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Sensory-cue enhancement of the bird repellency of methiocarb

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ABSTRACT. Methiocarb can be an effective, non-lethal repellent to bird pests in numerous agricultural situations world-wide. It elicits a conditioned aversion response (based on an internal physiological reaction) which birds presumably associate with a treated food crop and then avoid. However, in developing countries its cost is often prohibitive. Studies on *Quelea quelea* also indicate that repellency occurs at levels lower than birds can discriminate by taste. The cost of using methiocarb can be reduced by incorporating inexpensive sensory cues that birds associate with its soporific effects. In the laboratory, methiocarb/sensory-cue combinations applied to heads of sorghum significantly enhanced the repellent response to quelea. Likewise, field tests in Africa and the Philippines comparing a 1% methiocarb treatment with a 0·5% methiocarb/1·0% wattle tannin formulation applied to ripening sorghum, millet, and wheat resulted in equivalent protection and significantly less damage when compared with untreated heads. The results have practical implications to farmers, particularly in developing countries, for protecting their crops economically.

Introduction

Bird damage to cereal crops is a serious problem in many countries (De Grazio, 1978; FAO, 1981). One method of protecting crops that is receiving increasing use world-wide is to spray non-lethal chemical repellents on to the ripening heads of cereals. The chemical methiocarb (3,5-dimethyl-4-(methylthio)-phenyl methylcarbamate; Mesurol®) can be an effective, non-lethal, broad-spectrum repellent to pest birds in many agricultural situations (Guarino, 1972; Crase and DeHaven, 1976; Erickson, Jaeger and Bruggers (1980); Bruggers *et al.*, 1981). Methiocarb elicits a conditioned aversion response (Rogers, 1974, 1978) which birds presumably associate with a treated field crop and then avoid. However, the cost of the amount of

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chemical required to evoke the avoidance response in birds often prohibits its use for many farmers.

Repellent action can be either primary, in which an animal responds to the taste of the chemical, or secondary (conditioned aversion), in which the animal associates its detection of the repellent with adverse effects after ingestion (Rogers, 1978); in both situations the animal subsequently avoids the treated crop. Most primary repellents found during laboratory screening tests have not performed satisfactorily under field conditions. Investigators now recognize that conditioned aversion can be a key to the selection of avian repellents. The objective of our research was to determine if the addition of inexpensive tactile, visual or olfactory sensory cues to reduced quantities of methiocarb would effectively repel birds. This repellent combination is less expensive than methiocarb alone and, therefore, more affordable by farmers.

Laboratory studies with red-billed quelea (*Quelea quelea*), an important pest to cereal crops in Africa, indicate that methiocarb elicits its characteristic soporific effect at treatment levels below those which birds can orally discriminate (Bullard, Schafer and Bruggers, in press). In preference tests with equally preferred alternative foods, quelea avoided food treated with a colour or astringent tannins when positions were alternated (Bullard and Shumake, 1979; Bullard, Garrison, Kilburn and York, 1980), indicating that sensory cues might augment the learning process and enhance the effectiveness of a secondary repellent.

Experiments with red-winged blackbirds (*Agelaius phoeniceus*) showed that birds preconditioned to methiocarb-treated cracked corn did not exhibit a preference between methiocarb-treated and untreated sunflower seeds (Knittle, personal communication). Rogers (1974) also observed that red-winged blackbirds preferred untreated food to methiocarb-treated food, but that learned aversion occurred when methiocarb was applied to preferred cereal grain and an untreated alternative grain was available.

Material and methods

This research was conducted progressively by first identifying an effective methiocarb/sensory-cue combination at the Denver Wildlife Research Center (DWRC), then evaluating it in bird-pest situations in Africa and the Philippines in enclosures, on vulnerable heads of cereal crops in fields, and on entire plots of ripening cereal crops.

Laboratory test birds

Red-billed quelea were used in all of the laboratory preference tests. Quelea were trapped in Sudan, flown to the Denver Wildlife Research Center and held for a 90-day quarantine and acclimatization period in a $2{\cdot}4 \times 4{\cdot}8 \times 2{\cdot}1$ m aviary. During this period all birds had access to water, grit and a maintenance ration of whole-grain sorghum, yellow millet, and Purina Game Bird Breeder Layena.

Laboratory enclosure preference tests

Details of the preference test methods are given in Bullard and Shumake (1979). Briefly, 10 quelea (five male and five female) were placed in a $2{\cdot}5 \times 2{\cdot}4 \times 2{\cdot}2$ m screened cage which contained a hexagonally shaped turntable apparatus (with 63·5 cm sides) to which six sorghum heads were attached. The turntable apparatus was divided by a board 26 × 120 cm long. Birds were conditioned to eating untreated sorghum from the apparatus for at least 2 days before testing. During each test, three treated heads and three untreated heads were placed on opposite sides of the turntable. The positions of new treated and untreated heads were reversed daily. Each test was conducted for 6 consecutive days with a 12 h light and 12 h dark cycle.

The sorghum heads were treated by dipping them in a solution containing the candidate chemicals (sensory cues, methiocarb or methiocarb/sensory-cue suspensions) and the adhesive Rhoplex AC-33 (0·5% solids), then dried and weighed. Food consumption was determined by weighing the sorghum before and after testing each day; any spillage also was weighed. Preference for the candidate repellent formulation was measured as a percentage of the total food consumed:

$$\text{Preference} = \frac{\text{treated food consumed (g)}}{\text{treated} + \text{untreated food consumed (g)}} \times 100$$

Treatment differences were analysed by one-way analysis of variance (ANOVA) with repeated measures; means were separated by Duncan's multiple range test (Duncan, 1957).

Field tests

On the basis of positive laboratory test results and the need to reduce the cost of the repellent formulation, wattle tannin, an inexpensive commercially available astringent compound extracted from the wood and bark of the wattle tree (*Acacia mearnsii*), was combined with methiocarb. Methiocarb/wattle-tannin formulations were evaluated in enclosures, on exposed heads, and over entire plots using similar methods on ripening sorghum (*Sorghum bicolor*), millet (*Pennisetum typhoides*), and wheat (*Triticum vulgare*) between 1979 and 1982 in Sudan, Mali, and the Philippines. Large independent separated fields are preferred for field tests of chemical repellents (DeHaven, Guarino, Crase and Schafer, 1971), but were not available for these initial tests. Because we were obliged to work within the limitations of the trial sites provided, our tests must be considered to be simple demonstrations (Bruggers and Jackson, 1981).

Field enclosure studies. In the enclosure studies, wire cages (1 × 1 × 2 m) were positioned over plants of comparable size and maturity several metres apart in fields of sorghum, millet or wheat in Africa. Ten quelea, which had been trapped locally and held for 2 months in 2·0 × 1·5 × 3 m cages were released into each enclosure immediately after the chemical was applied. All cages were monitored regularly to ascertain subjectively the amount of damage, to replenish food and water, and to replace any birds that escaped in order to maintain a uniform number of bird days per cage. Each test was run for 10 days.

In the sorghum and millet trials each enclosure contained 10 ripening heads. Each head was sprayed with 3·2 ml of a suspension containing the repellent chemicals and the adhesive Rhoplex A-33 (0·05% solids). Heads in nine enclosures were sprayed with 0·5% methiocarb (w/v of Mesurol w.p. 75% a.i.) and 1·0% wattle tannin (w/v) combination; heads in nine other enclosures were sprayed with a 1·0% methiocarb formulation. In the wheat trial, heads in nine enclosures were sprayed with 3·2 ml of solution when at the milk stage, and heads in nine other enclosures were sprayed when at the dough stage.

Estimates of treatment effectiveness for sorghum and millet were based on the mean percentage damage to all heads at harvest and for wheat on the weight of the heads in each of the cages using Kruskal-Wallis and Wilcoxon rank sum statistical analyses. For the wheat trial, after 10 days, 25 randomly selected milk-stage heads from each of the nine enclosures were cut immediately below the first primary branch and weighed. The same procedure was followed for those heads sprayed during the dough stage. Finally, all heads in all enclosures were cut when the wheat was ripe (25 days after the trial began), counted, put in a sack, and weighed.

Field studies. Two 0·1 ha plots were selected and 25 similar-sized undamaged heads of milk-stage sorghum and millet were sprayed with the same concentration and application rate of methiocarb/wattle-tannin that was used in the enclosure studies. Twenty-five undamaged heads were also examined in each plot. Before the spray application, these heads had been covered by cloth bags to prevent damage; these were the only undamaged heads in the field. The percentage damage to these heads was estimated 10 days after treatment. Efficacy was based on comparative yields of treated and untreated heads in each plot after 25 or 30 days. For wheat, the heads in three adjacent 25 m rows were sprayed with the methiocarb/wattle-tannin suspension. The total weight of these heads at harvest was compared with the weight of heads from a similar-size untreated area on the opposite side of the field.

In Mali and the Philippines, small plots or parts of sorghum fields, ranging in size from 0·01 ha to 3 ha, were sprayed with the 0·5% methiocarb/1·0% wattle-tannin solution during the early milk stage with hand-pump backpack sprayers. A second application was usually made after 10 days. The adhesives Trition AE or Rhoplex AC-33 were used.

In the Philippines, two sites of ripening sorghum were selected for comparing the repellency of methiocarb and methiocarb/wattle-tannin to European tree sparrows (*Passer montanus*) and to nutmeg mannikins (*Lonchura punctulata*). The sites contained a mixture of sorghum varieties and maturation stages, and had 50–100 birds in the area damaging sorghum grain. Most of the sorghum was 3–6 weeks from harvest. The sites, 120–300 m^2 in area, were on the International Rice Research Institute (IRRI) farm and the University of the Philippines at Los Baños (UPLB) experimental farm. Both sites had a weather station within 200 m of the plot. The stalks of undamaged heads were marked with coloured plastic tape. From the time of application until harvest, these heads were scored at weekly intervals as attacked or unattacked. Efficacy estimates were based on the weight of these heads compared with the weight of undamaged heads and visual estimates of loss in the fields. Birds were identified and usually counted by flushing them from the fields at least once a week at 30 min intervals for 2 h during their morning and afternoon feeding periods. Some birds also were mist-netted each week and their crop contents analysed. Searches for dead birds were made after each application. Methiocarb residues were determined by an analytical method in which the carbamates were derivatized with bis(trimethylsilyl) trifluoroacetamide, then measured by gas chromatography with a flame photometric detector (Okuno, personal communication).

TABLE 1. Daily consumption (g) and daily mean percentage preferences† of *Q. quelea* for seven formulations of methiocarb and/or sensory cues on sorghum heads in paired preference enclosure tests

Treatment	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Mean percentage preference‡
	Trt.	Untrt.	Trt.	Untrt.	Trt.	Untrt.	Trt.	Untrt.	Trt.	Untrt.	Trt.	Untrt.	
0·5% wattle tannin	5·2	37·1	21·2	26·0	25·9	21·9	21·3	25·5	34·9	14·3	34·5	10·9	50·63b
0·1% blue food colour	6·6	29·3	28·6	32·3	16·0	36·5	24·4	23·3	12·9	32·0	13·7	24·3	35·29ab
0·1% peppermint oil	25·7	12·4	6·6	28·6	32·2	5·6	4·1	33·1	33·7	2·3	3·8	34·9	45·92b
0·1% methiocarb§	12·2	40·4	10·9	46·2	8·1	24·6	14·0	5·5	6·3	33·9	7·5	25·4	29·55ab
0·5% wattle tannin + 0·1% methiocarb	16·1	55·2	2·8	45·4	4·8	45·9	4·9	42·9	2·0	45·3	2·2	50·0	9·42a
0·1% blue food colour + 0·1% methiocarb	0·8	3·2	4·8	27·3	2·3	40·2	2·3	39·8	0·7	40·0	2·2	43·0	5·43a
0·1% peppermint oil + 0·1% methiocarb	10·4	39·1	6·3	38·6	5·6	41·0	5·3	38·9	1·6	41·6	1·5	43·5	11·01a

† Percentage preference = [(treated food consumed)/(treated + untreated food consumed)] × 100. (Large percentage preference numbers indicate poor repellency and vice versa.)

§ One bird died and was replaced with a new bird on days 2, 4 and 5.

‡ Any means followed by different letters are significantly different ($P < 0{\cdot}05$)

Trt = treated; Untrt. = untreated

Results and discussion

Laboratory enclosure preference tests

Methiocarb treatments, either alone or in combination with sensory cues, were more repellent to quelea than any of the individual sensory cues (Table 1). Overall, there was a significant difference ($P=0{\cdot}0025$) in average food consumption among the seven treatments. Separation of treatment means indicated comparable poor repellency for wattle tannin, blue food colour and peppermint oil. The lack of statistical significance in percentage preference between blue food colour ($\bar{x}=35{\cdot}39$) and methiocarb/blue-colour combination (the smallest mean; $\bar{x}=6{\cdot}6$) resulted from variations in daily food consumption. There was, however, no overall significant difference ($P=0{\cdot}9375$) in daily food consumption for the seven treatment types.

The percentage preference values for sensory-cue treatments were nearly always greater (less repellent) than for combinations of methiocarb and sensory cues; the repellency of the methiocarb treatment was intermediate (Table 1). Percentage preference in methiocarb/sensory-cue treatments consistently decreased after the first or second day of each test, but fluctuated in tests where seeds were treated with either methiocarb or the sensory cues alone. It appeared that, when food positions are shifted daily, the taste of 0·1% methiocarb is insufficient to inhibit quelea from eating food at a position that held untreated food the previous day. Birds consistently ate more treated seeds in the methiocarb test than in any of the methiocarb/sensory-cue combination tests between days 2 and 6 (Table 1). Three birds (one each on days 2, 4 and 5) ate fatal amounts of methiocarb. Physiologically, the overall result was also reflected in the fact that birds consumed only about half as much food per day during the last four days as they did during the first two, even though three new birds replaced those that died.

It therefore appeared that the taste of methiocarb was not involved in the early conditioned-aversion learning process. However, when the visual, tactile or olfactory cues were added to the methiocarb, birds recognized and avoided treatments. Incorporating sensory cues seems to facilitate learning to the extent that birds are able to associate the source of their adverse physiological reaction (sickness) with the treated grain and avoid it.

Field tests

Because wattle tannin has primary bird-repellent properties, is inexpensive and is normally locally available in many countries, and because the formulation with methiocarb performed satisfactorily in our laboratory tests, we chose to evaluate it in combination with a reduced amount of methiocarb in field situations. In enclosure studies conducted in Sudan, the median percentage damage to ripening heads of sorghum and millet treated with 1·0% methiocarb or 0·5% methiocarb/1·0% wattle-tannin combinations was minimal and significantly less ($P<0{\cdot}001$; Kruskal-Wallis test) for both grains (Table 2) than damage to untreated heads. In both studies, there was no significant difference in damage between the methiocarb and the methiocarb/wattle-tannin treatments.

Damage to the 25 heads of sorghum and millet treated with methiocarb/wattle-tannin was significantly less ($P<0{\cdot}005$; Wilcoxon rank sum test) than damage to the untreated heads (Table 2). A resident bird population of 50–75 birds, comprising

TABLE 2. Median percentage damage to sorghum and millet in repellency tests (two replicates) against grain-eating birds at Agricultural Research Corporation, Shambat, Khartoum, Sudan; 28 October–6 November 1979

Test	Treatment†		
	0·5% methiocarb/1·0% wattle tannin	1·0% methiocarb	Untreated
Field enclosure test			
Sorghum	1	4	100
Millet	20	10	100
Exposed heads			
Sorghum	0	Not applicable	10
Millet	2	Not applicable	15

† Respective repellents formulated with 0·05% Rhoplex AC-33 adhesive and 3·2 ml sprayed on both sorghum and millet heads.

about 50% bishops (*Euplectes* spp.), 25% golden sparrows (*Passer luteus*), 20% house sparrows (*Passer domesticus*) and weavers (*Ploceus* spp.), and 5% red-billed quelea, were attacking the fields daily.

Methiocarb and methiocarb/wattle-tannin also provide comparable protection to wheat from bird damage in Sudan (Table 3). The methiocarb treatment reduced damage by 80·3% and 82·9% at the milk and dough stages of the wheat crop, respectively; the methiocarb/wattle-tannin formulation reduced damage by 85·1% and 97·8% at the milk stage and dough stage. As judged by the weight of 25 heads, the methiocarb treatment resulted in 1·7 times more grain than in the untreated samples during both the milk and dough stages: the methiocarb/wattle-tannin treatment also increased the yield from enclosures treated at the milk and dough stages by 2·1 and 1·7 times, respectively. Methiocarb has previously protected plots of ripening grain in Sudan (Hamza *et al.*, 1982).

In March 1981, the methiocarb/wattle-tannin suspension was applied at the rate of 3 kg w.p./ha to milk-stage sorghum at Babougon Seed Farm in the Office du Niger, Mali. Bird damage at harvest was 75% in a 250 m^2 untreated plot and $<25\%$ in a 100 m^2 treated plot. In addition, 3% damage occurred in four 50 m treated rows compared with $>10\%$ damage in four adjacent untreated rows. Several thousand red-billed quelea were attacking sorghum at this seed farm during the study (Scheurling, personal communication).

In the Philippines, both methiocarb and methiocarb/wattle-tannin gave comparable protection to undamaged sorghum and prevented additional bird damage to previously damaged sorghum. On the IRRI trial site, individual heads treated with the 0·5% methiocarb/1·0% wattle-tannin formulation had less damage ($<2\%$) than either untreated heads (28%) or heads treated with methiocarb only (12·5%). Sorghum heads in all plots were nearly equivalent in length. For the previously damaged heads, those treated with methiocarb/wattle-tannin sustained only 15% more damage during maturation whereas those sprayed with methiocarb had 44% more (Table 4).

TABLE 3. Mean percentage damage and yields from enclosure and exposed-heads tests evaluating the protection of different methiocarb treatments applied at two maturation stages against pest birds on ripening wheat in Sudan, February–March 1980. Enclosure treatment types were replicated three times†

	Stage	Enclosure treatment‡ 0·5% methiocarb	Enclosure treatment‡ 0·5% methiocarb/1·0% wattle tannin	Enclosure treatment‡ Untreated	Exposed heads 0·5% methiocarb/1·0% wattle tannin	Exposed heads Untreated
Damage (%)	Milk	7·0	5·0	35·5	—	—
	Dough	4·5	0·7	26·4	—	—
Wt (g) of 25 heads	Milk	33·0	41·0	19·0	—	—
	Dough	33·3	33·3	20·0	—	—
Wt (g) of 1 m^2	Milk	236·3	312·6a	191·0b	—	—
	Dough	283·0a	224·0	178·0b	—	—
	Mean	259·6a	268·3a	184·5b	—	—
Wt (g) from 25 m rows	Milk	—	—	—	1061	881
	Dough	—	—	—	1103	1106
	Mean	—	—	—	1082	993

† Duncan's multiple range test comparisons ($P < 0{\cdot}05$). Any two means followed by different letters are significantly different.
‡ Respective repellents formulated with 0·05% Rhoplex AC-33 adhesive.

TABLE 4. Average percentage bird damage to ripening sorghum before and after application of 1·0% methiocarb or 0·5% methiocarb/1·0% wattle tannin at research fields of IRRI in Los Baños, Philippines, during March and April 1982

Treatment	Damage (%) Pretreatment	Post-treatment	Differences
Methiocarb	37	81	44
Methiocarb/wattle-tannin	40	55	15
Reference (untreated)	47	68	21

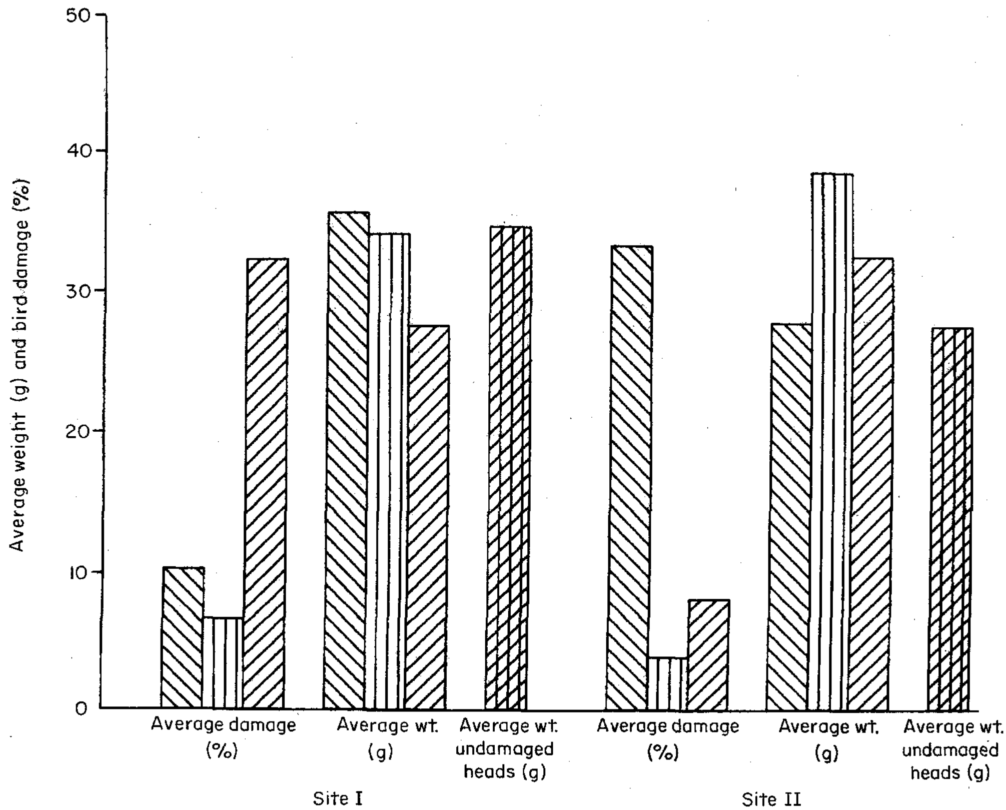

FIGURE 1. Average weight and percentage bird damage at harvest (6 April) to ripening sorghum at two sites in research fields of UPLB in Los Baños, the Philippines, 1982. ▧ 1·0% methiocarb; ▥ 0·5% methiocarb/1·0% wattle tannin; ▨ untreated; ▩ undamaged heads.

In the trial at the University of the Philippines at Los Baños, entire plots in two replicates were sprayed with the repellent chemicals. Treatments were compared both with undamaged heads (which had been covered at the time of application) and with untreated heads. The methiocarb/tannin combination reduced damage in both replicates, whereas methiocarb applied alone was effective in only one. About 200 birds, primarily *Passer montanus*, were feeding daily in the study areas; 64% of the birds had eaten sorghum. However, at one site the plots treated with methiocarb and methiocarb/wattle-tannin received less damage and weighted more than those left untreated (Figure 1). At the second site, the plots sprayed with methiocarb/wattle-tannin formulation again sustained less damage than the untreated plot, but the plot sprayed with methiocarb sustained more damage than the untreated plot, presumably due to its position adjacent to a cover. These kinds of inconsistent results have plagued many studies evaluating field applications of methiocarb.

When methiocarb is applied at normal repellent-use levels it is a safe non-toxic chemical. It is registered in the United States for use on several agricultural crops, including cherries and grapes, for which residue tolerance levels have been established at 25 ppm and 15 ppm, respectively (Schafer, 1979). The methiocarb residue levels of 44 ppm and 82 ppm found on the seeds in our study at 6 and 9 days after the second 1·0% methiocarb application (Table 5) are in the same order of magnitude as those of 13–36 ppm found in a previous study in Senegal (Gras, Hasselman, Pellissier and Bruggers, 1981). Bearing in mind the half-life of 6–7 days and the degradation curve during maturation established in the Senegal study, we would expect the residue levels in the present study to fall within the established tolerance limits and the daily acceptable dose (DAD) for human consumption for carbamates in general, provisionally established by a Joint FAO/WHO Committee, of 0·025 mg/kg (Roig, 1973) after approximately 3 weeks, particularly considering that the seed is usually processed and cleaned before being eaten. However, the

TABLE 5. Residues (ppm) of 1·0% methiocarb and 0·5% methiocarb/1·0% wattle-tannin application to ripening sorghum at the UPLB, Philippines, during 1982

	1·0% methiocarb		0·5% methiocarb/1·0% tannin	
Location	Seed	Glume & stalk	Seed	Glume & stalk
UPLB-Area I				
MeS†	44·0	440	14·0	104
MeSO	6·6	92	3·5	56
$MeSO_2$	1·7	53	1·6	18
UPLB-Area II				
MeS	82·0	510	3·1	98·0
MeSO	9·4	160	0·7	9·7
$MeSO_2$	3·0	36	<0·5	8·7

† MeS = methiocarb; MeSO = methiocarb sulfoxide metabolite; $MeSO_2$ = methiocarb sulfone metabolite.

lower methiocarb residue levels (3·1 ppm and 14·0 ppm) recovered from the 0·5% methiocarb/1·0% wattle-tannin application in our study, in conjunction with the protection comparable to the 1·0% methiocarb application, suggest that this repellent combination may be more appropriate. It is hoped that a methiocarb/sensory-cue formulation offering both primary and secondary repellency characteristics can solve this problem.

Conclusions

Although additional field studies and more detailed analyses of chemical breakdown are needed before the methiocarb/wattle-tannin combination can be recommended for widespread use, our initial studies indicate that it shows promise for economically protecting ripening cereals from birds. Apparently, the taste and visual properties of methiocarb, when applied alone and at the low levels that traditional farmers could afford, are insufficient to elicit its characteristic soporific effect; birds are unable to associate their adverse physiological reaction with a treated crop and continue to feed. The addition of a cue which is detectable by the olfactory, visual or tactile senses of a bird apparently enhances the effect of methiocarb. By finding ways to lower the costs of chemical repellents without losing efficacy, and employing economical field application techniques, farmers in developing countries may soon be able realistically to consider using repellents in particular situations to protect their crops from birds.

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