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REVIEW ARTICLE

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IS THE EFFECTIVENESS OF DIATOMACEOUS EARTH AGAINST STORED CEREAL INSECTS PEST BEETLE PESTS INFLUENCED BY THE CEREAL TO BE PROTECTED?

***,[1]DOUAN Bleu Gondo, [2]DANON Aubin Silvère Djiwha, [2]KRA Kouadio Dagobert, [2]KWADJO Koffi Eric and [2]DOUMBIA Mamadou**

[1]University Peleforo GON COULIBALY, Department of Animal Biology, Po Box 1328 Korhogo, Côte d'Ivoire
[2]University Nangui Abrogoua, UFR-SN Department of Natural Sciences, 02 Po Box 801 Abidjan 02 Côte d'Ivoire

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****Corresponding author:***
DOUAN Bleu Gondo

ABSTRACT

Maize and sorghum are among the most important cereals in the world. They are thus solutions for the fight against food insecurity. Both cereals are unfortunately subject to attack by several insects during storage. These include the maize weevil (*Sitophilus zeamais*) and the red flour beetle (*Tribolium castaneum*). Chemical control methods with adverse effects on the environment, applicators, and consumers have long been advocated against these pests. Sustainable management options including the use of Diatomaceous Earth were explored in this study which aimed to comparing the efficacy of a given concentration of Diatomaceous Earth against *S. zeamais* and *T. castaneum* on maize and sorghum separately. For this purpose, sorghum and maize were treated with four concentrations of Diatomaceous Earth (1.5, 3, 4.5, and 6 g/kg) and an insecticide-free control for each replicate. For each insect tested, twenty (20) unsexed adults were introduced into each jar. Mortality was measured for each treatment after 24, 48, 96 hours, 7, and 14 days of exposure. Mortalities were corrected for those observed in the control jars and compared for the two cereals (maize and sorghum) using the Mann-Whitney test. *Sitophilus zeamais* was more sensitive to 0.5 g/kg of Diatomaceous Earth on sorghum than on maize after 24 and 48 h ($U = 0.00$; $p = 0.005$). It then showed the same sensitivity regardless of the commodity and the concentration of diatomaceous earth. As for *Triboium castaneum*, it showed a higher sensitivity on sorghum than on maize. It emerges from this study that the determination of an effective concentration of Diatomaceous Earth should take into account the cereal to be protected and the insect pests to be controlled.

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INTRODUCTION

Maize (*Zea mays* L. 1753) and sorghum (*Sorghum bicolor Sorghum bicolor* (L.) Moench, 1794) are respectively the first and fifth most cultivated cereals in the world (Chantereau *et al.*, 2013; Hénin, 2018). Maize production in Côte d'Ivoire in 2020 was estimated at 1,175,715 tons. Sorghum production was 72,186 tons (FAOSTAT, 2022). While the importance of maize is well established, there has been renewed interest in sorghum in recent years due to its hardiness and nutrient content (Hénin, 2018). Unfortunately, these two commodities are subject to attack by insects pests of stored foodstuffs, the most harmful of which belong to the order Coleoptera. In fact, authors have noted that maize and sorghum, being bare grain cereals, are more susceptible to weevil attacks than those with dressed grains (paddy rice, barley, oats, etc.) (Cruz *et al.*, 2016). According to these authors, the maize weevil (*Sitophilus zeamais*) can attack all stored commodities and cause mass losses of about 35-40%. The presence of *Sitophilus zeamais,* and *Tribolium castaneum* was also noted on stored maize by Doumbia *et al.* 2014. As for *Tribolium castaneum*, it is considered, together with *Sitophilus zeamais*, to be among the most important insects pests of sorghum (Chantereau *et al.,* 2013; Kadi Kadi *et al.,* 2013; Vyavhare *et al.,* 2018). For effective protection of stored foodstuffs in Africa, chemical control was adopted for a long time with the use of organochlorines, organophosphates, carbamates, synthetic pyrethroids, etc. with the consequences of resistance in insects, environmental pollution, contamination of treated foodstuffs as well as health risks for applicators and consumers (Cissokho *et al.,* 2015). Sustainable and environmentally friendly management methods for stored food insect pests have been explored. Among them is the use of Diatomaceous Earth (Korunić, 2013; Doumbia *et al.,* 2014; Zeni *et al.,* 2021). Diatomaceous Earth is composed of amorphous silicon dioxide extracted from the fossilized skeletons of marine or freshwater siliceous organisms. Indeed, previous studies have shown the promising character of diatomaceous earth as it is non-toxic to mammals and does not affect the quality of processed grains (Korunic *et al.,* 1996; Zeni *et al.,* 2021). Studies conducted by Doumbia *et al.* (2014) demonstrated the efficacy of Diatomaceous

Earth against three maize beetle pests (*Sitophilus zeamais* and *Tribolium castaneum*). Several other studies highlighting the effectiveness of Diatomaceous Earth have been conducted (Ziaee *et al.,* 2007; Ziaee and Moharramipour, 2012; Korunić, 2013). These studies focused on the susceptibility of a given insect pest to a specific commodity. They do not take into account the sensitivity of a given pest to a concentration of Diatomaceous Earth for the protection of two different commodities such as sorghum and maize since the Diatomaceous Earth particles adhere to the grains according to Korunić (2013). Wouldn't the larger cereal grains with a greater tendency to fix more particles of Diatomaceous Earth have an impact on the effectiveness of the Diatomaceous Earth? This is the context of the present study, which compares the mortality of two insects (Sitophilus zeamais and Tribolium castaneum) due to four concentrations of Diatomaceous Earth on maize and sorghum. The objective is to compare the mortality of an insect between two cereals (maize and sorghum) for a given concentration of Diatomaceous Earth.

MATERIAL AND METHODS

Insect sampling and testing: The insects that were the subject of our study were sampled on maize and sorghum collected in different markets in the town of Abobo, Abidjan District, Côte d'Ivoire (5°25'08" N, 4°01'14" W; Altitude: 76 m). These infested commodities were stored in glass bottles with small holes in the lid for ventilation. Laboratory conditions were 29 ± 2 °C and 75 ± 5% relative humidity.

Table 1. Comparison of *S. zeamais* mortality on maize and sorghum treated with Diatomaceous Earth

Concentration of Diatomaceous Earth		Mortality Average (%) ± SD		U	p
		Maize	Sorghum		
0.5 g/kg	24 hours	0 ± 0 a	24 ± 9.61 b	0.000	0.005
	48 hours	0 ± 0 a	82.47 ± 8.72 b	0.000	0.005
	96 hours	5 ± 0.66 a	100 ± 0 b	0.000	0.005
3 g/kg	24 hours	30 ± 11.51 a	31 ± 15.57 a	12.00	0.91
	48 hours	87 ± 13.5 a	95.63 ± 39.44 a	8.00	0.34
	96 hours	100 ± 0 a	100 ± 0 a	12.50	1.00
4.5 g/kg	24 hours	33 ± 9.35 a	34 ± 17.67 a	6.00	0.17
	48 hours	93 ± 4.47 a	94.58 ± 3.66 a	6.50	0.18
	96 hours	100 ± 0 a	100 ± 0 a	12.50	1.00
6 g/kg	24 hours	33 ± 10.36 a	37 ± 11.51 a	10.50	0.76
	48 hours	98 ± 4.47 a	97.58 ± 3.40 a	11.00	0.7
	96 hours	100 ± 0 a	100 ± 0 a	12.50	1.00

In each row, the mortalities followed by the same letter are not statistically different according to the Mann-Whitney test at the 5% threshold (N=5); SD: Standard Deviation; U: Mann-Whitney statistic; p: critical probability

Table 2. Comparison of *T. castaneum* mortality on maize and sorghum treated with Diatomaceous Earth

Concentration of Diatomaceous Earth		Mortality Average (%) ± SD		U	p
		Maize	Sorghum		
0.5 g/kg	24 hours	0 ± 0 a	0 ± 0 a	12.50	1.00
	48 hours	0 ± 0 a	43 ± 18.00 b	0.000	0.005
	96 hours	0 ± 0 a	89 ± 8.94 b	0.000	0.005
	7 days	3 ± 0.47 a	100 ± 0 b	0.000	0.005
	14 days	40 ± 22.07	-	-	-
3 g/kg	24 hours	0 ± 0 a	5 ± 3.53 a	2.50	0.17
	48 hours	0 ± 0 a	49 ± 14.32 b	0.000	0.005
	96 hours	15 ± 5.00 a	92 ± 10.37 b	0.000	0.009
	7 days	34 ± 5.41 a	100 ± 0 b	0.000	0.005
	14 days	94 ± 6.52	-	-	-
4.5 g/kg	24 hours	0 ± 0 a	10 ± 7.58 a	0.50	0.18
	48 hours	5 ± 0.12 a	50 ± 9.35 b	0.000	0.005
	96 hours	22 ± 6.70 a	92 ± 4.47 b	0.000	0.008
	7 days	74 ± 31.57 a	100 ± 0 b	0.000	0.005
	14 days	98 ± 2.73	-	-	-
6 g/kg	24 hours	0 ± 0 a	10 ± 0.50 a	10.00	0.317
	48 hours	18 ± 8.36 a	57 ± 5.70 b	0.000	0.008
	96 hours	48 ± 10.95 a	98 ± 2.74 b	0.000	0.007
	7 days	94 ± 4.18 a	100 ± 0 a	2.50	0.018
	14 days	99 ± 2.23	-	-	-

The identification key for foodstuff beetles stored in warm regions written by Delobel and Tran (1993) was used to identify the two insects. Adults of *Sitophilus zeamais* and *Tribolium castaneum* were sampled from these cereals stored in the laboratory and used for the different tests. The concentrations of diatomaceous earth used were 0.5, 3, 4.5, and 6 g/kg. One hundred (100) grams of sorghum and one hundred (100) grams of maize were mixed with each of the concentrations of diatomaceous earth. Twenty (20) grams of each grain were then placed in jars. Twenty (20) insects of a given species were placed in contact with each treated grain in each jar. Each jar was accompanied by control without insecticide. The number of dead individuals in each jar was counted at 24, 48, 96 hours, 7, and 14 days. Adjusted mortality was calculated for each concentration of diatomaceous earth tested by taking into account the mortality in the control jars according to the formula of Abbot (1925).

Statistical Analyses: Avarage mortalities and standard deviations were calculated using Excel 2016. Adjusted mortality was the dependent variable. The commodity (maize and sorghum) was the independent variable. The mortality of a given insect, for a given concentration of diatomaceous earth and a given time, was compared according to the two commodities (maize and sorghum) using the Mann-Whitney test at the 5% threshold. The statistical software used was IBM SPSS version 20.

RESULTS

Comparison of S. zeamais mortality on maize and sorghum treated with Diatomaceous Earth: The mortality of *S. zeamais* on maize and sorghum is noted in Table 1. For a given concentration of Diatomaceous Earth and treatment time, a comparison was made according to the cereal to be protected (maize or sorghum). The concentration of 0.5 g/kg of Diatomaceous Earth resulted in mortality of 0% and 5 ± 0.66% respectively in 24, 48, and 96 hours on maize.

The same concentration resulted in 24 ± 9%, 82 ± 8%, and 100% mortality in 24, 48, and 96 hours respectively. The mortality of *S. zeamais* on maize treated with 0.5 g/kg of Diatomaceous Earth was statistically lower than that of this insect on sorghum treated with the same concentration of Diatomaceous Earth ($U = 0.00$; $p = 0.005$) (Table 1). Concentrations of 3, 4.5, and 6 g/kg of Diatomaceous Darth resulted in statistically identical mortality of *S. zeamais* on maize and sorghum regardless of treatment time ($p > 0.05$) (Table 1).

Comparison of T. castaneum mortality on maize and sorghum treated with Diatomaceous Earth: The mortality of *T. castaneum* on maize and sorghum is noted in Table 2. For a given concentration of Diatomaceous Earth and treatment time, a comparison was made according to the cereal to be protected (maize or sorghum). The Diatomaceous Earth concentration of 0.5 g/kg resulted in 0% mortality after 24 hours of treatment. After 48, 96 hours, and 7 days, 0%, and 3% mortality were recorded on maize respectively. Mortalities of 43%, 96%, and 100% were recorded in 48, 96 hours, and 7 days respectively on sorghum. The mortality of *T. castaneum* on maize treated with 0.5 g/kg of Diatomaceous Earth was statistically lower than on sorghum treated with the same concentration of Diatomaceous Earth ($U = 0.00$; $p = 0.005$) (Table 2). All (100%) *T. castaneum* individuals were dead after 7 days on sorghum treated with 0.5 g/kg of Diatomaceous Earth compared to 3% on maize treated with 0.5 g/kg of Diatomaceous Earth (Table 2). Concentrations of 3, 4.5 and 6 g/kg of Diatomaceous Earth resulted in lower mortality of *T. castaneum* on maize than on sorghum after 48, 96 hours, and 7 days ($p < 0.05$). All three concentrations of Diatomaceous Earth resulted in 100% mortality of *T. castaneum* after 7 days on sorghum (Table 2). On maize, *T. castaneum* mortalities of less than 100% were recorded after 14 days (Table 2). *T. castaneum* mortalities recorded on maize treated with Diatomaceous Earth were lower than those recorded on sorghum treated with Diatomaceous Earth (Table 2).

DISCUSSION

It appears from this study, which aimed to see the influence of the commodity to be protected on the efficacy of Diatomaceous Earth for a given insect pest, that the concentration of 0.5 g/kg of Diatomaceous Earth results in higher mortality of *S. zeamais* on sorghum compared to maize. This trend is even more visible on *T. castaneum* where higher mortalities are recorded on sorghum compared to maize. This superiority of the mortality of the two insects on sorghum compared to maize could be explained by the retention of the Diatomaceous Earth particles on the surface of the maize grains, which are larger than those of sorghum. Indeed, the particles of Diatomaceous Earth would have the capacity to adhere to the surface of the cereal grains, thus making them less available for the control of the insects present in the cereal stock. The larger maize grains would retain more diatomaceous earth particles than the smaller sorghum grains. These results corroborate those of Korunić (1997) who stated that Diatomaceous Earth particles could adhere to the surface of the cereal grains on which they were applied. Another study showed that Diatomaceous Earth retained its effectiveness against insects in stocks as long as there were enough abrasive particles to cause damage to the insects that came into contact with them (Korunić, 1998). This study also showed that *T. castaneum* was more tolerant of Diatomaceous Earth than *S. zeamais*. Indeed, all *S. zeamais* individuals died after 96 hours, i.e. 4 days, whereas 14 days ago, all *T. castaneum* individuals had not yet died on maize. This fact could be explained by the roughness of the cuticle of *S. zeamais* compared to that of *T. castaneum*, thus allowing more retention of Diatomaceous Earth particles by the *S. zeamais* individuals, leading to their more rapid desiccation and death. The Diatomaceous Earth particles would be easily transported by the insects to the rougher body surface. This could accentuate the damage caused to the insect by the absorption of hydrocarbons, causing death by dehydration. Tolerance towards Diatomaceous Earth of insects such as *Tribolium castaneum*, *Cryptolestes ferrugineus*, and *Rhyzopertha dominica* and sensitivity of insects of the genus *Sitophilus* have also been mentioned (Korunić, 1998; Korunić, 2013). Doumbia *et al.* (2014) also noticed a higher sensitivity of *S. zeamais* to Diatomaceous Earth compared to *T. castaneum*.

CONCLUSION

This study, which aimed to see the effect of the commodity to be protected on the effectiveness of the Diatomaceous Earth, showed that for a given concentration of Diatomaceous Earth, the mortality rates for an insect pest were different from one commodity to another. For example, mortality was high on sorghum compared to maize. Also, a tolerance of *T. castaneum* to Diatomaceous Earth was noted compared to *S. zeamais*. In the light of the results of this study, it would be judicious to take into account the pest to be controlled and the commodity to be protected in order to determine a concentration of Diatomaceous Earth for effective control.

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