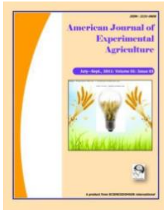

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Strategy for Insect Pest Control in Cocoa

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Authors' contributions

This work was carried out in collaboration between all authors. Authors RAA, JES, EFA and GA defined the research theme and wrote the first draft of the manuscript. Authors AN, PT and RS co-worked on associated data collection and their interpretation. Author EO provided additional information from field experiments. PT reviewed all drafts of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Farming systems in cocoa over the last three decades have involved the use of new hybrid plant varieties, which produce pods throughout the year, intensified fertilizer use, and misguided pesticide applications by some farmers. Resource availability in terms of abundance of feeding and breeding sites and ecological disruption as a consequence of climate change and bad agronomic practices have increased the importance of insect pests on cocoa. Historically the major management tool for hemipteran pests has been calendar spraying with conventional insecticides. Considerable progress was made at the turn of the last century by replacing organochlorine insecticides for cocoa mirid control. But inappropriate timing and inefficient application is probably reducing the viability of otherwise acceptable products in some areas. Integrated Pest Management (IPM) strategy for mirids and other insect control should involve great investment in pest surveillance, and be based primarily on the use of cultural practices of removal of excess chupons, shade management and

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host variety resistance. These practices must primarily aim at minimising mirid-associated dieback disease and stink bug deformation of pods, and should be supplemented in some cases by the use of insecticides (up to two applications in February to May at 28-days intervals) depending on the pest populations, damage levels as well as intensity of activity of pollinating insects, with additional two applications during September to December when pest problems may arise. Improved methods of monitoring and prediction should assist in early identification of specific problems in different farms. The rotational use of different active ingredients should also take into account factors such as application methods, compatibility and correct timing. Careful planning is necessary to formulate a flexible control system.

Keywords: Mirid; pest control; cocoa; farming systems; control strategy; correct timing; dieback disease; insect pest; flexible control system.

1. INTRODUCTION

Mirids (*Distantiella theobroma* [Dist.] and *Sahlbergella singularis* Hagl.) and stink bugs (*Bathycoelia thalassina* (Herrich-Schaeffer) are known for their importance in causing losses in cocoa (*Theobroma cacao* L.) in West Africa [1-3], with the most prevalent in Ghana being *S. singularis*. The authors have outlined the problems associated with mirid and stink bug infestation. Both nymphal and adult stages feed and inject saliva to liquefy plant tissues. Their feeding punctures provide entry points for fungal pathogens [4-7]. This secondary invasion of mirid feeding punctures causes dieback disease whilst that by stink bugs results in premature ripening and deformation of pods and beans. The main method of mirid control is by the application of conventional insecticides, but stink bugs have often been controlled indirectly by treatments normally used for the control of mirids.

In Ghana, new pests have emerged and their control is difficult compared with three decades ago [8]. There are several contributory reasons for this: farmers still have to be familiarized with optimal techniques of using the new generation insecticides that have largely displaced the organochlorine and carbamate compounds. The global quality standards of insect pest control in cocoa needed to guarantee high quality produce for global market outlets have increased, setting targets for maximum residue limits of pesticides, which in some instances are clearly not attainable.

A fast and correct diagnosis of pest incidence is the first important step in attempting any control procedure. Earlier studies [9] have concluded that pest control systems in cocoa must be revised as a result of changes in farming systems, pest cycles and shifts in pest population peaks.

Before discussing the strategy for mirid control in cocoa in Ghana it would be useful to examine the history of this insect's control.

Before the 1970s damage caused by mirids was well appreciated as well as the importance of dieback disease that follows mirid feeding on green unhardened tissue (pods and stem). Efforts were concentrated on understanding population fluctuations of mirids on different varieties of cocoa, their distribution within trees as well as the effect of water stress on the incidence of pests. The tendency for average population levels to remain low until a sharp rise in August or September was the basis for the establishment of the calendar spray regime beginning in August until December (but omitting November) [10]. This was to replace an older recommendation of June, July followed by a three-month gap [11]. Currently, two seasonal peaks varying from September-December and February-May in different locations is an average phenomenon. Plant breeders at the Cocoa Research Institute of Ghana (CRIG) have developed varieties of cocoa resistant to swollen shoot and black pod which are also high yielding but unfortunately this resistance does not seem to be durable enough when the varieties are challenged under farmer conditions. Very little effort was spent on breeding varieties with resistance to mirids or other insect pests. Field observations usually gave strong indications that mirids caused less damage to some Trinitario selections (e.g. SC1) than the common West African Amelonado [12]. This was confirmed later [13], with SC6 identified as one of the tolerant selections to fungal-induced dieback disease in cocoa. In compiling its list of recommended varieties to the seed gardens, CRIG takes a firm line in rejecting varieties susceptible to swollen shoot disease and encourage the development of resistance to black pod disease. Unfortunately, the Institute does not follow an equally firm policy for insect pests.

Insecticides (nicotine sulphate and DDT) were first introduced in the 1940s against mirids because accumulated knowledge highlighted these insects as the most important pests. In the following years, several insecticides including endrin, dieldrin, heptachlor and lindane were introduced against mirids, which were also aimed at the control of mealybugs (*Planococcoides njalensis* (Laing), *Planococcus citri* (Risso) and *Ferrisia virgata* (Ckll)) which are vectors of cocoa swollen shoot virus disease. Unfortunately, insecticides were applied prophylatically and at times when the pests were already present at damaging levels.

The percentage of cocoa trees that was treated with insecticides in the 1950s is difficult to estimate accurately, but it rapidly increased in the 1960s [14]. Cocoa output reached an all-time high of 560,000 tonnes in 1964/1965. Nearly all the insecticides used were against mirids due to their relative high economic importance while the adoption of insecticide use for other insect pests was slower. Later on, a growing concern for the environment and for the conservation of wildlife was raised. At present, environmental and consumer safety dictate the sustainable usage of chemicals. In this connection cocoa farms are unique because of the large areas they occupy (nearly 2 million hectares in Ghana) which is a major factor to be taken into account when considering strategies for pest control.

During the last two decades, and especially since 2000, there have been very significant developments in nearly all aspects of cocoa insect pest control. Farmers have become very conscious of the importance of insect pests, and data accumulated in mirid surveys on cocoa would enable objective assessments to be made [9]. Although data on yield and financial losses due to pests are not readily available (due to varying farm management systems), surveys demonstrated clearly that mirids and stink bugs are the most important pests [15].

The field of mealybug-vector control has seen fewer successes. The use of systemic insecticides such as Monocrotophos SC was a much more convenient way of controlling swollen shoot virus vector in cocoa. The method suffered a setback when it was detected that the chemicals (mainly organophosphate insecticides) caused tainting of beans [16].

For control of pod feeding insect pests, the present system of insecticide usage ensures that pests are kept at very low levels. A possible danger now is that famers faced with increased insecticide costs have tended to procure cheaper unapproved insecticides and omit the registered insecticide treatment. This calls for an urgent need to make the approved insecticide products sufficiently available (in pesticide retail shops) so as to cause a reduction in prices through market competition.

Improvements in the monitoring and forecasting of the major pests on the new varieties of cocoa recently became evident [17], but the shift in dominance between the two important mirid species is not adequately understood, and should be studied further. Cultural practices which reduce serious insect pest attacks should obviously play an important part in a control system. Such practices may include pruning, chupon removal, agro-forestry, shade management, removal of alternative hosts, weeding and fertilizer application [18]. Apart from these, the main emphasis in insect pest control will be on the use of resistant varieties reserving the use of chemicals for when economic threshold levels are exceeded.

2. BIOLOGICAL CONTROL

Past observations in Sierra Leone indicated low levels of mirid infestation. This prompted a search for natural enemies in Sierra Leone and the Congo but no significant effort to introduce natural enemies have thus far being done.

3. HOST PLANT RESISTANCE

Nearly all the damage to cocoa trees of the 1950-1960s was associated with the growing of very susceptible varieties including Amelonado [19]. But no variety has expressed a satisfactory level of resistance to *S. singularis* and *D. theobroma.* In one of the few studies to address the issue, [20] found that many local and international cocoa selections were highly preferred by mirids as suitable hosts for feeding and oviposition. This apparent lack of genetic variation in host preference requires further investigation, especially since genetic variation for resistance has been observed in several other systems [21,22]. However, the development of a strategy for pest control could include varieties resistant to dieback disease resulting from hemipteran related fungal invasions as was shown in later studies [13].

Identification and categorization of sources of resistance for developing pest resistant cocoa varieties should be pursued by biotechnology and traditional plant breeding. Observations at CRIG have shown that by mixing several varieties (each of them contributing a different form of genetic resistance), pest outbreaks can be reduced [23]. The push-pull effect through use of semio-chemicals to repel insect pests from the crop (‘push’) and to attract them into trap crops (‘pull’) must be exploited in future IPM strategy. Farmers seem to have understood the need for cocoa varieties as well as shade trees and food intercrops. It will be interesting to see whether this work will lead to at least a partial solution, of the cocoa mirid problem.

4. MONITORING AND PREDICTION

Hemipteran pest populations in cocoa are spatially and temporally patchy with many individuals exploiting cryptic habitats [24]. An ability to predict or forecast severe outbreaks of pests is obviously an advantage when planning control programmes as that can lead to the selective, timely and precise use of chemicals.

Information from farms can be collected and fed into a central computer database, which can be managed by CRIG and the Cocoa Health and Extension Division of Ghana Cocoa Board. These organizations can receive information from many sources apart from their staff, notably the representatives of the many licensed cocoa buying companies and certification agencies serving farmers, as well as directly from farmers themselves. This information can be processed and released at fortnightly or monthly intervals for use on radio, television and the press. Farmers can receive useful guidance on the pests they should be looking out for. An improvement in the use of information dissemination services would lead to timely awareness of insect pest problems in cocoa farms as well as drastically reduce response times.

There is, however, very little information which can be used to predict the spread of pests. Whilst it is unlikely that spraying for insect pest control could be based entirely on prediction systems, a planned programme of timely sprays could be modified if the status of the biology of the specific insect pest was known. For example, that certain weather conditions might be favourable for the spread of a particular insect pest. Moreover, it is suggested that a monitoring programme where pest incidence as well as meteorological parameters are monitored should be established.

5. CHEMICAL CONTROL

Insecticide use in cocoa in the future should aim to supplement the control given by cultural practices, varietal selection and other methods, within an Integrated Pest Management programme. Experience gained from pest assessments at CRIG may lead to timely chemical treatments of cocoa which is sustainable in the case of cocoa pest control. It is common for farmers who have invested a lot of time and money in maintaining their cocoa farms to spray prophylatically as a precaution against possible pest outbreaks [9]. It is also true that it is difficult to predict the development of some pests, such as stink bugs and stem borer adults in cocoa. Farmers may also be unable to spray a large area at short notice. Furthermore, a high yielding cocoa farm is more likely to be susceptible to insect pests than a low yielding cocoa farm (as there would be plenty of feeding and egg laying sites [9], and with a higher potential profit the farmer can afford treatment costs. There should, thus, be separate timely recommendations for potentially high yielding cocoa farms as routine sprays on cocoa farms with lower than average potential yields are generally uneconomical.

Where insecticide use is planned, the approach should be flexible, taking into account the likely occurrence of pests but will also depend on factors such as geographical situation, varietal choices, and weather at critical times, as well as facilities available to the famer to apply the chemical.

In recent years, insecticides registered for mirids have been used in more than 40% of cocoa farms in Ghana. Discussions with farmers suggest that the majority of the unsprayed cocoa farms would also have benefited from the government’s ‘mass spraying’ treatment. There are currently no pest management action thresholds for hemipteran pests of cocoa but guidelines outlined in Table 1 provide a general recommendation). Visual assessment up to hand-height (or two metres above ground level) [25] suggests that the rate of increase does not follow a definite pattern as severely devastated trees can have very low insect numbers. This is contrary to the case for many plant-pest relationships where severely damaged plants tend to have a lot more insect numbers some of which might undoubtedly be difficult to locate. There should, therefore, be a plan for timely treatment or contingency use of insecticide in cocoa farms for mirid and stink bug control. Some of the ways of considering insecticide use in cocoa are depicted in Table 1.

Table 1. Farm-specific recommendation for mirid and stink bug control in cocoa

Prediction	Recommended treatment
1. Mirid and stink bug damage unlikely (<5 individuals/100 trees	No spraying required; watch out
2. Mirid and stink bug slight/moderate (5-10 individuals/100 trees	Timed spray* spot treatment
3. Mirid and stink bug moderate/severe (>10 individuals/100 trees)	Spray whole farm and repeat approx. 4 weeks later

**Timed spray – insecticide applied as soon as 3-5% trees or pods are affected. Source: Emmanuel Obeng, CRIG, unpublished data*

In planning a pest management programme, it is often necessary to consider the speed of chemical application which comes with a cost. Subsequently, it would be unreasonable to rely on a calendar spray system if large areas are involved. Probably it will be better to use more than one of the programmes suggested above in order to spread the work-load. Nevertheless, farmers are advised to move entirely away from calendar sprays and to optimize the biological control component by spraying strategically. This is difficult in most of Africa where not all farmers have the necessary spraying equipment. In a situation of a second pest, the insect would have to be considered separately or the pest would have to be treated irrespective of the mirid situation as has happened in the past with *Anomis* sp. and other caterpillars.

In June to August in many years, most pests tend to occur intermittently and the economic benefit from spraying is much less obvious than during occurrence of mirids (i.e. September to May). On most cocoa farms a sensible programme should be to aim treatment at the control of mirids and the other important pests such as stink bugs. A two-spray regime programme- two sprays in the first quarter of the year to control mirids and stink bugs attacking cherelles (young cocoa pods) and a further two treatments in the major pest season – would cost (at 2014 prices) the equivalent of about GH¢80.00 ($26.60) per ha for the insecticide. To this should be added the cost of labour and hired equipment for the treatment. Evidence from revenues from farmers' passbooks suggests that over the past few years most cocoa farms could not repay this cost. However, as mentioned before, farmers who are achieving high yields find it necessary to have some insurance against insect pests and in these cases, the programme outlined would be justified.

The basic plan for insecticide use should, therefore, involve no, two or four strategically timed applications of recommended insecticides and the decision must be based first and foremost on the incidence of the primary pest with the present range of approved insecticides. Additional insecticides should only be used in exceptional cases when the key pest population increases beyond the economic threshold level. The blanket treatment of large areas with insecticides will undoubtedly have ecological consequences that may not be visible initially (unless effective bio-monitoring is carried out), but will manifest later and may be difficult to rectify. Furthermore, there is always the possibility that frequent spraying would encourage the development of insecticide resistant strains of the insect pests, destruction of beneficial non-target arthropods, and environmental pollution (e.g. contamination of water). Negative impacts on birds, reptiles and amphibians, which are of the most efficient predators of insects, are also a very common side effects of the use of insecticides. Moreover, many of the chemicals used to control mirids and other insect pests listed by the WHO in class II or III. Therefore, it is particularly important that they are used only when necessary. Spot spraying (where localized areas are treated, and minimum amount of chemical is used) involves minimal cost and minimum contamination of the environment.

6. GOVERNMENT-ASSISTED SPRAYING ('MASS SPRAYING')

Government-assisted spraying of pesticides by recruited spraying teams in cocoa was started in 2001 [26]. This is a government intervention that aims to treat large areas quickly to boost production and increase farmer income. Although the areas under treatment can be overwhelmingly large, many farmers need to plan their own treatment. Under the spraying programme dubbed 'mass spraying', delays in input supply to rural farming communities make timely application of pesticides difficult. Also, there are frequent cases where spraying teams may have been recruited from completely unfamiliar communities and which may hinder or delay spraying activities. Where chemicals are to be applied continuously in large blocks of cocoa farms and especially when these occur on mountain slopes, the provision of marked walking tracks would be an advantage, but the teams are often impatient. Nevertheless, the system appears to be beneficial as more than a 30% annual increase in yield was observed in the 2010/2011 cocoa season. The application of sprays are likely to be much quicker if the farmers made provision for this type of spray application.

A recent survey [9] showed that the spraying of cocoa is partially inefficient due to the large acreages involved, as well as the handling of large amounts of water. Expansion of the size of spraying teams across all communities and quicker filling from water tanks situated in large plantations is suggested as one method of speeding the process. Additionally, a more significant development will be the use of much smaller volumes of water through proper nozzle settings in applying the chemicals. The application technology is one field in which there have been remarkably little developments during the last 10 years. Recently it has been shown that for conventional insecticides, two application of 55 l/ha by motorised mistblower in February to May, and again in September to December at 28 days intervals per season, can give acceptable results on mirids and possibly for stink bugs and other insect pests as well [8]. However, more information is needed on the economics, as well as on the biological efficacy of the insecticides applied under the government spray programme.

7. INTEGRATION

When planning an Integrated Pest Management Programme, it is first necessary to consider the need for action regarding each insect pest separately and then to attempt to integrate the control measures into a system which may also include other chemicals such as herbicides, fungicides and fertilizers. Where possible, it is obviously convenient to apply more than one chemical at a time, but this can raise problems with timing and compatibility. The correct timing and frequency of chemical application is necessary for the chemical to be fully effective. It can be very risky in terms of accidental application of higher rates and also of phytotoxicity to compromise on the timing of a chemical application outside the limits set in the recommendation for its use. Most insecticides need to be applied in relation to a growth stage of the cocoa trees or the development stage of a pest; for many hemipteran pests, the phenology of the host plant is of critical importance. This can make planning easier and it should be possible to devise a system flexible enough to cope with most eventualities provided sufficient time is given to planning.

The use of insecticidal mixtures (cocktails) is becoming more common in cocoa in Ghana [27]. Current cocktail insecticides are mixtures from the two main insecticidal classes of neonicotinoid (e.g. imidacloprid SL 200g/litre, thiamethoxam SC 200 g or 240 g/litre, and acetamiprid EC 100g/litre) mixed with a synthetic pyrethroid (e.g. either bifenthrin EC 100g/litre or deltamethrin EC <10g/litre). Compatibility of chemicals often raises problems, since manufacturers can usually provide information on their own products, but it is difficult to do it for other products. The range of products and formulations, and the possible permutations for their use may make the task for compiling a compatibility table difficult.

8. PHEROMONES FOR COCOA INSECT PEST CONTROL

Sex pheromones are widely used for a variety of species, but for mirids, they are not very effective [28]. Aggregation pheromones are being used in some cases, though. Behavioural responses exploited to date in cocoa has been mainly the use of mating and sex attractants which detect adult male mirids only [28] and since the sex ratio of the insect is near 1:1, population levels of the pest can be accurately inferred from trap catches. A great step forward would be made if male produced pheromones could be found and used to monitor female populations directly. Field observation suggests that a great deal of potential exist for use of synthetic pheromones for the cocoa stem borer, *Eulophonotus myrmeleon* Fldr. (Lepidoptera Cossidae) [26].

9. CONCLUSION

Strategy for insect pest management in cocoa should be based primarily on environmentally safe pest control alternatives. Intensified research and use of cultural practices and resistant varieties or pheromone-based mating disruption against *Hemiptera*, supplemented with chemical treatments where necessary, will minimize the damaging effects of primary pests. Up to two timely applications of insecticides in February to May or September to December at 28 days intervals may be justified under certain conditions, but further applications should only be made when a serious pest problem arises. Because of the large areas under cocoa in Ghana (≈2 million ha), it is important to take into account the effects of chemicals, including their application, on the environment and on wild life.

Improvements of methods of surveillance and prediction would assist in early and more effective identification of specific pest problems. Development of efficient methods of application would enable a quicker and, therefore, more effective use of chemicals. Decisions on the use of chemicals by smallholder farmers must be based on consideration of factors including application methods, compatibility, correct timing and the resources available.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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