Insect losses on sorghum stored in selected Malian villages, with particular emphasis on varietal differences in grain resistance

A. Ratnadass, S. Berté, D. Diarra and B. Cissé*

Abstract

Surveys were conducted to assess losses caused by insect pests to sorghum grain stored in Malian villages. In April–September 1990, 27 sorghum granaries were sampled on a monthly basis in Nankilabougou, Dibaro, Siramana and Garasso. The major pest encountered in all four villages was the lesser grain borer (LGB) *Rhyzopertha dominica*.

Except in sorghum stored in bags, losses were very low — generally less than 1% weight loss over the storage period, especially in local sorghums stored as bundles of heads. A survey conducted in 1992 at Siramana on eight sorghum stocks broadly confirmed these results. To avoid the release at the village level of LGB super-susceptible sorghum cultivars, a laboratory screening technique was developed. In a test involving eight cultivars, CSM 388, whose grain is hard and vitreous, was the most resistant to LGB, whereas S 34, whose grain is soft and floury, was the most susceptible.

In both the village loss assessment surveys and the laboratory screening test, strong correlations were found between weight loss estimates and grain damage counts.

Introduction

An inventory of insect pests of stored commodities, including sorghum, has been initiated by the Institut d'Economie Rurale, Mali (IER, unpublished data), and traditional cereal grain storage techniques at the farm level in Mali have been described by Kodio (1989). However, information on the insect fauna of stored sorghum in Mali, and on losses incurred at the village level are scarce and fragmentary. On the other hand, the lesser grain borer *Rhyzopertha dominica* (Fabricius) (Coleoptera, Bostrychidae) is considered a very serious pest of stored cereal grains in central stores and in traditional village granaries (Coulibaly 1993).

Although insecticide tests were carried out by IER and the Office des Produits Agricoles du Mali (OPAM), they did not result in the extension of any protection technique at the farm level. The use of sorghum varieties resistant to storage pests could also constitute an efficient and economical alternative to chemical protection, as it would neither require any input from farmers, harm consumers or the environment, nor select strains of pests resistant to pesticides. However, its potential on stored sorghum has not been investigated in Mali.

In order to fill these gaps in our knowledge, the studies presented in this paper were carried out between 1989 and 1992 by the West African Sorghum Improvement Program (WASIP) of the International Crops Research Institute for the Semi-Arid Tropics in Mali. They comprise a first assessment of the insect pest fauna of stored sorghum, and losses incurred at the village level, and a preliminary appraisal of the relative resistance of some sorghum varieties to the lesser grain borer.

* ICRISAT/WASIP-Mali, Samanko, BP 320 Bamako, Mali.

Materials and Methods

Inventory of insect fauna and assessment of losses

In 1989, preliminary and qualitative observations were made on farmers' sorghum grain stored in the villages of Nankilabougou, Dibaro, Kayo, N'Galamadibi, Koulikoroni and Mafeya, all located in the Region of Koulikoro (Second Region of Mali: Fig. 1). A more detailed survey was carried out in 1990 in four Malian villages, namely: Dibaro and Nankilabougou, in the Second Region and Garasso and Siramana, in the Region of Sikasso (Third Region of Mali: Fig. 1).

In 1990, 27 storage structures were chosen on the basis of criteria such as the type of structure (e.g. mud bricks, woven grass basket granary, or bags in the house), the mode of storage (e.g. loose grain, or bundles of heads), or the sorghum variety stored. These structures were sampled monthly between April and September, using the 'coning and quartering technique' (Golob 1976), applied to the amount of grain taken by the farmer for food consumption at each sampling occasion. Sample size was about 300 g of grain. Insect fauna was determined after sieving samples in the laboratory with a 2.00 mm mesh sieve at weekly time intervals, until the development to adult and emergence from the grain of all hidden immature stages of insects. Weight loss due to insects was assessed in the laboratory, using a variant of the 'count and weigh method' (Adams and Schulten 1978), with a distinction made between grains actually bored and those attacked only superficially, and a second estimation made after the emergence of all hidden forms of insect pests (Ratnadass 1990; Ratnadass and Fleurat-Lessard 1991). Dry weight loss was calculated using the formula below:

$$\%\ \text{weight loss} = \frac{U(Ns + Nb) - Nu(S + B)}{U\ (Nu + Ns + Nb)} \times 100 \qquad (1)$$

where
U = weight of undamaged grains
Nu = number of undamaged grains
S = weight of superficially attacked grains
Ns = number of superficially attacked grains
B = weight of bored grains
Nb = number of bored grains.

In the case of the last samples taken at Siramana and Garasso, the 'expanded count and weigh method' (Boxall 1986) was used. A 3.15 mm mesh sieve was used for separating samples into two categories of grain size. Monthly loss figures were then related to the pattern of consumption and cumulative weight loss figures over the storage period obtained (Adams 1978). This calculation made it necessary to determine moisture content in each sample, using a Wîle moisture meter.

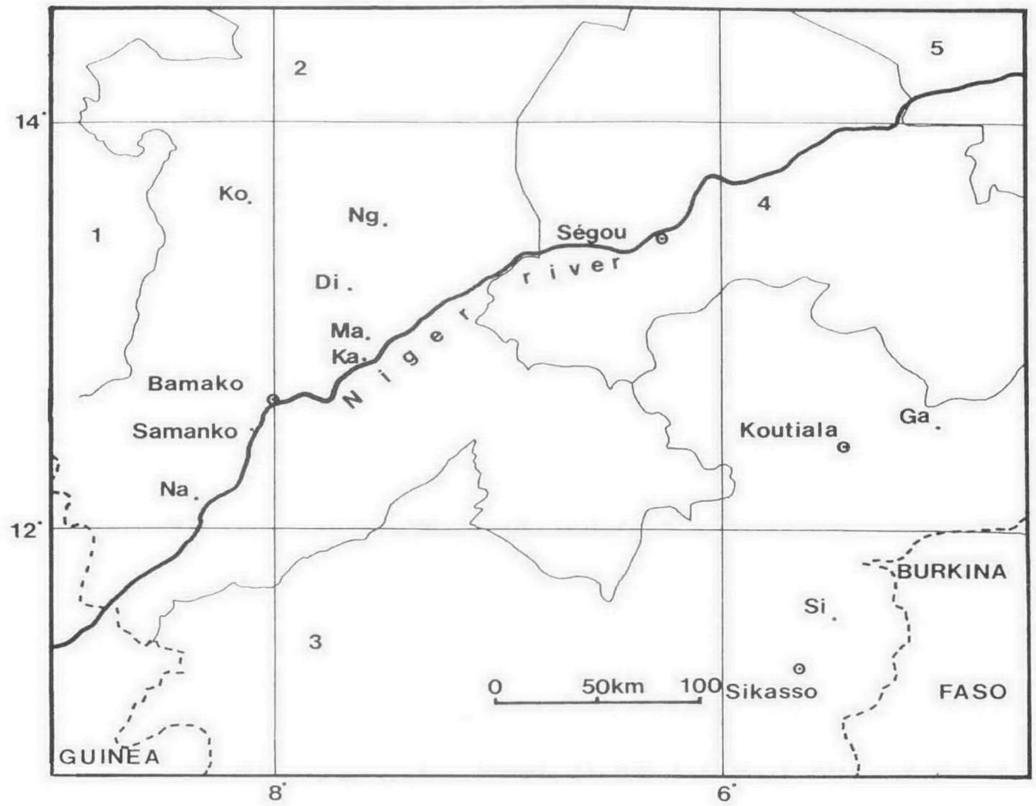

Fig. 1. Map with location of sampling sites in central and southern Mali. State boundaries —; regional boundaries ---. First to Fifth regions of Mali. Sampling sites: Di = Dibaro, Ga = Garasso, Ka = Kayo, Ko = Koulikoroni, Ma = Mafeya, Na = Nankilabougou, Ng = N'Galamadibi, Si = Siramana.

In 1992, studies were carried out in Siramana only. Grain samples were taken on three occasions in the sorghum stores of farmers who had grown improved sorghum cultivars in their fields, as part of WASIP's on-farm tests. The same analyses were performed as in 1990, except that attacked grains were counted, and dry-weight loss was assessed only once, after all hidden forms of the pests had emerged from the grain. It was possible to take samples of improved cultivars on the first occasion (on 22 May 1992, after a storage period of about five months), as small amounts of threshed grain of such cultivars were to be found stored in bags. On the following sampling occasions (13 August and 2 October 1992, respectively, after a storage period of 8 to 10 months), however, only local cultivars were found, stored on the head, and were sampled.

Screening sorghums for resistance to lesser grain borer

Grains of eight sorghum cultivars (IRAT 202, S 34, Malisor 84–7, ICSV 1063, ICSV 1079, Malisor 84–1, CSM 388 and Bimbagalawili), were evaluated for lesser grain borer resistance in the laboratory at Samanko between February and July 1992, under natural photoperiod and controlled temperature and relative humidity. Laboratory conditions (temperature, relative humidity and day length) were respectively 26±2°C, 75±5%, and 11 hours 30 min to 12 hours 45 min. Grains were kept in lots of 10 g for one month in 0.25 L transparent plastic containers with mesh-covered perforations to provide aeration, to allow their moisture content to reach equilibrium with the ambient relative humidity. They were then infested with 30 unsexed newly emerged adults of *R. dominica* (strain from Samanko) in a randomised complete block design with five replications. Adults were left on the grain for mating and oviposition period of one week and then removed using a sieve.

Grain lots were undisturbed for a period of one month after which sieving was resumed on a weekly basis until no further emergence was observed. After the last sieving, the undamaged grains were separated from the damaged ones, and superficially attacked and actually bored grains were distinguished. The grains in each category were then counted to provide the percentage of damaged grain. Each category was then weighed to assess dry-weight loss by using formula (1). A sample of the grain lots was analysed by the IER Cereals Technology Laboratory at Sotuba, Mali for grain hardness, using the 'abrasive hardness index' (AHI) method (Reichert et al. 1982).

Development of the loss assessment methodology

To provide further evidence of the adaptation of the weight loss assessment method used, and of the scope for its simplification by using conversion coefficients like in the converted percentage method (Adams and Schulten 1978), several correlation and regression calculations were made for different parameters measured on grain samples from the village surveys and the laboratory screening test.

Results and Discussion

Major insect pests

A tentative inventory of insect fauna of stored sorghum, based on 1989, 1990 and 1992 surveys, is provided in Table 1. The major pest encountered in all six villages visited in 1989, and in all four villages in 1990, was the lesser grain borer, *R. dominica*, with a maximum population level of more than 6000 insects/kg, on a sample taken at Nankilabougou in 1990. In 1990, this species was predominant at Nankilabougou and Dibaro, but was less abundant at Garasso and Siramana (Table 2). As for other primary pests, *Corcyra cephalonica* (Stainton) and *Sitotroga cerealella* (Olivier) were respectively absent only from Nankilabougou and Dibaro, while *Sitophilus* spp were to be found in all villages except Dibaro. *Trogoderma* sp was observed at Dibaro, and *Plodia interpunctella* (Hübner) at Garasso. In 1992 at Siramana, *C. cephalonica* was the dominant species. The sampling pattern used does not allow the actual evolution of infestation to be taken into account, nor does it enable a comparison of the different stores on that criterion.

The distribution and relative importance of these pests can be explained by their biological characteristics, and the climate of the regions surveyed, referring to the adaptability index as defined by Sinha (1974). *R. dominica* tolerates temperatures higher than those which suit weevils, and is able to attack very dry grain. Although it was also reported as the dominant species of stored sorghum in northern Togo (Lausmann et al. 1984), it was found only occasionally in the Central African Republic (CAR) where *Sitophilus oryzae* (Linnaeus) was dominant (Ratnadass 1990). Although its area of adaptation is limited, *C. cephalonica* can be a dominant pest in the humid and dry lowlands (Sinha 1974). *Anisopteromalus calandrae* (Howard) was the only parasitoid identified. This parasitic wasp is known to have several hosts among storage pests, notably *Sitophilus* spp and *R. dominica*.

Losses sustained at the farm level

Table 3 provides an example of the calculation of the overall percentage loss by summation of individual losses. It is notably based on the assumption that loss was negligible before the first sampling occasion. However, in two cases at Nankilabougou, on sorghum grain stored in bags, dry-weight loss on the first sampling occasion was more than 6%, and got as high as 15.9% in May and 8.7% in July, on the last sampling occasions. Similarly at Dibaro, in a mud granary where grain was stored loose, dry-weight loss was 2.4% on the first sampling occasion and 8.9% one month later. Cumulated dry-weight loss figures over the storage period, as calculated for the other 24 storage structures, are given in Table 4. Except for the cases mentioned above, losses were very low—generally less than 1% over the storage period, especially in sorghum stored as bundles of heads. However, given the small number of stores studied, we found no significant differences among

Table 1. Preliminary inventory of the insect fauna of sorghum stored in 10 Malian villages.

Order	Family (sub-family)	Scientific name	Status
Coleoptera	Bostrychidae	*Rhyzopertha dominica* (Fabricius)	Primary
	Dermestidae	*Trogoderma* sp	Primary
	Curculionidae	*Sitophilus oryzae* (Linnaeus)	Primary
		Sitophilus zeamais Motschulsky	Primary
	Cucujidae	*Oryzaephilus mercator* (Fauvel)	Secondary
		Cryptolestes sp	Secondary
	Nitidulidae	*Carpophilus* sp	Secondary
	Tenebrionidae	*Tribolium castaneum* (Herbst)	Secondary
Lepidoptera	Gelechiidae	*Sitotroga cerealella* (Olivier)	Primary
	Pyralidae		
	(Gallerinae)	*Corcyra cephalonica* (Stainton)[a]	Primary
	(Phycitinae)	*Plodia interpunctella* (Hübner)	Primary
Hymenoptera	Pteromalidae	*Anisopteromalus calandrae* (Howard)[a]	Parasitoid

[a]Identification by CIRAD-CA taxonomy laboratory; other identifications made after Weidner and Rack (1984)

Table 2. Maximum infestation levels in sorghum grain stored at the farm level in four Malian villages (April–September 1990) by the main pest species (insects/kg)

Insect species	Villages			
	Nankilabougou	Dibaro	Garasso	Siramana
Rhyzopertha dominica	6154	1780	25	42
Tribolium spp	205	27	44	5
Sitophilus spp	5	0	66	24
Oryzaephilus mercator	16	35	6	37
Sitotroga cerealella	10	0	10	3
Corcyra cephalonica	0	15	5	30

Table 3. Evolution of dry-weight loss of sorghum (cultivar Tiémarifing) stored in Sidiki Dembélé's mud bricks granary at Garasso, Mali (May–September 1990), and its relation with grain consumption pattern.

Month	Jan–April	May	June	July	August	September	Total
Quantity removed (kg fresh matter)	3800	540	540	540	540	540	6500
Moisture content (%)	11.1	11.1	12.6	12.6	13.9	13.3	–
Quantity removed (kg dry matter)	3378	480	472	472	465	468	5735
Dry weight loss in sample(%)	0	1.5	2.1	2.2	1.6	1.3	–
Dry weight loss as % of total grain stored	0	0.12	0.17	0.19	0.14	0.10	0.73

Table 4. Cumulative dry-weight loss figures observed on sorghum stored in villages of Mali (Apr–Sep 1990).

Village	Cultivar	Type of structure	Mode of storage	No. of structures	Cumulative dry-weight loss[a]
Dibaro	N'déréni	Roughcasted woven grass granary	Loose grain	4	0.70 ± 0.22
	Tiémarifing	Roughcasted woven grass granary	Loose grain	2	0.99 ± 0.36
Nankilabougou	Tiémarifing	Mud	Loose grain	2	2.13 ± 1.52
		Non rough-casted woven grass granary	Loose grain	1	1.09
			Individual heads	1	0.76
Garasso	Tiémarifing	Mud	Individual heads	1	1.13
			Loose grain	1	0.73
	Magnon blen	Mud	Bundles of heads	4	0.32 ± 0.14
	Sozankalaga	Mud	Bundles of heads	1	1.64
	Séguétana	Mud	Bundles of heads	2	0.26 ± 0.04
Siramana	Séguétana	Mud	Bundles of heads	2	0.21 ± 0.13
	Gnomba and Bimbiriba	Mud	Bundles of heads	3	0.35 ± 0.14

[a] As % of total: mean (±standard deviation, when applicable).

sorghum varieties, types of storage structure, or methods of storage.

The results of the 1992 study at Siramana, as given in Table 5, show that insect infestation and dry-weight loss figures were higher than those recorded in 1990 in the same village for the same cultivars. However, the loss figures provided for 1992 are second estimates (i.e. over-estimates) of the actual weight loss in the samples. In view of these figures, the percentage loss over the whole storage period should not exceed 2–3% for local cultivars, stored on the head. After a period of about five months of storage as loose grain, all three improved caudatum cultivars ICSV 1063, ICSV 1079, and Malisor 84–1, sustained heavier loss than the improved local guinea cultivar CSM 388.

Our figures from the 1990 and 1992 surveys are consistent with others obtained in similar studies. For Schulten (1988), losses at the farm level, expressed as weight loss of the initial quantity stored, are in the order of 1.5% for insect losses for storage periods up to nine months. As for sorghum, such losses have been reported as 1.7% in Malawi (Golob 1981), 2.8% in Swaziland (De Lima 1983), and less than 1% in the CAR (Ratnadass 1990). Giles (1965, in Omoregie 1990) reported a loss due to insect attacks of 4% in sorghum stored in local granaries in Nigeria. More recently, Nyambo (1993)

Table 5. Results of entomological analyses performed on samples of stored sorghum grain taken at Siramana in 1992

Date	Cultivar	Mode of storage	No. of samples	No. of insects/kg	Damaged grains %	Dry-weight loss %
22/05	Séguétana	head	3	508 ± 346	5.9 ± 4.3	1.6 ± 1.0
	Bimbiriba	head	2	527 ± 490	11.3 ± 6.5	2.3 ± 0.9
	CSM 388	loose	5	275 ± 245	10.5 ± 5.8	2.1 ± 0.9
	Malisor 84–1	loose	2	608 ± 13	16.0 ± 9.5	6.7 ± 3.8
	ICSV 1063	loose	3	224 ± 61	7.3 ± 1.2	3.8 ± 1.5
	ICSV 1079	loose	2	557 ± 219	84 ± 2.2	2.3 ± 1.2
13/08	Séguétana	head	5	777 ± 1118	3.7 ± 1.7	1.5 ± 1.3
	Bimbiriba	head	2	1847 ± 9	2.1 ± 0.7	0.2 ± 0.2
02/10	Séguétana	head	5	1560 ± 1569	10.8 ± 7.5	4.5 ± 3.3
	Bimbiriba	head	2	676 ± 62	7.3 ± 1.4	2.5 ± 0.4

reported losses of 3.6–14.3% on sorghum after four months of storage at the farm level in Kenya. However, these last two loss figures were not expressed as weight loss of the initial quantity stored.

On the other hand, one should bear in mind that we reported only dry-weight losses, while the actual loss for the consumer may be greater, especially when food preparation involves soaking of the grain; actual loss would then be more accurately approached by the percentage of bored grains, whose value is 2–3 times higher than that of the dry-weight loss. As for quality losses proper, they are also trivial at the weight loss levels observed (1%). However, when weight losses reach 10–20%, then quality losses assume a different order of importance. For instance, in the case of bag storage observed at Nankilabougou, where infestation was more than 6000 insects/kg and weight loss close to 16%, the whole quantity of grain could actually be considered as unfit for human consumption.

Screening for resistance to lesser grain borer

Results presented in Table 6 show that CSM 388, an improved local guinea cultivar which has a hard and vitreous grain, was the most resistant to entry, while S 34, an improved caudatum cultivar with a soft and floury grain, was the most susceptible. Bimbagalawili, a local guinea from Nankilabougou ranked second after CSM 388.

As mentioned above, although there are reports in the world literature on sorghum resistance to storage pests other than the lesser grain borer (e.g. Doggett 1957 in Doggett 1988; Rogers and Mills 1974; Teetes et al. 1981) and on resistance to lesser grain borer in cereals other than sorghum (Breese 1960; Sauphanor 1988), no published information is available that deals specifically with sorghum resistance to lesser grain borer, particularly from West Africa. Factors reported to confer resistance to *Sitophilus* spp in sorghum were notably grain hardness (Doggett 1957 in Doggett 1988; Fadelmula and Horber 1984) and glume coverage (Rogers and Mills 1974).

Grains of all cultivars evaluated in our study threshed free of their glumes. However, grain hardness was not the only factor involved in resistance to *R. dominica*. The grains of IRAT 202, which are among the softest, but possess a subcoat, with high contents in tannins and phenolic compounds, were more resistant than Malisor 84–7 grains, which are the hardest of all compact panicle types, but have very low contents in such compounds (Fliedel et al. 1993). Because of its powerful grinding mouthparts, the lesser grain borer is probably less affected by differences in grain hardness than other pests. On the other hand it could be repelled by the ‘bitterness’ of IRAT 202 grains.

Development of the loss assessment methodology

On the last samples taken at Siramana and Garasso, correlation coefficients between percentage of damaged grains and loss percentages (second estimates for both parameters) were significant at the $P = 0.001$ level ($r = 0.89$; 9 d.f.), while differences between weight loss figures obtained with and without separation of grains into categories of size were not significant at the $P = 0.05$ level. As a matter of fact, sorghum grain size was fairly constant within a single variety, and such a separation was therefore not justified, as it would have been if several varieties had been mixed (Ratnadass and Fleurat-Lessard 1991). In the case of Tiemarifing landrace at both Nankilabougou and Dibaro, highly significant correlations ($P< 0.001$) were found between the first estimate of the percentage of bored grains (X) and the mean of the two estimates of the percentage of weight loss (Y). The equation:

$$Y = 0.21X + 0.46 \quad (2)$$

explained 78% of the global variance at Nankilabougou, while the equation:

$$Y = 0.39X + 0.16 \quad (3)$$

explained 85% of the global variance at Dibaro.

These significant correlations are an indication of the adaptation of the loss assessment method used. The importance of the hidden infestation provided an a posteriori justification to the second loss assessment. Contrary to *Sitophilus* spp and *S. cerealella*, whose larval exit holes allow a clearcut distinction between damaged and undamaged grains (Ratnadass and Sauphanor 1989; Ratnadass 1990), feeding by *R. dominica* adults and *C. cephalonica* larvae affects grains in a variable way, which justified a separation of the grains according to the level of damage. Regression equations calculated will also

Table 6. Lesser grain borer (*Rhyzopertha dominica*) population buildup and damage on the grains of eight sorghum cultivars in a laboratory screening trial, Samanko, Mali, 1992[a]

Cultivars	No. adults	Damaged grains (total) %	Bored grains %	Dry-weight loss %	Grain hardness (s)[b]
IRAT 202	16 (3.8)[c]	8.1 (16.4)[d]	5.1 (12.9)[d]	3.5 (10.6)[d]	3.5
ICSV 1063 BF	28 (4.9)	12.9 (20.6)	9.2 (17.1)	5.5 (13.0)	3.5
ICSV 1079 BF	24 (4.7)	11.3 (20.6)	7.1 (14.8)	3.9 (11.0)	4.6
S 34	71 (7.8)	13.8 (21.3)	12.5 (20.0)	8.3 (15.8)	4.3
Malisor 84–1	32 (5.3)	15.2 (22.4)	12.1 (19.8)	5.5 (13.3)	5.8
Malisor 84–7	43 (6.3)	14.3 (22.0)	9.1 (16.9)	4.5 (11.6)	8.2
Bimbagalawili	12 (3.2)	9.2 (17.4)	5.1 (12.7)	2.6 (9.0)	8.4
CSM 388	6 (2.2)	3.2 (9.5)	2.4 (8.3)	1.3 (6.0)	9.1
SE	(±0.51)	(±3.47)	(±1.65)	(±1.36)	na
Mean	(3.2)	(18.6)	(15.3)	(11.3)	na
CV (%)	(36)	(19)	(24)	(27)	na

[a]Randomised complete block design with five replications; infestation for one week with 30 unsexed newly emerged lesser grain borer adults.
[b]Grain hardness measured using the abrasive hardness index method (Reichert et al. 1982).
[c]Figures in parentheses are square-root values
[d]Figures in parentheses are arc-sine transformed values.

allow a pretty accurate assessment of weight loss on the basis of the first estimate of the percentage of damaged grains alone, making the loss assessment exercise quicker and less labour-intensive. As for the laboratory screening test, correlation coefficients between the parameters measured are presented in Table 7. Given the significance levels observed, observations could be simplified in future studies; for instance, only insect numbers could be taken, making the screening test also less tedious.

Table 7. Linear correlation coefficients between parameters measured on sorghum grain samples in the lesser grain borer resistance screening test.

Parameters	Insects/kg	Bored grains (%)	Dry-weight loss (%)[a]
Insects/kg	1.000		
Bored grains (%)	0.849[b]	1.000	
Dry-weight loss (%)	0.924[c]	0.930[c]	1.000

[a]Second estimates
[b]Significant at the P = 0.01 level (10 df).
[c]Significant at the P = 0.001 level (10 df)

Conclusion

Our studies showed that *R. dominica* was the predominant species of insect pest in sorghum grain stored in villages of Mali, but that it was generally responsible for only negligible loss on local cultivars stored in traditional granaries. However, high yielding caudatum cultivars were found to be more heavily attacked by storage pests than local guinea types. Care should therefore be taken that breeders routinely subject their improved material to screening for resistance to storage pests, to ensure that super susceptible cultivars are not released at the farm level. As a first step, we successfully developed and tested such a routine screening technique for *R. dominica.*

Acknowledgments

We are grateful to Messrs C.A.T. Thiéro, B. Camara, B. Sidibé, I. Maïga and B. Badadéré, of ICRISAT/WASIP-Mali for their assistance in conducting village surveys, and to farmers in the villages of Dibaro, Nankilabougou, Garasso and Siramana for their collaboration. We also thank Dr. G. Delvare and his colleagues at the CIRAD-CA Taxonomy Laboratory in Montpellier for insect identifications, and Ms. M. Haidara and her colleagues at the IER Cereal Technology Laboratory at Sotuba for measurement of grain hardness in sorghum samples. This paper was approved as ICRISAT CP # 778.

References

Adams, J.M. 1978. The chronological approach: losses as reflected by use patterns. In: Harris, K.L. and Lindblad, C.J. eds, Post harvest grain loss assessment methods. St Paul, USA. American Association of Cereal Chemists, 135–137.

Adams, J.M. and Schulten, G.G.M. 1978. Losses caused by insects, mites and microorganisms. In: Harris, K.L. and Lindblad, C.J. eds, Post harvest grain loss assessment methods. St Paul, USA. American Association of Cereal Chemists, 83–85.

Boxall, R.A. 1986. A critical review of the methodology for assessing farm-level grain losses after harvest. Report of the Tropical Development and Research Institute G 191. Chatham, U.K. Natural Resources Institute. 139 p.

Breese, M.H. 1960. The infestability of stored paddy by *Sitophilus sasakii* (Tak.) and *Rhyzopertha dominica* (F.). Bulletin of Entomological Research 51, 599–630.

Coulibaly, C.O. 1993. Biotype variation in *Tribolium castaneum* (Herbst) from Mali. Ph.D. thesis, University of Leicester, U.K.

De Lima, C.P.F. 1983. An evaluation of the postharvest losses occurring on farm on all grain types and containers in homesteads from the National Agricultural Survey, 1980–81 and 1981–82. FAO Action Program SWA/002/PFL, Swaziland, 18 p.

Doggett, H. 1988. Sorghum. 2nd edn. London, U.K. Longman Scientific & Technical. 512 p.

Fadelmula, A. and Horber, E. 1984. Resistance of sorghum varieties to *Sitophilus oryzae* and *Sitotroga cerealella.* In: Proceedings of the 3rd International Working Conference on Stored-Product Protection, Manhattan, USA. Manhattan, USA. Kansas State University, 418–434.

Fliedel, G., Ratnadass, A. and Yajid, M. 1993. Study of some physico-chemical characteristics of developing sorghum grains in relation with head bug resistance. Presented at the ICC International Symposium: Cereals Science and Technology: Impact on a Changing Africa, 9–13 May 1993, Pretoria, South Africa. Montpellier, France. CIRAD-CA. (Limited distribution).

Golob, P. 1976. Techniques for sampling bagged produce. Tropical Stored Product Information 31, 37–48.

Golob, P. 1981. A practical assessment of food losses sustained during storage by small holder farmers in the Shire Valley agricultural development project area of Malawi. Report of the Tropical Products Institute no. G 138. Chatham, U.K. Natural Resources Institute, 32 pp.

Kodio, O. 1989. Structures paysannes de stockage. (In Fr.). In: Parmentier, M. and Foua-Bi, K. eds, Céréales en régions chaudes: conservation et transformation: proceedings of an AUPELF-UREF International Technology Workshop, 22–26 Feb 1988, N'Gaoundéré, Cameroun. Paris, France. John Libbey Eurotext, 19–25.

Laussmann, H., Biliwa, A., Akou-Edi, D., Krall, S., Lawson, B. and Atchikiti, A. 1984. Enquête sur la conservation traditionnelle du maïs et du sorgho au Togo. (In Fr.) Bulletin de la protection des végétaux no. 3. Lomé, Togo, Service national de la protection des végétaux du Togo, 44 p.

Nyambo, B.T. 1993. Post-harvest maize and sorghum grain losses in traditional and improved stores in South Nyanza District, Kenya. International Journal of Pest Management 39(2), 181–187.

Omoregie, A.U. 1990. Problems of food storage and preservation in Nigeria: an overview. Tropicultura 8(2), 55–58.

Ratnadass, A. 1990. [Losses caused by insects to sorghum stored in Ouham-Pendé and Ouham villages (the Central African Republic).] Les pertes occasionnées par les insectes au sorgho stocké dans des villages de l'Ouham et de l'Ouham-Pendé (République centrafricaine). (In Fr. Summaries in En, Es.) Agronomie Tropicale 45(1), 31–41.

Ratnadass, A. and Sauphanor, B. 1989. Les pertes dues aux insectes sur les stocks paysans de céréales en Côte d'Ivoire. (In Fr.) In: Parmentier, M. and Foua-Bi, K. eds, Céréales en régions chaudes : conservation et transformation: proceedings of an AUPELF-UREF International Technology Workshop, 22–26 Feb 1988, N'Gaoundéré, Cameroun. Paris, France. John Libbey Eurotext, 47–55.

Ratnadass, A. and Fleurat-Lessard, F. 1991. Improvements in the practical methods of assessment of losses caused by insects in grain stored at the village level in tropical Africa. In: Fleurat-Lessard, F. and Ducom, P. eds, Proceedings of the 5th International Working Conference on Stored-Product Protection, 9–14 Sep 1990, Bordeaux, France. Villenave d'Ornon, France, Institut national de la recherche agronomique, 1681–1191.

Reichert, R.D., Youngs, C.G. and Oomah, B.D. 1982. Measurement of grain hardness and dehulling quality with a multisample Tangential Abrasive Dehulling Device (TADD). In: Proceedings of the International Symposium on Sorghum Grain Quality, 28–31 Oct 1981, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Center, Patancheru, India. Patancheru, AP 502 324, India: ICRISAT, 186–193.

Rogers, R.R. and Mills, R.B. 1974. Evaluation of a world sorghum collection for resistance to the maize weevil, *Sitophilus zeamais*

Motsch., (Coleoptera: Curculionidae). Journal of the Kansas Entomological Society 47(1), 36–41.

Sauphanor, B. 1988. Influence des caractéristiques de glumelles sur la résistance variétale du riz aux insectes des stocks. Entomologia Experimentalis et Applicata 47, 55–67.

Schulten, G.G.M. 1988. FAO's experience with crop loss assessment. Insect Science and its Application 9(6), 763–767.

Sinha, R.N. 1974. Climate and the infestation of stored cereals by insects. Proceedings of the 1st International Working Conference on Stored-Product Protection, Savannah, USA. University of Georgia, 117–141.

Teetes, G.L., Chantrasorn, W., Johnson, J.W., Granovsky, T.A. and Rooney, L.W. 1981. Maize weevil: A search for resistance in converted exotic sorghum kernels. Report of the Texas Agricultural Experiment Station B-1371. College Station, USA. Texas Agricultural Experiment Station, 38 p.

Weidner, H. and Rack, G. 1984. Tables de détermination des principaux ravageurs des denrées entreposées dans les pays chauds. Schriftenreihe no. 129. Eschborn, Germany. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), 148 p.