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FIELD EVALUATION OF NEW STRATEGIES IN INTEGRATED MANAGEMENT OF RICE STRIPED STEM BORER (*CHILO SUPPRESSALIS*) IN RICE FIELDS

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Abstract

The present study comprised three separate experiments to evaluate the effectiveness of biocompatible strategies in controlling *Chilo suppressalis* Walker in rice fields. The results of the first experiment showed that the lowest number of infested tillers, number of larvae, pupae, and dead hearts was related to the oil-spraying treatment with an interval of 7 days. The results of the second experiment in part 1 showed that mineral oil, 5% kaolin, mineral oil + kaolin, and diazinon caused 79.20, 58.40, 83.21, and 77.27% reductions in dead heart and 77.86, 69.47, 88.04, and 93.13% reductions in the white head in rice plants and 72.00, 50.74, 76.89 and 97.37% reduction in *C. suppressalis* ovipositing, respectively, compared to the control. According to the results of the second experiment in Part 2, 3% mineral oil, 5% kaolin, 5% kaolin + trap crop, and 3% mineral oil + trap crop had a 57.50, 64.67, 96.47, and 92.83% repelling effect, respectively, against adult rice striped stem borer (RSSB) insects and reduced oviposition. These treatments reduced the number of dead hearts by 66.07, 76.75, 89.45, and 85.64% and the number of whiteheads by 57.80, 65.12, 73.90, and 69.02 compared to the control. The results of the second experiment in Part 3 showed that mineral oil, kaolin 5%, and mineral oil + kaolin caused 42.83, 64.24, and 78.59% reductions in the number of infested tillers, respectively, compared with the control. In the third experiment, mineral oil and mineral oil + kaolin reduced the number of *C. suppressalis* larvae by 80.65 and 90.32%, respectively. These treatments also resulted in 55.56 and 75% in dead hearts and 73.29 and 79.45% in whiteheads, respectively. The findings show that mineral oil and kaolin can be applied individually and in combination with each other or in combination with trap cropping to control *C. suppressalis*.

KEY WORDS: rice stem borer; mineral oil; kaolin; trap crop; IPM

Introduction

Rice is one of the three main foods in the world, and after wheat, it occupies the largest area of land under the cultivation of agricultural products (Majidi Shilsar *et al.,* 2011). Currently, Guilan and Mazandaran provinces in north Iran are key rice production areas and the largest rice producers in the country. Mazandaran province has first place in Iran, with a cultivated area of 253,900 ha and a production rate of 1.28 million tons (Anonymous, 2022). Among the agricultural products in Iran, the highest consumption of chemical pesticides was related to rice. Among the pests that damage rice, the rice striped stem borer (RSSB), *Chilo suppressalis* Walker (Lepidoptera Crambidae), is the most prevalent (Noorhosseini Niaki & Noorhosseini Niaki, 2010; Jalaeian *et al.,* 2017).

The RSSB attacks all parts of rice seedlings, especially the stem, and feeds on the internal contents of the stem after boring and penetrating it. The most noticeable symptoms of *C. suppressalis* are 'dead hearts', produced when stem borer larvae kill the growing points of young shoots, and 'whiteheads', caused by interference with inflorescence development. Stems weakened by stem borers may also lodge (Amouoghli Tabari *et al.,* 2011; Majidi Shilsar & Ebadi, 2013; Majidi Shilsar, 2017). The RSSB has been considered a dangerous pest in rice fields in north Iran for more than 30 years, with its control mainly relying on the use of chemical pesticides. Application of these chemicals has resulted in adverse and harmful effects on humans and the environment, including an increase in diseases among farmers and community members, the destruction of natural enemies, the development of resistance to insect pests, and the outbreak of secondary pests (Majidi Shilsar *et al.,* 2011; Majidi Shilsar & Ebadi, 2013; Majidi Shilsar, 2017).

To control this pest, between 4,000 and 8,000 tons of insecticides are used in the rice fields annually (Majidi Shilsar & Amouoghli Tabari, 2011). Because the larva of this insect lives and feeds inside the rice stem, its control by chemical methods is difficult and often ineffective (Bagheri *et al.,* 2020). Factors such as larvae hiding inside the stem, which prevents effective doses of insecticides from reaching them, the rapid emergence of resistance to various groups of chemical insecticides, and the destruction of natural enemy populations often decrease the efficacy of these compounds (Zibaee *et al.,* 2009; Cheng *et al.,* 2010; Yao *et al.,* 2017). As a result, every year, a significant amount of chemical insecticides are introduced into the environment to control this pest, which has caused many concerns for marine animals, birds, soil microorganisms, livestock, as well as farmers and rice consumers (Zibaee *et al.,* 2009; Su *et al.,* 2014). Therefore, considering environmental considerations, human health, and natural enemies of RSSB, it is essential to reduce the use of high-risk chemical insecticides in rice fields through integrated pest management strategies.

Mineral oils have been widely used in pest control for over a century (Angello, 2002). These compounds have a wide range of effects, are more compatible with the environment than synthetic pesticides, and are considered a fundamental component of integrated pest management programs for agricultural products worldwide (Weissling *et al.,* 1997; Beattie, 2005; Helmy *et al.,* 2012; Damavandian & Kiaeian Moosavi, 2014). The non-toxicity of mineral oils for living beings, especially vertebrates (Beattie & Smith, 1993; Damavandian, 2007), their minimal residue levels and rapid decomposition through environmental evaporation (Davidson *et al.,* 1991; Beattie *et al.,* 1995), along with no reported instances of pest resistance or secondary pest outbreaks due to extended use (Beattie & Smith, 1993; Fernandez *et al.,* 2005), may contribute to this.

In some cases, mineral oils had repellent and deterrent effects on pests such as the citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera Gracillaridae) (Damavandian & Kiaeian Moosavi, 2014) and the European corn borer, *Ostrinia nubilalis* Hübner (Lepidoptera Crambidae) (Mensah *et al.,* 2005). Additionally, a method of controlling and reducing the damage caused by pests such as aphids, mites, and the eggs of certain pests, as well as managing diseases of fruit trees, is to use Volck® mineral oil (Helmy *et al.,* 2012). In recent years, several studies have been conducted on using mineral oils to control pests, especially lepidopteran pests. Damavandian & Kiaeian Moosavi (2014) and Dashti *et al.* (2018a, b) reported that a concentration range of 0.65-0.95% (650-950 ml in 100 L of water) of mineral oil caused a significant reduction in damage caused by *P. citrella*. Kord Firozjaee & Damavandian (2018) stated that the mortality percentage of *P. citrella* larvae in concentrations of 0.7 (700 ml / 100 L of water) and 0.9 (900 ml / 100 L of water) was 51.85 and 77.57%, respectively. Marzban Abbasabadi *et al.* (2019) showed that the application of a 1.5% concentration of mineral oil reduced the damage caused by the citrus leafroller, *Archips rosanus* L. (Lepidoptera, Tortricidae) from 21.33 to 8.89 infected buds per tree. Riedl *et al.* (1995) stated that mineral oils are used to control the egg masses of the codling moth *Cydia pomonella* L. (Lepidoptera, Tortricidae). Also, Al Dabel *et al.* (2008) reported that mineral oils have a high ovicidal effect on *O. nubilalis* eggs. In another experiment, Rezanezhad Ghadi *et al.* (2018) reported that a 2.5% concentration of mineral oil resulted in the highest number of non-hatching eggs and had a maximum ovicidal effect on *C. suppressalis* eggs.

The pest-repellent properties of compounds obtained from plants can be very important due to their environmental compatibility and lack of adverse effects on human health. Kaolin can be included among these plant materials. Kaolin is a white mineral material containing aluminum silicate, soluble in water, and free of harmful environmental effects. It is edible and used in food processes as it is non-toxic to mammals. It is, therefore, a suitable and safe compound for integrated pest management programs (Glenn & Puterka, 2005; Jaastad *et al.,* 2006; Braham *et al.,* 2007; Showler & Harlien, 2022).

The use of kaolin powder has been effective in controlling many lepidopteran pests, including the pomegranate cutworm, *Ectomyelois ceratoniae* Zeller (Lepidoptera, Pyralidae) (Moshiri *et al.,* 2011), tomato leafminer, *Tuta absoluta* Meyrick (Lepidoptera, Gelechiidae) (Abdollahi *et al.,* 2016), *C. pomonella* (Farazmand, 2017), spruce budworm, *Choristoneura fumiferana* Celemens (Lepidoptera, Tortricidae), diamondback moth, *Plutella xylostella* L. (Lepidoptera, Plutellidae) (Barker *et al.,* 2006), cotton bollworm, *Helicoverpa armigera* Hübner, cotton leafworm, *Spodoptera litoraliss* Boisduval, cotton spiny bollworm, *Earias* sp. (Lepidoptera, Noctuidae), cotton leafroller, *Sylepta derogata* Fabricius (Lepidoptera, Pyralidae) *C. pomonella* (Alavo *et al*, 2010), fruit tree leafroller, *Archips argyrospilus* Walker (Lepidoptera, Tortricidae), western tentiform leafminer, *Phyllonorycter elmaella* Doganlar & Mutuura (Lepidoptera, Gracillariidae) (Knight *et al.,* 2012), cotton leafworm, *Alabama argillacea* Hübner, and soybean looper, *Chrysodeixis includens* Walker (Lepidoptera, Noctuidae) (Galdino *et al.,* 2021).

Trap cropping is an effective and promising tool in conservation biological control that involves cultivating and growing another non-crop species in a designated area to draw pests away from the main crop, thereby preventing them from reaching the crop. Ultimately, it is a method to control the pest and minimize damage to the main crop (Hokkanen, 1991; Shelton & Badenes-Perez, 2006; Sarkar *et al.,* 2018). Trap cropping is an attractive option to reduce dependence on conventional pest management practices involving insecticide use (Gao *et al.,* 2012). Trap cropping can also be combined with a repellent intercrop to develop a push-pull strategy for insect pest management (Sarkar *et al.,* 2018). In Kenya, Khan *et al.* (2001) reported that the maize stem borer, *Busseola fusca* Fuller (Lepidoptera, Noctuidae), can be effectively managed using a push-pull strategy. This involves intercropping *Desmodium grasses* (Fabaceae) with Napier grass, *Pennisetum purpureum* Schumach (Poaceae), which is cultivated as a peripheral trap plant. However, the efficacy of trap cropping in controlling several lepidopteran pests such as *H. armigera* on tomatoes (Sandhu & Aruta, 2014), chickpeas (Kumar *et al.,* 2017), and Egyptian clover (Kumar & Cheema, 2020), *P. xylostella* and *Pieris rapae* Linnaeus (Lepidoptera, Pieridae) on cabbage (Luther *et al.,* 1996), *Pieris brassicae* L. (Lepidoptera, Pieridae) on Indian mustard (Kumar, 2017) and *Busseola fusca* Fuller (Lepidoptera, Noctuidae) on sorghum (Khan *et al.,* 2008).

Considering the extensive rice cultivation and frequent pesticide applications in Mazandaran province, coupled with the adverse effects of pesticides on water resources and soil and the risks to residents, it is necessary to introduce alternative and low-risk methods to farmers. Since mineral oils have repellent and lethal properties against certain lepidopterans, it is possible to control the RSSB using mineral oil, provided its use does not induce phytotoxicity.

Materials and Methods

This study was conducted in three separate experiments in three different regions as follows:

Experiment 1

Study location: A rice field in Doneh Sar village, Babol City, Mazandaran province (36˚ 47´N, 52˚ 38´E, and 20 m a.s.l.) from July to October 2019. The village has a temperate climate, and its annual rainfall and average temperature are 899 mm and 18˚C, respectively.

Experimental design: The experiment was conducted in a completely randomized design with four treatments and three replications. The treatments included chemical insecticides (diazinon + cypermethrin), oil spraying at an interval of 7 days (as push), oil spraying at an interval of 14 days (as push), and a control (water spraying). The rice plants were planted with a spacing of 50 cm and a density of 32 plants/m^2 along the field's border at the same time as the pull. The mineral oil (Volck®, 80% L; sulphonation degree 92%) used was manufactured by Kia Sabz Ashian Kosha Company (Kiagreen Co., Tehran, Iran).

Land preparation and plan implementation: Land preparation was carried out in the summer of 2019. Based on the amount of conventional fertilizers used in the region, 180 kg/ha of urea fertilizer in two stages and 100 kg/ha of potassium fertilizer were used. The rice variety used in this experiment was Binam, obtained from reliable agricultural sales centers. The planting dates in the treasury and the main field were July 11 and August 15, respectively. Each experimental plot was 600 m^2 (20x30 m). Transplanting was done conventionally with a density of 16 plants/m^2.

Irrigation and other activities were conducted following the traditional practices in the region. The amount of mineral oil applied was 3 L/1,000 m^2. Seven days after transplanting, the first application of treatments was on August 13, 2019. The oil spraying continued based on the moths flying in the two light traps installed on the field's western and eastern edges. In general, mineral oil spraying treatments at intervals of 7 and 14 days were carried out six and three times, respectively. In the chemical insecticide treatment, diazinon (10% G) at a rate of 20 kg/ha and cypermethrin (40% EC) at a rate of 1 L/ha were sprayed twice to control *C. suppressalis*. The last oil spraying took place on October 8, 2019.

Sampling and measurements: The sampling was conducted on August 30, September 19, and October 9, 2019. A sampling square measured 1 x 1 m. There were ten squares in each experimental plot, and 4 plants were randomly planted in each square (a total of 40 plants per plot). The total number of tillers, healthy and infested tillers, larvae, pupae, and dead hearts were counted. It should be noted that the sampling was conducted on three dates (in each sampling stage in each experimental plot, the plants in ten squares were randomly counted and checked.

Experiment 2

Study location: A rice field in the deputy of Iran Rice Research Institute, Amol City, Mazandaran province, Iran (36˚ 28´N, 52˚ 27´E, and 23.7 m a.s.l.), March to August 2021. In this location, the average humidity is between 70 and 79%, and annual rainfall and temperature are 800 mm and 16˚C, respectively.

Experimental design: This experiment was done in three parts:

Part 1: The experiment was conducted in a randomized complete block design with five treatments: mineral oil (80% L; sulfonation degree of 92%) at the level of 3% (volume/volume), kaolin aqueous solution at the level of 5% (volume/volume), a combination of mineral oil (3%, V/V) and kaolin aqueous solution (5%), diazinon insecticide (60% EC) at a concentration of 3 L/ha and a control (water spraying). The experiment was repeated three times. The area of each plot was 1 m^2. The rice variety used in this experiment was Hashemi, and the seeds were obtained from the Gene Bank of the deputy of Iran Rice Research Institute.
There were two seedlings on each hill, and there were five hills per plot. Before transferring the seedlings to the experimental plots, the experimental site was screened with a cage (1 m^2) covered by netting. Before releasing the full complement of RSSB adults into the cages, the experimental treatments were applied to different plots, each with three replications. Subsequently, 20 adults per plot were released over the course of three nights.

Part 2: This experiment was conducted in semi-field conditions (screened environment) in a randomized complete block design with six treatments and three replications. Experimental treatments included mineral oil (80% L; sulfonate on degree of 92%) at a rate of 3% (v/v), kaolin aqueous solution at a rate of 5% (v/v), kaolin aqueous solution at 5% (v/v) + trap crop (Tarom Mahalli rice variety), mineral oil at a rate of 3% (v/v) + trap crop (Tarom Mahalli rice variety), diazinon (60% EC) at a concentration of 3 L/ha and control (water spraying). The area of the plots in this experiment was 4 m^2. The rice variety used in this experiment was Hashemi, and the seeds were obtained from the Gene Bank of the deputy of Iran Rice Research Institute. The planting date of seeds in the treasury and the transplanting date were similar to Part 1. Before transferring the seedlings to the experimental plots, the experiment site was screened by a cage 3 x 12 x 8 m in size that was covered by a netting. There were two seedlings on each hill, and there were 10 hills per plot. For the plots requiring a trap crop, seedlings of the Tarom Mahalli variety were planted in a row around the plots at the same time as the Hashemi variety was planted in the plot. Before releasing the RSSB adults in the caged experimental plots, the treatments were applied according to each block. For each plot, 40 adults and a total of 720 adults were released inside the screened environment in the plots. The RSSB adults were collected from the light traps installed in the field located in the deputy of Iran Rice Research Institute and released in the screened environment about three weeks after transplanting.

Sampling and measurements: To investigate the repellent effect of the studied treatments in these two parts, three days after releasing adults, the RSSB egg masses were counted on the upper and lower surfaces of the leaves. All plants in each plot were sampled to evaluate the deterrent effect of the treatments. During the vegetative stage, the number of dead hearts was counted, and during the reproductive stage, the number of whiteheads was counted. The ONATE formula (Onate, 1965) was used to calculate the percentage of dead hearts and whiteheads (Equation 1).

$$D.HorW.H(\%) = \frac{No.of\ infested\ plants}{No.of\ total\ measured\ plants} \times \frac{No.\ of\ infested\ tillers}{No.\ of\ total\ tillers} \times 100 \quad (1)$$

Part 3*:* This experiment was carried out in pots in cages of the same dimensions as the previous experiments. The dimensions of each pot were 12 x 9 cm. The potting soil was prepared from paddy field soil, and two rice seedlings of the Hashemi variety were planted in each pot. Ten days after transplanting, 1 g of nitrogen fertilizer was added to the soil to promote further vegetative growth of the plants. Ten RSSB adults were released per pot (a total of 150 adults) inside the cages. In this experiment, five treatments, including mineral oil (80% L; 92% sulfonate) at the rate of 3% (v/v), kaolin aqueous solution at the rate of 5% (v/v), a combination of mineral oil (3%) and kaolin aqueous solution (5%), diazinon insecticide (60% EC) at a concentration of 3 L/ha and control (water spraying) were evaluated in a randomized complete block design. Four weeks after transplanting and the female adults had oviposited, the treatments were applied to the pots inside the respective cages.

Sampling and measurements: To assess the effects of the treatments, 24 h after the treatment, the eggs were monitored one to three times each day, and eight days after the treatment, egg mortality was examined in the laboratory to evaluate the ovicidal efficacy of the treatments. The total number of egg masses, the number of hatched and unhatched egg masses, the total number of tillers, the number of infested tillers, and the number of healthy tillers were examined.

Experiment 3

Study location: A rice field in Agha Malek village, Laleh Abad district, Babol city, Mazandaran province, northern Iran (36˚ 28´N, 52˚ 34´E and 13 m a.s.l.) from May to August 2022. This village has a temperate climate, its annual rainfall is 879 mm, and the average temperature is 17.5˚C.

Experimental design: This experiment was conducted in a randomized complete block design with four treatments and replications. The treatments included mineral oil (80% L; sulfonate on degree of 92%) at the rate of 3% (volume/volume), the combination of mineral oil (80% L; sulfonate on degree of 92%) at the rate of 3% (volume/volume) and aqueous kaolin solution at the rate of 5% (volume/volume), fenitrothion (50% EC) at a concentration of 3 L/ha and control (water spraying).

Land preparation and plan implementation: The rice variety used in this test was Hashemi, which was purified (removing the damaged seeds) and disinfected according to the method mentioned in the previous experiments. Seeds were planted in the treasury in mid-April and transplanted to the main field in mid-May, 2022. Each experimental plot covered an area of 3,500 m^2, with a total field area of 56,000 m^2 used for this experiment. In the middle of March 2022, two light traps and two pheromone traps were installed in the four directions of the farm. The traps were monitored, and trapped RSSB adults were counted three times a week. Based on the information obtained from these traps and the developmental stage of the pest in the rice field, the appropriate time to apply the treatments in the plots was determined. Mineral oil and mineral oil + kaolin (as repellent treatments) were applied at the first observation of the flight of moths on June 12, 2022, and the insecticide was sprayed at flight peak on July 1, 2022. The mineral oil treatment was repeated once, ten days after the first application on June 22, 2022.

Sampling and measuring traits: To determine the deterrent effect of the compounds used in this experiment, sampling was done as follows: in the vegetative stage, 20 squares were randomly placed along two diameters of each 3,500 m^2 plot. Each square contained 4 hills, and each hill had two rice plants. Then the total number of tillers and the number of tillers infested with dead hearts were counted for each plant. Sampling in the reproductive stage was similar to sampling in the vegetative stage, with the total number of tillers and the number of whiteheads counted for each plant. To calculate the percentage of dead hearts and whiteheads, the ONATE formula (Onate, 1965) was used. The yield was also calculated for each box and then estimated per hectare.

Statistical analysis: The data were analyzed using SAS software (version 9.3). A mean comparison of data was done using Duncan’s multiple range test at a significance level of 5%.

Results

Experiment 1

The analysis of variance (ANOVA) results for the first sampling date (August 30, 2019) revealed a significant difference between the control and other treatments regarding the total number of tillers per plant, the number of infested tillers per plant, the number of RSSB larvae per plant, and the number of dead hearts per the plant (P<0.01). However, this difference was not statistically significant for the number of healthy tillers per plant and the number of pupae per plant (P>0.05).

The results of the mean comparison of the assessed traits at the first sampling date are shown in Table I. As can be seen, the highest total number of tillers per plant was recorded in the control (C) with an average of 17.7, which was not significantly different from the oil treatment applied every 14 days (B). There was no significant difference between the number of healthy tillers in the two treatments of oil spraying at intervals of 7 and 14 days (A and B). However, there was a significant difference between these oil spraying treatments and both the insecticide treatment (D) and the control (C). Additionally, infected tillers were observed in all treatments except for the oil spraying at 7- day intervals (A). As Table I illustrates, no larvae were observed in oil spraying treatments at 7- day intervals (A), whereas RSSB larvae were found in the other treatments. The number of pupae was similar to the number of larvae. Additionally, the highest number of dead hearts counted was related to the control (C), with an average of 2. Dead hearts were also observed in the other treatments except for the oil spraying treatment at 7- day intervals (A) (Table I).

Table I. Mean comparison of the characteristics affected by treatments on RSSB damage on the first sampling date (August 30, 2019) in the first experiment

Treatment*	**No. of plants**	**Mean ± SE** (per the plant)**					
		Total no. of tillers	**No. of healthy tillers**	**No. of infested tillers**	**No. of larvae**	**No. of pupae**	**No. of dead hearts**
A	40	14.02b	14.02a	0.00c	0.00c	0.00b	0.00c
B	40	16.43a	15.05a	1.38b	0.45b	0.08ab	0.85b
C	40	17.70a	12.73b	4.97a	0.65a	0.20a	2.00a
D	40	13.80b	12.53b	1.27b	0.35bc	0.10ab	0.50bc

*A – oil spraying at 7-day intervals; B – oil spraying treatment at 14-day intervals; C – control; D – insecticide

**Different letters in each column indicate a statistically significant difference (P<0.01)

Based on the ANOVA results for the second date of sampling (September 19, 2019), there was no significant difference between the control and other treatments in terms of the total number of tillers, and the number of healthy tillers per plant was not statistically significant (P>0.05). On the other hand, the control exhibited a statistically significant difference from other treatments as regards the number of infested tillers, the number of larvae, the number of dead hearts per plant (P<0.01), and the number of pupae per plant (P<0.05). Based on the results obtained from the mean comparison (Table II), although there were no statistically significant differences between the treatments in terms of the total number of tillers per plant, the highest and the lowest means were obtained for the control (C) and oil spraying at 14 - day intervals (B), with averages of 17.08 and 16, respectively. Additionally, despite the absence of statistically significant differences between the treatments concerning the number of healthy tillers per plant, the highest and the lowest counts per plant were related to oil spraying at 7-day intervals (A) and control (C), with averages of 16.53 and 14.55, respectively. The results of the mean comparison showed that the highest number of infested tillers per plant was counted for the control (C), with an average of 2.53, whereas no infested tillers were observed in the oil spraying treatments at intervals of 7 and 14 days (A and B). Additionally, the control group (C) had the highest number of larvae per plant, averaging 1.25, whereas no larvae were observed in the oil spraying treatments at 7- and 14-day intervals (A and B) (Table II).

Based on the results, the highest number of pupae counted per plant was related to the insecticide (D) and control (C), with a similar average of 0.13. Conversely, the number of pupae per plant was zero for the oil spraying treatment at 7- and 14-day intervals (A and B). Also, as seen in Table 2, the highest number of dead hearts was obtained for the control (C), with an average of 1.30, while dead hearts were not observed for oil spraying treatments at 7- and 14-day intervals (A and B) (Table II).

Table II. Mean comparison of the characteristics affected by treatments on RSSB damage on the second sampling date (August 30, 2019) in the first experiment

Treatment*	No. of observations	Mean ± SE** (per the plant)					
		Total No. of tillers	No. of healthy tillers	No. of infested tillers	No. of larvae	No. of pupae	No. of dead hearts
A	40	16.53a	16.53a	0.00c	0.00b	0.00b	0.00c
B	40	16.00a	16.00ab	0.00c	0.00b	0.00b	0.00c
C	40	17.08a	14.55b	2.53a	1.25a	0.13a	1.30a
D	40	16.15a	15.03ab	1.12b	0.45b	0.13a	0.58b

*A – oil spraying at 7-day intervals; B – oil spraying treatment at 14-day intervals; C – control; D – insecticide

**Different letters in each column indicate a statistically significant difference (P<0.01)

ANOVA results for the third sampling date (October 9, 2019) showed that there was a significant difference between control and other treatments regarding the number of infested tillers, the number of larvae, and the number of dead hearts per plant (P<0.01); however, there was a significant difference between the treatments regarding the number of healthy tillers and the number of pupae per plant (P<0.05). The results of the mean comparison for the third time are presented in Table III. As can be seen, the highest total number of tillers per plant was obtained for the control (C), with an average of 19.9, and there was no significant difference between this treatment and the oil spraying treatment at an interval of 14 days (B). On the other hand, the lowest total number of tillers counted per plant was related to oil spraying at 7- day intervals (A), with an average of 16.95, which did not exhibit a statistically significant difference compared to the oil spraying treatment at an interval of 7 days (A) and the insecticide treatment (D).

Based on the results, the highest number of healthy tillers per plant was counted in the treatment of oil spraying at a 14 - day interval (B), with an average of 18.05, which was not significantly different from oil spraying at a 7 - day interval (A). Conversely, the lowest number of healthy tillers per plant was obtained for the control (C), with an average of 15.03, which was not significantly different from the oil spraying treatment at a 7 - day interval (A) and the insecticide treatment (D) (Table III). The results of the mean comparison for the number of infested tillers per plant showed that the highest mean was obtained for the control (C), with an average of 4.87, whereas no infested tillers per plant were observed in oil spraying at intervals of 7 (A) and 14 days (B). Additionally, the control (C) had the highest number of larvae per plant, with an average of 0.68, which did not differ significantly from the insecticide treatment (D). Conversely, no larvae per plant were observed in oil spraying at intervals of 7 (A) and 14 days (B) (Table III). The results of the mean comparison for the number of pupae per plant (Table III) showed that the highest number of pupae counted per plant was related to the control (C), averaging 0.23, which was not significantly different from the insecticide treatment (D). On the other hand, no pupae per the plant were observed in the oil spraying treatments at intervals of 7 (A) and 14 days (B).

According to the results, the highest number of dead hearts per plant was obtained for the control (C) with an average of 1.7, while no dead hearts per plant were observed in the oil spraying treatments at intervals of 7 (A) and 14 days (B) (Table III).

Table III. Mean comparison of the characteristics affected by treatments on RSSB damage on the third sampling date (August 30, 2019) in the first experiment

Treatment*	No. of observations	Mean ± SE** (per the plant)					
		Total No. of tillers	No. of healthy tillers	No. of infested tillers	No. of larvae	No. of pupae	No. of dead hearts
A	40	16.95b	16.95ab	0.00c	0.00b	0.00b	0.00b
B	40	18.05ab	18.05a	0.00c	0.00b	0.00b	0.00b
C	40	19.90a	15.03b	4.87a	0.68a	0.23a	1.70a
D	40	17.95b	16.15b	1.80b	0.45a	0.13ab	0.58b

*A – oil spraying at 7-day intervals; B – oil spraying treatment at 14-day intervals; C – control; D – insecticide

**Different letters in each column indicate a statistically significant difference ($P<0.01$)

ANOVA results showed a significant effect of the control method on rice grain yield ($P<0.01$). The mean comparison results of grain yield are shown in Fig. 1. As can be seen, the highest grain yield was obtained for oil spraying at 7-day intervals (A), with an average of 3,260.40 kg/ha, which was significantly different from other treatments. The lowest yield was that of the control (C), with an average of 1,979.20 kg/ha. It should be noted that the product yield was lower compared to its typical yield because the experiment was carried out during the double cropping of rice, which often results in lower yields compared to the first cropping due to the cold weather.

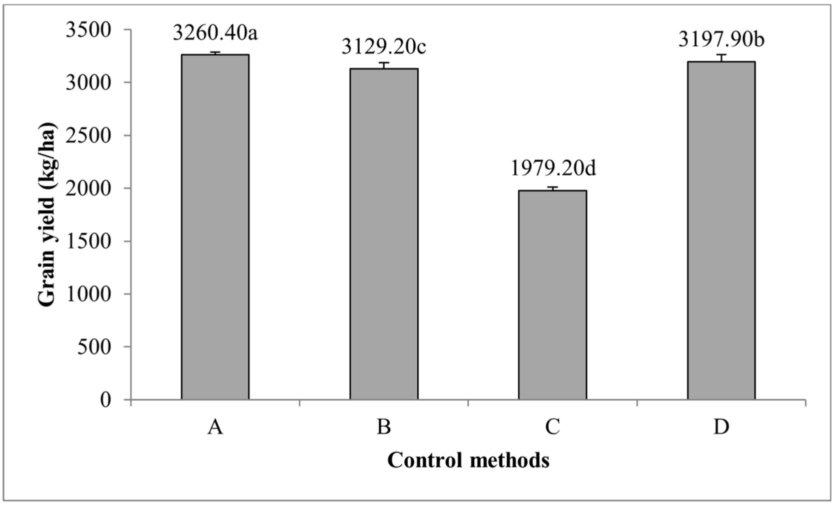

Figure 1. Mean comparison of rice grain yield in different control methods in the first experiment (A – oil spraying at 7-day intervals; B – oil spraying treatment at 14-day intervals; C – control; D – insecticide). Different letters indicate a statistically significant difference between the control methods.

Experiment 2 (Part 1)

RSSB egg masses on upper and lower surfaces of the leaves: There was a significant difference between treatments on the number of egg masses on the upper surface of the leaves. The results showed that the highest number of egg masses on the upper surface of the leaves was observed in the control (CO), with an average of 0.27, with no significant difference observed between CO and kaolin alone (KA). Also, no egg masses were observed in the diazinon treatment (DZ) (Table IV). ANOVA results for the number of egg masses on the lower surface of the leaves showed that applying the studied treatments had a significant effect on the control of this pest ($P<0.05$). The mean comparison results on the number of RSSB egg masses on the lower surface of the leaves are shown in Table IV. The highest number of egg masses counted on the lower surface of the leaves was that of the control (CO), with an average of 1.33, which differed significantly from the other treatments. Conversely, the lowest number of egg masses on the lower surface of the leaves were observed for diazinon (DZ), with an average of 0.07, which was not significantly different from the mineral oil + kaolin treatment (MO+KA) (Table IV). The results showed that the repellent effects of mineral oil (MO) and the combination of mineral oil + kaolin (MO+KA) on oviposition were significant compared to the control (Table IV).

Number of dead hearts in the vegetative stage*:* Based on the ANOVA, the application treatments significantly affected the control of this pest regarding the number of tillers infested with dead heart ($P<0.05$). The mean comparison results revealed that the control (CO) had the highest number of dead hearts, with an average of 6.73, which was significantly different from other treatments. On the other hand, the lowest number of dead hearts among the treatments was recorded for mineral oil + kaolin (MO+KA) and mineral oil alone (MO), with averages of 1.13and 1.40, respectively, which was not significantly different from the diazinon (DZ) and kaolin alone (KA) treatments (Table IV).

Percentage of dead hearts in the vegetative stage: ANOVA revealed that applying the treatments significantly affected the control of rice stem borer, as indicated by the percentage of dead hearts ($P<0.05$). Based on the results obtained from the mean comparison, the control (CO) had the highest percentage of dead hearts, with an average of 12.49%, which was significantly different from the other treatments. Kaolin alone (KA) was ranked next with an average of 6.30%. The lowest percentage of dead hearts among the treatments was related to diazinon (DZ), with an average of 2.15%, which was not significantly different from mineral oil + kaolin (MO+KA) and mineral oil alone (MO) treatments (Table IV).

Number of whiteheads in the reproductive stage: ANOVA results showed that the application of treatments significantly affected the number of whiteheads ($P<0.05$). The control (CO) had the highest number of whiteheads, with an average of 3.93. The kaolin (KA), and mineral oil (MO) alone treatments yielded the highest number of whiteheads after the control (CO), with averages of 1.2 and 0.87, respectively. The difference between KA and MO treatments was not significant. On the other hand, the lowest number of whiteheads observed among the treatments was that of diazinon (DZ), with an average of 0.27, which was not significantly different from mineral oil + kaolin (MO+KA) treatments (Table IV).

Percentage of whiteheads in the reproductive stage: ANOVA results revealed significant differences among the treatments studied in terms of the percentage of whiteheads ($P<0.05$). According to the results obtained from the mean comparison, the highest percentage of whiteheads was that of the control (CO), with an average of 14.78%, which was significantly different from the other treatments. Diazinon (DZ) had the lowest whitehead percentage among the treatments, with an average of 0.89%, which was not significantly different from the mineral oil + kaolin (MO+KA), averaging 1.6% (Table IV).

Table IV. Mean comparison of the number of RSSB egg masses on leaf surfaces, number and percentage of dead hearts, and number and percentage of whiteheads per plant in treatments during the vegetative and reproductive stages of rice (Part 1)

Treatment*	Mean ± SE** (per plant)					
	No. of egg masses on the upper surface of leaves	No. of egg masses on the lower surface of leaves	No. of dead hearts	dead heart (%)	No. of whiteheads	whiteheads (%)
MO	0.07±0.01b	0.40±0.06c	1.40±0.19b	3.46±0.26c	0.87±0.16b	3.24±0.36c
KA	0.13±0.06ab	0.67±0.04b	2.80±0.21b	6.30±0.35b	1.20±0.25b	4.53±0.41b
MO+ KA	0.07±0.02b	0.27±0.06cd	1.13±0.13b	2.25±0.30c	0.47±0.12c	1.60±0.55d
DZ	0.00±0.00c	0.07±0.01d	1.53±0.19b	2.15±0.15c	0.27±0.07c	0.89±0.25d
CO	0.27±0.09a	1.33±0.13a	6.73±0.22a	12.49±0.40a	3.93±0.37a	14.78±0.51a

*MO – mineral oil, KA – kaolin, MO+KA – mineral oil+kaolin, DZ – diazinon, CO – control

**Different letters in each column indicate a statistically significant difference (P<0.05)

Rice grain yield: According to ANOVA results, there was a significant difference between the treatments as regards grain yield (P<0.01). The mean comparison results of grain yield presented in Fig. 2 show that diazinon (DZ) had the highest grain yield, with an average of 323.33 g/5 plants, which did not significantly differ from the mineral oil + kaolin (MO+KA) treatments. The control (CO) had the lowest yield, with an average of 230 g/5 plants, significantly different from the other treatments. Mineral oil (MO) and kaolin (KA) alone treatments ranked after diazinon (DZ) and mineral oil + kaolin (MO+KA) (Fig. 2).

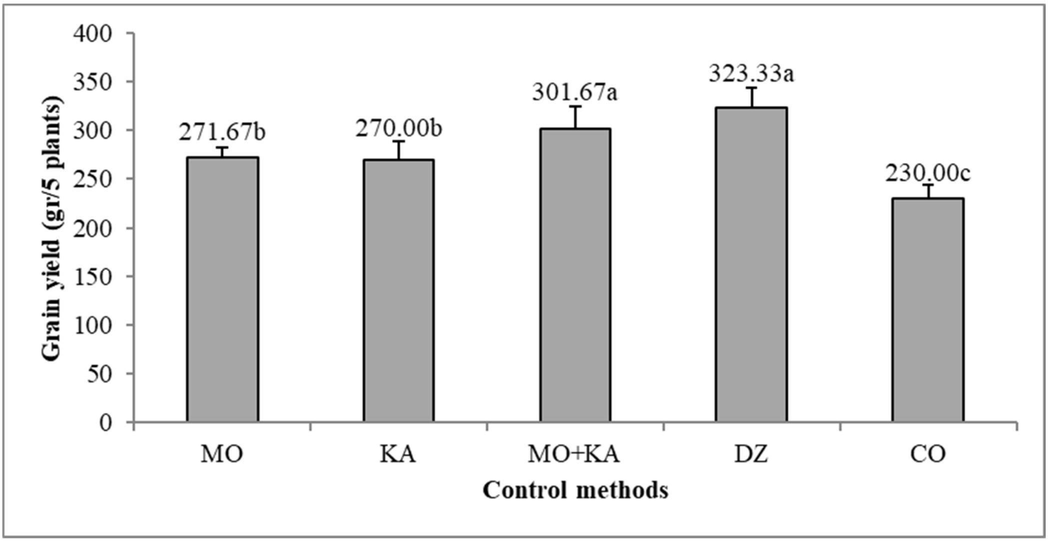

Figure 2. Mean comparison of rice grain yield in different control methods in the second experiment (Part 1) (MO – mineral oil, KA – kaolin, MO+KA – mineral oil+kaolin, DZ – diazinon, CO – control). Different letters indicate a statistically significant difference between the control method.s

Experiment 2 (Part 2)

RSSB Egg masses on leaf surfaces: ANOVA results indicated that the applied treatments had a significant and different effect on controlling this pest and reducing the number of egg masses on the upper surface of the leaves ($P<0.01$). The mean comparison results showed that the control (CO) had the highest number of egg masses on the upper surface of the leaves, with an average of 0.67, which was significantly different from the other treatments. On the other hand, no egg masses on the upper surface of the leaves were observed for kaolin + trap crop (KA+TC) and mineral oil + trap crop (MO+TC) treatments (Table V).
Based on the ANOVA results, the studied treatments were significantly different from each other in the number of egg masses on the lower surface of the leaves ($P<0.01$). According to the mean comparison, the control (CO) had the highest number of egg masses on the lower surface of the leaves, with an average of 4.67. The lowest number of egg masses on the lower surface of the leaves was observed for Kaolin + trap crop (KA+TC), with an average of 0.33, and did not differ significantly from the mineral oil + trap crop (MO+TC) and diazinon (DZ) treatments (Table V).

Number of dead hearts in the vegetative stage: The ANOVA results showed that there was a significant difference among the treatments regarding the number of dead hearts ($P<0.01$). The mean comparison results presented in Table 5 indicated that the highest number of infested tillers was in the control (CO), with an average of 7.87, and significantly different from the other treatments. The diazinon (DZ) treatment rendered the lowest number of dead hearts among the treatments, with an average of 0.80, which was not significantly different from the kaolin + trap crop (KA+TC) treatment (Table V).

Percentage of dead hearts in the vegetative stage: According to the ANOVA results, the control methods studied significantly affected the percentage of dead hearts ($P<0.01$). According to the mean comparison, the control (CO) had the highest percentage of dead hearts, with an average of 21.44%, which was significantly different from the other treatments. The lowest percentage of dead hearts among the treatments was that of diazinon (DZ), with an average of 2.19%, which was not significantly different from the kaolin + trap crop (KA+TC) treatment (Table V).

Number of whiteheads in the reproductive stage: The ANOVA results on the number of whiteheads showed a significant difference between the treatments ($P<0.01$). The mean comparison results presented in Table 5 revealed that the highest number of whiteheads was related to the control (CO), with an average of 4.1. The lowest number of whiteheads observed was that of the kaolin + trap crop (KA+TC) treatment, with an average of 1.07, which did not differ significantly from the diazinon (DZ) treatment (Table V).

Percentage of whiteheads in the reproductive stage: According to the ANOVA results, there was a significant difference between the treatments in the percentage of whiteheads ($P<0.01$). Based on the results of the mean comparison, the control (CO) had the highest percentage of whiteheads, with an average of 15.47%. The lowest percentage was that of the kaolin + trap crop (KA+TC) treatment, with an average of 4.37%, which was not significantly different from the diazinon (DZ) treatment. Also, there was no significant difference between the kaolin (KA) and mineral oil + trap crop (MO+TC) treatments, which ranked after diazinon (DZ) in terms of effectiveness in reducing whiteheads (Table V).

Rice grain yield: The ANOVA results indicated that treatments differed significantly in grain yield ($P<0.01$). The diazinon (DZ) treatment had the highest grain yield, averaging 626.67 g/10 plants. The control (CO) had the lowest grain yield, with an average of 385 g/10 plants, significantly different from the average yield obtained for the other treatments. The kaolin + trap crop (KA+TC) treatment, with a yield of 528.33 kg/ha, ranked second after diazinon (DZ), followed by the mineral oil + trap crop (MO+TC) and kaolin (KA) treatments, with no significant difference between them (Fig. 3).

Table V. Mean comparison of the number of RSSB egg masses on leaf surfaces, number and percentage of dead hearts, and number and percentage of whiteheads per plant in treatments during the vegetative and reproductive stages of rice (Part 2)

Treatment*	Mean ± SE** (per plant)					
	No. of egg masses on the upper surface of leaves	No. of egg masses on the lower surface of leaves	No. of dead hearts	dead hearts (%)	No. of whiteheads	whiteheads (%)
MO	0.33±0.03b	1.67±0.13b	2.73±0.26b	7.65±0.78b	1.73±0.36b	6.76±0.46b
KA	0.33±0.05b	1.00±0.12b	1.83±0.22c	4.95±0.57c	1.43±0.32b	5.27±0.35c
KA+TC	0.00±0.00c	0.33±0.13c	0.83±0.14d	2.24±0.49e	1.07±0.32c	4.37±0.25d
MO+TC	0.00±0.00c	0.67±0.10c	1.13±0.16c	3.31±0.66d	1.27±0.38bc	4.99±0.29c
DZ	0.33±0.04b	0.67±0.14c	0.80±0.22d	2.19±0.33e	1.10±0.27c	4.41±0.23d
CO	0.67±0.09a	4.67±0.24a	7.87±0.38a	21.44±1.42a	4.10±0.35a	15.47±0.65a

* MO – mineral oil, KA – kaolin, KA+TC – kaolin+trap crop, MO+TC – mineral oil + trap crop, DZ – diazinon, CO – control

**Different letters in each column indicate a statistically significant difference (P<0.05)

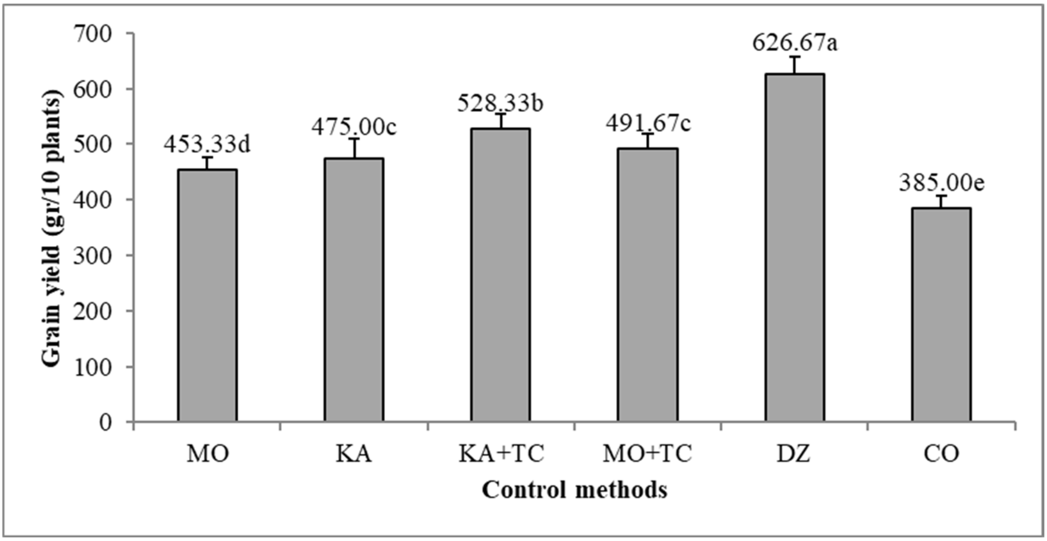

Figure 3. Mean comparison of rice grain yield in different control methods in the second experiment (Part 2) (MO – mineral oil, KA – kaolin, KA+TC – kaolin+trap crop, MO+TC – mineral oil + trap crop, DZ – diazinon, CO – control). Different letters indicate a statistically significant difference between the control methods.

Experiment 2 (Part 3)

Total number of RSSB egg masses: The ANOVA results showed a significant difference between the treatments in the total number of egg masses (P<0.01). Based on the mean comparison results, the control (CO) had the highest total number of egg masses, with an average of 5.33, differing significantly from the other treatments. The lowest total number of egg masses was that of the mineral oil + kaolin (MO+KA) and diazinon (DZ) treatments, with the same average of 1. There was no significant difference between these treatments and the kaolin (KA) treatment (Table VI).

Number of hatched egg masses and percentage of unhatched eggs: According to the ANOVA results. There was a significant difference between the applied treatments in the number of hatched egg masses and percentage of unhatched eggs (P<0.01). According to the mean comparison results in Table VI, the control (CO) had the highest number of hatched egg masses, with an average of 4.33, which was significantly different from the other treatments. The mineral oil + kaolin (MO+KA) and diazinon (DZ) treatments had the lowest number of hatched egg masses, with averages of 0.33, which was significantly different from other treatments (Table VI). The mineral oil + kaolin (MO+KA) and diazinon (DZ) treatments had the highest percentage of unhatched egg masses, with averages of 67%. The lowest number of unhatched eggs among the treatments was that of the control (CO), with an average of 18.76% (Table VI).

Total number of tillers: According to the ANOVA results, no significant difference was found among the studied treatments in the total number of tillers per plant (P>0.05). The highest number of tillers was counted in the diazinon (DZ) and control (CO) treatments, with averages of 6.67 per plant. The mineral oil + kaolin (MO+KA) treatment had the lowest number of tillers among the treatments, with an average of 6 per plant (Table VI).

Number of infested tillers: ANOVA results showed a significant difference between treatments in the number of infested tillers (P<0.05). The highest number of infested tillers was recorded for the control (CO), with an average of 4.67, which was significantly different from the other treatments. The mineral oil + kaolin (MO+KA) and diazinon (DZ) treatments had the lowest number of infested tillers, with an average of 1, and did not significantly differ from the kaolin (KA) treatment (Table VI).

The number of healthy tillers: ANOVA results revealed a significant difference between the treatments in the number of healthy tillers (P<0.05). The lowest number of healthy tillers was in the control (CO), with an average of 2 per plant. The highest value was obtained for the diazinon (DZ) treatment, with an average of 5.67 per plant, which was not significantly different from the mineral oil (MO), kaolin (KA), and mineral oil + kaolin (MO+KA) treatments (Table VI).

Table VI. Mean comparison of the total number of RSSB egg masses, number of hatched egg masses, number of unhatched eggs, total number of tillers, number of infested tillers, and number of healthy tillers per the plant in the studied treatments (Part 3)

Treatment*	**Mean ± SE** (per plant)**					
	Total No. of egg masses	**No. hatched of egg masses**	**unhatched egg masses (%)**	**Total No. of tillers**	**No. of infested tillers**	**No. of healthy tillers**
MO	2.00±0.25b	1.33±0.13b	33.50±2.11c	6.33±0.36a	2.67±0.21b	4.00±0.31a
KA	1.67±0.17bc	0.67±0.07c	59.88±2.14b	6.33±0.25a	1.67±0.21c	4.67±0.21a
MO+ KA	1.00±0.18c	0.33±0.03d	67.00±3.09a	6.00±0.23a	1.00±0.17c	5.00±0.35a
DZ	1.00±0.09c	0.33±0.02d	67.00±2.10a	6.67±0.28a	1.00±0.13c	5.67±0.25a
CO	5.33±0.25a	4.33±0.24a	18.76±1.16d	6.67±0.31a	4.67±0.23a	2.00±0.09b

*MO – mineral oil, KA – kaolin, MO+KA – mineral oil+kaolin, DZ – diazinon, CO – control

**Different letters in each column indicate a statistically significant difference (P<0.05)

Experiment 3

ANOVA results showed no significant difference among the treatments regarding the total number of tillers per plant (P>0.05). Conversely, there was a significant difference between the treatments regarding the number of larvae and dead hearts per plant (P<0.05). A significant difference was observed between the treatments regarding the number of whiteheads per plant (P<0.05).

As mentioned, there was no significant difference between the studied treatments in the total number of tillers per plant. Based on the mean comparison results, the lowest number of RSSB larvae was counted for the treatment of mineral oil + kaolin (MO+KA), with an average of 0.03 larvae per plant, while there was no significant difference in the treatments of mineral oil alone (MO) and fenitrothion (FN). The mineral oil + kaolin (MO+KA) treatments had the lowest number of dead hearts and whiteheads, with averages of 0.09 and 0.30, respectively; there was no significant difference between this treatment and the mineral oil alone (MO) and fenitrothion (FN) treatments (Table VII).

Table VII. Mean comparison of the total number of tillers, RSSB larvae, dead hearts, and whiteheads per plant

Treatment*	Mean ± SE** (per plant)			
	Total No. of tillers	No. of larvae	No. of dead hearts	No. of whiteheads
MO	16.41±0.51a	0.06±0.01b	0.16±0.02b	0.39±0.04b
MO+ KA	16.60±0.42a	0.03±0.00b	0.09±0.01b	0.30±0.05b
FN	17.44±0.59a	0.09±0.01b	0.10±0.02b	0.59±0.05b
CO	16.41±0.47a	0.31±0.05a	0.36±0.04a	1.46±0.19a

*MO – mineral oil, KA – kaolin, MO+KA – mineral oil+kaolin, DZ – diazinon, CO – control

**Different letters in each column indicate a statistically significant difference (P<0.05)

The ANOVA results showed that the treatments differed significantly from each other in grain yield (P<0.01). The Mineral oil (MO) treatment had the highest grain yield, with an average of 6,456.00 kg/ha, which did not significantly differ from the mineral oil + kaolin (MO+KA) treatment. The control (CO) treatment had the lowest grain yield, with an average of 4,902.8 kg/ha, differing significantly from other treatments (Fig. 4).

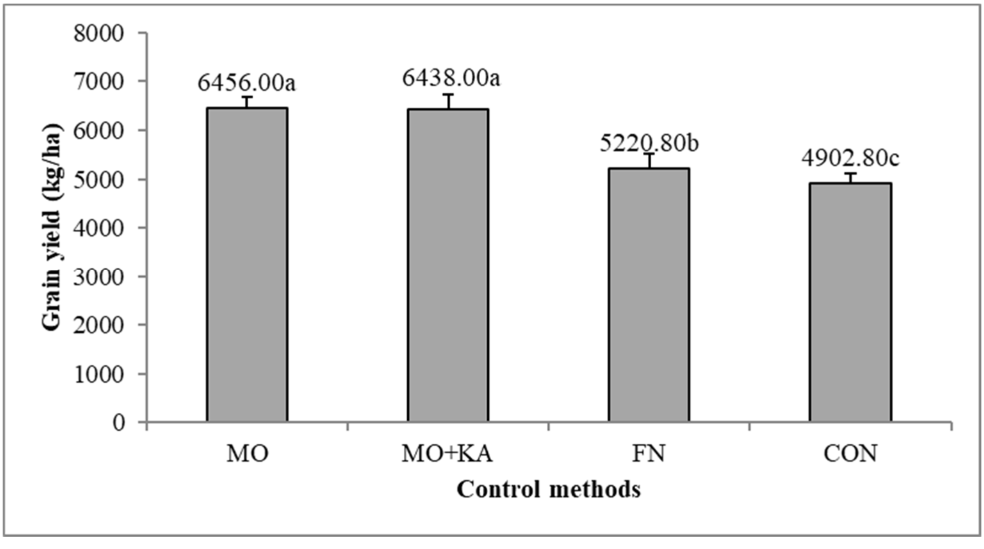

Figure 4. Mean comparison of rice grain yield in different control methods in experiment 3 (MO – mineral oil, MO+KA – mineral oil + kaolin, FN – fenitrothion, CO – control). Different letters indicate a statistically significant difference between the control methods.

Discussion

In the literature review, no references were found regarding the use of mineral oil for controlling RSSB on rice plants. In contrast, the phytotoxicity effect of mineral oil on field crops consistently imposes limitations on their use. Therefore, the first concern was the potential phytotoxic effect of mineral oil on rice plants, especially on seedlings transplanted to the main field in the first week. Even after oil spraying once a week for five cycles, no indications of phytotoxicity were observed on the plants, as noted by the author.

As evident from Tables I, II, and III, not only did mineral oil not cause phytotoxicity, but it also had no significant effect on the number of tillers per plant. It should be noted that in the first experiment, where mineral oil was applied alternately five times with a 5-day interval, the number of infested tillers, larvae, pupae, and dead hearts per plant was zero, and no infestation was observed throughout the treatment. Since mineral oil has lethal effects on the eggs and larvae of lepidopterans (Riedl *et al.,* 1995; Al-Dabel *et al.,* 2008; Rezanezhad Ghadi *et al.,* 2018; Kord Firouzjaee & Damavandian, 2018) and repellent properties against lepidopterans (Rae *et al.,* 2000; Liu*et al.,* 2006; Damavandian & Kiaeian Moosavi, 2014), the obtained results are not unexpected. Since the RSSB larvae typically infest the stem after the first or second larval instars (Amouoghli Tabari *et al.,* 2011), the absence of plant infestation may be attributed to the lethal or/and repellent effects of mineral oil during the growth stages of the rice plant.

The results of the second experiment (Part 1) showed that mineral oil (MO), kaolin (KA), and the combination of mineral oil + kaolin (MO+KA) were effective in controlling RSSB both by repelling and inhibiting. These treatments caused 74.07 and 69.92%, 51.85 and 49.62%, and 74.07 and 79.70% reduction, respectively, in the oviposition of RSSB on the upper and lower surfaces of the leaves compared to the control. Furthermore, they exhibited good efficiency compared to diazinon insecticide, with a 100 and 94.74% reduction in oviposition. Additionally, mineral oil (MO), kaolin (KA), and the combination of mineral oil + kaolin (MO+KA) caused a decrease of 79.20, 58.40, and 83.21%, respectively, in the number of dead hearts compared to diazinon with a 77.27% reduction. The treatments above caused a reduction of 77.86, 69.47, and 88.04%, respectively, in the number of whiteheads compared to the control, showing promising efficacy compared to diazinon, which achieved a 93.13% reduction.

The results Part 2 of the second experiment showed that mineral oil (MO), kaolin + trap crop (KA+TC), and mineral oil + trap crop (MO+TC) caused a 50.75, 100 and 100% reduction, respectively, in the number of egg masses on the upper surface of the leaves and the reduction rate for the kaolin (KA) treatment was 50.75%. Additionally, the kaolin + trap crop (KA+TC) and mineral oil + trap crop (MO+TC) treatments caused a 92.93 and 85.65% decrease, respectively, in the number of egg masses found on the lower surface of the leaves. The damage assessment of rice plants showed that the mineral oil (MO), mineral oil + trap crop (MO+TC), and kaolin + trap crop (KA+TC) treatments caused reductions in the number of dead hearts of 66.07, 85.64 and 89.45%, respectively. The results concerning the number of whiteheads also showed that the kaolin + trap crop (KA+TC), mineral oil + trap crop (MO+TC), kaolin (KA), and mineral oil (MO) treatments reduced the infestation rate by 73.90, 69.02, 65.12 and 57.80%, respectively, compared to diazinon (DZ) 73.17%.

The results obtained from the third experiment in Part 3 showed that mineral oil (MO), kaolin (KA), and mineral oil + kaolin (MO+KA) led to reductions in the total number of egg masses of 62.48, 68.67 and 81.24%, respectively, which were comparable to diazinon (DZ), which showed a decrease of 81.24%. Notably, there was no significant difference between DZ and mineral oil + kaolin (MO+KA). ANOVA results showed that mineral oil (MO), kaolin (KA), and mineral oil + kaolin (MO+KA) caused 69.28, 84.53 and 92.38% reductions in the number of hatched egg masses and 42.83, 64.24 and 78.59% in the number of infested tillers compared to the control. According to Helmy *et al.* (2012), mineral oils form a thin layer on the surface of insect eggs, disrupting gas exchange between the interior of the egg and the external environment. They also stated that the use of mineral oil hardens the eggshell and causes problems in hatching the eggs. Smith & Pearce (1948) studied the respiratory effects of mineral oils on the eggs of the oriental fruit moth, *Grapholita molesta* Busck, and found that they probably reduced the respiration rate through mechanical interference with natural gas exchange. These researchers concluded that less reactive paraffinic oils showed greater ovicidal efficiency than more reactive unsaturated oils. Al-Dabel *et al.* (2008) demonstrated a potent ovicidal effect of mineral oils on the egg masses of the European corn borer, *O. nubilalis*, with application ratios of 3-10% (v/v). Buteler & Stadler (2011) believe that mineral oil treatment arrests the development of the embryo and eliminates the embryo inside the egg; however, the mechanism underlying the ovicidal action needs further study. Wins-Purdy *et al.* (2009) stated that topical application of 2% horticultural mineral oil resulted in complete egg mortality in the oblique banded leaf roller, *Choristoneura rosaceana* Harris, through both contact toxicity and suffocation. Taverner *et al.* (2011) reported that mineral oils showed ovicidal properties against the eggs of the light brown apple moth, *Epiphyas postvittana* Walker. The findings of these studies demonstrated the ovicidal properties of mineral oil on various pests, especially lepidopterans, which is consistent with the results of our research.

Results from the third experiment revealed that mineral oil + kaolin (MO+KA) and mineral oil alone (MO) caused 90.32 and 80.65% reductions in the number of RSSB larvae, respectively, compared to Fenitrothion insecticide (FN), with a decrease of 70.97%. The efficacy of mineral oil + kaolin (MO+KA) and mineral oil alone (MO) in reducing dead hearts and whiteheads was 75.00% and 55.56% and 79.45% and 73.29%, respectively, while fenitrothion (FN) caused 72.22% and 59.59% reductions, respectively.
Abdullahi *et al.* (2016) found that in their study on the impact of kaolin on second-instar larvae of *T. absoluta*, concentrations of 2.5, 5, and 7.5% of kaolin resulted in larval escape, with a 20% mortality rate. Showler (2003) showed that kaolin reduced oviposition and feeding by third instar larvae of the beet armyworm, *Spodoptera exigua* Hubner (Lepidoptera Noctuidae). In another study on the diamondback moth, *P. xylostella*, it was found that treating with kaolin significantly decreased the survival and feeding rate of second and third-instar larvae, as well as the number of first-instar larvae, compared to the control (Barker *et al.,* 2006). The findings of the aforementioned studies validate the significant effect of the kaolin compound on lepidopteran pests, which is consistent with the results of the present study.

Kord Firouzjaee & Damavandian (2018) reported that applying mineral oil at concentrations of 700 and 900 mL per 100 L of water resulted in 51.85 and 77.57% mortality in citrus leafminer larvae, *P. citrella*, respectively. Damavandian & Kiaeian Moosavi (2014) found that concentrations of 0.65% or higher of mineral oil caused a significant reduction in citrus leafminer damage. Research also indicated that applying mineral oils alongside insecticides caused a decrease in the hatching of light-brown apple moth *E. postvittana* eggs (Taverner *et al.,* 2011). The effectiveness of mineral oils in controlling other pests such as the codling moth *C. pomonella* (Fernandez *et al.,* 2005), and the southern armyworm, *S. eridania*, on tomato (Stansly & Conner, 2005) has also been established. In the present study, mineral oil alone (MO) and in combination with kaolin (MO+KA) or a trap crop (MO+TC) resulted in a significant reduction in the number of dead hearts and white heads, confirming the efficacy of mineral oil in controlling lepidopteran pests. As seen in the results, the use of a trap crop in combination with mineral oil (MO+TC) and kaolin (KA+TC) increased the efficacy of these compounds compared to their individual application.

Diversifying plant cultivation as a form of conservation biological control is an effective strategy for pest management (Sarkar *et al.,* 2018). Several conservation biological control practices, such as farmscaping, have gained popularity in pest control due to their capacity to meet fundamental criteria such as efficiency, predictability, and cost (Hatt *et al.,* 2018). Trap cropping is a promising means of conservation biological control. It involves cultivating non-crop species alongside main crop species in a selected area to lure pests away from the primary crop, thereby protecting the crop and controlling pest populations to minimize damage (Shelton & Badenes-Pérez, 2006). Trap cropping is an attractive alternative to reduce dependence on traditional pest management practices involving insecticides (Gao *et al.,* 2012). However, the effectiveness of trap cropping in controlling various lepidopteran pests, such as *H. armigera* on tomatoes (Sandhu & Arota, 2014), chickpeas (Kumar*et al.,* 2017), and Egyptian clover (Kumar & Cheema, 2020), *P. xylostella* and *P. rapae* on cabbage (Luther *et al.,* 1996), *P. brassicae* on Indian mustard (Kumar, 2017), and corn stem borer, *B. fusca* on sorghum (Khan*et al.,* 2008), has been demonstrated. The findings of the current research also demonstrate the beneficial effect of this technique in reducing damage and managing RSSB.

Conclusion

This research showed that biocompatible compounds of mineral oil and kaolin, in comparison to common insecticides such as diazinon and fenitrothion, had satisfactory efficiency in repelling and inhibiting RSSB. Furthermore, their combination with other techniques, such as trap cropping, enhanced their efficacy. As a result, their efficiency in reducing the number of whiteheads increased from 80.15 to 91.08% and from 58.49 to 89.74%, respectively. The findings of the present research indicate that mineral oil and kaolin can be used individually or in combination with each other, and with trap plants, to control the RSSB in rice paddies across northern Iran and other parts of the world. The aim is to reduce the use of chemical insecticides in these regions. The findings of this study represent a novel advancement in the use of low-risk control methods for managing this pest. Investigating the adverse effects of mineral oil and kaolin on the quality of rice grains, natural enemies, paddy soil, and the associated application costs is essential.

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ПРОЦЕНА НОВИХ СТРАТЕГИЈА У ИНТЕГРИСАНОЈ КОНТРОЛИ *CHILO SUPPRESSALIS* НА ПИРИНЧАНИМ ПОЉИМА

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Извод

У раду су анализирана три одвојена експеримента за процену ефикасности биокомпатибилних стратегија у контроли *Chilo suppressalis* Walker у пољима пиринча.

Резултати првог експеримента су показали да је најмањи број заражених изданака, број ларви, лутки и увелих изданака био везан за третман прскањем уља у интервалу од 7 дана.

Резултати другог експеримента у првом делу показали су да су минерално уље, 5% каолин, минерално уље + каолин и диазинон изазвали смањење увелих изданака за 79,20, 58,40, 83,21 и 77,27% и смањење за 77,86, 69,47, 88,04 и 93,13%. У белим галама код пиринча и 72,00, 50,74, 76,89 и 97,37% смањења у *C. suppressalis* овипозицији, респективно, у поређењу са контролом. Према резултатима другог експеримента у другом делу, 3% минералног уља, 5% каолина, 5% каолина + замка усев и 3% минералног уља + замка усев имало је ефекат одбијања од 57,50, 64,67, 96,47 и 92,83%, респективно, против одраслих инсеката пиринчаних пругастих минера и смањене овипозиције. Ови третмани су смањили број увелих изданака за 66,07, 76,75, 89,45 и 85,64% и број белих гала за 57,80, 65,12, 73,90 и 69,02 у односу на контролу. Резултати другог експеримента у трећем делу показали су да су минерално уље, каолин 5% и минерално уље + каолин изазвали смањење броја заражених плодова за 42,83, 64,24 и 78,59% у поређењу са контролом.

У трећем експерименту, минерално уље и минерално уље + каолин смањили су број ларви *C. suppressalis* за 80,65 и 90,32%, респективно. Ови третмани су такође резултирали са 55,56 и 75% у увелим изданцима и 73,29 и 79,45% у белим галама, респективно. Налази показују да се минерално уље и каолин могу применити појединачно и у комбинацији једно са другим или у комбинацији са замка усевима за контролу *C. suppressalis*.

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