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Diet and development of the fall armyworm *Sopodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in maize treated with the homeopathic preparation *Silicea terra*

Alimentação e desenvolvimento da lagarta-do-cartucho *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) em plantas de milho tratadas com o preparado homeopático *Silicea terra*

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ABSTRACT: The objective of the present study was to assess the diet and development of pupa and moth of *S. frugiperda* fed with maize plants treated with the homeopathy *Silicea terra* applied through different methods. We applied the dynamizations 12, 36, 60, and 84 CH were applied to the corn plants by the methods through of spraying (a), irrigation (b), and seed treatment (c). We kept individual third-instar caterpillars in test tubes under controlled laboratory conditions and fed them daily with leaf sections of maize plants that reached stage V6. We assessed consumption and digestion of food by caterpillars, formation and sex ratio of pupae and adults, fertility, fecundity, adult lifespan, and food preferences in a free-choice test. We observed that S. frugiperda fed with leaf sections of maize, which were sprayed or irrigated with *Silicea* 36 CH, showed lower consumption and lower use of the food, as well as a larger number of deformed pupae and adults, and shorter oviposition and post-reproductive periods, smaller number of egg mass, eggs per oviposition, and eggs per female. The results show that the caterpillar *S. frugiperda* has difficulty to feed on maize plants sprayed or irrigated with the homeopathic preparation *Silicea* 36CH, but when it does, the preparation affects its fertility and fecundity.

KEYWORDS: high dilution, homeopathy, fall armyworm, insect.

RESUMO: O objetivo deste trabalho foi avaliar a alimentação e desenvolvimento de pupas e mariposas de *Spodoptera frugiperda* alimentadas no período de lagarta com plantas de milho, tratadas com o preparado homeopático *Silicea terra* aplicado em diferentes métodos. As dinamizações 12, 36, 60 e 84CH foram aplicadas nas plantas de milho através dos métodos de pulverização (a), irrigação (b) e tratamento de semente (c). Quando as plantas atingiram o estágio V6, secções foliares foram fornecidas diariamente às lagartas individualizadas de 3o ínstar, em tubos de ensaio e mantidas em condições controladas em laboratório. Foram avaliados o consumo e digestão do alimento pelas lagartas, formação e razão sexual de pupas e adultos, fertilidade, fecundidade, longevidade de adultos e a preferência alimentar em ensaio de livre escolha. Verificou-se que lagartas S. frugiperda alimentadas com seções foliares de milho pulverizado ou irrigado com *Silicea* 36CH apresentaram menor consumo e baixa utilização do alimento, além de maior número de pupas e adultos deformados, menor período de oviposição e pós-reprodutivo, menor número de massas de ovos, de ovos por postura e de ovos por fêmea. Os resultados indicam que há dificuldade das lagartas em se alimentar de plantas de milho pulverizadas ou irrigadas com o preparado homeopático *Silicea* 36CH, o que interfere na fertilidade e fecundidade de *S. frugiperda*.

PALAVRAS-CHAVE: Altas diluições, homeopatia, lagarta-do-cartucho, inseto.

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Introduction

Maize (*Zea mays* Linnaeus) has high socio-cultural importance and is suitable for crops that use few agricultural implements, as most farmers are poorly qualified and do not own large properties (BRASIL, 2006). Maize is still essential for the subsistence of rural families; 60% of it is used for human and animal consumption (CRUZ et al., 2006). In all farming systems, but particularly for family farmers, pest insects reduce production. In the case of maize, *Spodoptera frugiperda*, the fall armyworm, is considered one of the major crop pests. In the early stages of infestation on maize plants, the caterpillars scrape off and eat part of the leaves, keeping the leaf epidermis intact, and leaving scratch marks on the leaves. From the third instar on, the caterpillars have more developed mandibles and are able to pierce the husk and access the corn ear, as well as to bore into the stalk, tassel, and cob (BASTOS and TORRES, 2004). The damage caused to the corn ear favors the entry of pathogens and humidity, which results in rotting (FARINELLI and FORNASIERI FILHO, 2006). The polyphagous habit of *S. frugiperda* hinders the management of this species. Family farmers fall vulnerable, as they cultivate other species, such as tomato, potato, grasses, rice, and sorghum, which can be attacked by the same pest (BASTOS and TORRES, 2004).

This difficulty requires it is necessary to manage the environment of the crop, in order to increase the number of natural enemies of *S. frugiperda*. It is also necessary to develop and use diversified agricultural techniques and implements that do not contaminate the food, farmer, and environment. At last, these agricultural techniques and implements should be viable in the whole agrosystem.

The use of homeopathic preparations may be an alternative to fill this need. It is a simple, low-cost method, with the benefit of allowing the rural community to take hold of the technology (BOFF, 2008). Its use in organic agriculture is approved in the Brazil by the normative instruction (BRASIL, 2014). These preparations are indicated not only for the control of diseases and pests, but also managements of physiological disorders in plants (BRASIL, 2014).

The use of homeopathic preparations in agriculture has shown promising results in the management of insects. The homeopathic preparation Belladonna reduced the foraging of leaf-cutter ants *Acromyrmex* and *Atta sexdens piriventris* (GIESEL et al. 2012; 2013). Homeopathy *Sulphur* decreased the tomato damages caused by the tomato fruit borer (*Neoleucinodes elegantalis*) (MODOLON et al., 2012). Non-preference of *Cerotoma tingomarianus* for plants was observed with a nosode of *C. tingomarianus* (FAZOLIN et al., 1997). Nosodes of Euchlaena and Dorus reduced the infestation of S. frugiperda caterpillar (ALMEIDA, 2003). The spraying of homeopathy *Sulphur* and homeopathy *Arnica montana* reduced the population of *Agathomerus selatus* in tomato plant (MODOLON et al., 2013).

Aiming to contribute with information about the use of homeopathic preparations in the management maize crop pests, the present study had the objective to assess the diet and biological cycle of *S. frugiperda* fed with maize treated with the homeopathic preparation *Silicea terra* (in different potencies) applied through spraying, irrigation, and seed treatment.

Material and Methods

The experiments were carried in the greenhouse and laboratory under controlled conditions of temperature (25 ± 3 ºC) and a photoperiod of 14 h. We grew maize in greenhouse in polyethylene vases with a volume of 5 L^{-1}, using as substrates non-sterilized Eutroferric Red Latosol soil and humus, at the proportion 1:1. We sowed three seeds per vase and then thinned out seedlings, leaving only one plant per vase.

Mass rearing of *Spodoptera frugiperda* - to start rearing *S. frugiperda*, we collected caterpillars at different ages, in areas of commercial maize crops and sent them to the laboratory of Biological Control of the State University of West Paraná (UNIOESTE) at the campus Marechal Cândido Rondon, state of Paraná, Brazil. The caterpillars were fed with leaves of maize from plants grown in vase without phytosanitary treatment.

We identify the sex of the pupae according to the methodology described by Butt and Cantu (1962). Afterwards, we did the group of caterpillars in the number of couples 20, which were placed in cages for the emergence, mating and oviposition. The cages consisted of multiuse plastic boxes with lid, measuring 78 cm in height, 54.5 cm in length, and 55 cm in width, lined the cages with A4 bond paper for oviposition.

We lined the cages with A4 bond paper for oviposition. To feed the adults, we placed inside each cage a container with cotton impregnated with a solution made of honey (6%), sugar (1%), ascorbic acid (1%), and methylparaben (Nipagin®) (1%). We changed the container with the solution every day. We kept the boxes with adults in semi-climatized rooms, under a temperature of 25 ± 3 ºC and photoperiod of 14 h. We replaced the bond paper of the cages to collect eggs every day. We cut out egg masses and disinfected them by immersing them in 1% sodium hypochlorite solution. Next, we placed the egg masses in transparent polypropylene containers (14 cm in diameter × 9 cm in height), containing approximately 150 mL of an artificial diet proposed by Greene et al. (1976) and modified by Garcia et al. (2006).

When the caterpillars reached the third instar, we individualized them in flat-bottom glass tubes (10 cm in length × 2 cm in diameter), containing approximately 5 mL of artificial diet, and closed with a hydrophobic cotton swab involved in voile. Next, we placed the caterpillars in a climatic chamber of the type B.O.D (biochemical oxygen demand) at a temperature of 25 ± 2 ºC and photoperiod of 14 h. We replaced the food whenever necessary. We identified the sex of the pupae and transferred 50 couples to each rearing cage.

<u>Obtainment of the homeopathic preparations</u> - we handled the homeopathic preparations at the laboratory of Homeopathy and Plant Physiology of the State University of Marigá (UEM), state of Paraná, Brazil, following the methodology described in the Brazilian Homeopathic Pharmacopoeia (BRASIL, 1997) and raised to the dynamizations 12 CH, 36 CH, 60 CH, and 84 CH (twelfth, thirty-sixth, sixty, and eighty-fourth order of hahnemannian centesimal dilution). We obtained matrices (basic dynamizations) of *Silicea terra* from homeopathic pharmacies in the municipality of Maringá, state of Paraná, Brazil.

We made the homeopathic preparations initially taking one part of the matrix diluted in 99 parts of 70% alcohol and successed with a mechanical arm (Autic® Mod. Denise 10-50), which resulted in the dynamization 1 CH. We obtained the dynamization 2 CH taking one part of the previous dynamization (1 CH) diluted in in 99 parts of 70% alcohol and successed up to 100 times. We followed this procedure until reaching the dynamizations used in the present study: 12 CH, 36 CH, 60 CH, and 84 CH. We used the solution of 1% ethanol in distilled water as an inert ingredient in these dynamizations.

<u>Application of the homeopathic treatments</u> - we used the following treatments: *Silicea terra* at 12 CH, 36 CH, 60 CH, and 84 CH, and the control treatments with 1% ethanol (inert ingredient in the dynamizations), distilled water, and no intervention, with equipment individualized in applications.

We applied the treatments at the dose of 1 mL L^{-1} in distilled water, via seed treatment, plant irrigation, or spraying.

In the seed treatment we used the imbibition method, and immersed 100 seeds in 0.5 L of the homeopathic preparation or control for 38 h at 20 °C, photoperiod 12 h, and no additional oxygen supply to allow seed imbibition to occur, but prevent germination. After this period, we sowed the seeds in vases, containing the previously described substrate.

In the irrigation method, we applied 300 mL of the solution in the soil of vases. In the spraying method, we used a manual spray pump (Guarany®) until dripping point. In irrigation and spraying methods, we made three applications: the first right after emergence, the second in the stage V2 (second leaf developed) and the third in the stage V3 (third leaf developed).

The spacing between the vase were of the 40 cm between, which was used a physical barrier around the vessel drift blocking possibilities for other plants.

<u>Experiment 1: Consumption and digestion of maize plants treated with the homeopathic preparation *Silicea terra* by *S. frugiperda*</u> - we measured on a precision scale (initial weight) and individualized in previously sterilized glass tubes (2 cm in diameter × 10 cm in depth) third-instar caterpillars of *S. frugiperda*, from the breeding stock kept at the laboratory of UNIOESTE. We closed the tubes with a hydrophobic cotton swab involved in voile. Daily at 7:00, we collected leaves from maize plants in V6 stage, previously treated as described in the methods section. With these leaves, we made 4 × 5 cm sections, immersed them in distilled water for 30 min to maintain their turgescence, and disinfected them in 1% solution of sodium hypochlorite. Next, we washed the leaf sections in distilled water, dried them, and provided them to the caterpillars in the tubes. After seven days of a leaf diet from maize treated with the homeopathic preparation of *Silicea terra*, we weighted the caterpillars again on a precision scale (final weight).

We maintained the caterpillars' diet until they began the pre-pupal phase, when caterpillars start changing the color of the tegument (pinkish color) and stop feeding. We recorded the data of pupa formation.

We weighted daily the fresh food and provided them to the caterpillars. We kept the remaining food and frass at 55-60 °C, until they reached constant weight (approximately 72 h) and then weighted them on a precision scale of 0,001 g (Bel Engineering® mod. Mark 500). In parallel, we separated an aliquot of 10 flat-bottom glass tubes containing only leaves of each treatment and made the same procedure in order to determine the initial dry weight of the diet (PARRA et al.,

, 2009).

To determine the quantitative nutrition of the larval phase, we used the method proposed by Waldbauer (1968) and modified by Scriber and Slansky Jr. (1981). We determined the indices of consumption and use for each treatment, through the following formulas:

- Relative consumption rate (g/g/day)
- Relative growth rate (g/g/day)
- Relative metabolic rate (g/g/day)
- Approximate digestibility (%)
- Efficiency of conversion of ingested food (%)
- Efficiency of conversion of digested food (%)
- Metabolic cost (%)

For calculating these indices, we used the following variables (in dry mass):

T = duration of the feeding period (days);

Af = weight of the food provided to the insect (g);

Ar = weight of what is left from the food provided to the insect (g), after T;

F = weight of the frass produced (g) during T;

B = weight gain by caterpillars (g) during T;

P = mean weight of caterpillars (g) during T;

I = weight of ingested food (g) during T;

I - F = assimilated food (g) during T;

M = (I - F) - B = food metabolized during feeding period

We used the sampling design of random blocks with four replicates; each plot consisted of 10 individualized caterpillars in glass tubes arranged in plastic trays.

<u>Experiment 2: Development of pupa and moth of *S. frugiperda* feed in period of caterpillar with corn plants treated with homeopathic preparation *Silicea terra*</u> - we weighed *S. frugiperda* pupae 24 h after their formation on a precision scale and then kept them on the same glass tubes until the emergence of adults. We determined the duration of the pupal phase and the percentage of deformed adults, following Ng et al. (1985).

Up to 24 h after emergence, we placed moth couples of each treatment in PVC cylindrical cages (7.5 cm in diameter × 20 cm in height), lined with A4 bond paper and closed at the lower extremity with a Petri dish and at the upper extremity with voile attached with a rubber.

We checked the cages daily, when we replaced the A4 bond paper and counted egg masses and clutch size. We removed the egg masses and placed them on a Petri dish with artificial diet to check for egg hatching, their viability, and the embryo development period. We determined the pre-oviposition, oviposition, and post-oviposition periods, number of clutches per female, clutch size, female fecundity, embryo development, egg viability, and longevity of females and males.

We used the sampling design of random blocks with ten replicates; each plot consisted of a mouth couple in a PVC cylindrical cage.

<u>Experiment 3: Feeding preference of *S. frugiperda* for maize plants treated with the homeopathic preparation Silicea terra</u> - we assessed the feeding preference of *S. frugiperda* in a free-choice test at the laboratory. We removed a 4 × 5 cm leaf section from the fourth completed outstretched leaf of the plants of each treatment, weighted them and arranged them circularly in arenas with lids (30 cm in diameter), which contained a cotton swab moistened with distilled water. In each arena we placed one section of each treatment.

Next, we released 35 third-instar caterpillars in the center of the arena. The number of caterpillars on the leaves of each treatment was recorded every 3 h until completing 15 h after release. In parallel, we separated an aliquot of 10 leaf sections, with no caterpillars for each treatment to determine the initial dry weight of the diet (PARRA et al., 2009).

Fifteen hours after release, we removed the remaining leaf sections and kept them at 55-60 °C until they reached constant weight, displaying complete dehydration, and then, weighed them on a precision scale. With these values we calculated preference (number of caterpillars present in each treatment) and leaf consumption (initial dry weight – final dry weight).

We used a completely randomized sampling design (DIC) with four replicates; each plot consisted of one free-choice arena.

<u>Data analysis</u> - we carried out data analysis following the sampling design described above, and we used one-way ANOVA to test for differences between treatments. We also tested for the assumptions of normality (Shapiro-Wilk test) and homoscedasticity (Cochran test). The variables that did not meet these assumptions were arcsin- (percentage of unviable pupae and deformed adults) or log10-transformed (number of eggs per mass and number of eggs per female).

Results and Discussion

Feeding, development and reproduction of *S. frugiperda* were significantly different between caterpillars fed with maize treated with *Silicea terra* 36CH applied through both spraying and irrigation and the other treatments (Table 1).

The amount of food ingested by caterpillars provided

Table 1: Amount of food ingested, frass produced, weight gain, food assimilated, and food metabolized by *Spodoptera frugiperda* caterpillars fed with maize treated with the homeopathic preparation *Silicea terra* at different centesimal Hahnemanian (CH) dynamizations.

Application method / Dynamization	Ingested food (g)	Produced frass (g)	Weight gain (g)	Assimilated food (g)	Metabolized food (g)
Spraying					
12CH	3.27 Aa*	0.22 Ab	0.21 Aa	3.06 Aa	2.84 Aa
36CH	1.65 Bb	0.14 Bb	0.08 Bb	1.52 Bb	1.44 Bb
60CH	3.29 Aa	0.21 Ab	0.20 Aa	3.08 Aa	2.87 Aa
84CH	3.31 Aa	0.21 Ab	0.20 Aa	3.10 Aa	2.90 Aa
Ethanol 1%**	3.30 Aa	0.22 Ab	0.19 Aa	3.08 Aa	2.89 Aa
Water**	3.31Aa	0.20 Ab	0.22 Aa	3.10 Aa	2.88 Aa
No intervention	3.24 Aa	0.21 Ab	0.20 Aa	3.03 Aa	2.83 Aa
Irrigation					
12CH	3.24 Aa	0.24 Ab	0.22 ABa	3.00 Aa	2.79 Aa
36CH	1.73 Bb	0.14 Bb	0.08 Cb	1.59 Bb	1.50 Bb
60CH	3.23 Aa	0.22 Ab	0.18 ABa	3.00 Aa	2.82 Aa
84CH	3.26 Aa	0.22 Ab	0.17 Aa	3.04 Aa	2.87 Aa
Ethanol 1%**	3.24 Aa	0.22 Ab	0.22 Ba	3.02 Aa	2.80 Aa
Water**	3.19 Aa	0.22 Ab	0.22 Ba	2.96 Aa	2.74 Aa
No intervention	3.26 Aa	0.22 Ab	0.19 ABa	3.05 Aa	2.85 Aa
Seed treatment					
12CH	3.28 Aa	0.33 Aa	0.20 ABa	3.02 Aa	2.82 Aa
36CH	3.27 Aa	0.33 Aa	0.20 ABa	3.02 Aa	2.82 Aa
60CH	3.23 Aa	0.32 Aa	0.17 Ba	2.99 Aa	2.83 Aa
84CH	3.20 Aa	0.31 Aa	0.20 ABa	2.98 Aa	2.77 Aa
Ethanol 1%**	3.25 Aa	0.33 Aa	0.20 ABa	3.02 Aa	2.83 Aa
Water**	3.25 Aa	0.32 Aa	0.21 Aa	3.03 Aa	2.81 Aa
No intervention	3.28 Aa	0.34 Aa	0.20 ABa	3.05 Aa	2.85 Aa
C.V.%	3.72	3.61	8.62	4.07	4.43

*Means followed by the same letter in the column do not differ from each other. Intra-group comparisons: uppercase within the same application method. Inter-group comparisons: lowercase between application methods with Tukey test ($p \leq 0.05$).

**Not dynamized.

with maize plants sprayed (1.65 g) and irrigated (1.73 g) with *Silicea terra* 36CH was smaller than in the other treatments (Table 1). Therefore, these caterpillars produced a smaller amount of frass (0.14 g in both methods) and had significantly lower weight gain (0.08 g in both methods) compared to the other treatments (Table 1).

The amount of assimilated (1.52 g and 1.59 g) and metabolized food (1.44 g and 1.50 g) by caterpillars fed with leaf maize sections sprayed and irrigated with *Silicea terra* 36CH was significantly smaller than that of caterpillars fed with leaf maize sections treated with ethanol, water, or that had no intervention (Table 1). The amount of assimilated food refers to the part of the food ingested that was used by the caterpillar for conversion into biomass or energy for metabolism. The amount of metabolized food represents the amount of food used in the form of metabolic energy.

The ingestion by caterpillars of a smaller amount of leaf sections of maize sprayed or irrigated with *Silicea terra* 36 CH may have been caused by a lack of aspartic acid, an increase in silicon content on the leaves, or repellence. The lack of aspartic acid is a common characteristic of maize lineages resistant to *S. frugiperda*; contrarily, susceptible lineages, which present this acid, stimulate caterpillar feeding (SILVEIRA et al., 1998). An increase in silicon deposit on epidermal cells, which makes leaf tissues more rigid, could also have hindered the feeding of *S. frugiperda* caterpillars (GOUSSAIN et al., 2002).

The repellence hypothesis, though, becomes invalid when we observed the similar numbers of caterpillars on leaf sections between treatments in the free-choice test (Table 2). However, Mapeli et al. (2010), studied the great southern white butterfly, Ascia monuste orseis, fed with kale discs and observed a repellence effect of plants treated with the many homeopathic preparations including *Silicea terra* 6CH and 30CH.

Table 2: Food preferences and consumption of leaf sections of maize plants treated with the homeopathic preparation Silicea terra at different centesimal Hahnemanian (CH) dynamizations of *Spodoptera frugiperda* caterpilars in free-choice tests.

Application method / Dynamization	Number of caterpillars on leaf sections (sum of the evaluations)	Ingested food (dry mass in g)
Spraying		
12CH	13.8 ns	87.3 Aa*
36CH	13.8	26.8 Bb
60CH	15.8	86.8 Aa
84CH	16.8	80.6 Aa
Ethanol 1%**	15.5	85.9 Aa
Water**	15.0	88.8 Aa
No intervention	16.0	88.5 Aa
Irrigation		
12CH	12.3 ns	86.8 Aa
36CH	13.0	32.0 Bb
60CH	15.3	86.7 Aa
84CH	16.8	81.9 Aa
Ethanol 1%**	14.5	87.6 Aa
Water**	14.5	86.8 Aa
No intervention	15.8	87.7 Aa
Seed treatment		
12CH	15.5 ns	84.5 Aa
36CH	16.0	89.1 Aa
60CH	16.3	81.7 Aa
84CH	15.8	83.2 Aa
Ethanol 1%**	16.3	88.3 Aa
Water**	16.0	86.5 Aa
No intervention	15.3	86.1 Aa
C.V.%	14.28	9.81

*Means followed by the same letter in the column do not differ from each other. Intra-group comparisons: uppercase within the same application method. Inter-group comparisons: lowercase between application methods with Tukey test ($p \leq 0.05$). ns Non-significant in intra- and intra-group comparisons with Tukey test ($p \leq 0.05$).

In terms of nutritional indices, we observed that the caterpillars fed with maize treated with the dynamization 36CH differed significantly from the control treatment with water in some nutritional variables applied through spraying and irrigation methods (Table 3). Caterpillars fed with maize treated with the homeopathic preparation *Silicea terra* 36 CH through spraying showed higher relative consumption rate (RCR) and higher relative metabolic rate (RMR) in relation to those fed with plants sprayed with water (Table 3).

The caterpillars fed with maize treated with *Silicea terra* 36CH through soil irrigation also showed higher relative consumption rate (RCR) (1.024 g/g/day) in relation to plants irrigated with water and hydroalcoholic solution (1% ethanol) (Table 3). These caterpillars showed an efficiency of conversion of ingested food (ECI) (4.96%) and efficiency of conversion of digested food (ECD) (5.40%) lower than the caterpillar fed with leaf sections of control maize irrigated with water (Table 3).

Also in the experiment of consumption and digestion, there was no significant difference in relative growth rate (RGR) (0.049 g/g/day), which is biomass gain in relation to weight, and in approximate digestibility (AD) (93%), an index that represents the percentage of ingested food effectively assimilated by the insect (data not shown).

The leaf sections from plants that received the homeopathic preparation Silicea terra through seed treatment did not interfere in the feeding activity of the fall armyworm, which gives evidence that this application method in the studied dynamizations is not appropriate to control S. frugiperda (Table 3).

Photosynthetic area loss is a cause of low yield of cultivated species. A reduction in the leaf area consumed by caterpillars decreases photosynthetic area loss, and hence improves the productivity of cultivated species (TAIZ and ZEIGER, 2009). Based on that and on our results, we can infer that maize plants sprayed and irrigated with the homeopathic preparation *Silicea terra* at the dynamization 36 CH will have a smaller leaf

Table 3: Feeding activity of *Spodoptera frugiperda* caterpillars fed with maize treated with the homeopathic preparation *Silicea terra* at different centesimal Hahnemanian (CH) dynamizations.

Application method / Dynamization	Relative consumption rate (RCR) (g/g/day)	Relative metabolic rate (RMR) (g/g/day)	Efficiency of conversion of ingested food (ECI) (%)	Efficiency of conversion of digested food (ECD) (%)	Metabolic cost (%)
Spraying					
12CH	0.747 Ba*	0.648 Ba	6.56 Aa	7.03 Aa	92.97 Aa
36CH	1.091 Aa	0.954 Aa	4.86 Aa	5.35 Aa	94.65 Aa
60CH	0.803 ABa	0.703ABa	6.19 Aa	6.61 Aa	93.38 Aa
84CH	0.800 ABa	0.701 ABa	6.16 Aa	6.58 Aa	93.42 Aa
Ethanol 1%**	0.848 ABa	0.744 ABa	5.81 Aa	6.22 Aa	93.78 Aa
Water**	0.739 Ba	0.643 Ba	6.68 Aa	7.13 Aa	92.87 Aa
No intervention	0.791 ABa	0.691 ABa	6.23 Aa	6.66 Aa	93.34 Aa
Irrigation					
12CH	0.759 ABa	0.653 Aa	6.49 ABa	7.01 ABa	92.99 ABa
36CH	1.024 Aa	0.891 Aa	4.96 Ba	5.40 Ba	94.59 Aa
60CH	0.879 ABa	0.769 Aa	5.59 ABa	6.01 ABa	93.99 ABa
84CH	0.953 ABa	0.841 Aa	5.15 ABa	5.53 ABa	94.47 ABa
Ethanol 1%**	0.718 Ba	0.620 Aa	6.91 Aa	7.42 ABa	92.58 ABa
Water**	0.708 Ba	0.610 Aa	6.96 Aa	7.47 Aa	92.53 Aa
No intervention	0.823 ABa	0.719 Aa	5.98 ABa	6.40 ABa	93.60 ABa
Seed treatment					
12CH	0.793 Aa	0.682 Aa	6.23 Aa	6.78 Aa	93.23 Aa
36CH	0.819 Aa	0.709 Aa	6.12 Aa	6.62 Aa	93.38 Aa
60CH	0.947 Aa	0.830 Aa	5.19 Aa	5.59 Aa	94.41 Aa
84CH	0.778 Aa	0.676 Aa	6.33 Aa	6.80 Aa	93.20 Aa
Ethanol 1%**	0.819 Aa	0.712 Aa	6.00 Aa	6.46 Aa	93.54 Aa
Water**	0.745 Aa	0.643 Aa	6.61 Aa	7.09 Aa	92.90 Aa
No intervention	0.787 Aa	0.685 Aa	6.28 Aa	6.74 Aa	93.26 Aa
C.V.%	10.99	11.98	10.35	10.58	0.74

*Means followed by the same letter in the column do not differ from each other. Intra-group comparisons: uppercase within the same application method. Inter-group comparisons: lowercase between application methods with Tukey test (p ≤ 0.05).

**Not dynamized.

area damaged and, therefore, lower loss in the production of grains.

In the experiment of development of pupa and moth of *S. frugiperda* fed in period of caterpillar with corn plants treated with homeopathic preparation *Silicea terra*, the caterpillars fed with leaf sections of maize with of dynamization 36 CH through spraying and irrigation originated female pupae with lower weight (0.089 g and 0.093 g, respectively) and presented a longer pupal period (13.3 and 12.3 days) (Table 4). Lower weight of the female pupa is directly related to lower fecundity (ROGERS and MARTI JR, 1994; SIMMONS and MARTI JR, 1992). Therefore, the caterpillar will not only consume less, but the moths originated from these caterpillars will lay fewer eggs, impacting the population of this species and contributing to reduce the damage to crops caused by the next generation. Some studies reported that caterpillars can extend their larval phase when the food is not suitable for their development, as a compensatory strategy, so that they remain a longer period feeding to form vigorous pupae and adults (SILVEIRA et al., 1997; PARRA et al., 2009), however we did not observe this fact in the present study.

The pupae not only presented a longer development time but also generated adults with a higher percentage of deformations (crooked and short wings) than control, reaching a percentage between 40 and 50% of deformed adults originated from caterpillars fed with maize plants treated via spraying and irrigation, respectively (Table 4). These results corroborate the study by Rosa et al. (2012). Usually, these deformations in Lepidoptera can be a result of a diet deficient in fatty acids, especially linoleic and linolenic acids (PARRA, 2009). Therefore, maize plants sprayed and irrigated with the preparation *Silicea terra* 36CH may contain a lower index of fatty acids, or the absorption of these elements by the caterpillars was not enough due to digestion and food assimilation problems, as we

Table 4: Biological characteristics of *Spodoptera frugiperda* fed in the larval phase with maize plants treated with the homeopathic preparation *Silicea terra* at different centesimal Hahnemanian (CH) dynamizations.

Application method / Dynamization	Pupal period (days)	Weight of the female pupa (g)	Inviability of the pupa (%)	Deformed adults (%)
Spraying				
12CH	7.3 Bb*	0.128 Aa	5.0 Aa	10.0 BCa
36CH	13.3 Aa	0.089 Bb	17.5 Aa	40.0 Ab
60CH	7.3 Bb	0.117 ABa	2.5 Aa	12.5 Ba
84CH	7.5 Bb	0.123 Aa	5.0 Aa	12.5 Ba
Ethanol 1%**	8.0 Bb	0.117 ABa	2.5 Aa	0.0 Ca
Water**	7.3 Bb	0.117 ABa	5.0 Aa	0.0 Ca
No intervention	7.0 Bb	0.132 Aa	4.5 Aa	2.5 BCa
Irrigation				
12CH	7.3 Bb	0.115 ABa	2.5 Ba	10.0 BCa
36CH	12.3 Aa	0.093 Bb	20.0 Aa	50.0 Aa
60CH	7.3 Bb	0.120 ABa	5.0 ABa	12.5 Ba
84CH	7.8 Bb	0.115 ABa	5.0 ABa	12.5 Ba
Ethanol 1%**	7.8 Bb	0.122 Aa	2.5 Ba	0.0 Ca
Water**	8.0 Bb	0.117 ABa	5.0 ABa	0.0 Ca
No intervention	7.0 Bb	0.132 Aa	5.0 ABa	2.5 BCa
Seed treatment				
12CH	7.0 Bb	0.132 Aa	5.0 Aa	0.0 Aa
36CH	7.0 Bb	0.132 Aa	5.0 Aa	0.0 Aa
60CH	8.0 Bb	0.117 Aa	5.0 Aa	0.0 Aa
84CH	7.5 Bb	0.115 Aa	5.0 Aa	0.0 Aa
Ethanol 1%**	7.8 Bb	0.120 Aa	5.0 Aa	0.0 Aa
Water**	7.5 Bb	0.123 Aa	5.0 Aa	0.0 Aa
No intervention	7.3 Bb	0.122 Aa	5.0 Aa	2.5 Aa
C.V.%	11.35	8.34	3.91	1.72

*Means followed by the same letter in the column do not differ from each other. Intra-group comparisons: uppercase within the same application method. Inter-group comparisons: lowercase between application methods with Tukey test ($p \leq 0.05$).

**Not dynamized.

reported previously.

We also observed that feeding the caterpillars with leaf sections of maize plants sprayed and irrigated with *Silicea terra* 36CH led to higher percentage of dead pupae than other treatments (Table 4). This may be related to lesser feeding as showed the results described previously and low assimilation of nutrients by the caterpillar, which probably would not suffice to allow it complete its development properly, as no increase in feeding time through the increase of the larval period was observed (ROGERS and MARTI JR, 1994; SIMMONS and MARTI JR, 1992).

We observed that the fertility and fecundity of moths originated from caterpillars fed with maize treated with Silicea terra 36 CH via spraying and irrigation were also affected, producing 95% and 94% fewer eggs, respectively, than the moths originated from moths fed with maize with no intervention (Table 5).

In addition, the same treatments led to a reduction in the number of egg masses per females (1.4 and 1.3, respectively) and number of eggs per clucth^{-1} (38.3 and 37.9 respectively), compared to other treatments (Table 5).

The longevity of adults did not differ significantly ($p \leq 0.05$) between treatments, with average values of 14.4 days for female moths and 14.2 days for male moths.

We did not observe a significant difference in pre-oviposition period among dynamizations and application methods. The pre-oviposition period lasted on average, 4.5 days (Table 5).

There was no significant difference in embryo development period; the average values found in the present study are identical to those found by Santos et al. (2004), who observed embryo development period lasting, on average 2.4 days.

Hence, taking into account the results observed, we can infer that the caterpillars ingested a smaller quantity of maize treated with *Silicea terra* 36CH via spraying and irrigation, had a lower efficiency in the conversion of ingested food, formed lighter pupae, and consequently, the adults had lower fecundity. Although the dynamization 36 CH of the homeopathic preparation

Table 5: Oviposition period, post-reproductive period, number of egg mass per female, number of eggs per egg mass, and fecundity of adults of originated from caterpillars fed with maize plants treated with the homeopathic preparation *Silicea terra* at different centesimal Hahnemanian (CH) dynamizations.

Application method / Dynamization	Oviposition period (days)	Post-reproductive period (days)	Egg mass per female (un)	Eggs per egg mass (un)	Fecundity (un)
Spraying					
12CH	5.8 Aa*	4.4 Bb	4.8 Aa	142.1 Aa	684.4 Aa
36CH	1.4 Bb	8.7 Aa	1.4 Bb	38.3 Bb	55.0 Bb
60CH	5.7 Aa	4.9 Bb	4.8 Aa	123.2 Aa	600.2 Aa
84CH	5.8 Aa	4.1 Bb	4.9 Aa	222.9 Aa	1045.4 Aa
Ethanol 1%**	5.4 Aa	4.3 Bb	4.8 Aa	246.2 Aa	1175.8 Aa
Water**	6.0 Aa	4.1 Bb	5.2 Aa	168.0 Aa	870.1 Aa
No intervention	5.7 Aa	4.1 Bb	5.3 Aa	210.1 Aa	1091.7 Aa
Irrigation					
12CH	5.6 Aa	4.7 Bb	4.8 Aa	134.0 Aa	661.4 Aa
36CH	1.3 Bb	8.2 Aa	1.3 Bb	37.9 Bb	56.90 Bb
60CH	5.8 Aa	4.3 Bb	5.0 Aa	117.1 Aa	582.0 Aa
84CH	5.6 Aa	3.9 Bb	5.0 Aa	221.8 Aa	1105.2 Aa
Ethanol 1%**	5.7 Aa	4.3 Bb	5.2 Aa	232.4 Aa	1143.3 Aa
Water**	5.4 Aa	4.0 Bb	4.8 Aa	158.9 Aa	745.1 Aa
No intervention	5.9 Aa	3.6 Bb	4.9 Aa	200.8 Aa	1001.3 Aa
Seed treatment					
12CH	5.7 Aa	4.0 Bb	5.1 Aa	219.3 Aa	1143.2 Aa
36CH	5.4 Aa	4.7 Bb	5.1 Aa	233.0 Aa	1267.8 Aa
60CH	5.7 Aa	4.0 Bb	5.3 Aa	173.7 Aa	911.6 Aa
84CH	5.6 Aa	4.6 Bb	4.8 Aa	120.2 Aa	567.6 Aa
Ethanol 1%*	5.7 Aa	3.5 Bb	4.3 Aa	212.1 Aa	949.3 Aa
Water*	5.7 Aa	3.4 Bb	5.2 Aa	148.0 Aa	786.6 Aa
No intervention	5.7 Aa	4.7 Bb	5.0 Aa	166.3 Aa	806.4 Aa
C.V.%	14.42	35.66	19.04	11.35	9.51

*Means followed by the same letter in the column do not differ from each other. Intra-group comparisons: uppercase within the same application method. Inter-group comparisons: lowercase between application methods with Tukey test ($p \leq 0.05$).

**Not dynamized.

silver nitrate. Similarly, Bonato (2007) observed that an increase in the dynamization of homeopathic preparations does not have a linear effect on the accumulation of plant biomass. The results confirm that each homeopathic preparation, each dynamization, and each application method has a different dynamics. Still, it is recommended to use not only one single homeopathic preparation, dynamization, or application form when carrying out experiments with homeopathy in plants, otherwise the treatment can be wrongly considered inefficient (BONATO, 2004).

Instead of aiming at the elimination of the pest insect, the ecological production system aims at the maintenance of the pest insect population at a smaller size. The spraying and irrigation of *Silicea terra* 36 CH on maize plants evidenced this potential, as these treatments did not kill the *S. frugiperda* caterpillars, but rather reduced the fertility and fecundity of this species.

Currently, there are few or no treatments in conventional or organic production system that reduce the damage cause by feeding of *S. frugiperda* caterpillars on maize and that also affect the adult phase of the insect, reducing its fecundity and consequently the population of this species in the field. The results of the present study go in this direction and show the potential of the use of the homeopathic preparation *Silicea terra* 36CH, sprayed or irrigated as a method farmers can use for the management of the fall armyworm, which will reduce the leaf area consumed by caterpillars and decrease the fecundity of moths, are necessary field test for the validation of results.

Conclusion

The most suitable methods for application of the homeopathic preparation *Silicea terra* and the management of *S. frugiperda* in maize crops are spraying in the aerial part of the plant and soil irrigation. The homeopathic preparation *Silicea terra* at the

the dynamization 36 CH applied through spraying or irrigation on maize plants interferes in the feeding of caterpillars and consequently the fertility and fecundity of *S. frugiperda* adults, thus reducing the population of the insect.

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