Limiting the amount of pesticide applied to small bulks of maize in rural stores

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Abstract

The simplest and most effective method for African farmers to protect maize against *Prostephanus truncatus* and *Sitophilus* spp is to shell cobs and treat the resulting grain with a suitable insecticidal dust Such pesticide application is a considerable expense for subsistence farmers and may pose risks to health and the environment Observed downward migration of insect pests in grain bulks suggested that insecticide application need not be uniform but may still be effective if restricted to specific locations, thus reducing the amount of pesticide used

To test the potential of localised treatments, laboratory studies were undertaken to observe the behaviour of *P truncatus* in grain columns, with and without localised pesticide treatment, and field trials were implemented in mud silos in northern Ghana In a laboratory study with maize bulks 275cm deep, there was a strong downward movement in the grain, to depths of 275cm after three weeks, and over half the population penetrated below 75cm. In maize bulks 126cm deep, localised treatment of the bottom 30cm depth (20% of grain) together with a treatment of the top 10cm (about 9% of grain) gave adequate protection over a period of fifteen weeks Grain preservation in mud silos was tested by treatment of the bottom 15cm (30% of grain) and top 10cm (20% of grain) To simulate farmer consumption most of the untreated portion of grain, in between the two treated layers, was removed by regular withdrawals during a 24-week storage period. Good grain preservation was achieved. The results of these studies are discussed in relation to the adoption of reduced pesticide usage for the protection of small bulks of farm stored maize

Introduction

Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae) is a well known pest of farm-stored maize and cassava. It was introduced into Africa from Meso-America in the late 1970s and since then has spread widely in that continent (Hodges, 1994) where it has been the cause of substantial food losses The simplest and most effective method of controlling *P truncatus* in maize is to shell cobs and to treat the grain with a suitable insecticidal dust to protect against both *P. truncatus* and weevils (*Sitophilus* spp.) The application of pesticide is necessary to prevent substantial losses but this is a considerable expense for subsistence farmers and may pose risks to health and the environment (Ecobichon and Joy, 1993)

However, treatment of the whole grain bulk may not be necessary It is known that insects will adopt characteristic distribution patterns within grain bulks (Surtees, 1964) and there have been several reports that *P truncatus* migrates downwards towards the base in stores containing shelled maize (Verstraeten and Haubruge, 1987; Tierto, 1994) or maize cobs (Wright et al , 1993; Wekesa 1994). This has led to a suggestion that grain bulks may be adequately protected if only the deeper portions of grain are treated with insecticide. A number of ingenious designs for farm stores that would facilitate selective treatment of shelled maize have been suggested (Tierto, 1994), although to date there have been no studies on the response of storage pests to such treatments. To test whether these would give satisfactory control a series of laboratory investigations was undertaken to observe the distribution of the beetle in grain at depths typical of farm bulks and also the protection offered by treating portions of the grain at the bottom and the top of the bulk This was followed by a field trial in northern Ghana, in which grain was stored for five months in mud silos with only 50% of the bulk receiving a pesticide application

Methods

General

Laboratory Studies

Laboratory studies were undertaken in a CTH room set at 25℃ and 70% r h. The distribution of insects in maize was observed in grain confined to plastic tubes of 18cm diameter and various lengths. The grain was newly purchased American yellow maize (No 4 quality) and, except the in

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first experiment, the grain was placed in a freezer at −18℃ for one week to kill any insects present The grain was then conditioned in the CTH room, in small lots, for two weeks The plastic tubes were sealed at the base with a plastic plug, mounted vertically in the CTH room and, once filled, the tops closed with muslin. At the time of filling, four samples of maize were taken and tested for moisture content by drying in a ventilated oven at 130℃ for 3 hours

Unless otherwise stated, beetles of mixed age were added to the top of tubes in a manner intended to simulate the arrival of beetles at a food source. The first additions were 2, 4, 8 and 16 males added on each of the first four days On the fifth and eighth days, 16 females were added, giving a total of 62 beetles. At various intervals after adding the last beetle, depending on the particular study, the distribution of insects was determined by removing maize from the bottom of the tubes in aliquots equivalent to depths of 25cm or 14cm, depending on whether tubes were filled with maize to a depth of 275cm or 126cm respectively Potentially, this gave 11 or 9 samples/tube although, due to settling and insect damage, sometimes fewer than this were recovered. For maize removal, the tubes were held at an angle of 45° and the plastic plug sealing the base opened gently. Between each extraction, the tube was returned to the upright position to ensure that the grain did not slip between layers as further samples were taken. Unless otherwise stated, insects were removed from these maize samples by sieving for five minutes on an Octogon 200 mechanical sieve (setting 7) then inspected manually for any further beetles which might be extracted

The *P truncatus* used in this study were a Ghanaian strain obtained in 1996, cultured on yellow maize at 27℃ and 70% r h To provide beetles that were representative of those seeking a new food source, *P truncatus* were mostly obtained by placing a culture in a glass tank over which a light was suspended Those beetles flying off from the culture were collected and sexed (Shires and McCarthy, 1976) Where these were insufficient, additional beetles were obtained by sifting the culture

When grain was to be treated with insecticide, a dilute dust formulation of Actellic Super was admixed at the rate of 1.0g/kg grain The concentration of active ingredient of this insecticide was confirmed at Natural Resources Institute by GLC analysis and found to be 0.79% pirimiphos methyl and 0 26% permethrin Thus the insecticides were applied at 7.9 mg/kg and 2.6 mg/kg respectively Differences in grain quality according to treatment were investigated by one-way analysis of variance The standard error of the difference (SED) between two means was calculated in order to compare treatments; where the difference between two means was at least twice the SED then the means are considered to be significantly different at the 5% level ($p \leqslant 0.5$)

Field Study

At Tamale in northern Ghana, eight traditional mud silos were constructed from a mixture of soil from termite mounds and grass The silos were more or less spherical, measuring about 1.5m high and 1.3m wide and when full of maize would hold about 300kg The silos were supported on three mud legs about 30cm from the ground and sealed with a mud lid which was covered by a conical thatched-roof Each silo was loaded with 100kg of maize which had recently been fumigated with phosphine

Grain treatments were as follows:

4 silos had the bottom 30kg of maize (approximately 20cm depth) treated with Actellic Super at 1g/kg; in addition the top 20 kg (approximately 10cm depth) was treated with insecticide in the same manner to provide a top screen Between the two layers was sandwiched 50kg of untreated grain.

4 silos had untreated maize (control)

To ensure that infestation had the opportunity to start early, each mud silo, whether treatment or control, was seeded with a small portion of *P truncatus* culture placed at the centre of the grain mass Thus even in the treated silos, the beetles were placed on untreated grain. A discharge port was made in each silo, with its bottom edge in line with the height reached by 30kg of grain, i e in the case of treated silos the bottom edge of the discharge port was in line with the top surface of treated grain. The port was sealed with mud and reopened each time a sample was required

The condition of the grain was observed over a period of 24 weeks Of the eight silos prepared at the start of the test, two of the controls had to be abandoned due to termite infestation: one at 18 weeks, the other at 22 weeks Six weeks after the trial was initiated, each silo had 5kg of maize withdrawn by hand from the discharge port to simulate grain consumption by a farmer. This procedure was repeated every two weeks up to and including the 22nd week (giving nine samples/silo) Thus a total of 45kg was removed; in the case of the treated silos the grain removed was mainly from the 50kg of grain sandwiched between the top and bottom treated layers, i e. it would have been mostly untreated grain The samples were sifted and live and dead insects counted, and four sub-samples of about 50g were assessed for insect damage. At the end of the 22nd week, grain weight loss of two replicate 100g samples from each silo was estimated using the count and weigh method (Adams and Schulten, 1978). In some cases, where insect damage was low, this resulted in a false negative estimate of weight loss: where this happened the weight loss was recorded as zero. Of the six silos remaining at the end of the 24-week period, all the grain at or above the discharge port was removed, coned and quartered to give a 2kg sample The same procedure was followed for the grain below the discharge port which was removed through a new hole made at the base of the silo. In the case of the treated silos nearly all this grain would have been exposed to insecticide treatment. The two 2kg samples were screened for insects, and two sub-samples from each of approximately 100g were taken and weight losses estimated again using the count and weigh method.

Results and Conclusions

Laboratory Studies

Depth of penetration into grain bulks

The depth to which *P. truncatus* would penetrate into a bulk of grain was investigated to establish whether an insecticide treatment localised towards the base of the bulk would have any effect on the pest.

Three plastic tubes were filled to a depth of 275cm with maize with a mean moisture content of 13.6%. Beetles were added to the tops of the tubes, as described in the general methods, and after three weeks the distribution of beetles in the grain was determined. In this test, the maize was also found to be infested by *Sitophilus zeamais* Motschulsky which had apparently been present as a hidden infestation at the time the maize was purchased. This unexpected infestation provided information on the distribution of *S. zeamais* in bulk grain

Of the *P truncatus* added to the tubes only 35% were actually recovered They proved particularly difficult to find in a substantial mass of grain. It is assumed that the efficiency of recovery was the same for all grain samples so that observed differences between samples in the numbers of beetles are true differences in beetle distribution. On average, thirteen percent of the *P. truncatus* penetrated to the full depth of the tube (Table 1) and over half penetrated below 75cm from the top. There is clearly a strong downward movement in the grain The observed distribution of *P. truncatus* is little different from what might be expected if the beetles had spread out evenly within the bulk (Table 1) suggesting that within three weeks the beetles move to occupy the grain more or less evenly. However, the distribution of *Sitophilus* was much more strongly clustered with about 90% occurring in the lower 45% of grain, i. e. below 1.5m. It is assumed that although the two species were present in the same grain mass their populations did not interact in such a way as to affect their vertical distribution within the tubes. Subsequent testing with *P. truncatus* by itself revealed that this is probably a valid assumption.

Table 1. % of adult *P truncatus* recovered at different depths from maize in plastic tubes and actual numbers of *S. zeamais* recovered.

	Depth (cm)	% recovery of *P truncatus* Tube 1	Tube 2	Tube 3	Mean % at each depth	Number of *S. zeamais* recovered Tube 1	Tube 2	Tube 3	Mean % at each depth
Top	0 - 25	15	9	4	10.3	0	7	0	0.1
	25 - 50	20	0	17	12.3	0	0	0	0
	50 - 75	35	27	13	25.0	0	20	8	1.9
	75 - 100	15	13.6	0	9.5	0	27	18	3.0
	100 - 125	0	13.6	4	5.9	0	16	14	2.0
	125 - 150	0	9	4	4.3	0	21	10	3.1
	150 - 175	5	18	4	9.0	0	26	19	4.6
	175 - 200	0	4.5	0	1.5	0	41	24	4.4
	200 - 225	0	0	13	4.6	0	>100	30	8.2
	225 - 250	0	4.5	8.6	4.4	0	>100	63	11.0
Bottom	250 - 275	10	0	30	13.3	8	>400	>200	61.7
	No. beetles recovered	20	22	23					

Effect of initial means of access to grain on the final distribution of P. truncatus in the grain mass

How the initial means of access of *P. truncatus* to a grain bulk might affect the subsequent distribution of this species was investigated to determine whether this variable might influence the efficacy of localised pesticide treatments. Six plastic tubes were filled to a depth of 126cm with maize with an average moisture content of 14.5%. Male and female *P. truncatus* were added to the grain bulks in the following three ways to simulate three possible modes of entry into the grain bulk

Simulation of beetles arriving at the top of the bulk-once the tubes had been filled with maize, adult beetles were added to the top in the manner described in the general methods.

Simulation of infestation resulting from the presence of infested residues at the bottom of a grain store-a single large culture of *P. truncatus* was added to the bottom of each tube and the tubes then filled with uninfested maize The cultures were prepared one week earlier by adding 36 male and 36 female *P. truncatus* to jars containing 500g of maize

Simulation of an infested crop being added to the store-At the time the tubes were filled with maize, six small cultures of beetles were added at regular intervals The small cultures were prepared one week earlier with six male and six female *P. truncatus* added to 200g of maize.

There were two replicates of each treatment and insect distribution was determined eight weeks after starting the test.

The numbers of *P. truncatus* recovered from the maize samples were considerably greater than in the first test (compare Tables 1 and 2). The reason for this is that in the second test the beetles had been given sufficient time to reproduce. Irrespective of the initial means of access to the grain mass, beetle distribution in the grain was very similar. In all three cases the observed distribution was much less even than in the first test with a distinct aggregation towards the bottom; an average of 31% of the beetles were in the bottom 14 cm of grain although only 11% would have been expected if the distribution had been even (Table 2). This suggests either that the higher population density of beetles in the shorter tubes of the second test may lead to more aggregation or, probably more likely, there is greater reproductive potential at depth in the grain mass as grain there is more stable (Cowley et al., 1980).

These results confirm the observation that beetles added to the top of the grain column migrate downwards and suggest that larger populations develop in the deeper portions of grain. The similarity in the final distribution, irrespective of the initial means of access to the grain, suggests that selective treatment of deeper layers with pesticide may be effective irrespective of the means by which the grain mass becomes infested.

Table 2. Mean * (± s.d) numbers of adult *P truncatus* and cumulative % of beetle at different depths in columns of maize grain eight weeks after beetles were added at the top or bottom of the maize column or added evenly.

Depth of grain	Insects added to top		Insects added to bottom		Insects added evenly	
	Mean no. insects	Mean % at each depth	Mean no. insects	Mean % at each depth	Mean no insects	Mean % at each depth
0 - 14 cm	4.0 ± 4.2	1.0	36.5 ± 21.9	4.8	4.0 ± 5.7	1.2
14 - 28 cm	24.5 ± 28.0	6.0	35.5 ± 20.5	4.7	10.5 ± 14.8	3.1
28 - 42 cm	22.5 ±30.4	5.6	49.5 ± 19.1	6.5	8.5 ± 12.0	3.0
42 - 56 cm	38.0 ± 49.5	9.5	57.5 ± 6.4	7.6	27.5 ± 38.9	8.2
56 - 70 cm	39.5 ± 54.4	9.8	82.0 ± 5.7	10.8	19.0 ± 26.9	5.7
70 - 84 cm	58.0 ± 65.0	14.4	109.0 ± 4.7	14.3	40.0 ± 43.8	12.0
84 - 98 cm	44.0 ± 48.0	10.9	92.0 ± 21.2	12.1	35.5 ± 43 1	10.6
98 - 112 cm	45.5 ± 3.5	11.3	120.0 ± 7.1	15.7	60.0 ± 21.2	17.9
112 - 126 cm	126.0 ± 25.2	31.3	180.5 ± 44.6	23 7	129.5 ± 21.9	38.7

* Mean of two replicates

Protection of grain with insecticide treatment localised at the base of the bulk or at both the base and top of the bulk

The potential for insecticide application to the base of a maize bulk to give long-term protection (15 weeks) against *P. truncatus* was investigated in plastic tubes These tubes were loaded to a depth of about 126cm with maize grain at a moisture content of 14.1%. The bottom 25cm of grain (20%) or bottom 50cm (40%) were treated with Actellic Super or the grain was untreated (control). Three replicates were prepared of each treatment. In a further test, the potential for localised insecticide application at both the top and bottom of grain bulks to give long-term protection (15 weeks) was investigated in similar plastic tubes loaded with maize grain with a mean moisture content of 14.25%. The bottom 25cm (20%) of nine grain bulks were treated with Actellic Super and all nine had a top screen of treated grain to depths of about 5cm (4.2%), 10cm (8.5%) or 25cm (20%), with three replicates of each depth There were also three control tubes with only untreated grain.

In both tests beetles were added to the top of the tubes as described in the general methods. Grain quality was checked after 15 weeks The grain was removed from the tubes and processed by hand sieving, rather than mechanical sieving, to avoid further grain damage. In the first test, to indicate what percentage of grains was damaged by insects, 100g sub-samples were taken from the bottom three samples and the top two samples of the tubes. In the second test, 100g sub-samples were taken from all sections to assess insect damage and a count and weigh loss assessment undertaken. The weight loss results were averaged across the samples to give a general indication of the extent of losses. Where there was little insect damage some values for weight loss were negative: these were regarded as zero

In the first test, in which insecticide application was restricted to only the base of the grain bulks, much less grain damage and much less grain dust was observed in the treated bulks than in the control (Table 3). The percentage of grain damaged in the 20% treated bulks differed little from those with 40% treated (Table 3). There was however strong evidence for differences between treatments in the amount of dust produced ($F = 15.78_{2\ 78}$ $p < 0.0001$) with significant differences between the control and treated bulks as well as significantly better grain preservation conferred by 40% treatment than only 20% (Table 3)

For bulks of grain with insecticide treatment at both bottom (20%) and top (4%, 9% or 20%) there was strong evidence of significant differences between the various treatments in the amount of dust produced by insect attack ($F = 24.47_{3\ 98}$ $p < 0.0001$). All treatments differed significantly from the control and the grain columns with a 4% top screen of treated grain had significantly more dust than those with 9% or 20% (Table 4). The last two did not differ significantly. The 4% top treatment reduced dust production and grain damage values to about 50% of those experienced in the untreated control. In contrast, 9% and 20% top screens were considerably more effective but differed little with dust production and grain damage about 95% and 66% lower than the control respectively (Table 4).

The estimated mean percentage weight loss (± sd) for the untreated control was 9.3 ± 3.6%, but in the treated grain with the 4% top screen this was reduced to 3.6 ± 2.9%. Further reductions to 1.3% ± 1.4 and to only 0.7% ± 0.4 were achieved with the 9% and 20% top screens respectively. It is clear that a top screen of insecticide would be of particular value in protecting against *P. truncatus* infestation gaining access to the grain bulk from the top surface but that this screen would need to extend to a depth of not less than about 10cm.

Table 3. Mean* % grain damage and mean weight of dust from grain samples treated with pesticide to different depths, fifteen weeks after 62 beetles were added at the top of the maize column.

Depth of grain	Mean % grain damage ± sd			Mean weight of dust (g) ± sd		
	No insecticide	Insecticide in bottom 20 %	Insecticide in bottom 40%	No insecticide	Insecticide in bottom 20 %	Insecticide in bottom 40%
0 - 14 cm	73.8±16.8	14.7±3.8	12.0±5.1	126.2±9.5	1.0±1.7	0.6±1.0
14 - 28 cm	46.8±19.9	29.8±7.1	13.1±5.4	79.5±4.4	28.6±14.7	0.7±1.2
28 - 42 cm	-	-	-	38.8±8.3	46.9±19.4	6.0±5.2
42 - 56 cm	-	-	-	56.1±13.0	68.7±9.8	24.0±21.8
56 - 70 cm	–	–	–	52.8±20.1	56.7±26.1	42.9±12.0
70 - 84 cm	–	–	–	102.6±17.5	48.2±27.1	42.7±12.3
84 - 98 cm	80.1±4.4	53.4±6.7	46.8±14.2	126.4±37.2	128.4±43.5	58.9±7.1
98 - 112 cm	82.4±3.7	47.3±6.3	41.8±17.7	219.1±27.1	120.5±34.2	80.2±34.3
112 - 126 cm	70.3±21.3	37.6±13.0	37.3±18.5	187.7±49.3	117.7±88.2	38.7±5.8
Mean	70.7±13.2	36.6±7.4	30.2±12.2	109.9±20.7	68.5±29.4	32.7±11.2

* Mean of three replicates SED between mean values for dust = 13 75

NB Shaded zone is approximate area treated with Actellic Super

Table 4. Mean* % grain damage and mean weight of dust from grain samples treated with insecticide at the bottom of the bulk and to different depths at the top of the bulk, fifteen weeks after 62 *P. truncatus* were added to the top of the bulk.

Depth of grain	Mean % damaged grain ± sd				Mean weight of dust(g) ± sd			
		Bottom 20% of grain treated				Bottom 20% of grain treated		
	Control	+ top 4%	+ top 9%	+ top 20%	Control	+ top 4%	+ top 9%	+ top 20%
0 - 14 cm	62.7±12.2	**21.6±0.06**	**20.3±4.6**	**21.9±3.4**	83.1±18.1	**1.6±1.4**	**3.7±1.0**	**3.9±1.8**
14 - 28 cm	44.7±8.5	23.5±2.0	18.5±2.7	**19.5±3.1**	40.2±10.4	27.8±6.1	7.7±3.8	**4.7±0.9**
28 - 42 cm	38.9±3.3	34.4±5.3	22.7±1 4	23.9±1.2	45.3±5.8	49.6±6.5	11.0±7 4	4.5±1.8
42 - 56 cm	38.9±12.3	36.4±11.0	25.6±8.6	19.2±3.9	65.4±23.6	65.7±20.0	13.9±10.0	3.9±1.5
56 - 70 cm	60.3±20.4	36.2±2.8	22.5±10.0	17.4±2.1	78.6±31.9	57.0±35.2	16.3±12.9	3.7±0.7
70 - 84 cm	63.7±30.8	35.5±4.6	23.4±7.9	17.6±1.8	102.4±51.1	63.2±34.6	14.7±12.4	5.0±2.6
84 - 98 cm	86.6±12.6	35.9±8.6	22.6±10.5	20.2±2.5	191 7±113 2	63.7±29.8	10.4±8.8	3.8±0 5
98 - 112 cm	82.6±11.1	**32.4±5.8**	**21.7±5.0**	**18.3±4.1**	338.7±119 4	**74.2±52.9**	**8.8±4.3**	**5.1±1.2**
112 - 126 cm	98.3	**25.6±8.3**	**19.2±1.5**	**20.8±1.4**	231.0	**23.0±23.5**	**5.8±5.5**	**5.9±0.7**
Mean	64.1±13.9	31 3±5.4	21.8±5.8	19.9±2.6	130.7±46.6	47.3±23.3	10.2±7.3	5.0±1.3

*Mean of four replicates SED between mean values for dust = 1 95

NB Shaded zone is approximate area treated with Actellic Super

Field Study

Protection of maize grain stored long-term in mud silos using localised pesticide treatment at the top and bottom of the bulk

In the treated silos, grain damage was on average about 13% lower than the untreated control (Table 5) However, a more substantial difference was observed in weight losses suggesting that the damage suffered by treated grain was more superficial Weight losses after 22 weeks in treated silos had reached only 1.6% compared with nearly 8% in the control. At the end of 24 weeks, separate estimates were made of the weight losses at the top and bottom of the silos: again there was a large difference between treatment and control with the treated grain remaining below 2% and the untreated silos suffering at least 9.5% weight loss (Table 5). The grain at the top of the silos tended to suffer a small but consistently greater weight loss compared with that at the bottom (Table 5). In neither the treated nor control silos were the numbers of *P truncatus* high and over the whole trial the mean numbers (± sd) of live and dead adults were only 1.40 (± 1.50)/kg and 0.07 (± 0.09)/kg in the control and treated silos respectively. Numbers of two other species were broadly comparable between untreated and treated silos: *Sitophilus* sp. (7.50 ± 7.80/kg and 6.40 ± 4.90/kg) and *Tribolium castaneum* (Herbst) (31.80 ± 34.40/kg and 24.80 ± 20.30/kg) respectively. The major difference was in the numbers of *Rhyzopertha dominica* (F): the untreated silos averaged 31.0(±50.1)/kg over the whole test and had 163.0/kg at the end of the trial while treated silos averaged only 0.6 (± 0.8)/kg and had 5.2/kg at the end of the trial

In view of the much lower weight losses observed in treated silos, it is clear that localised treatment, involving the application of only 50% of the standard insecticidal dust, gives adequate protection of the grain.

Discussion

Laboratory studies, undertaken using long plastic tubes filled with maize, have confirmed that a substantial proportion of the population of both *P truncatus* and *S. zeamais* will penetrate to considerable depths in bulk maize within a fairly short period (less than three weeks). Application of pesticide to only the lower portions of the grain bulk, the bottom 25cm out of a full depth of 126cm, can reduce attack by *P truncatus* but the addition of a top screen of about 10 cm depth appears to be important for keeping grain losses low over extended storage periods if insects can gain access to the grain from the top of the bulk It is of interest to note that grain treated with Actellic Super at the recommended rate, with a confirmed active ingredient, still suffered some insect damage and weight loss. It must be assumed that inadequacies of insecticide admixture allow some insect survival It would appear that the probability of insects being killed is proportional to the depth of treated grain through which they have to move: thus a 5cm treated top layer apparently caused little mortality of the insects that moved through it, while 10cm and 25cm gave progressively greater mortalities

The laboratory observations of the efficacy of insecticide treatment of the base and top layer of the maize bulk were confirmed in a field trial in mud silos, over a storage period of 24 weeks. However, the main focus of this investigation, *P. truncatus*, played little part in the field study since for some reason it did not thrive in the control silos. However, the untreated silos became heavily infested with *R. dominica*, a closely related beetle, while in the treated silos this species was severely limited and significant grain losses prevented

Good protection in grain bulks with localised treatments may not be achieved under all circumstances, particularly if insects do not to venture from the untreated portions into those with pesticide. This might be the case where there is significant variation in grain quality or micro-climatic factors across the bulk or where there is no regular grain consumption, i. e no regular disturbance that might cause insect dispersal onto the treated grain Further study is required to determine whether significant long-term protection can be achieved in the absence of grain consumption.

If partial grain treatment is to be adopted by farmers, then mud silos with two discharge ports would be useful. The middle discharge port would be used for grain removal until all the middle and upper portions of grain have been removed. Thereafter, the lower discharge port would be used. Currently, in Ghana, mud silos are traditionally emptied by removal of grain from the top. There would therefore have to be some changes in design to accommodate the treatment method. Mud silos with discharge ports are built in other parts of Africa, such as Tanzania, so it may not be too difficult to modify the existing design.

Table 5. Mean % grain damage and mean % weight loss (± s. d.) from grain in mud silos with either no insecticide treatment or treatment confined to top and bottom layers.

Weeks after treatment	Untreated silos			Treated silos		
	% grain damage	% weight loss		% grain damage	% weight loss	
6	1.0 ± 1.08	-		6.0 ± 4.1	-	
10	15.6 ± 11.5	-		3.8 ± 2.5	-	
14	23.3 ± 14.9	-		7.3 ± 4.7	-	
18	19.5 ± 4.5*	-		13.6 ± 4.1	-	
22	28.8 ± 5.3+	7.8 ± 1.5+		13.9 ± 3.6	1.6 ± 1.0	
		Top	Bottom		Top	Bottom
24	36.0 ± 2.6+	14.5 ± 2.4+	9.5 ± 4.0+	20.1 ± 10.5	1.6 ± 2.2	0.84 ± 1.2

Estimates made on four replicate silos except where indicated otherwise * Reduced to three replicates + Reduced to two replicates

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