American Journal of BioScience
2022; 10(5): 160-164
http://www.sciencepublishinggroup.com/j/ajbio
doi: 10.11648/j.ajbio.20221005.11
ISSN: 2330-0159 (Print); ISSN: 2330-0167 (Online)

Diatomaceous Earth Effectiveness Against Two Stored Sorghum [(*Sorghum bicolor* (L.) Moench, 1794)] Insects Pest

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To cite this article:

Douan Bleu Gondo, Kra Kouadio Dagobert, Kwadjo Koffi Eric, Danon Aubin Silvère Djiwha, Doumbia Mamadou. Diatomaceous Earth Effectiveness Against Two Stored Sorghum [(*Sorghum bicolor* (L.) Moench, 1794)] Insects Pest. *American Journal of BioScience*. Vol. 10, No. 5, 2022, pp. 160-164. doi: 10.11648/j.ajbio.20221005.11

Received: August 22, 2022; **Accepted**: September 27, 2022; **Published**: October 17, 2022

Abstract: Grain sorghum and other cereals are very important to ensure food security. However, during storage they are susceptible to insect pests; hence, the necessity to find sustainable strategies for storage pests control. The efficacy of Diatomaceous Earth (DE) was assessed in the management of two major beetle pests of stored sorghum: *Sitophilus zeamais*, and *Tribolium castaneum*. Sorghum was treated with four concentrations of DE (1.5, 3, 4.5, and 6g/kg) and four concentrations of Actellic Super®Dust, a chemical insecticide used as a reference (0.25, 0.5, 0.75, and 1g/kg). The mortality was measured for each treatment after 24, 48, 96 hours, and 7 days of exposure. Mortalities have been corrected for those observed in control jars without insecticides. Both species tested were susceptible to Diatomaceous Earth with a higher susceptibility of *S. zeamais* compared to *T. castaneum*. The lowest concentration of Diatomaceous Earth, 0.5 g/kg allowed control of all individuals tested within 96 hours, i.e. 4 days for *Sitophilus zeamais* and 7 days for *Tribolium castaneum*. Diatomaceous Earth could be an alternative to chemical insecticides for the control of stored sorghum insect pests, more specifically *S. zeamais* and *T. castaneum*.

Keywords: Diatomaceous Earth, Effectiveness, Sorghum, *Sitophilus zeamais*, *Tribolium castaneum*, Ivory Coast

1. Introduction

Sorghum, maize, rice, millet, and wheat make up the bulk of the world's food production and the most produced cereals in Sub-Saharan Africa [1]. Sorghum (*Sorghum bicolor*) is grown worldwide on 42,143,146 hectares (ha) for an estimated production of 59,342,103 Tons. According to statistics from the UN Food and Agriculture Organization (FAO), In Côte d'Ivoire, sorghum was grown on 92,924 ha in 2018 with a yield of 710 kg per hectare [2]. The production was 66,053 tons which was 0.48% of the West African production estimated at 13,703,207 tons [2]. These data reveal the low production of sorghum in Ivory Coast. Therefore, an increase in sorghum production is crucial regarding the rich nutritional qualities of this cereal. It is an important crop for food security [3-6]. This requires sustainable management of insect pests of sorghum on farms and at the post-harvest stage [7]. Indeed, grain post-harvest losses are also significant in Sub-Saharan Africa [8, 7]. The main storage pests responsible for the losses are the larger grain borer (*Prostephanus truncatus*), the grain weevil (*Sitophilus granarius*), the lesser grain borer (*Rhyzopertha dominica*), the maize weevil (*Sitophilus zeamais*), the red flour beetle (*Tribolium castaneum*) and the angoumois grain moth (*Sitotroga cerealella*) [8-11]. One hundred and fifty (150) insect species can infest sorghum varieties worldwide in the field and after harvest [3]. Chemical insecticides such as organochlorines, carbamates, organophosphates, and synthetic pyrethroids have been widely used in the

management of stored food insect pests in Africa resulting in the resistance of insects, poisoning, and pollution [7]. However, some eco-friendly management practices have been implemented to control insect pests of stored commodities in sub-Saharan Africa in recent years [10, 12, 7, 13, 1]. The use of diatomaceous earth is one of these practices. Indeed, diatomaceous earth has low mammalian toxicity, low insect resistance potential, and a good residual effect. Research undertaken by [12] showed the efficacy of diatomaceous earth against three insect pests of maize stocks in Côte d'Ivoire. However, it should be noted that very few studies have been devoted to the management of insects pest of sorghum stocks using Diatomaceous Earth. The use of an insecticide of such ecological value could significantly reduce post-harvest losses of sorghum in Ivory Coast. It is in this context that this study was undertaken. It aims at evaluating and comparing the efficacy of four different concentrations of Diatomaceous Earth, a new product for stored product pest control in Ivory Coast, with a chemically active ingredient, Actellic Super®Dust, against two important beetle pest of stored sorghum: *S. zeamais* and *T. castaneum*.

2. Material and Methods

Surveys were carried out at different markets in the municipality of Abobo, Abidjan, Côte d'Ivoire (5°25'08'' N, 4°01'14'' W; Altitude: 76 m) to collect some insect-infected sorghum. the infected sorghum was sampled, then transported to the laboratory and stored in glass bottles with small holes in the lid for ventilation. The laboratory conditions were 29 ± 2°C and 75 ± 5% Relative Humidity. One month after, adult *S. zeamais* and *T. castaneum* were collected from the bottle. Their identification was possible thanks to the identification key of Coleoptera harmful to foodstuffs stored in tropical countries [14]. The Diatomaceous Earth (DE) concentrations used were 0.5, 3, 4.5, and 6g/kg. The chemical insecticide used (Actellic Super®Dust) contains 16 g/kg of pirimiphos-methyl and 3 g/kg of permethrin. The concentrations of the formulation used were 0.25, 0.5, 0.75, and 1g/kg.

One hundred (100) grams of sorghum were mixed with each of the insecticide concentrations under study. Twenty (20) grams were then put into other jars. Twenty insects of a given species were placed in contact with the treated sorghum in each of the jars. Each jar was accompanied by a control jar that did not contain insecticide. The number of dead individuals in each jar was counted after 24, 48, 96 hours, and 7 days later. The corrected mortality was calculated, for each insecticide concentration [15].

Corrected mortality was the dependent variable. Time (24; 48; 96 hours and 7 days) and insecticide concentration were the independent variables. The one-way ANOVA (Time at four levels was performed at the 5% threshold. Another one-way ANOVA (Concentration) with four levels for each insecticide was performed at the 5% level. A homogeneity test using Levene's statistic was used to check the homogeneity of variances. Once a difference between average was found, a post hoc Student-Newman-Keuls (SNK) multiple comparison tests were undertaken to classify the means into homogeneous groups. The statistical software used was IBM SPSS version 20.

3. Results

3.1. Evolution of the Mortality of Two Insect Pests of Sorghum

This study allowed to evaluate the efficacy of Diatomaceous Earth on two main Coleoptera pest of sorghum (*Sitophilus zeamais* and *Tribolium castaneum*). Diatomaceous Earth was found to be as effective as the reference chemical insecticide (Actellic Super®Dust). However, *Tribolium castaneum* was more tolerant than *Sitophilus zeamais* (Tables 1 and 2).

Table 1. *Corrected and cumulative Mortality of S. zeamais on sorghum treated with Diatomaceous earth and Actellic Super®Dust.*

INSECTICIDE	CONCENTRATION	Corrected and cumulative mortality (%) ± SD			F	*p*
		24 Hours	48 Hours	96 Hours		
Diatomaceous Earth	0.5 g/kg	24 ± 9.61 B a	82.47 ± 8.72 B b	100 ± 0 c	140.94	*0.000*
	3 g/kg	31 ± 15.57 B a	95.63 ± 39.44 B b	100 ± 0 b	86.29	*0.000*
	4.5 g/kg	34 ± 17.67 B a	94.58 ± 3.66 B b	100 ± 0 b	38.41	*0.000*
	6 g/kg	37 ± 11.51 B a	97.58 ± 3.40 C b	100 ± 0 b	132.37	*0.000*
Actellic Super®Dust	0.25 g/kg	0 ± 0 A a	52 ± 21.68 A b	100 ± 0 c	79.83	*0.000*
	0.5 g/kg	62 ± 21.21 C a	100 ± 0 C b	-	17.19	*0.003*
	0.75 g/kg	86 ± 11.40 D a	100 ± 0 C b	-	7.54	*0.024*
	1 g/kg	88 ± 26.83 D a	100 ± 0 C a	-	1.00	*0.347*
F		17.08	17.88	-		
p		*0.000*	*0.000*	-		

- 100 % mortality already achieved since the previous count.

In each row, the mortality followed by the same letter (in lower case) are not statistically different according to the Student-Newman-Keuls test at the 5% threshold.

In each column, the mortality followed by the same letter (capital letter) are not statistically different according to the Student-Newman-Keuls test at the 5% threshold; F: Statistic; p: critical probability; SD: Standard Deviation.

Table 2. *Corrected and cumulative Mortality of T. castaneum on sorghum treated with Diatomaceous earth and Actellic Super®Dust.*

INSECTICIDE	CONCENTRATION	Corrected and cumulative mortality (%) ± SD				F	*p*
		24 Hours	48 Hours	96 Hours	7 Days		
Diatomaceous Earth	0.5 g/kg	0 ± 0 A a	43 ± 18.00 B b	89 ± 8.94B c	100 ± 0 B d	420.93	*0.000*
	3 g/kg	5 ± 3.53 A a	49 ± 14.32 B b	92 ± 10.37B c	100 ± 0 B c	118.17	*0.000*
	4.5 g/kg	8 ± 7.58 A a	50 ± 9.35 B b	92 ± 4.47B c	100 ± 0 B c	218.30	*0.000*
	6 g/kg	11 ± 24.6 A a	57 ± 5.70 B b	98 ± 2.74B c	100 ± 0 B c	54.62	*0.000*
Actellic Super®Dust	0.25 g/kg	2 ± 4.47 A a	6 ± 6.51 A a	16 ± 14.74 A a	23 ± 16.43 A a	3.30	*0.50*
	0.5 g/kg	19 ± 8.01 A a	68 ± 28.40 C b	87 ± 12.04B c	91 ± 11.93 B c	64.76	*0.000*
	0.75 g/kg	61 ± 14.31 B a	79 ± 4.18 D b	93 ± 7.58 B c	99 ± 2.23 B c	20.02	*0.000*
	1 g/kg	81 ± 4.18 C a	97 ± 2.73 E b	100 ± 0B b	-	62.6	*0.000*
F		40.17	63.81	47.83	69.32		
p		*0.000*	*0.000*	*0.000*	*0.000*		

- 100 % mortality already achieved since the previous count.

In each row, the mortality followed by the same letter (in lower case) are not statistically different according to the Student-Newman-Keuls test at the 5% threshold.

In each column, the mortality followed by the same letter (capital letter) are not statistically different according to the Student-Newman-Keuls test at the 5% threshold; F: Statistic; p: critical probability; SD: Standard Deviation.

3.2. Comparison of the Evolution of Sitoplilus zeamais Mortality over Time

A significant difference was noted in mortality as a function of time (24 hours) (F =17.08; p = 0.000) and 48 hours (F =17.88; p = 0.000). At 24 hours, Actellic Super®Dust caused statistically significantly higher mortalities than Diatomaceous Earth. 48 hours after application, mortalities above 80% were recorded with both insecticides (Table 1). The efficacy of both insecticides was noted 48 hours after application. The lower concentration of Diatomaceous Earth (0.5 g/kg) was as effective as the higher ones 48 hours after application to *S. zeamais*. Diatomaceous Earth acted with a delay on *S. zeamais* compared to Actellic Super®Dust with which mortalities higher than 50% were recorded 24 hours after treatment.

3.3. Comparison of the Evolution of Mortality of Tribolium castaneum Over Time

A significant difference was noted in mortality as a function of time (24 hours) (F = 40.17; p = 0.000); 48 hours (F = 63.81; p = 0.000); 96 hours (F = 47.83; p = 0.000) and 1 week (F = 69.32; p = 0.000). In 24 hours, only the two highest concentrations of Actellic Super®Dust (0.75 and 1 g/kg) resulted in statistically higher mortalities than Diatomaceous Earth. 48 hours after application, only the highest concentration of Actellic Super®Dust caused mortality above 80%. Mortalities above 80% were obtained 96 hours after application of both insecticides (Table 2). The efficacy of both insecticides is noticed 96 hours after application. The lower concentration of Diatomaceous Earth (0.5 g/kg) was as effective as the higher ones 96 hours after application to *T. castaneum*. Diatomaceous Earth acted with a delay on *T. castaneum* compared to Actellic Super®Dust. To have the same efficacy as Actellic Super®Dust 96 hours after treatment is necessary with the application of Diatomaceous Earth (Table 2).

4. Discussion

The main objective of this study was to contribute to the improvement of sorghum production in Côte d'Ivoire by finding sustainable means of managing insects pest that cause important damages to stocks. Thus, the efficacy of a biological insecticide, Diatomaceous Earth, was evaluated on two sorghum insects pest (*Sitophilus zeamais* and *Tribolium castaneum*). Indeed, these two insects are very harmful pests of sorghum stocks. Other authors such as Chantereau *et al.* [16], Kadi Kadi *et al.* [17], and Vyavhare *et al.* [11] mentioned these two beetle pest among the most important ones of sorghum as rice weevils (*Sitophilus oryzae*) or maize weevils (*Sitophilus zeamais*); the grain beetle (*Rhyzopertha dominica*); the grain beetle (*Trogoderma granarium*) and the tribolium beetles (*Tribolium castaneum* and *Tribolium confusum*). According to these authors, while *S. zeamais* is able to develop on intact grains, *T. castaneum* is a secondary pest that develops on cracked or broken grains, or on grains already attacked by primary pests such as *S. zeamais*. The presence of *Sitophilus zeamais* and *Tribolium castaneum* was also noted on stored maize by Doumbia *et al.* [12] in Ivory Coast.

A tolerance of *T. castaneum* to both insecticides compared to *S. zeamais* was noted. Infact, 100% mortality was obtained in 96 hours, i.e. 4 days on *S. zeamais* while the same concentrations resulted in 100% mortality in 7 days on *T. castaneum*. This fact can be explained on the one hand by a tolerance developed by *T. castaneum* towards the chemical insecticide and on the other hand by its capacity to bear the physical injuries due to the Diatomaceous Earth. Indeed, cases of tolerance of *T. castaneum* to organophosphates were noted during a study in which phosphine, a fumigant used for the protection of stored products insects pest, was used [18]. Diatomaceous Earth is an insecticide composed almost entirely of amorphous silica dioxide, formed from fossilized diatoms (single-celled algae). Amorphous silica dioxide is a substance with low toxicity to mammals [19]. It was

demonstrated in the laboratory that after 5 to 7 generations of *Tribolium castaneum*, the susceptibility of insects to diatomaceous earth decreased significantly [20]. According to these authors, individuals that develop a tolerance to Diatomaceous Earth seem to have a tendency to lose less water as a result of the injuries caused to them by the tiny silica particles that diatomaceous earth is composed of.

It was also observed that Actellic Super®Dust has faster effects compared to Diatomaceous Earth. This difference between the responses of insects treated with the two insecticides is thought to be due to the neurotoxic action of Actellic Super®Dust. Indeed, insects treated by Actellic Super®Dust die rapidly by asphyxiation, whereas those treated with Diatomaceous Earth die slowly by desiccation.

The lowest concentration of Diatomaceous Earth in this study was 0.5g/kg. It allowed control of all individuals tested within 96 hours, i.e. 4 days on *Sitophilus zeamais* and 7 days on *Tribolium castaneum*. The Diatomaceous Earth formulation tested in this study proved to be more effective than that used by Ziaee *et al.* [19]. Indeed, these authors still had *T. castaneum* individuals surviving 21 days after treatment with the Diatomaceous Earth formulations (Protect-It®, SilicoSec®, Insecto®, Perma-Guard™ D-10, and Dryacide®). This difference in response could be explained by the quality of the Diatomaceous Earth sources tested and the different tolerance of the *T. castaneum* strains.

5. Conclusion

At the end of this study, which aimed at contributing to the sustainable management of sorghum insects pest in Ivory Coast, it should be noted that all *S. zeamais* individuals are controlled after four days, while it takes seven days for all *T. castaneum* individuals to die. This implies a certain tolerance of *T. castaneum* to *S. zeamais* towards Diatomaceous Earth. Nevertheless, Diatomaceous Earth could validly serve as an alternative to chemical insecticides for the control of sorghum insect pests, more specifically *S. zeamais* and *T. castaneum*. This study could be referred to in other research works about insect pests of other cereals in Ivory Coast.

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