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Facilitating the use of alternative capsid control methods towards sustainable production of organic cocoa in Ghana

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Abstract. Cocoa (*Theobroma cacao* L.) is an important foreign exchange earner for Ghana. However, production is constrained by a high incidence of pests and diseases. Based on farmers' needs, this study focused on the control of capsids, mainly *Sahlbergella singularis* Haglund and *Distantiella theobroma* (Distant) (both Hemiptera: Miridae). Annual crop loss caused by capsids is estimated at 25–30%. To control capsids, formal research recommends application of synthetic insecticides four times between August and December. However, farmers hardly adopt this recommendation, which they consider unsuitable for their conditions and context. Three alternative control methods were tested with farmers: mass trapping, using sex pheromones; applying crude aqueous neem *Azadirachta indica* A. Juss. (Meliaceae) seed extract (ANSE) and using the predatory ant *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae) as a biological control agent. Contrary to most previous reports, studies on temporal distribution of cocoa capsids indicated that the population peaked in March. ANSE was effective against capsids and other cocoa insect pests and did not affect the predatory ant. When *O. longinoda* occurred in high numbers, capsid incidence was low. Shade did not influence ant or capsid abundance significantly. ANSE caused 100% mortality of capsids in cage and 79–88% in field experiments. The sex pheromone was as effective as ANSE or ants in suppressing capsids. All the three methods were effective and compatible; hence, they can be used in an integrated pest management strategy for cocoa, including organic production in Ghana.

Key words: *Distantiella theobroma*, integrated pest management, neem, *Oecophylla longinoda*, *Sahlbergella singularis*, sex pheromone traps, *Theobroma cacao*

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Introduction

Cocoa *Theobroma cacao* L. (Sterculiaceae) has been grown in Ghana since the second half of the nineteenth century. Ghana became the world's leading producer of cocoa from 1910 to 1979, contributing to a maximum of 40% of the total supply (Anon., 2000). Ghana's cocoa attracts premium prices for its quality when compared with cocoa beans from other countries. Cocoa remains an important foreign exchange earner for Ghana. However, after 1965, production consistently plummeted and became as low as 158,000 MT in 1983–1984 (Anon., 2000). This decline was due to low yields caused by the high incidence of pests and diseases, poor crop husbandry because of low producers' prices and increased labour costs (Padi *et al.*, 2002). Cocoa production rose from 496,846 t in 2002–2003 to an all time record high of 736,911 t in 2003–2004, an increase of 48.3% (Anon., 2005). In spite of this increase, the national average yield of about 400 kg/ha falls short of an expected 1–5 t/ha achieved on experimental plots (Asante and Ampofo, 1999). Low yields in cocoa require further attention since massive clearing of the already largely reduced virgin forest lands for cocoa cultivation (as in the Western Region of the country) as a measure to increase production appears unlikely.

Presently, there are three major limiting factors for cocoa production in Ghana: cocoa swollen shoot virus (CSSV) disease, black pod disease and capsids (Hemiptera: Miridae). Other cocoa pests but of less importance include the stemborer *Eulophonotus myrmeleon* (Felder) (Lepidoptera: Cossidae), termites and pod feeders *Bathycoelia thalassina* (Herrich–Schaeffer) (Heteroptera: Pentatomidae) (Padi *et al.*, 2002). CSSV disease is transmitted by mealybugs (Homoptera: Pseudococcidae). The black pod fungal disease is mainly caused by two *Phytopthora* species *P. palmivora* (Butler) and *P. megakarya* (Brasier & Griffin). The latter is the more aggressive of the two pathogens and can cause total loss of pods (Opoku *et al.*, 2000); the former causes less severe crop losses and can be controlled using cultural practices.

Capsids are considered to be one of the main causes for low yields of cocoa in Ghana. The main species involved are *Distantiella theobroma* Distant and *Sahlbergella singularis* Haglund. Capsids can cause an annual crop loss of 25–30% (Anon., 1951). Both adults and immature nymphs use their needle-like mouthparts (stylets) to inject saliva into plant cells and ingest sap from stems, branches, cherelles and pods (Entwistle, 1972). As a result, the penetrated host cells die producing necrotic lesions. This usually does not affect mature pods but immature pods may wilt. Capsid feeding on shoots is usually followed by a fungal infection, often resulting in the death of terminal branches and leaves affecting the cocoa tree canopy, and ultimately causing dieback (Entwistle, 1972). In the end, yields decline and the infested trees may eventually die. Estimating capsid impact is complicated because they are part of a pest–disease complex (Padi *et al.*, 2002) and are associated with physiological dieback (Entwistle, 1972).

The main method recommended by the Cocoa Research Institute of Ghana (CRIG) for capsid control has been the use of synthetic insecticides. The major insecticides being used by motorized mist blower spraying machines are: Confidor 200 SL (imidacloprid) 150 ml/ha; Cocostar (methylpirimiphos) 500 ml/ha and Carbamult (promecarb) 1.4 l/ha. The insecticides are supposed to be applied as a prophylactic measure four times from August to December, omitting November. However, there are several constraints to the adoption of chemical control methods: the high cost of insecticides and labour, expensive spraying equipment and low return on investments due to low producer prices (Henderson *et al.*, 1994). Meanwhile, there are reports about abuse and misuse of insecticides by cocoa farmers, including the application of unapproved insecticides such as pyrethroids Decis (deltamethrin) and Karate (lambda-cyhalothrin) and the organochlorine Thiodan (endosulphan) (Henderson *et al.*, 1994; Padi *et al.*, 2000). In addition to the human and environmental health risks as well as the high costs involved, there are concerns about development and/or resurgence of capsid resistance as was first found at Pankese in the Eastern Region of Ghana in 1956 (Entwistle, 1972). These constraints motivate the search for more affordable, effective and environmentally acceptable alternative capsid control methods that would rely on low external inputs and better fit into farmers' conditions and context.

CRIG and others have begun investigations into alternative capsid control methods such as the use of resistant/tolerant cocoa varieties, botanical pesticides and sex pheromone traps (Padi *et al.*, 2002). We conducted a diagnostic study with farmers and scientists at Brong-Densuso in the Eastern Region of Ghana. Following this study, it was agreed with the farmers to investigate three alternative methods to control capsids. These were the use of: (i) sex pheromone traps suggested by CRIG; (ii) crude aqueous neem *Azadirachta indica* A. Juss. (Meliacea) seed extracts (ANSE), suggested by the farmers' association and CRIG and (iii) the predatory ant species *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae) as a biological control agent, proposed by farmers (Ayenor *et al.*, 2004).

Materials and methods

Experiments

The following experiments were conducted:

1. Determination of the effective dosage of neem in a cage experiment.
2. Effect of predatory ants (*O. longinoda*) on capsids.
3. Effect of shading on capsid and predatory ant incidence in cocoa.
4. Effect of different control methods on capsid population and damage: neem, predatory ants and sex pheromone traps.

Study area

The study was conducted with farmers from Brong-Densuso in the Suhum/Kraboa/Coaltar District of the Eastern Region of Ghana (Ayenor *et al.*, 2004). As the study area was exempted from the government-organized Cocoa Disease and Pests Control (CODAPEC) spraying programme with synthetic pesticides, these farmers are attempting to grow organic cocoa. Most of the farmers practise mixed farming where cocoa is sparsely intercropped with various other crops (e.g. oil palm, banana, plantain) on small parcels of land usually inherited from their parents. The cocoa farms have large overhead shade trees, most of which were wild and either left to grow during establishment or deliberately planted to provide shading to the young cocoa trees. The field experiments were conducted on already established cocoa farms; each plot selected measured 0.25 ha and plots were separated from each other by at least 100 m. The field experiments were negotiated and conducted with farmers who, because of time constraints, insisted on only three replicates.

Experiment 1: Effective neem dosage

Neem seeds were bought from Kodiabe in the Eastern Region, and were dried, weighed (150, 200, 250 and 300 g), milled and soaked in 1 l of water for 24 h. Each suspension was sieved using a 0.5 mm mesh width and the filtrate was used as the neem spray. Sixty adult capsids (*S. singularis*) were placed in 15 cages of $0.4 \times 0.5 \times 1.5$ m made with nylon mesh and wood. Each cage contained two cocoa seedlings of about 0.7 m height and two pods of similar surface area as food for four capsids. The capsids were observed for 24 h and when no mortality occurred, treatments were applied. Crude neem seed extracts were compared with a control treatment (1 l of distilled water). A hand sprayer was used for the application, which released about four squirts of the spray to cover each of the feeding materials in the cages. Data collected were numbers of dead insects and lesions caused on the seedlings and pods in 24 h before and 6, 12, 24, 36 and 48 h after spraying.

Experiment 2: Effect of predatory ants on capsids

The effect of the predatory ants was established by comparing six plots, where ant nests were abundant in the three plots and virtually absent in the others. During 1 year, for each month, we counted capsid numbers on the trunks of cocoa trees and pods within reach of about 2 m from the ground as well as the number of visible ant nests about 3–4 m from the ground when looking into the canopy.

Experiment 3: Effect of shading on incidence of cocoa capsids and presence of ant nests

The shading was mostly caused by large wild trees and two criteria were used to distinguish two shade conditions:

1. The number of fully established overhead shaded medium to big trees had to be at least 12 per plot for the heavily shaded and less than five for the lightly shaded plots.
2. Open space without any cover from cocoa trees or wild overhead trees (broken canopy) was not exceeding 3 m^2 within the plot to qualify for a heavy shaded plot/treatment.

The data collected from July 2003 to December 2005 were monthly numbers of capsids and *O. longinoda* (ants) nests.

Experiment 4: Effect of different control methods on cocoa capsids' population and damage

The design was (almost) a randomized complete block; replicated three times. Each block had four plots, of which one was the control (sprayed with water) and the other three being separate treatments: (i) sex pheromone traps, (ii) neem applications and (iii) predatory ants. Weeding was done twice a year to ensure uniformity across all the fields. The mistletoe *Tapinanthus bangwensis* (parasitic plants), infested pods caused by black pod disease, chupons and dead branches were removed from all fields every 3 months.

Crude aqueous neem seed extract (ANSE)

Crude neem extract was sprayed with a Solo motorized mist blower of 12.5 l capacity at 200 g/l (20 kg/ha) based on the result of the cage (Experiment 1). Spraying was carried out when the threshold of six (adult) capsids per 10 trees was reached (Entwistle, 1972). In the last year (2005), the mean capsid numbers were below the threshold. However, in two plots, the threshold was reached and we decided spraying on those. To avoid contamination with synthetic insecticides, the Solo motorized mist blower was used exclusively for neem spraying.

Sex pheromone traps

Eight pheromone traps per plot were used. Each trap had the same standard lure recommended by CRIG and the Natural Resources Institute (Padi *et al.*, 2001). The traps were suspended on cocoa trees branches at 2 m above the ground level, 6 m apart. A ninth trap per plot with no lure was added to serve as a control. The traps caught males of both capsid species (*D. theobroma* and *S. singularis*) which were distinguished and recorded. The rectangular traps were constructed from Corex sheet (38 cm long with cross section 10 cm wide × 14 cm high) with Corex liner (28 cm long coated with polybutene sticker (Tanglefoot)) on both inner base and inner side surfaces. The traps were baited with the synthesized pheromones (supplied by Natural Resource Institute, UK to support CRIG's pest management programme) to lure the male capsids into the sticky medium where they would die. The lures and the Corex liner were replaced with new ones after every 3 months. The outer layer of the traps was changed annually.

Predatory ants

Areas with abundant nests of naturally occurring *O. longinoda* were identified with farmers. Their average occurrence or abundance per 50 trees/plot was rated as 1 (low: 0 nest), 2 (average: 1–2 nests), 3 (high: 2–5 nests) and 4 (very high: >5 nests). Plots of high *O. longinoda* occurrence (level 3) were selected for the experiment.

Data collection and analysis of the three alternative control methods

In each plot, 50 cocoa trees were randomly selected and tagged for monthly data collection. The data collected (July 2003–December 2005) were number of capsids, number of fresh capsid lesions on pods and number of cocoa trees with other cocoa insects. They were cocoa mosquito/mirid *Helopeltis* spp., mealybugs *Planococcoides njalensis* (Laing), termites *Glyptotermes parvulus* (Sjost), aphids *Toxoptera aurantii* (Boyer de Fonscolombe), podborers *Conopomorpha cramerella* (Snellen) and the predatory ant *O. longinoda*. Insects on the trees were counted up to about 2 m above the ground and ant nests that could be seen up to about 3–4 m from the ground. Pods were lifted to find all insects. For the neem experiment, the monthly counting served as a basis to decide whether to spray. Sampling was conducted 48 h after spraying. Pods were harvested each month within the periods from September to December in 2003, 2004 and 2005. Cocoa trees with capsid damage on canopy (foliage) were assessed each July in 2003, 2004 and 2005 using the Hammond index: no damage (0%); mildly damaged (1–20%); moderately damaged (21–50%) and severely damaged (51–100%) (Johnson and Burge, 1971). The data were analysed using univariate ANOVA (*post hoc* Tukey: $P < 0.05$) to test the efficacy of the three capsid control methods.

Results

Effective neem dosage

During the first 24 h before spraying in the cage, no mortality was observed at the different neem concentrations used. The control (sprayed with water only) did not show any mortality in the entire duration of the experiment. However, 100% mortality was achieved after 24, 36 and 48 h in the 300, 250 and 200 g/l treatments, respectively. Since the 200 g/l dose rate achieved 100% mortality after 2 days, this concentration was chosen for the field trial. After the application of neem, capsids' feeding ceased on both substrates, while in the control, 215 lesions on pods and 73 on seedlings were counted.

Capsid population dynamics

The population dynamics of capsids monitored using sex pheromone traps are shown in Fig. 1. In two successive years, March was the peak of capsid population followed by August to December. At high numbers of the two capsids, *D. theobroma* and *S. singularis*, the incidence of the first one increased even up to 100% in March and April.

Effect of ant abundance on cocoa capsid

Where *O. longinoda* nests were abundant, capsids were virtually absent (Fig. 2). Capsids in control plots increased while ants' nests population was low.

Effect of shading on capsid and ant incidence

Capsids' counts recorded in the lightly shaded areas were higher than those in the heavily shaded areas, although the pattern of incidence over time was similar (Fig. 3). Further analysis concentrating on the peak and low capsid occurring periods showed that capsids were more abundant in lightly shaded areas than in the heavily shaded areas,

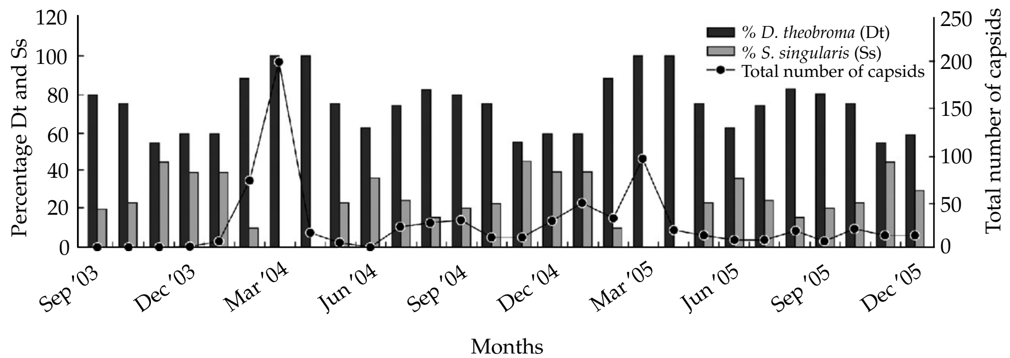

Fig. 1. Numbers of capsids trapped by sex pheromones (in 24 traps) showing the relative abundance of *Distantiella theobroma* and *Sahlbergella singularis* in experimental cocoa plots in Ghana (September 2003–December 2005)

while ant nests were generally more abundant in the heavily shaded areas, although the differences were not significant (Table 1).

Alternative capsid control methods

The means of capsid incidence and fresh feeding lesions in the three treatments (neem, sex pheromones and ants) were all significantly lower compared with the control, both in 2004 and 2005 (Table 2). The treatments with ants and sex pheromones significantly reduced capsid incidence more than the neem treatment in both 2004 and 2005. With regard to capsids' lesions, there was only a significant difference in 2005: ants performed better than the sex pheromone and the neem treatment.

No significant differences in canopy foliage scores of treatments between July 2003 and July 2005 were found (Table 3). The ant and the sex pheromone treatments did not perform differently from the control. Only the neem treatment had better canopy cover and, therefore less, though not significantly, damage than the control.

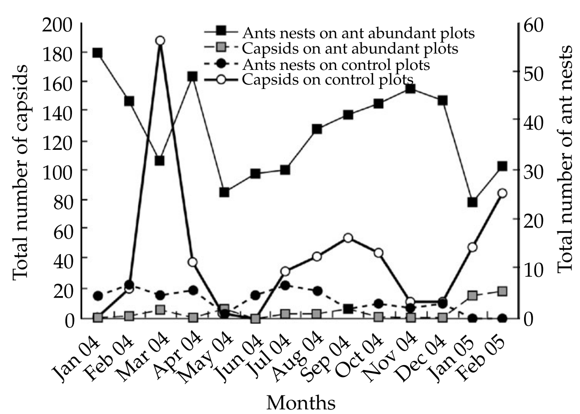

Fig. 2. Effects of ant abundance on capsid incidence on 150 trees in experimental cocoa plots in Ghana

In 2003, yields (number of pods per ha) of the neem and the ant treatments did not differ significantly from the control (Table 4). The yield in the sex pheromone treatment was significantly lower than that of the control and other two treatments. In 2004, only the yield in the ant treatment did not differ significantly from the control, although it was about a quarter higher. The yield in the neem treatment was highest and significantly different from the control and the ant treatment. Due to low rainfall (Table 5), yields in 2005 were generally lower. Yields in this year in the three treatments did not significantly differ from each other, but were significantly higher (>70%) than the control (Table 4).

Neem applications reduced the number of capsids and the number of fresh capsid lesions by 80–95% in 48 h after treatment (Table 6). In the control treatment, both the incidence of capsids and their lesions showed, in most cases, an increase during the 3-day interval.

The neem treatment reduced the numbers of other (non-targeted) insects such as *Helopeltis* spp., *P. njalensis* and *B. thalassina* to very low levels in 2.5 years (Table 7). However, neem did not affect the incidence of the predatory ant *O. longinoda*.

Discussion

Cage experiment on effective neem dosage

The cage experiment was used to determine the appropriate dosage of neem and its mode of action on cocoa capsids. The concentration of 200 g/l was chosen because it was effective and required less neem seeds to process than the two higher dose rates of 250 and 300 g/l. Neem does not only kill on contact, but also inhibits capsids' feeding. In addition to neem's antifeedant properties and lethal effect on capsids, other studies have documented its additional ability to repel insects (Adu-Acheampong, 1997; Padi *et al.*, 2004).

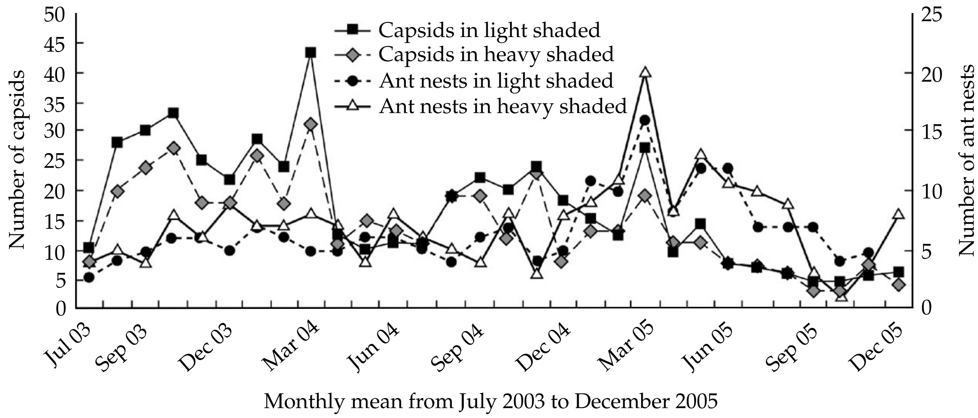

Fig. 3. Effect of shade on capsid and ant nests in cocoa using 150 cocoa trees in experimental plots in Ghana

Capsid population dynamics

The numbers of capsids caught in the traps indicated the general population fluctuations during the year, although some caution is needed during a high incidence of capsids as the natural pheromone may compete with the synthetic one and so trap catches could be undervalued. *Distantiella theobroma* was more prevalent in the area than *S. singularis*, particularly during the peak periods (March and April).

The peak period for capsids was observed to be in two successive years (Fig. 1). This finding contradicts previous reports on the temporal distribution of capsids in Ghana which indicated August to December as the peak periods (Entwistle, 1972; Padi and Adu-Acheampong, 2003). This period was figured as the second peak period of capsids' incidence in our study. The government's sponsored mass spraying is based on the peak in August to December. Although, our study was conducted in a relatively smaller area as compared with nationwide surveys, Padi and Adu-Acheampong (2003) working in different areas of the country also found that sometimes high numbers of capsids may occur in February and March.

Distantiella theobroma was more common in our study area than *S. singularis*. This used to be the case but recent surveys by CRIG in the country suggested the contrary (e.g. Padi and Adu-Acheampong, 2003). They attributed the dominance of *D. theobroma* or *S. singularis* in an area to be associated with the prevalence of Amelonado or hybrid cocoa varieties, respectively. Hence, they explained their findings by the general shift from the cultivation of Amelonado to hybrid varieties as the reason for the common ascendancy of *S. singularis* in Ghana. However, it is unlikely that the prevalence of one of the species in a location is only due to the most dominant cocoa variety in the area because the varieties used in our study fields were highly mixed.

Effect of O. longinoda *on capsids*

Farmers perceive the ant *O. longinoda* to be an effective predator of cocoa capsids. Based on similar observations in the 1950s and the 1960s, Leston (1971) suggested the ants as a potential biological control agent. Leston's efforts to investigate this subject was met with criticism by Marchart (1971). This criticism was at the time

Table 1. Capsids and nests of *Oecophylla longinoda* (ants) under light and heavy shade conditions in cocoa in Ghana

High and low capsid incidence periods	Capsid and ant nests counted	Mean (± SD) from different shade conditions: Light	Heavy	*F*-value	*P*-value
March 2004 (peak)	Capsids	0.86 ± 0.06	0.62 ± 0.30	2.48	0.26
	Ants nests	0.10 ± 0.04	0.16 ± 0.04	7.34	0.11
March 2005 (peak)	Capsids	0.57 ± 0.08	0.38 ± 0.05	9.23	0.09
	Ants nests	0.32 ± 0.07	0.40 ± 0.01	3.31	0.21
June 2004 (low)	Capsids	0.22 ± 0.11	0.27 ± 0.05	0.33	0.63
	Ants nests	0.13 ± 0.01	0.16 ± 0.07	1.00	0.42
June 2005 (low)	Capsids	0.14 ± 0.03	0.16 ± 0.02	0.44	0.58
	Ants nests	0.24 ± 0.07	0.22 ± 0.08	0.13	0.76

Table 2. Effect of neem extract, predatory ants (*Oecophylla longinoda*) and sex pheromone traps on capsid incidence and their feeding lesions on cocoa in Ghana (2004–2005)

Treatments	Mean (±SD) number of capsids		Mean (±SD) number of fresh capsid lesions	
	2004	2005	2004	2005
Neem extract	12.6 ± 0.9b	7.6 ± 0.7b	22.6 ± 2.2b	17.3 ± 1.7b
O. longinoda	6.1 ± 0.5c	3.9 ± 0.3c	11.3 ± 0.9b	7.8 ± 0.6c
Sex pheromone	7.0 ± 0.4c	5.0 ± 0.2c	21.7 ± 1.3b	16.4 ± 0.4b
Control	26.9 ± 0.3a	21.7 ± 0.4a	59.1 ± 15.6a	42.8 ± 3.1a

Means with the same letter in the same column do not differ significantly ($P \leq 0.05$).

Table 3. Effect of neem extract, predatory ants (*Oecophylla longinoda*) and sex pheromone traps on cocoa canopy damage by capsids between July 2003 and July 2005 in Ghana

Treatments	Mean (±SD) difference of canopy damage	*F*-Value	*P*-Value
Neem extract	0.27 ± 0.05	4.49	0.056
O. longinoda	0.18 ± 0.18		
Sex pheromone	0.17 ± 0.26		
Control	−0.17 ± 0.10		

when many believed that chemical control was the best solution (the ‘silver bullet’) for effective pest management. Brew and Koranteng (1984) reported that the ant establishes its colonies only in the vicinity of good closed canopies or on available shade trees, and equally concluded that it cannot be used as a predator of capsids. Despite these findings, some farmers continue to believe that *O. longinoda* can be used as a biological control measure, insisting that their neglect by scientists is mainly to persuade them to purchase costly synthetic pesticides. Other scientists have reported on the use of the predatory ant *Oecophylla smaragdina* Fabricius by other farmers in cashew and citrus in Australia to suppress various pests (Peng *et al.*, 1999; Van Mele and Cuc, 2003).

Effect of shading on capsid populations and O. longinoda *nests*

We could not confirm Marchart, 1971 finding that capsids are found in the lightly shaded areas and *O. longinoda* in the heavily shaded areas. He claimed that *O. longinoda* cannot be an effective predator of capsids because the two insects have different habitats and ecological requirements. Entwistle (1972), however, suggested that capsids retreat from feeding sites (lightly shaded/broken canopy areas) into areas of acceptable light intensity (heavily shaded/closed canopy) for shelter and safety. According to him, capsids and ant habitats overlap. He also found that *O. longinoda* workers preyed on *D. theobroma*; however, he was uncertain whether the ants could sufficiently protect cocoa trees against *S. singularis*, which according to him, was the more important of the two capsid species in West Africa (Entwistle, 1972).

The seemingly high population of capsids in lightly shaded areas could well be explained by the fact that the penetration of sunlight improves visibility of the cryptic insects. Capsids tend to feed more in the night and early hours of the day and not during hot hours of the day; they also prefer to hide in dark places and in microhabitats such as under pods where the relative humidity is higher (Entwistle, 1972). Therefore, it is possible that heavily shaded areas may actually contain higher numbers of capsids than observed.

Table 4. Effect of neem extract, predatory ants (*Oecophylla longinoda*) and sex pheromone traps on cocoa yields in Ghana in September–December of 2003, 2004 and 2005

Treatments	Mean (±SD) cocoa yields (pods/ha)		
	2003	2004	2005
Neem extract	13,100 ± 268a	17,676 ± 718a	10,604 ± 140a
O. longinoda	13,296 ± 275a	14,052 ± 437bc	10,364 ± 121a
Sex pheromone	10,500 ± 714b	16,452 ± 537ab	10,956 ± 304a
Control	12,880 ± 862a	11,400 ± 1,769c	6,128 ± 861b

Means with the same letter in the same column do not differ significantly (*post hoc* Tukey: $P \leq 0.05$).

Table 5. Monthly rainfall (mm) at Brong-Densuso, eastern region of Ghana (2003–2005)

Month	2003	2004	2005
January	15.3	11.2	0.9
February	53.3	73.8	38.7
March	45.8	92.0	140.8
April	153.9	59.8	55.4
May	129.7	132.3	173.3
June	194.0	184.9	72.8
July	109.3	51.0	23.8
August	78.0	54.4	59.9
September	49.9	261.1	106.3
October	242.5	119.5	133.0
November	75.7	97.8	23.3
December	21.0	82.4	18.3
Annual	1168.4	1220.2	846.5

Unlike cocoa, cashew and citrus are not normally cultivated under heavily shaded trees and *O. smaragdina*, the behaviour and ecology of which is similar to that of *O. longinoda*, is abundant enough to warrant its use as a biological control agent (Peng *et al.*, 1999; Van Mele and Cuc, 2003). Hence, we believe that shading is not an issue and that *O. longinoda* can effectively be used for capsid control in cocoa.

Evaluation of alternative capsid control methods

The three capsid control methods, sex pheromone trapping, employment of predatory ants and application of neem seed extract, were effective in suppressing capsids' numbers when compared with the control. Concerning the incidence of capsids and their feeding, the ant and the sex pheromone treatments were most effective. The difference of these two treatments with that of neem is that they remain effective, while neem works only for a few weeks. It is also possible that neem mainly repels the insects under field conditions, although it improved the cocoa canopy better than the other two treatments.

Yields obtained from all the three treatments were significantly higher than in the control. Under conditions of high and low rainfall and the control regime having been effective for 15 months (2004 and 2005), the treatments were equally effective. In 2005,

Table 6. Effect of neem extract on capsids and their feeding lesions on pods in cocoa in Ghana (average of 50 trees)

		Before/after neem treatment						Before/after water treatment (control)					
		No. of capsids			No. of lesions			No. of capsids			No. of lesions		
Year	Month sprayed	BT	AT	% Mort	BT	AT	% DecL	BT	AT	% Mort	BT	AT	% DecL
2003	September	38	5	87	126	19	85	39	39	0	139	247	−78
	November	32	4	88	121	23	81	27	30	−11	146	134	8
2004	March	34	7	79	122	11	91	46	48	−4	225	169	25
	October	30	2	93	138	15	89	31	35	−13	154	188	−22
2005+	January	13	2	85	132	7	95	22	35	−61	154	194	−26
	March	22	4	82	130	13	90	29	38	−31	167	205	−23

BT, 1 day before treatment; AT, 2 days after treatment; % Mort., percentage mortality; % DecL, percentage decrease in lesions.
+Spot spraying on two plots in January and March of 2005.

Table 7. Effect of neem extract on other cocoa insects (AT/BT) on average of 50 trees 24 h before (BT) and 48 h after treatment (AT) in cocoa in Ghana (2003–2005)

	Helopeltis sp.		*Planococcoides njalensis*		Termites		*Bathycoelia thalassina*		*Conopomorpha cramerella*		*Toxoptera aurantii*		*Oecophylla longinoda*	
Periods	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT	BT	AT
September 2003	32	0	22	13	17	9	8	5	12	3	19	7	7	6
November 2003	37	2	18	10	19	11	0	0	7	3	21	7	4	3
March 2004	39	0	19	8	24	15	3	0	5	2	11	3	9	9
October 2004	26	2	11	4	20	11	0	0	3	0	3	1	3	2
January 2005	15	5	7	3	12	8	2	0	6	0	0	0	14	11
March 2005	11	2	4	2	4	3	0	0	3	2	0	0	8	6

BT, 1 day before treatment; AT, 2 days after treatment.

the remarkable drop in cocoa yields across treatments was due to a nationwide cocoa crop failure caused by unfavourable rainfall conditions. Wood and Lass, 1985 mentioned that reduced rainfall or unsuitable distribution of rainfall can greatly affect cocoa yields. But the effect of the treatments relative to the control was still very good in 2005. Therefore, from the point of view of a stable income, it might be very worthwhile to apply especially in a dry year.

The use of neem seed extract reduced the incidence of some non-targeted cocoa insect pests that are increasingly becoming important in cocoa (Padi *et al.*, 2002). Neem does not seem to affect the predatory ant *O. longinoda*. This indicates that neem could be a more sustainable capsid control method than the use of synthetic insecticides that tend to reduce the abundance of natural enemies.

In conclusion, the three alternative capsid control methods were equally effective in reducing capsids' incidence and their lesions on cocoa pods and in increasing yields. Therefore, all three methods can be used in an IPM strategy for sustainable production of cocoa. They can also play a role in the production of fair-trade and organic cocoa products.

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