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Comparative study of field and laboratory evaluations of the ethnobotanical *Cassia sophera* L. (Leguminosae) for bioactivity against the storage pests *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) and *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae)

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Abstract

The powdered leaves of *Cassia sophera* along with hot- and cold-water leaf extracts of this plant were tested in laboratory experiments in the UK and in field trials in Tamale, Northern Ghana, using traditional storage containers, to determine their inhibitory and toxic effects against *Sitophilus oryzae* and *Callosobruchus maculatus* infestation of stored rice and cowpea, respectively. Laboratory and field experiments with cowpea showed that the use of *C. sophera* hot-water extracts was more effective at reducing *C. maculatus* infestation and adult emergence on cowpea than the traditional leaf-powder application (1% and 5% w/w) or the use of a cold-water extract of *C. sophera.* Hot-water extracts of *C. sophera* might be a more effective technique of applying the plant material on to stored cowpea than using powdered *C. sophera* leaves, the currently used application by small-scale farmers. In contrast, experiments with *S. oryzae* on rice showed that *C. sophera* leaf powder (5% w/w) effectively reduced adult emergence in the laboratory, but this could not be confirmed under field conditions. The hot and dry climatic conditions in the field might impart a natural protection against rice infestation by *S. oryzae*, making the use of protectants and pesticides less necessary for farmers. This was supported by the negligible rice grain damage after 6 months of field storage and by the failure of the *S. oryzae* population to establish itself under field conditions. The implications of using botanicals in pest control are discussed.

Keywords: *Cassia sophera*; *Sitophilus oryzae*; *Callosobruchus maculatus*; Stored products; Pest control; Botanical insecticides; Ethnobotanicals; Sub-Saharan Africa

1. Introduction

The use of species of the genus *Cassia*, such as *C. nigricans* Vahl, *C. occidentalis* L. or *C. siamea* Lam. as protectants of stored legumes has been reported by Babu et al.(1999), Dwivedi and Maheshwari (1996), and Lambert et al. (1985). *Cassia sophera* L., which is distributed throughout the tropics, is traditionally used by subsistence farmers in northern Ghana to protect stored cowpea (*Vigna unguiculata* (L.) Walp.), bambara groundnuts (*Vigna subterranea* L.), millet (*Pennisetum glaucum* L.), sorghum (*Sorghum bicolor* L. Moench) and maize (*Zea mais* L.) against insect infestation. It is traditionally used as powder obtained by pounding the dried leaves and mixing with the stored commodity (Belmain et al., 1999). The species is abundant and widespread, grows along roadsides and on waste ground and is reported to be a common weed in uncultivated lands (Belmain and Stevenson, 2001). In laboratory experiments, dry leaf powder of *C. sophera* increased adult mortality of *Callosobruchus maculatus* (F.) and *Rhyzopertha dominica* (F.) when admixed at 5% w/w to cowpea or wheat (*Triticum aestivum* L.), respectively (Belmain et al., 2001). In the same study, 1% and 5% concentrations of the leaf powder also significantly reduced F1 adult emergence of *C. maculatus*, *R. dominica* and

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Sitophilus zeamais Motsch. on cowpea, wheat and maize, respectively. In addition, the 5% w/w leaf powder of *C. sophera* was reportedly repellent towards *R. dominica* and *Prostephanus truncatus* (Horn) when insects were given the choice between treated and untreated commodities (Belmain et al., 1999).

In order to improve recommendations to farmers in northern Ghana about the use of *C. sophera* as a storage protectant, laboratory and field experiments with traditional storage containers were conducted to validate the use and compare the efficacy of different application methods of the plant material. Little research evaluating botanicals has attempted to assess bioactivity under field conditions and has instead focussed predominantly on laboratory work that does not always give useful results. Under field conditions a wide range of variables, such as temperature, humidity, grain quality, storage environment, previous or existing infestation, commodity variety or different insect species and biotypes might influence the efficacy of plant-based pesticides. Before giving any recommendations to farmers about the use of plant-based pesticides and repellents, it is therefore essential to verify laboratory results under field conditions (Songa and Rono, 1998). The targeted species in this study were *C. maculatus* on cowpea and *Sitophilus oryzae* on rice. Rice is gaining increasing importance as a staple food in West Africa (Djayeola, 2000). This trend can be observed in Ghana but, in comparison to cowpea, little attention has been given to traditional storage techniques of rice. Therefore, this study introduces an innovative approach to the use of traditional plant-based pesticides for rice in Ghana.

2. Materials and methods

2.1. Plant material

Cassia sophera was collected in Ghana, Northern District, between September and November 1998. The leaves were shade-dried and ground to a powder in a two-stroke engine hammer mill commonly used by local people in Tamale, Ghana, for grinding commodities. Cowpea and brown rice used in the laboratory were purchased from wholesalers in the UK (Gillet A. Cook, Faversham, UK, and Canterbury Wholefoods, Canterbury, UK), frozen for 7 days and equilibrated to 14.5% moisture content in a room with controlled temperature and humidity set at 28 ± 1 °C, 58 ± 10% r.h. (12 h light cycle) and 25.5 ± 1 °C, 45 ± 10% r.h. (12 h dark cycle). Brown rice and cowpea used under field conditions were purchased at Tamale market, Northern Ghana, and fumigated with phosphine for 5 days prior to their use in experiments to ensure insect-free commodity.

2.2. Insect material

Callosobruchus maculatus and *S. oryzae* cultures were reared on cowpea and brown rice, respectively, under controlled temperature and humidity at 28 ± 1 °C, 58 ± 10% r.h. (12 h light cycle) and 25.5 ± 1 °C, 45 ± 10% r.h. (12 h dark cycle). The same strains of *C. maculatus* and *S. oryzae*, in culture since 1996, were used for all laboratory studies and to infest cowpea and rice used in the field experiment.

2.3. Commodity treatment

Rice and cowpea were mixed either with ground *C. sophera* leaves at concentrations of 1% and 5% w/w or treated with hot- and cold-water extracts of *C. sophera*. Organic solvent extracts were not investigated, as these solvents would not be readily available to Ghanaian farmers. The hot-water extract used in the laboratory was obtained by adding 100 g of *C. sophera* leaf powder to 800 ml of boiling distilled water (12.5% w/v), boiled for 15 min and subsequently filtered through a muslin cloth. The cold-water extract was obtained using the same procedure, except that the plant material was extracted for 2 h in cold water before filtering. A longer extraction time was used for cold-water extracts to compensate for the lower rate of solution of compounds in water at lower temperature. After filtering, grain used under laboratory conditions was immediately dipped in hot- or cold-water extracts for 10 s and dried on top of filter paper for 1 h in a fume cupboard.

The amount of plant material used to prepare hot- and cold-water extracts in the field experiment was chosen according to the protocol of local farmers, using a reduced concentration of 8% w/v, compared to the 12.5% used in the laboratory. The hot-water extract used for the field experiment was prepared by boiling 2 kg of *C. sophera* whole dry leaves and stems in 25 l of water (8% w/v) for 10 min, after which the plant material was removed. The cold-water extract was obtained using a similar procedure, except that the plant material was soaked for 12 h overnight in 25 l of cold water before using the extract the next day. Grains used in the field experiment were dipped in hot- or cold-water extracts twice consecutively for 5 s and subsequently spread on top of plastic sheets to dry for 90 min before using them in the experiment. Separate extracts were used to coat rice and cowpea. Controls consisted of untreated grains and grains treated with hot or cold water alone.

2.4. Laboratory experiment

Two experiments, one with rice and one with cowpea, were set up by introducing 20 unsexed *S. oryzae* (7-day-old) or *C. maculatus* (4-day-old) adults into glass jars (250 ml volume) filled with 100 g of rice or cowpea, respectively. The introduced adults were removed after 10 days. Each experiment consisted of seven treatments (1% and 5% *C. sophera* leaf powder, untreated control, *C. sophera* hot- and cold-water extracts (12.5% w/v), and hot- and cold-water controls). Each treatment was replicated 10 times. Replicates were obtained by treating the entire quantity of grain and subdividing it subsequently into 10 separate parts.

2.5. Data collection and analysis of the laboratory experiment

The number of *S. oryzae* adult progeny produced in the F1 and the number of *C. maculatus* adults emerging in the F1 and F2 generation (sum of F1 and F2 progeny) from treated and control grains were recorded 54 days after the beginning of the experiment. Statistical analysis of the laboratory experiment was undertaken using one-way ANOVA ($P<0.05$) after log transformation of the data.

2.6. Field experiment

Two experiments were established with rice and cowpea in an open-walled shed with a metal roof and a concrete floor (18 × 6 m), located on the outskirts of Tamale city, northern Ghana. The shed was protected from direct sunlight on three sides by erecting woven straw mats. Four hundred and twenty clay pots (8–10 l) were filled with 3 kg of commodity (either rice or cowpea). Each experiment consisted of the following seven treatments: 1% and 5% *C. sophera* leaf powder, untreated control, *C. sophera* hot- and cold-water extracts (8% w/v) and hot- and cold-water controls. Each treatment was replicated 30 times and arranged in a completely randomised block. Pots containing rice were infested by introducing 10 g of previously infested rice, which contained a mean of 17.6 ± 1.25 live adults. Pots containing cowpea were infested with insects by adding 17 g of previously infested cowpea (4.0 ± 0.4 live adult bruchids per replicate corresponding to 70.4% cowpea damage). The level of infestation and the grain damage in the rice and cowpea trials were evaluated monthly over a 6-month period, starting immediately after harvest (December 1999), and ending at the beginning of the rainy season (June 2000).

2.7. Data collection and analysis of the rice field experiment

The level of insect infestation and mortality in the rice experiment was monitored by quantifying the number of dead and live *Sitophilus* and the number of other dead and live insects from two separate samples (100 g) taken from a single clay pot. The infested rice in each pot was stirred with a wooden stick before samples were taken to ensure that the insects were distributed uniformly throughout the container. From each of the two samples used to assess insect mortality, one small sub-sample (3 ml) was taken to determine grain damage (assessed as the number of whole and broken grains in the sample). The average percentage of broken grains in each treatment was plotted against time (December 1999–June 2000), and statistical comparison between treatments was undertaken over the aggregate period of time (December–June) using the area under curve analysis (Campbell and Madden, 1990) and by comparing the treatments using a one-way ANOVA ($P<0.05$). The same analysis was done for the total number of dead and live insects other than *S. oryzae,* and Bootstrap analysis (Manly, 1997) was used to perform comparisons between the treatments (95% Bootstrap confidence interval, resampling rate = 1000 times). The December count represented the baseline infestation.

2.8. Data collection and analysis of the cowpea field experiment

The level of insect infestation and mortality in each replicate was measured by averaging the number of dead and live *C. maculatus* adults and the number of other dead and live insects from two separate samples of 100 g of cowpea from each pot. Seed damage was assessed with these samples by counting the number of seeds with holes formed by emerging adults. The average number of damaged cowpea was plotted on a line graph against the time of observation (December 1999–June 2000). Separate curves were obtained for each replicate of each treatment and used for statistical analysis following the method of Ngugi et al. (2000), whereby data on the number of damaged seeds were linearised by log-transformation and the rates (b) and intercepts (a) were estimated by linear regression analysis and represented the equation $y = a + bx$. The rate parameters (b) representing the damage increase in the replicates of the different treatments were then compared using ANOVA ($P<0.05$). Data analysis of cowpea insect infestation was assessed as described for rice infestation. The December count represented the baseline infestation.

3. Results

3.1. S. oryzae emergence from rice in the laboratory

The lowest number of F1 *S. oryzae* adults emerged from rice grains mixed with 5% and 1% ground leaf powder (Fig. 1), but only the 5% leaf powder treatment significantly reduced the number of F1 adults compared to the untreated control ($P<0.05$). The *C. sophera* hot-water treatment also significantly ($P<0.05$) reduced the number of *S. oryzae* adults that emerged from treated grains compared to grains treated with hot water alone (Fig. 1). However, rice treated with hot- and cold-water extracts of *C. sophera* or with hot- and cold-water controls, all resulted in a significantly higher F1 compared to untreated rice (Fig. 1).

3.2. C. maculatus emergence from cowpea in the laboratory

There was no significant difference in the number of F1 *C. maculatus* adults recorded among the treatments ($P>0.05$). However, data from the F2 showed that significantly ($P<0.05$) fewer *C. maculatus* adults emerged from cowpea seeds treated with *C. sophera* hot-water

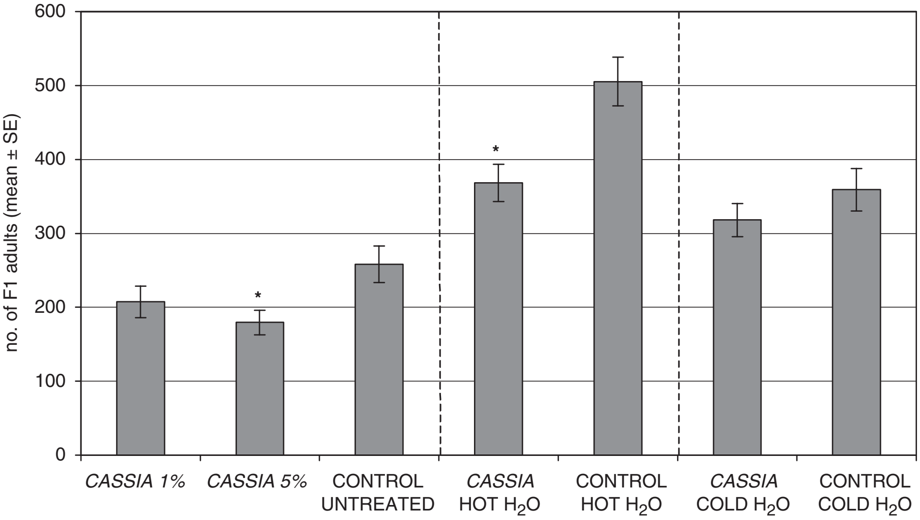

Fig. 1. Number of F1 *S. oryzae* adults (mean ± SE) hatched from rice grains treated with *C. sophera* powdered leaves, *C. sophera* hot- and cold-water extracts and controls consisting of untreated grains or grains treated with hot and cold water only (* indicates significant differences between number of insects hatched from treated rice and its respective controls, ANOVA, $P<0.05$, $n=10$).

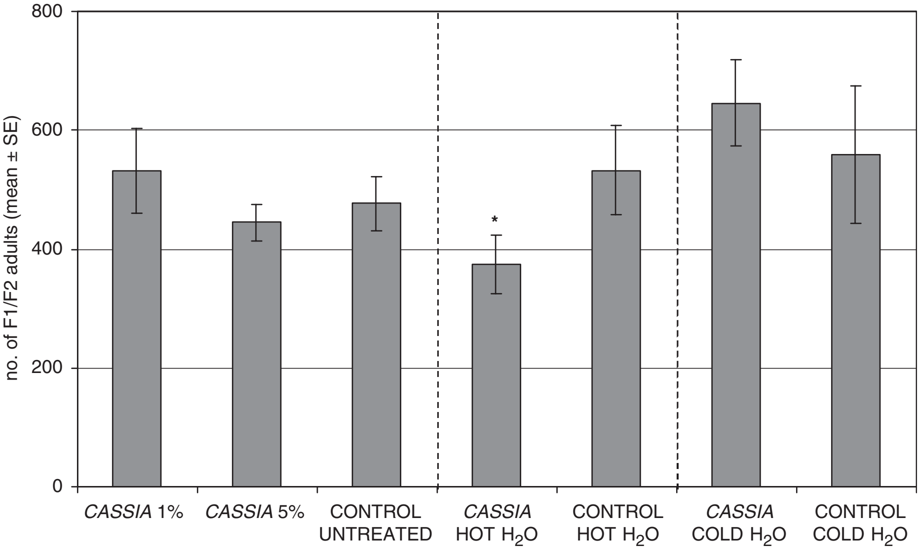

Fig. 2. Number of F1/F2 *C. maculatus* adults (mean ± SE) hatched from cowpea seeds treated with *C. sophera* powdered leaves, *C. sophera* hot- and cold-water extracts and controls, consisting of untreated seeds or seeds treated with hot and cold water only (* indicates significant differences between number of insects hatched from treated cowpea and its respective controls, ANOVA, $P<0.05$, $n=10$).

extract than from cowpea treated with hot water alone (Fig. 2), suggesting that the hot-water extract contained compounds that reduced insect population increase, while the cold-water extract did not. In contrast to the laboratory experiment with rice, the powdered plant material did not reduce insect emergence, indicating that *C. maculatus* and *S. oryzae* are not equally susceptible to the powdered plant material.

3.3. *Rice infestation and damage in the field*

Rice grain infestation by *S. oryzae* was very low and ranged between 0.06 and 0.67 insects per 100 g samples of rice (Table 1) indicating that despite introducing *S. oryzae* into the clay pots, insects were not successful in infesting the commodity. The *C. sophera* cold-water treatment was the most effective in reducing the total number of *S. oryzae* (dead and live) compared to the cold-water control and to the untreated control. The number of other insect species recorded in the experiment was significantly higher (2.47–4.88 live and 0.36–1.41 dead insects; Table 1) than the number of recorded *S. oryzae*, indicating that other insects had infested the stored rice more effectively. The predominant of these species was *Tribolium* sp., which was prevalent from March onwards and corresponded to a simultaneous reduction of *S. oryzae* infestation in the pots,

Table 1
Mean ± SE number of dead and live *S. oryzae* and other insects recorded between December 1999 and June 2000 in 100 g samples of rice treated with different *C. sophera* applications and controls

Treatment	*S. oryzae*		Other insects	
	Live	Dead	Live	Dead
Cassia 1%	0.30 ± 0.06[a]	0.38 ± 0.05	4.60 ± 0.60[a]	0.83 ± 0.10
Cassia 5%	0.25 ± 0.06	0.28 ± 0.04	4.88 ± 0.74[a]	0.36 ± 0.06[a]
Control (untreated)	0.14 ± 0.04	0.34 ± 0.04	3.20 ± 0.37	0.82 ± 0.11
Cassia hot water	0.37 ± 0.09	0.52 ± 0.08	3.07 ± 0.25	1.10 ± 0.13[a]
Hot-water control	0.27 ± 0.06	0.43 ± 0.06	2.80 ± 0.31	0.67 ± 0.10
Cassia cold water	0.06 ± 0.02[a]	0.23 ± 0.04[a]	2.47 ± 0.37	0.54 ± 0.08[a]
Cold-water control	0.67 ± 0.12	0.42 ± 0.05	3.27 ± 0.26	1.41 ± 0.17

[a] Significant differences in Bootstrap 95% confidence interval between number of dead or live insects on treated rice grains and on their respective controls, $n = 30$.

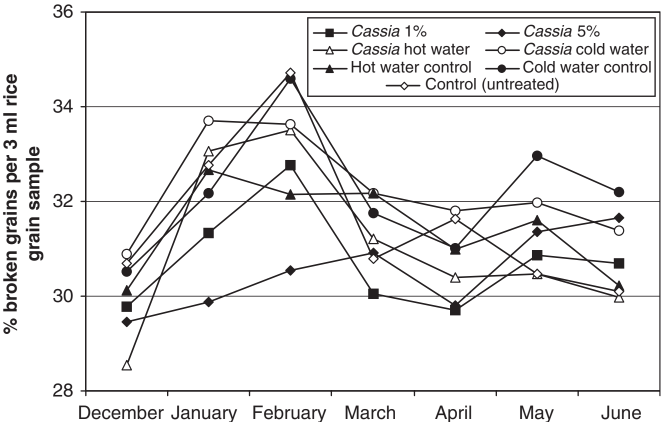

Fig. 3. Rice grain damage expressed as the percentage of broken rice grains recorded in 3 ml samples of rice grains between December 1999 and June 2000 ($n = 30$).

suggesting that *S. oryzae* were displaced by *Tribolium*. Similarly, *C. sophera* cold-water extract was also the most effective treatment at reducing infestation by *Tribolium* spp.

There was no clear trend in rice grain damage, except for a general increase in January and February, followed by a decrease in March (Fig. 3). Damage recorded in rice grains treated with 1% and 5% *C. sophera* leaf powder, was significantly lower than in untreated grains ($P < 0.05$), suggesting that the presence of the plant powder was effective in reducing rice damage by either *S. oryzae* or *Tribolium* sp.

3.4. Cowpea infestation and damage in the field

Bruchid infestation of cowpea varied across the treatments with the lowest total number of insects (dead and live) recorded on cowpea treated with *C. sophera* hot-water extract (Table 2). Cowpea treated with *Cassia* 5% leaf powder also exhibited lower infestation than untreated cowpea (Table 2; Bootstrap 95% confidence interval) but was infested more heavily than cowpea treated with the hot-water extract, suggesting that the hot-water extract was more effective in reducing bruchid infestation than the traditional powder application. *Callosobruchus maculatus* was the major insect species infesting the cowpea trial, but the number of other insect species recorded in the pots (Table 2) reflected the trends observed for the bruchid, indicating that *Cassia* hot-water extract was overall the most effective treatment for insect control.

In all treatments, there was an increase in cowpea damage from March to June (Fig. 4). Statistical analysis of the curve rate parameters (b) indicated significant overall differences in damage increase among treatments ($P = 0.018$), whereby the lowest rate of damage increase was recorded for cowpea treated with *Cassia* hot-water extract, with only a 2.2-fold damage increase from December to June. In comparison, the damage increase

Table 2
Mean ± SE number of dead and live *C. maculatus* and other insects recorded between December 1999 and June 2000 in 100 g samples of cowpea treated with different *C. sophera* applications and controls

Treatment	*C. maculatus*		Other insects	
	Live	Dead	Live	Dead
Cassia 1%	1.62 ± 0.31	7.66 ± 0.86	2.53 ± 0.30	0.62 ± 0.10
Cassia 5%	1.43 ± 0.24	5.62 ± 0.69[a]	2.31 ± 0.28	0.61 ± 0.10
Control (untreated)	2.18 ± 0.56	9.17 ± 1.14	3.10 ± 0.43	0.77 ± 0.11
Cassia hot water	0.62 ± 0.14	4.17 ± 0.52[a]	1.77 ± 0.18[a]	0.59 ± 0.07
Hot-water control	0.84 ± 0.19	6.30 ± 0.84	2.41 ± 0.30	0.68 ± 0.11
Cassia cold water	1.18 ± 0.28	6.85 ± 0.95	2.22 ± 0.29	0.71 ± 0.12
Cold-water control	1.12 ± 0.33	6.17 ± 0.85	2.21 ± 0.28	0.68 ± 0.10

[a] Significant differences in Bootstrap 95% confidence interval between number of dead or live insects on treated rice grains and on their respective controls, $n = 30$.

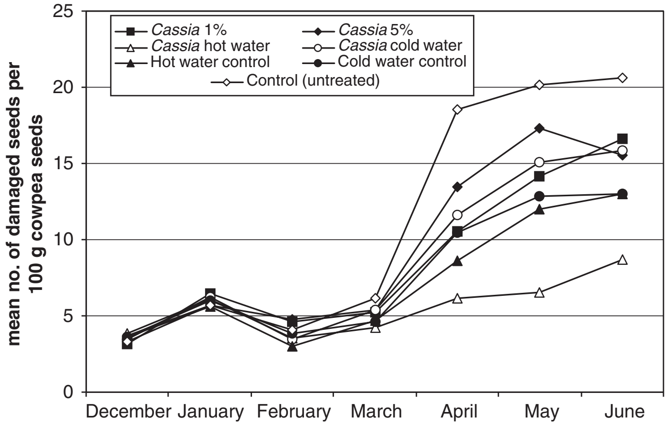

Fig. 4. Cowpea damage expressed as the mean number of seeds with bruchid emergence holes recorded in 100 g samples of cowpea seeds between December 1999 and June 2000 ($n = 30$).

in the untreated control was 6.2 times greater than the initial damage (Fig. 4). The rates of damage increase in cowpea treated with *Cassia* 1% and 5% leaf powder were significantly higher ($P < 0.05$) than those of cowpea treated with *Cassia* hot-water extract (Fig. 4). This was in agreement with the low infestation levels of *C. maculatus* and other insects recorded on cowpea treated with *C. sophera* hot-water extract.

4. Discussion

4.1. Laboratory experiments

The results indicate that *C. maculatus* and *S. oryzae* differ in their susceptibility to the anti-insect activity of different *C. sophera* treatments under laboratory conditions. This is a frequent finding in studies on plant bioactivity against insects (Shaaya et al., 1991; Ho et al., 1994; Huang et al., 1997; Paneru et al., 1997; Obeng-Ofori et al., 1998). For example, it was reported that *C. sophera* leaf powder mixed with different commodities at 1% and 5% concentrations significantly reduced F1 emergence of *S. zeamais*, *C. maculatus* and *R. dominica* in laboratory experiments, but these treatments did not affect *P. truncatus* (Belmain et al., 2001). In addition, in the same experiment, a significant increase in F1 adult mortality was only recorded for *C. maculatus* and *R. dominica* with the 5% concentration, but the plant powder was not toxic to *S. zeamais* and *P. truncatus* (Belmain et al., 2001).

In the present study, the high number of *S. oryzae* emerging in the F1 from rice grains treated with hot and cold water and from grains treated with *C. sophera* hot- and cold-water extracts could be explained by the increased moisture content of the grains after treatment with water. Indeed, it was reported that high grain moisture contents obtained by dipping wheat, sorghum and split pea in aqueous solutions increased the number of eggs hatched and the subsequent development of larvae of *S. zeamais* (Holloway, 1985). In general, high grain moisture content significantly increases oviposition by *S. oryzae* females and larval survival (Singh et al., 1974), probably by facilitating larval penetration into the grains. Although in the present study *C. sophera* hot-water extracts significantly reduced the number of emerging insects compared to the hot-water control, the experiment also showed that this was not the best method of application and that using water extracts to treat rice could result in higher rather than lower infestation and that, hence, this method might be of no practical value for farmers.

In the laboratory experiment with *C. maculatus*, however, it was the *C. sophera* hot-water treatment that resulted in the lowest adult emergence in the F2 compared to all other treatments, while *C. sophera* leaf powder did not reduce F1/F2 emergence. This was surprising since *C. sophera* leaf powder is traditionally used in the protection of stored legumes and significantly reduced F1 emergence of *C. maculatus* in Belmain's study (2001) at 0.5, 1.0 and 5.0% w/w. Although rice and cowpea are affected by hot-water extracts in a similar way, it is possible that changes in the physical and chemical properties of the cowpea surface resulting from the *C. sophera* hot-water treatment might have affected the oviposition behaviour of bruchid females or the survival of eggs and larvae and might, therefore, be responsible for the lower F1/F2. However, since moisture content was not assessed throughout the trial it is not possible, at present, to confirm whether higher moisture content is the reason for higher insect fecundity.

4.2. Rice infestation and damage in the field

Although *S. oryzae* adults were introduced into the clay pots, this species was not successful in colonising the rice grains over a 6-month period. Since *S. oryzae* usually attacks undamaged, whole grains (Dobie et al., 1991; Longstaff, 1981), the substrate used in this experiment may not have been suitable for optimal oviposition and insect development due to the high percentage (about 30%) of broken grains recorded at the beginning of the experiment. The high rice grain damage may have been a consequence of the poor processing of the grains, associated with insufficient drying prior to putting the commodity on the market. On the other hand, the initial rice grain damage would have been attractive to secondary pests such as *Tribolium*, since species of this genus are mainly unspecialised pests, which live on a wide range of commodities (Dobie et al., 1991) and *T. castaneum* (Herbst) and *T. confusum* (Du Val) have often been found infesting stored rice (Cogburn, 1980; White and Jayas, 1996; Hodges et al., 1996; Ho et al., 1997). Additionally, the high temperatures (30–40 °C daytime) and dry climate over the storage period from December to June might have contributed to the low *S. oryzae* fitness since, over the optimum temperature range of 25–30 °C, *S. oryzae* mortality increases significantly (Longstaff, 1981; Birch, 1945; Baker et al., 1991). Under these climatic conditions, the rice grain moisture content would be low, which would also have represented less suitable conditions for survival and oviposition. Indeed, it has been suggested that keeping cereal grains at low moisture content is an effective method of protection against attack by *S. oryzae* (Baker et al., 1991), while other species like *Tribolium* spp. are less affected by lower grain moisture content than *S. oryzae* (Fields and Korunic, 2000). Therefore, rice storage under dry and hot climates, such as in the savannah areas of Sub-Saharan Africa, might represent a natural way of controlling *S. oryzae* on rice, making the use of protectants or pesticides superfluous.

4.3. Cowpea infestation and damage in the field

The *C. sophera* hot-water extract was the most effective treatment at reducing insect infestation and seed damage, the latter being up to 58% lower than in untreated controls. These results are consistent with the laboratory experiment suggesting that the use of *C. sophera* hot-water extracts might be more effective at reducing cowpea infestation by *C. maculatus* than the use of *C. sophera* leaf powder. This might have very practical consequences for small-scale farmers, who may be persuaded to replace the traditional application of *C. sophera* with hot-water extracts, obtaining a more effective protection of their stored commodity.

It was also interesting to observe that treating cowpea with hot or cold water alone under field conditions reduced cowpea damage and infestation by bruchids and other insects to some extent whereas under laboratory conditions the opposite effect was observed. Interestingly, in a study conducted by Belmain et al. (1999), the use of hot water also significantly reduced cowpea insect damage over a 6-month period in a field experiment. However, the effect of the hot water temperature in the present study would not have been the only cause of insect death because a similar effect was also recorded for cold water. Water may have changed the physical and chemical properties of the cowpea surface making it less suitable for bruchid females to oviposit.

5. Conclusions

This study showed that significant differences occur between laboratory and field experiments, an outcome that stresses the importance of conducting field experiments to validate the efficacy of a botanical where laboratory testing indicates some activity. The results from this field trial are of practical consequence for local farmers, who can improve their traditional method of cowpea protection by using water-based extracts of *C. sophera* instead of the dry powder. In addition, the finding that local climatic conditions can have a favourable effect on rice storage, making the use of protectants superfluous, would allow subsistence farmers to save precious time and resources that they can then invest in other activities. More studies on botanical pesticides conducted under field conditions will contribute to assessing their real potential for local farming communities thus providing safer and cost-effective alternatives to synthetic pesticides and stimulating the establishment of conservation programmes for high value plants.

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