical characteristics of maize, in particular on increasing plant
height and leaf area. The effect strengthened by increasing concentration and spraying periods. The same effect occurred on leaf chlorophyll content with silver nanoparticles, but high concentration of hydrophilic silica nanoparticles reduced chlorophyll content while hydrophobic silica nanoparticles have no statistically significant effect on leaf chlorophyll content. This study recommends that the application of nanoparticles improve plant strength and have a toxic effect on corn borer insect pest *S. cretica*.

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