EFFECT OF WETTABLE POWDERS ON THE THIRD LARVAL INSTAR OF FALL ARMYWORM, *Spodoptera frugiperda* (J.E. SMITH) (LEPIDOPTERA: NOCTUIDAE)

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ABSTRACT

Wettable powders are natural agents with insecticidal action against various pests. Their application in agriculture is explored in the management of economically important insect pests. This study investigated the insecticidal effect of wettable powders on the 3rd larval instar of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), which is an invasive pest of corn, rice, and sugarcane in the Philippines. Several concentrations of these wettable powders were prepared and sprayed to surface-sterilized corn leaves. Larval feeding on treated leaves resulted in mortality, but no residual insecticidal effect was observed since mortality did not progress significantly after further incubation. Desiccation was, however, evident in the larval cadavers. At 3 days after treatment (DAT), 20% kaolin clay caused the highest larval mortality (50.37%) followed by 10% kaolin clay (18.15%), and 20% sodium carbonate (11.57%). No toxicity was observed in bentonite, diatomaceous earth, and talcum. The wettable powders had varying effect on the growth and development of surviving larvae. Higher concentrations (10% and 20%) of sodium carbonate prolonged larval period while lower concentrations (0.01% and 0.02%) of sodium carbonate and 0.01% bentonite caused shorter larval period. Among the treatments, only kaolin clay, at 20% concentration, caused a decrease in pupation rate of surviving *S. frugiperda* larvae. Pupal mass was not significantly affected (127.61 to 183.94 mg). Adult emergence was observed to decrease (33.33% and 28.52%) in treatments with 10% diatomaceous earth and 20% kaolin clay, respectively. The insecticidal effect of kaolin clay and other powders must be further explored to maximize its control benefit against *S. frugiperda*.

Key words: armyworm, biological control, desiccation, pest management, sustainable

INTRODUCTION

Integrated Pest Management (IPM) encourages a sustainable approach in crop protection through integration of environment friendly methods to prevent the overuse of synthetic insecticides. Several crop protection solutions are available such as the use of naturally occurring materials with insecticidal properties. Inert dusts or wettable powders prevent and control many arthropod pests (Zeni et al., 2021). These insecticides are considered biorational substances that have relatively low environmental impacts (Aniwanou et al., 2020) and generally recognized as safe (GRAS) products when applied for intended use. Diatomaceous earth (DE) (Aniwanou et al., 2021; Zeni et al., 2021) and kaolin clay (Aniwanou et al., 2021; Ebadollahi & Sadeghi, 2018) are among the wettable powders assessed for insect pest control in agriculture. It is a soft siliceous sedimentary rock with fossilized exoskeleton of unicellular algae known as diatoms (Zeni et al., 2021). They further added that DE is utilized for the management of household and storage insect pests as well as for the control of fungal and bacterial pathogens. Lastly, this powder has been used against various arthropod pest taxa including Acarina, Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Ixodida, and Lepidoptera. Non-silica dusts and coarse grain silicates are used traditionally by small scale farmers as grain protectants (Golob, 1997). These materials control various storage insect pests and are also used as carriers for agricultural products such as pesticides. Inert dusts are most effective under low humidity because they induce mortality by causing desiccation wherein the dusts remove the waxy layer of the cuticle of the exoskeleton and adsorb water (Golob 1997).

This research assessed the effect of wettable powders on fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). In the Philippines, *S. frugiperda* is one of the recent invasive insect pests detected infesting corn (Navasero et al., 2019), rice (Valdez et al., 2021), and sugarcane (Ocampo, 2020). This lepidopteran insect pest can reproduce several generations in a single season if there are suitable host plants (Rwomushana, 2019). It infests 353 plants species including those economically important crops such as grains and vegetable crops (Montezano et al., 2018). This polyphagous insect pest damages the seedlings and reproductive structures of the plant. Although a variety of IPM programmes have been recommended, insect pests like armyworms are usually managed by farmers through synthetic insecticide application due to their rapid toxic effect. However, a safer method must be explored for a sustainable IPM. In bio-efficacy studies conducted by Aniwanou et al. (2021), they discovered that biorational insecticides including soap (Palmida) at 0.5% concentration, neem oil at 4.5 L/ha, and DE (Dezone) at 7.5 kg/ha are cost-effective options for *S. frugiperda*. No physiological pest resistance is also expected in using wettable powders (Zeni et al., 2021). In addition, formulations of entomopathogenic fungi aim to use wettable powders as possible carriers. Hence, this present study investigated whether the wettable powders had toxicity against the 3rd larval instar of *S. frugiperda* under laboratory conditions.

MATERIALS AND METHODS

Rearing of *S. frugiperda*

Spodoptera frugiperda was reared in the Biological Control Laboratory of the National Crop Protection Center, College of Agriculture and Food Science, University of the Philippines Los Baños. This pest has been reared for several generations in the laboratory for bio-efficacy testing. Male and female moths were paired in mylar cages. Resulting neonates were fed with fresh young corn leaves (10-15 days after sowing, DAS) daily. The bioassay was conducted when there was a significant number of 3rd larval instar for testing. The experiment was conducted for two months.

Preparation of wettable powders

Five (5) wettable powders were assessed for their toxicity to *S. frugiperda* under laboratory conditions. Bentonite, DE, kaolin clay, sodium carbonate, and talcum powder were sieved using #100 mesh sieve (150 μm) to ensure homogenous fine powder for testing. After sieving, these powders were sterilized at 121 psi for 15 min. Several concentrations of these powders (0.01%, 0.02%, 10%, and 20% w/v) were prepared for the bioassay by weighing specific mass of powders and mixing with Tween 80 solution. Lower concentrations of these powders were tested following previous research (Ebadollahi & Sadeghi, 2018; Knight et al., 2000; Shafighi et al., 2014; Bougherra-Nehaoua et al., 2015) for practical application.

Bioassay of wettable powders against *S. frugiperda*

Young corn leaves (10-15 DAS) were washed in running water and subsequently surface-sterilized with sodium hypochlorite (0.5% v/v) and washed twice with sterile distilled water. After airdrying, both sides of the leaves were sprayed with the suspension of the powders. Sprayed leaves were also air dried before placing inside the UV-sterilized Petri plates. One larva was introduced in each Petri plate. Each of the treatments was replicated thrice with ten 3rd instar larvae per replicate. A moistened cotton was placed inside the Petri plate to maintain the freshness of leaves. In the control set-up, leaves were sprayed with Tween 80 solution. The test insects were exposed to the treated leaves for 24h. Treated leaves were then replaced with fresh surface-sterilized corn leaves. The test insects were fed with fresh surface-sterilized corn leaves daily. Larval mortality was also recorded daily. Effects on larval growth and development were also determined. Adult emergence was computed using the formula: (number of pupa that pupated/ number of test larvae per replicate) x 100%. The experiment was laid out in Completely Randomized Design (CRD). Analysis of variance was done to compare treatment means using Tukey's Honest Significant Difference at $p< 0.05$.

RESULTS AND DISCUSSION

This research determined the effect of 5 wettable powders on the 3rd larval instar of *S. frugiperda*. The larvae that acquired the wettable powder upon exposure to the treated corn leaves exhibited slower movement, and molting did not proceed as compared to the control. Larvae also had reduced feeding. Desiccation was evident in larvae that were killed by DE, kaolin clay, sodium carbonate, and talc (**Figure 1**). This observation can be attributed to the action of wettable powders such as removal of the waxy layer of the cuticle of the exoskeleton (Golob, 1997). Diatomaceous earth particles, for instance, act as an abrasive material by removing the protective liquid layer of insect's cuticle through desiccation (Aniwanou et al., 2021). Kaolin, on the other hand, serves as protective film against insect pests on plant surfaces (Bateman et al., 2018).

Figure 1. *Spodoptera frugiperda* larvae exposed to wettable powders compared with the control.

At 3 days after treatment (DAT), the treatments such as kaolin clay (10% and 20%), sodium carbonate (10% and 20%), DE (10%), and talcum (10% and 20%) incited 3.33%–50.37% larval mortality (**Figure 2**). Among the treatments, the highest number of mortalities were recorded in 20% kaolin clay (50.37%) followed by 10% kaolin clay (18.15%), and 20% sodium carbonate (11.57%). Progression in mortality appeared low with no increase in insecticidal activity except for kaolin clay (0.02% and 10%) and bentonite (0.01%) with only 3.33% additional mortality at 5 DAT. Kaolin clay (10% and 20%) continued to induce significant mortality at 5 DAT with 21.48% and 50.37%, respectively. It was evident that low concentrations (0.01% and 0.02%) of wettable powders were not toxic to *S. frugiperda* larvae.

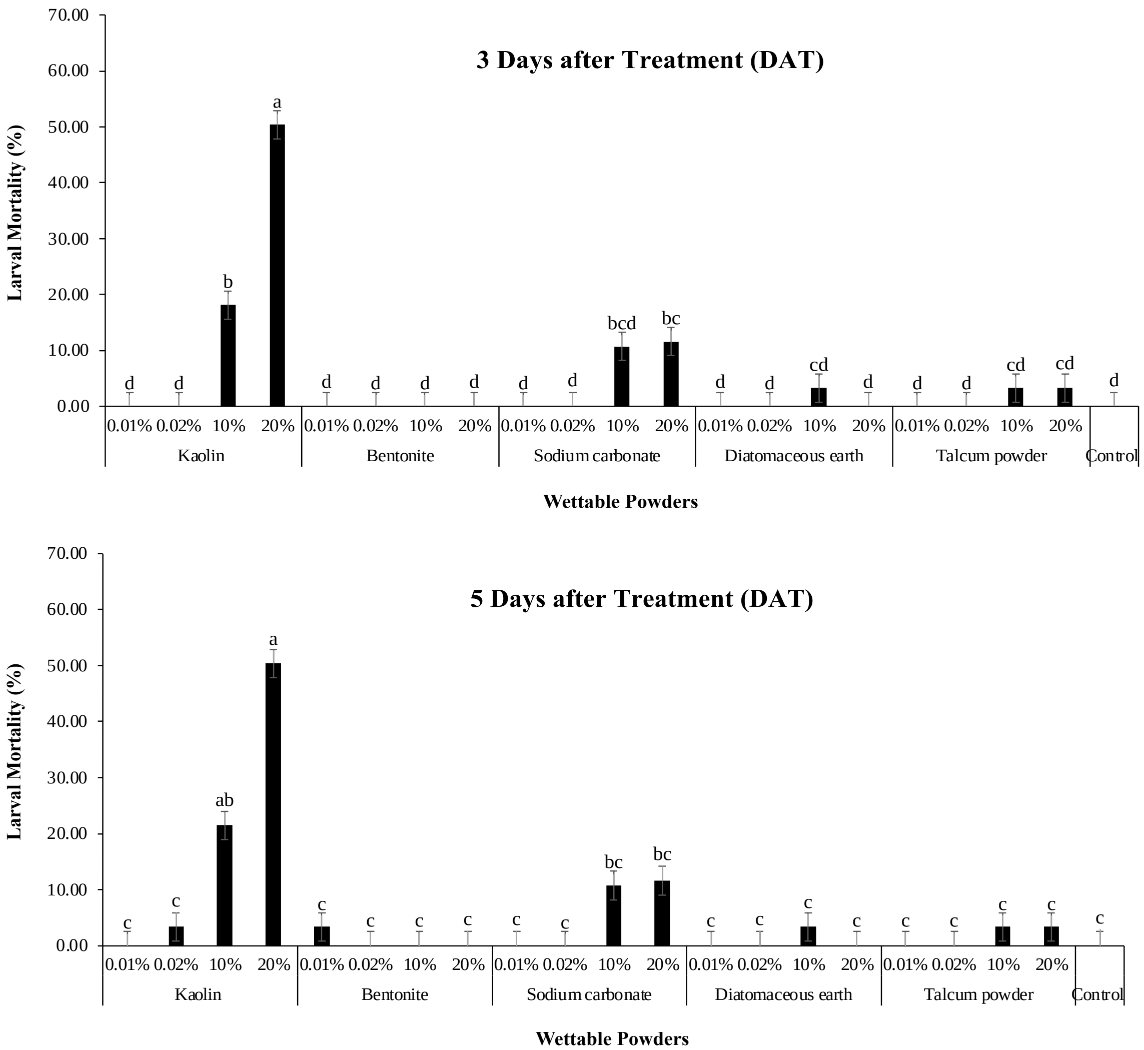

Figure 2. Effect of selected wettable powders on larval mortality of *Spodoptera frugiperda* at 3 and 5 days after treatment. Means with the same letters are not significantly different at Tukey's HSD ($p<0.05$). Bars represent standard error of the mean.

Among the wettable powders evaluated, kaolin clay implicated significant mortalities as compared to other treatments. Kaolin is a white, non-porous, non-swelling, non-abrasive, fine-grained, platy aluminosilicate mineral, being used to suppress arthropod pests (Peng et al., 2011). It creates a protective physical or mechanical barrier against insect pests that may result to less movement and feeding since the plant surface is covered with the wettable powder making it less palatable to the insect pest and cause abrasiveness. This mineral clay must be applied before insect attack to ensure protective coating of plant surface (Bateman et al., 2018). They further documented that kaolin clay and DE are inorganic compounds and minerals registered for use against *S. frugiperda*, and have been recommended for further bioassays to countries they are registered. Likewise, kaolin clay is found effective against lepidopteran species including *S. frugiperda* and other *Spodoptera* species under laboratory and field studies in America and Africa, however, its use may not be compatible with wet climates. The growth and survival of *S. frugiperda* larvae was shown to be affected by DE under laboratory conditions, however, there is little evidence of field efficacy against this insect pest. They further recommended to test this compound as a dust and apply in the whorl of attacked maize (Bateman et al., 2018).

Several literatures suggest the bio-efficacy of kaolin clay against other insect pests. Repellency and reduced oviposition of potato psyllid were observed in plants treated with kaolin particle film (Peng et al., 2011). Kaolin-based particle film significantly reduced survival to adulthood and increased development time of *Plutella xylostella* (Barker et al., 2006). In addition, Sacket et al. (2005) noted the effect of kaolin clay particle film formulation against *Choristoneura rosaceana* (Lepidoptera: Tortricidae) wherein kaolin acted as physical barrier to feeding and caused changes in dispersal and rolling behaviors of the said larvae. Similarly, Knight et al. (2000) demonstrated the effect of kaolin-based particle film formulations against *C. rosaceana* with negative effects on adult survivorship, longevity, oviposition, and larval feeding and survivorship.

On the other hand, several studies suggest the insecticidal activity of DE; however, this wettable powder was unable to cause mortality against *S. frugiperda* in this study. Ebadollahi & Sadeghi (2018) cited that DE caused higher mortality than kaolin clay to *S. exigua* larvae. However, our results imply that larvae must be continuously exposed to this wettable powder to achieve a significant toxicity. Likewise, DE was found effective when applied at 20% while kaolin at 5% caused the lowest mortality (Ebadollahi & Sadeghi, 2018).

There are few literatures on the insecticidal activity of sodium carbonate. Salama et al. (1985), however, noted that the crystalline protein solubility of *Bacillus thuringiensis* in the insect gut may be affected by addition of alkaline compounds such as sodium carbonate. Marwa et al. (2020) also observed higher toxicity of *B. thuringiensis* when mixed with either 0.1% sodium carbonate and 0.3% mint oil against 2nd instar larvae of *S. littoralis* due to increase in pH value and viscosity resulting in reduced LC_{50} value from 7.079 ml/L to 3.972 and 3.549 ml/L after adding sodium carbonate and mint oil, respectively.

This study also indicated that bentonite had no toxic effect. In other insects like the onion thrips, bentonite has been shown to cause reduced feeding and leaf damage (Abd El-Aziz, 2013).

Results of this study also showed that wettable powders did not have residual insecticidal effect on the larvae. This is because the mortality was observed few days after exposure, but did not further increase after prolonged incubation. This finding can be associated with molting of the larvae, wherein the powder-coated exoskeleton is being shed off. Hence, the larva can survive unless they are exposed continuously to the powders after ecdysis. For instance, nymphs of bed bugs that did not succumb to a desiccant dust may survive due to removal of old cuticle (Potter et al., 2013).

Aside from causing larval mortality, this study also demonstrated the effect of wettable powders on the larval period, pupation, pupal weight, and adult emergence of *S. frugiperda* (**Table 1**). The growth and development were moderately affected by the wettable powders. Larval period ranged from 9.40 to 12.73 days wherein longer larval period was recorded in sodium carbonate (10% and 20%) at 12.18 to 12.73 days, respectively. Shorter larval period was observed on the other hand, in 0.01% sodium carbonate (9.40 days), 0.01% bentonite (9.50 days), and 0.02% sodium carbonate (9.50 days). Pupation rate, on the other hand, was significantly lower in treatments that induced significant larval mortalities, particularly 20% kaolin clay, with only 39.26%.

Table 1. Effect of selected wettable powders on growth and development of *Spodoptera frugiperda*.

Wettable Powder*	Concentration (% w/v)	Larval Period (days)	Pupation (%)	Pupal Mass (mg)	Adult Emergence (%)
Kaolin Clay	0.01	9.83bc	90.00ab	132.67cd	53.33abc
	0.02	10.10bc	96.67ab	133.84cd	84.87a
	10	10.15bc	75.19b	139.21bcd	60.74abc
	20	10.75b	39.26c	145.09bcd	28.52c
Bentonite	0.01	9.50c	80.00ab	157.35abc	73.33ab
	0.02	9.93bc	100.00a	139.26bcd	76.67ab
	10	9.87bc	100.00a	133.58cd	86.67a
	20	10.63b	100.00a	136.74cd	73.33ab
Sodium Carbonate	0.01	9.40c	100.00a	183.94a	100.00a
	0.02	9.50c	100.00a	165.57ab	90.00a
	10	12.18a	89.26ab	144.70bcd	82.22a
	20	12.73a	88.43ab	136.48cd	57.41abc
Diatomaceous Earth	0.01	10.13bc	86.30ab	141.38bcd	65.56abc
	0.02	9.75bc	80.00ab	127.61d	33.33bc
	10	10.37bc	96.67ab	147.00bcd	83.33a
	20	10.03bc	96.67ab	143.24bcd	80.00a
Talcum	0.01	9.76bc	96.67ab	136.11cd	80.00a
	0.02	10.37bc	90.00ab	145.31bcd	86.67a
	10	10.05bc	93.33ab	142.36bcd	86.67a
	20	10.63b	96.67ab	137.89cd	86.67a
Control (Tween 80)	0.1	10.59b	96.67ab	151.76bcd	86.67a

*Means within the same column followed by the same letter are not significantly different at Tukey's HSD (p<0.05).

Pupal mass which ranged from 127.61 to 183.94 mg was similar to some degree in all of the treatments. Among the treatments, 20% kaolin clay and 10% diatomaceous earth had significant reduction in adult emergence with 28.52 and 33.33%, respectively.

Findings in this study also showed the negative effects of wettable powders particularly kaolin clay on the survival and growth of *S. frugiperda*. Sacket et al. (2005) noted the effect of kaolin against *C. rosaceana* wherein they observed that feeding with apple leaves with kaolin spray increased larval mortality and time to pupation, however, the pupal mass significantly decreased. When kaolin was mixed with artificial diet, physiological effects of consuming diets did not affect mortality, pupation time, and pupal mass. Similarly, potato tuber moth (*Phthorimaea operculella* (Zella) as reported by Turgut et al. (2021) at concentrations 2.5, 5, 10, 20 g/m^2 and exposure time of 24, 48, 72, 96, 120, 144, and 168 hrs. of pupal eclosion significantly affected weights depending on exposure time. Pupal eclosion was prevented and no adult emergence was observed. Athanassiou (2006) also reported that two formulations of DE were equally effective against *Ephestia kuehniella* on barley, rye, and wheat. First instars were very susceptible to both DEs and mortality at 1000 ppm exceeded 86%. Fifth instars were the least susceptible having mortality of <22% at 1000 ppm.

The wettable powders under the present study will be further assessed and integrated with other pest management strategies; for example, as possible carriers of entomopathogens. Bentonite is often used as carrier in the development of insecticide granule (Synek, 1983). Similarly, sodium carbonate and talcum powder are used as carrier and diluents of insecticides and other control agents.

Several literatures noted an increase in control efficacy when wettable powders were mixed with other compounds or control agents. Zeni et al. (2021) noted that combination of DE with plant extracts, essential oils, and other plant-based products have improved insecticidal performances at lower doses and under varying conditions. These powders must be mixed with other substances with other insecticidal agents such as neem and DE against *Myzus persicae* (Sulzer) (El-Wakeil & Saleh, 2009). In addition, Bougherra-Nehaoua et al. (2015) noted the enhanced insecticidal activity of combining kaolin and DE with aromatic plant essential oils against stored grain insect pests.

The wettable powders were also observed as effective carriers of microbial agents. Dal Bello et al. (2011) demonstrated the synergism of *Beauveria bassiana* and DE as biocontrol agents against Coleopteran pests in stored grains. In their study, there was a 2% mortality in *Tribolium castaneum* treated with DE powder or *B. bassiana* while 20% mortality in mixture of DE powder and *B. bassiana*; and 100% in the combination of fenitrothion 50%, DE, and *B. bassiana*. Likewise, mortality increased in *Rhyzopertha dominica* in mixtures of several insecticidal agents from 44% (DE powder) and 46% (*B. bassiana*) to 54% (DE powder and *B. bassiana*) and 100% (fenitrothion 50% + DE + *B. bassiana*). Shafighi et al. (2014) also discovered enhanced efficacy of adding DE to *Metarhizium anisopliae* and *B. bassiana* against stored pests. Also, kaolin-based formulation of *M. anisopliae* (Bioterminator) was effective against termites infesting tea under laboratory and field conditions causing 43.28%–72.94% and 85.21%85.97%, respectively (Hoque et al. 2016).

Furthermore, Galdino et al. (2020) demonstrated higher susceptibility of *Chrysodeixis includens* and *Alabama argillacea* to *B. bassiana* (CG 138) + kaolin than when applied separately. Aside from using these powders as carriers of entomopathogenic fungi, a talc-based granulovirus formulation was also observed with better control efficiency than aqueous virus suspension in controlling potato tuberworm (*P. operculella*) (Mascarin & Delalibera, 2012). Dusting potato tubers with this talc-based granulovirus formulation at 5 x 10^8 OBs/g resulted in 100% mortality. Similarly, talc-based formulations of *B. bassiana* and *Bacillus subtilis* lowered the incidence of *Fusarium* wilt and fruit borer under glasshouse and field conditions (Prabhukarthikeyan et al., 2014).

To conclude, findings of this research suggest the varying insecticidal activity of wettable powders on the 3rd larval instar of *S. frugiperda*. Among the powders, kaolin clay appeared to significantly affect the insect pest in terms of implicating larval mortality, and decreasing pupation and adult emergence. The potential use of powders in pest management will be further explored such assessing their compatibility as carriers of various microbials.

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REFERENCES CITED

ABD EL-AZIZ SE. 2013. Laboratory and field evaluation of kaolin and bentonite particle films against onion thrips, *Thrips tabaci* (Lind.) (Thysanoptera: Thripidae) on onion plants. Journal of Applied Sciences Research 9: 3141-3145.

ANIWANOU CT, SINZOGAN AA, DEGUENON JM, SIKIROU R, STEWART DA & AHANCHEDE A. 2021. Bio-efficacy of diatomaceous earth, household soaps, and neem oil against *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae in Benin. Insects 12(1): 18.

ATHANASSIOU CG. 2006. Influence of instar and commodity on insecticidal effect of two diatomaceous earth formulations against larvae of *Ephestia* *kuehniella* (Lepidoptera: Pyralidae). Journal of Economic Entomology 99(5): 1905-1911.

BARKER JE, FULTON A, EVANS KA & POWELL G. 2006. The effects of kaolin particle film on *Plutella xylostella* behaviour and development. Pest Management Science: formerly Pesticide Science 62(6): 498-504.

BATEMAN ML, DAY RK, LUKE B, EDGINGTON S, KUHLMANN U & COCK MJ. 2018. Supplementary Material Assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa. Retrieved from https://www.researchgate.net/profile/Mjw-Cock/publication/328478145_FAW_Biopesticide_management_supplementary_materialpdf/data/5bd05a964585152b14516082/FAW-Biopesticide-management-supplementary-material.pdf on 15 October 2022.

BOUGHERRA-NEHAOUA HH, BEDINI S, COSCI F, FLAMINI G, BELHAMEL K & CONTI B. 2015. Enhancing the insecticidal efficacy of inert dusts against stored food insect pest by the combined action with essential oils. Integrated Protection of Stored Products IOBC/WPRS Bulletin 111: 31-38.

DAL BELLO G, FUSÉ C, JUAREZ P, PEDRINI N, IMAZ A & PADIN S. 2011. Insecticidal effect of fenitrothion, diatomaceous earth and *Beauveria bassiana* against Coleopteran pests on stored grain. Integrated Protection of Stored Products IOBC/WPRS Bulletin 69: 175-180.

EBADOLLAHI A & SADEGHI R. 2018. Diatomaceous earth and kaolin as promising alternatives to the detrimental chemicals in the management of *Spodoptera exigua*. Journal of Entomology 15(2): 101-105.

EL-WAKEIL NE & SALEH SA. 2009. Effects of neem and diatomaceous earth against *Myzus persicae* and associated predators in addition to indirect effects on artichoke growth and yield parameters. Archives of Phytopathology and Plant Protection 42: 1132-1143.

GALDINO JS, SILVA CAD, ZANUNCIO JC & CASTELLANI MA. 2020. Susceptibility of *Alabama argillacea* and *Chrysodeixis includens* (Lepidoptera: Noctuidae) larvae to *Beauveria bassiana* associated with kaolin. Brazilian Journal of Biology 81: 1023-1029.

GOLOB P. 1997. Current status and future perspectives for inert dusts for control of stored product insects. Journal of Stored Products Research 33(1): 69-79.

KNIGHT AL, UNRUH TR, CHRISTIANSON BA, PUTERKA GJ & GLENN DM. 2000. Effects of a kaolin-based particle film on obliquebanded leafroller (Lepidoptera: Tortricidae). Journal of Economic Entomology 93(3): 744-749.

HOQUE AKMR, ASLAM AFM, AHMED M, MAMUN MSA & HOWLADER AJ. 2016. Laboratory and field evaluation of an entomopathogenic fungus formulation-bioterminator (*Metarhizium anisopliae* Metchnikoff) against termite infesting tea. Journal of Tea Science Research 6(9): 1-6.

MARWA AM, ABDEL-AZIZ AK, ABDEL-HAFEZ FH & ZAHIA KM. 2020. Effect of sodium carbonate and mint oil as additives on the potency of the entomopathogenic bacteria, *Bacillus thuringiensis* against the cotton leaf worm *Spodoptera littoralis* (Lepidoptera: Noctuidae). Egyptian Journal of Plant Protection Research Institute 3(2): 654-661.

MASCARIN GM & DELALIBERA I. 2012. Insecticidal activity of the granulosis virus in combination with neem products and talc powder against the potato tuberworm *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae). Neotropical Entomology 41(3): 223-231.

MONTEZANO DG, SOSA-GÓMEZ, DR, SPECHT A, ROQUE-SPECHT VF, SOUSA-SILVA JC, PAULA-MORAES SD, PETERSON JA & HUNT TE. 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. African Entomology 26(2): 286-300.

NAVASERO MV, NAVASERO MM, BURGONIO GAS, ARDEZ KP, EBUENGA MD, BELTRAN MJB, BATO MB, GONZALES PG, MAGSINO GL, CAOILI BL, BARRION-DUPO ALA & AQUINO MFGM. 2019. Detection of the fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) using larval morphological characters, and observations on its current local distribution in the Philippines. The Philippine Entomologist 33(2): 171-184.

OCAMPO KR. 2020. Fall armyworm pest threatens PH corn production. Retrieved from https://business.inquirer.net/ on 18 September 2021.

PENG L, TRUMBLE JT, MUNYANEZA JE & LIU TX. 2011. Repellency of a kaolin particle film to potato psyllid, *Bactericera cockerelli* (Hemiptera: Psyllidae), on tomato under laboratory and field conditions. Pest Management Science 67(7): 815-824.

POTTER MF, HAYNES KF, CHRISTENSEN C., NEARY TJ, TURNER C & WASHBUR L. 2013. [Bed bug supplement] Diatomaceous earth: where do bed bugs stand when the dust settles? Pest Control Technology. Retrieved from https://www.pctonline.com/article/pct1213-diatomaceous-earth-study/ on 14 July 2022.

PRABHUKARTHIKEYAN R, SARAVANAKUMAR D & RAGUCHANDER T. 2014. Combination of endophytic *Bacillus* and *Beauveria* for the management of Fusarium wilt and fruit borer in tomato. Pest Management Science 70(11): 1742-1750.

RWOMUSHANA I. 2019. *Spodoptera frugiperda* (fall armyworm). Invasive Species Compendium. Wallingford, UK: CABI. DOI:10.1079/ISC.29810.20203373913.

SACKETT TE, BUDDLE CM & VINCENT C. 2005. Effect of kaolin on fitness and behavior of *Choristoneura rosaceana* (Lepidoptera: Tortricidae) Larvae. Journal of Economic Entomology 98(5): 1648-1653.

SALAMA HS, FODA MS & SHARABY A. 1985. Potential of some chemicals to increase the effectiveness of *Bacillus thuringiensis* Berl. against *Spodoptera littoralis* (Boisd.). Journal of Applied Entomology 100(5): 425-433.

SYNEK J. 1983. Formulation, development, and application of an insecticide granule. Pesticide Formulations and Application Systems: Third Symposium, ASTM STP 828, T.M. Kaneko and N.B. Akesson Eds. American Society for Testing and Materials, Philadelphia 123-131 pp.

TURGUT ATAY, ALKAN M & ERTÜRK S. 2021. Insecticidal Efficacy of Native Diatomaceous Earth against Potato Tuber Moth, [*Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae)], Pupae. Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi 24(1): 165-170.

VALDEZ EM, RILLON GS, DONAYRE DK, MARTIN EC, DELA CRUZ KB, SANDOVAL FR, JOSHI RC, QUILANG EJP, FAHEEM M & ANNAMALAI S. 2021. Fall armyworm (*Spodoptera frugiperda*) (J.E. Smith): A first record of damage on rice in the Philippines. Poster paper presented during the Online Conference “Developing smallholder-oriented IPM strategies for fall armyworm (*Spodoptera frugiperda* Smith) management” on 24-26 August 2021.

SHAFIGHI Y, ZIAEE M & GHOSTA Y. 2014. Diatomaceous earth used against insect pests, applied alone or in combination with *Metarhizium anisopliae* and *Beauveria bassiana*. Journal of Plant Protection Research 54(1): 62-66.

ZENI V, BALIOTA GV, BENELLI G, CANALE A & ATHANASSIOU CG. 2021. Diatomaceous earth for arthropod pest control: Back to the future. Molecules 26(24): 7487.