

Future strategies towards control of mirid (Hemiptera: Miridae) and common insect pests of cocoa (*Theobroma cacao* L.) in Ghana

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Abstract

Changing farming systems in cocoa over the last two decades has brought about the use of new hybrid plant varieties and intensified fertilizer and pesticide applications 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 the inadequate timing and inefficient application is probably reducing the viability of otherwise acceptable products. The future strategy for mirid and other insect control should be based primarily on the use of cultural practices of removal of excess chupons, shade management and host variety resistance. These practices are primarily aimed at minimising dieback disease and stink bug deformation of pods, and may then 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 in 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.

Key words: mirid, pest control, cocoa, farming systems, control strategy, correct timing, dieback disease, insect pest, flexible control system

Running title: Strategy for pest control in cocoa

32 Introduction

33 Mirids (*Distantiella theobroma* [Dist.] and *Sahlbergella singularis* Hagl.) and stink bugs
34 (*Bathycoraliathalassina* (Herrich-Schaeffer)) are known for their importance in causing losses
35 in cocoa (*Theobroma cacao* L.) in West Africa (Johnson, 1971, Entwistle, 1972, Owusu-
36 Manu, 1976 and Adu-Acheamponget al. (2012), with the most prevalent in Ghana being *S.*
37 *singularis*. The authors have outlined the problems associated with mirid and stink
38 bug infestation. Both nymphal and adult stages feed and inject saliva to liquefy plant
39 tissues. Their feeding punctures provide entry points for fungal pathogens (Crowdy (1947),
40 Owen (1956), McGhee (1997), McPherson and McPherson (2000) causing dieback disease
41 (main mirid damage) and premature ripening and deformation of pods and beans, (main stink
42 bug damage). The main method of mirid control is by the application of conventional
43 insecticides, but stink bugs have often been controlled indirectly by treatments normally used
44 for the control of mirids.

45 In Ghana, control of the most important pests of cocoa has become more difficult nowadays,
46 compared with three decades ago (Owusu-Manu, 2001). There are several contributory
47 reasons for this: farmers still have to be familiarized with optimal techniques of using the new
48 generation insecticides that have largely displaced the organochlorine and carbamate
49 compounds. The global quality standards of insect pest control in cocoa needed to guarantee
50 high quality produce for global market outlets have increased, setting targets for maximum
51 residue limits of pesticides, which in some instances are clearly not attainable.

52 A fast and correct diagnosis of pest incidence is the first important step in attempting any
53 control procedure. Adu-Acheamponget al. (2014) have concluded that pest control systems in
54 cocoa must be revised as a result of changes in farming systems, pest cycles and shifts in pest
55 population peaks.

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

58 Before the 1970s damage caused by mirids was well appreciated as well as the importance of
59 dieback disease that follows mirid feeding on green unhardened tissue (pods and stem).
60 Efforts were concentrated on understanding population fluctuations of mirids on different
61 varieties of cocoa, their distribution within trees as well as the effect of water stress on the
62 incidence of pests. The tendency for average population levels are to remain low until August

63 or September. ~~A when a sharp rise is then normally evident began which has had~~ an important
 64 bearing on the ~~initiation??setting~~ of another spray sequence during the beginning of ~~in~~ August
 65 (i.e. August-December) instead of an older recommendation of June, July followed by a
 66 three-month gap (Peterson and Bond, 1964). Currently, two seasonal peaks varying from
 67 September-December and February-May in different locations is an average
 68 phenomenon. Plant breeders at the Cocoa Research Institute of Ghana (CRIG) have developed
 69 varieties of cocoa resistant to swollen shoot and black pod ~~which are also and~~ high yielding
 70 ~~but unfortunately, though~~ this resistance does not seem to be durable enough when the
 71 varieties are challenged under farmer conditions. Very little ~~effort was spent~~ ~~attempt was~~
 72 ~~made to on~~ breeding varieties with resistance to mirids ~~or~~ other insect pests. Field
 73 observations usually ~~gave~~ ~~have given~~ strong indications that mirids caused less damage to
 74 ~~some~~ Trinitario selections (e.g. SC1) than the common West African Amelonado (Anon.
 75 1946). This was confirmed by Adu-Acheampong (2009), who identified SC6 as one of the
 76 tolerant selections to fungal-induced dieback disease in cocoa. In compiling its list of
 77 recommended varieties to the seed gardens, CRIG takes a firm line in rejecting varieties
 78 susceptible to swollen shoot disease and encourage the development of resistance to black
 79 pod disease. Unfortunately, the Institutedoes not follow an equally firm policy for insect
 80 pests.

Comment [SPS1]: Do you mean beginning of August or do you mean during the beginning of the August – December period?

81 Insecticides (nicotine sulphate and DDT) were first introduced in the 1940s ~~against mirids~~
 82 ~~because. As~~ accumulated knowledge ~~had~~ highlighted ~~these insects~~ ~~mirids~~ as the most
 83 important pests, ~~these insecticides were initially applied against this group of insects~~. In the
 84 following years, several insecticides (endrin, dieldrin, heptachlor and lindane) ~~against~~
 85 mirids were introduced, which were also aimed at the control of
 86 mealybugs (*Planococcoides njalensis* (Laing), *Planococcus citri* (Risso) and
 87 *Ferrisia virgata* ~~3irgate~~ (Ckll)) which are vectors of cocoa swollen shoot virus disease.
 88 Unfortunately, insecticides were applied when the pests were already present in damaging
 89 levels on most in the cocoa farms.

Comment [SPS2]:

90 The percentage of cocoa trees that was treated with insecticides in the 1950s is difficult to
 91 estimate accurately, but it ~~was~~ rapidly increased in the 1960s (Johnson, 1971). Cocoa output
 92 reached an all-time high of 560,000 tonnes in 1964/1965. Nearly all the insecticides used was
 93 against mirids due to their relative high economic importance while the adoption of
 94 insecticide use for other insect pests was slower because the emphasis was on mirids owing
 95 to their relative high economic importance. Later on, a growing concern for the environment

Comment [SPS3]: Do you mean they were applied prophylactically?

and for the conservation of wild life has been 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 the strategy for pest control.

During the last two decades, and especially since 2000, there have been very significant developments in nearly all aspects of cocoa pest insect pest control. Farmers have become very conscious of the importance of insect pests, and data accumulated in mirid surveys on cocoa have enabled objective assessments to be made (Adu-Acheamponget *al.*, 2014). 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.

The field of mealybug-vector control has seen fewer successes. The use of systemic insecticides such as Azodrin (Monocrotophos SC –add the pedigree of the chemical that was used, always use the active as trade names may vary in different countries) 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 (Owusu-Manu, 1977).

For control of pod feeding insect pests, the present system of insecticides usage? ensures that pests are kept at a very low level. A possible danger in the future is that farmers faced with increased insecticide costs may procure cheaper unapproved insecticides and omit the registered insecticide treatment.

~~Pest control has seen~~ improvements in the monitoring and forecasting of the major pests on the new varieties of cocoa recently became evident, but the shift in dominance between the two important mirid species is not adequately understood, and should be studied further. hence there is more to learn about the insect complex of cocoa.

125 Cultural practices which reduce serious insect pest attacks should obviously play an
126 important part in a control system. Such practices may include pruning, chupon removal,
127 agro-forestry, shade management, removal of alternative hosts, weeding and fertilizer
128 application. Apart from these, the main emphasis in insect pest control will be on the use of
129 resistant varieties reserving the use of chemicals for when economic threshold levels are
130 exceeded, special purposes.

131

132 **Biological control**

133 Past observations in Sierra Leone indicated low levels of mirid infestation. This prompted
134 a search for natural enemies in Sierra Leone and the Congo ~~but no. Except in so far as we~~
135 ~~have accumulated knowledge on the biology of the important mirids (*Sahlbergella singularis*~~
136 ~~Hagl. and *Distantiella theobroma* [Dist.] and mealybugs, there has been no significant effort~~
137 to introduce natural enemies have thus far being done.

138

139 **Host plant resistance**

140 Nearly all the damage to cocoa trees of the 1950-1960s was associated with the growing of
141 very susceptible varieties including Amelonado. But no varieties have expressed a
142 satisfactory level of resistance to *S. singularis* and *D. theobroma*.

143 In one of the few studies to address the issue, Adu-Acheamponget *al.* (2007) found that many
144 local and international cocoa selections were highly preferred by mirids as suitable hosts for
145 feeding and oviposition. This apparent lack of genetic variation in host preference requires
146 further investigation, ~~especially since given that~~ genetic variation for resistance has been
147 observed in several other systems (Byers *et al.* 1996, Strong *et al.* 1996). However, the
148 development of a strategy for pest control could include varieties resistant to dieback
149 disease resulting from hemipteran related fungal invasions as was shown by Adu-
150 Acheampong, (2009). Identification and categorization of sources of resistance for developing
151 pest resistant cocoa varieties should be pursued by traditional plant breeding. Recent
152 observations at CRIG have shown that by mixing several varieties (each of
153 them contributing a different form of genetic resistance), pest outbreaks can be reduced. Farmers
154 seem to have understood the need for cocoa varieties as well as shade trees and food

Comment [SPS4]: What about genetically modified plants?

Comment [SPS5]: You should also consider the work done on push – pull systems.

155 intercrops. It will be interesting to see whether this work will lead to at least a **partial**
156 solution, of the cocoamidrid problem.

157

158 **Monitoring and prediction**

159 **Hemipteran pest populations in cocoa are spatially and temporally patchy with many**
160 **individuals exploiting cryptic habitats (Williams, 1953).** An ability to predict or forecast
161 severe outbreaks of pests is obviously **an** advantage when planning control programmes as
162 **that** can lead to the selective, **timely and precise** use of chemicals.

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

173

174 There is, however, very little information which can be used to predict the spread of pests.
175 Whilst it is unlikely that spraying for insect pest control could be based entirely on prediction
176 systems, a planned programme of timely sprays could be modified **if it was known.** For
177 **example, that certain weather conditions might be favourable for the spread of a particular**
178 **insect pest.**

179

180 **Chemical Control**

181 Insecticide use in cocoa in the future should aim to supplement the control given by cultural
182 practices, varietal selection and other methods, within an **Integrated Pest Management**
183 **programme.**

Comment [SPS6]: Don you mean the status of the biology of the specific insect?

Comment [SPS7]: Suggest looking at degree day models. Models based on info submitted by farmers are problematic as they are often inaccurate. Suggest you start a monitoring programme where all the pests as well as meteorological parameters are monitored

184

185 | Experience gained from pest assessments at CRIG may lead to timely chemical treatments of
 186 | cocoa which is sustainable in the case of cocoa mirid control. It is common for farmers who
 187 | have invested a lot of time and money in maintaining their cocoa farms to take to
 188 | spray prophylactically as a precaution against possible pest outbreaks, unexpected developments
 189 | of pests. It is also true that it is difficult to predict the development of some pests, such
 190 | as stink bugs and stem borer adults in cocoa, is difficult to be predicted at present and
 191 | farmers may also may be unable to spray a large area at short notice. Furthermore, a high
 192 | yielding cocoa farm is more likely to be susceptible to insect pests than a low yielding cocoa
 193 | farm (as there would be plenty of feeding and egg laying sites (Adu-Acheamponget *al.*,
 194 | 2014), and with a higher potential profit the farmer can afford treatment costs. There should,
 195 | therefore, be separate timely recommendations for potentially high yielding cocoa farms as
 196 | ~~r-~~ Routine sprays on cocoa farms with lower than average potential yield are generally
 197 | uneconomical.

Comment [SPS8]: This should be the case for all insect control not just mirids

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

202 | In recent years, insecticides registered for mirids have been used in more than 40% of cocoa
 203 | farms in Ghana. Discussions with farmers suggest that the majority of the unsprayed cocoa
 204 | farms would also have benefited from the government chemical treatment. There are
 205 | currently no pest management action thresholds for hemipteran pests of cocoa (but guidelines
 206 | outlined in Table 1 provide a general recommendation), but visual assessment up to hand-
 207 | height (Collingwood and Marchart, 1971) suggest that the rate of increase does not follow a
 208 | definite pattern as severely devastated trees can have very low insect numbers. There should,
 209 | therefore, be a plan for timely treatment or contingency use of insecticide in cocoa farms for
 210 | mirid and stink bug control. Some of the ways of considering insecticide use in cocoa are
 211 | depicted might be as shown in Table 1.

Comment [SPS9]: Is that of the entire tree?

Comment [SPS10]: I disagree! If the plants were severely damaged there should have been a lot of insects. I know they are undoubtedly difficult to locate but that does not mean there are no insects present!

212 | Table 1. Area-specific recommendation for mirid and stink bug control in cocoa

Prediction	Recommended treatment
1. Mirid and stink bug damage unlikely (<20 individuals/100)	No spraying required; watch out
2. Mirid and stink bug slight/moderate (20-	Timed spray*spot treatment

50 individuals/100 trees	
3. Mirid moderate/severe (>50 individuals/100 trees)	Spray whole farm and repeat 4 weeks later.

*Timed spray – insecticide applied as soon as 3-5% trees or pods are affected.

214

215 In planning a **pest management** programme, it ~~is often~~**will be** necessary to consider the **speed**
216 **of chemical application**. It would be unreasonable to rely on a calendar spray if a large area is
217 involved, and it is probably better to use more than one of the programmes suggested above
218 in order to spread the work-load. The possibility of the likely occurrence of a second (or
219 more) insect pests will only arise in some circumstances, **e.g., *Anomis* sp. caterpillars** in the
220 Volta, Eastern and Ashanti Regions or stem borer adults in highly susceptible varieties, and it
221 may not always be feasible to include the appropriate insecticide with a mirid spray,
222 especially when this is a calendar spray. **Nevertheless, farmers are advised to move entirely**
223 **away from calendar sprays and to use optimized the biological control component by spraying**
224 **very strategically.** This is difficult in most of Africa where not all farmers have the necessary
225 **spraying equipment. In a situation of a second pest, the insect** would have to be considered
226 separately or the pest would have to be **treated** irrespective of the mirid situation as has
227 happened in the past with *Anomis* sp. and other caterpillars.

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

240 The basic plan for insecticide use would, therefore, involve no, two or four **strategically**
241 ~~timely~~**ed** applications of recommended insecticides **against the primary pest**. Additional
242 insecticides should only be used **in exceptional cases** when a **key** pest **population increases**

243 beyond the economic threshold level. Although there are no obvious environmental hazards
244 associated with the use of the present range of approved insecticides, there may be objections
245 to the frequent spraying of very large areas such as in the treatment of cocoa by the spraying
246 gangs. Furthermore, there is always the possibility that frequent spraying would encourage
247 the development of insecticideresistant strains of the insect pests, destruction of beneficial
248 non-target arthropods? organisms, and environmental pollution (e.g. contamination of
249 water). Negative impactson birds, reptiles and amphibians, which are of the most efficient
250 predators of insects, are also a very common side effects of the use of insecticides. Moreover,
251 many of the chemicals used to control mirids and other insect pests listed byare in the WHO
252 in class II ~~Thereforeso that~~ it is particularly important that they are used only when necessary.
253 Spot spraying (where localized areas are treated, and minimum amount of chemical is
254 used)involves minimal cost and minimum contamination of the environment.

Comment [SPS11]: I disagree, if you blanket spray large areas with a contact spray, it will have considerable ecological consequences. These consequences may not be visible initially unless effective bio-monitoring is carried out but will manifest later and are difficult to rectify

255

256

257

258 Government-assisted spraying ('mass spraying')

259 Government-assisted spraying of pesticides by recruited spraying teams in cocoa was started
260 in 2001. This is a government intervention that aims to treat large areas quickly. Although the
261 areas under treatment can be overwhelmingly large, many farmers need to plan their own
262 treatment. Under the spraying programme dubbed 'mass spraying', delays in input supply to
263 rural farming communities maketimely application of pesticides difficultunfeasible. Also,
264 there are frequentcases where spraying teams may have been recruited from completely
265 unfamiliar communities and which may hinder or delay spraying activities. Where chemicals
266 are to be applied continuouslyin large blocks of cocoa farms and especially when these occur
267 on mountain slopes, the provision of marked walking tracks would be an advantage, but the
268 teams are often impatient. Nevertheless, the system appears to bebeneficialing as more thana
269 >30%annual increasein yield was observed (When?). The application of sprays are likely to
270 be much quicker if the farmers made provision for this type of spray application.

271

272 A recent survey (Adu-Acheamponget *al.*, 2014) showed that ~~a part of~~ the spraying of ~~a~~ cocoa
273 is partially inefficient due to the large acreages involved, as well as the handling of large
274 amounts of water. Expansion of the size of spraying teams across all communities and
275 quicker filling from water tanks situated in large plantations is suggested as one method of
276 speeding the process. Additionally, a more significant development will be the use of much
277 smaller volumes of water through proper nozzle settings in applying the chemicals. The
278 application technology is one field in which there have been remarkably little developments
279 during the last 10 years. Recently it has been shown that for conventional insecticides, two
280 application of 55 l/ha by motorised mistblower in February to May, and again in September
281 to December at 28 days intervals per season, can give acceptable results on mirids and possibly
282 for stink bugs and other insect pests as well. However, more information is needed on the
283 economics, as well as on the biological efficacy of the insecticides applied under the
284 government spray programme.

285

286 **Integration**

287 When planning an Integrated Pest Management Programme, it is first necessary to consider
288 the need for action regarding each insect pest separately and then to attempt to integrate the
289 control measures into a system which may also include other chemicals such as herbicides,
290 fungicides and fertilizers. Where possible, it is obviously convenient to apply more than one
291 chemical at a time, but this can raise problems with in methods of application, such as timing
292 and compatibility.

293

294 The correct timing and frequency of chemical application is necessary for the chemical to be
295 fully effective. It can be very risky in terms of accidental application of higher rates and also
296 of phytotoxicity to compromise on the timing of a chemical application outside the limits set in
297 the recommendation for its use. Most insecticides need to be applied in relation to a growth
298 stage of the cocoa trees or the development stage of a pest; for many hemipteran pests, the
299 phenology of the host plant is of critical importance. This can make planning easier and it
300 should be possible to devise a system flexible enough to cope with most eventualities
301 provided sufficient time is given to planning.

The use of insecticidal mixtures (cocktails) is becoming more common in cocoa in Ghana (Adu-Acheampong and Acknor 2005). Current cocktail insecticides are mixtures from the two main insecticidal classes of neonicotinoid (e.g. imidacloprid SL 200g/litre, thiamethoxam SC 240g/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/impracticable.

In cocoa insect pest management systems, there is still little evidence of one control measure adversely affecting another. However, evidence suggests that extensive usage of lindane 3-4 decades ago in cocoa extensively treated with lindane 3-4 decades ago not only have disrupted the ecological balance of hemipterans, it probably would have affected the entire arthropod complex (Owusu-Manu, 1976).

Pheromones for cocoa insect pest control

The appeal of sex attractants is that they are generally species specific and, therefore, they are often used for monitoring purposes. Pheromones are unfortunately not widely used for hemipterous insects yet. Behavioural responses exploited to date in cocoa has been mainly the use of mating and sex attractants which detect adult male mirids only (Sarfo, 2013) 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) (Adu-Acheampong *et al.*, 2004).

Comment [SPS12]: Is this what you are trying to say? Sex pheromones are widely used for a variety of species but for stink bugs, they are not very effective yet. Aggregation pheromones are being used in some cases though

Conclusion

The future 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 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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