Quality Changes in Farm-stored Sorghum Grain Grown in the Wet or Dry Season in Southern India—a Technical and Social Study

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Abstract

In the last 20 years, production and consumption of sorghum in parts of southern India have declined. To understand the factors responsible for this, a survey of postharvest practice was undertaken which included a participatory rural appraisal with farmers and sampling to test the quality of grain in their stores. Twelve villages were chosen which grow sorghum during the monsoon rains (kharif season) or after the rains (rabi season). The grain samples were taken from stores both before and after the monsoon, analysed for quality, and tested for mycotoxins.

Overall, grain storage problems of farmers in southern India seem not to be a disincentive to sorghum cultivation. Both crops suffered mycotoxin contamination but this was below limits likely to represent a health hazard. Hybrid sorghum varieties, by virtue either of the season in which they grow or intrinsic characteristics, suffered considerable quality decline in storage, although this is clearly not an issue in the current scenario of farming practice. This does not mean that these traits are not impacting on the wider sorghum economy, but only that they are not impacting on the components of the sorghum production and utilisation system examined. A related project has shown a different picture for storage by wholesale traders and industrial users. So, while the current study has certainly laid to rest many concerns relating to farm storage, components of the utilisation chain where these factors now seem to be more critical remain to be studied in detail. In addition, if farmers in the future wish to retain stocks between seasons, in order to market grain strategically, then current practice may be inappropriate since grain quality at the end of the storage season was poor.

SORGHUM production and consumption has either stagnated or declined in many areas of southern India over the last 20 years (Hall and Brough 1997; Marsland 1998). In an effort to address agricultural policy needs and future research priorities for sorghum, a study was undertaken of postharvest quality issues to determine whether or not these are involved in the apparent decline in production. Two other projects, not reported here, considered sorghum utilisation and marketing issues.

The extent of storage losses and quality deterioration were investigated in sorghum grain from farmers' stores, and a study made of farmers' perceptions of these parameters, and of the relative importance of these to household food security, using participatory rural appraisal. The study was undertaken in 12 selected villages in the states of Karnataka, Maharashtra and Andhra Pradesh. In addition to assessing the visible grain quality characteristics, further insights into postharvest problems were gained by an analysis of mould and mycotoxin contamination, since these can have an important bearing on issues of human and animal health. During a rapid rural appraisal in March 1997, it was established that farmers considered most grain deterioration to occur during the period of the monsoon. In view of this, a decision was made to collect grain samples before the rains in June and after the rains in October (Table 1).

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Table 1. Summary of season of origin and age in store of sampled grain.

	Samples taken (date)		
	June 1997	October 1997	January 1998
Kharif (harvested October '96)	7–8 months	12 months	Not sampled
Rabi (harvested February '97)	4–5 months	7–8 months	11 monthd

The working hypotheses identified during the rapid rural appraisal were that: measurable losses in quantity are small and much lower than the figure stated by many postharvest scientists (e.g. 20% weight loss); quality deterioration is unlikely to present any health hazard (especially in relation to mycotoxin contamination); and farmers' perceptions were that losses occurred in storage but that these were low and not a major constraint in production and utilisation systems. These hypotheses conflict with the views of many agricultural workers (other than farmers) who expressed the view that postharvest problems are a serious constraint in sorghum agriculture.

Methods

Selection of districts and villages for participatory rural appraisal and grain sampling

Twenty-seven major sorghum-producing districts were identified. These had the area planted to kharif or rabi crops at 15% or more of the total cultivated area. A purposeful selection of six of these districts was made to represent a good cross-section of production and utilisation scenarios. Within each of these districts, two sub-districts were chosen at random and within each of these one village was selected at random but rejected if it was on a main road, was excessively urbanised or was atypical in some other characteristic. This yielded a total of 2 villages for each district and 12 villages in all (details of the villages are given in Hodges et al. 1999).

A small team of socio-economists, together with two grain survey staff, visited villages in June 1997 just before the start of the monsoon. A second sample survey was undertaken in October 1997, after the monsoon, when samples were taken mostly from the same farmers and same stores as in June. At the second visit some farmers were absent or no longer had any stock. Where this occurred, replacement farmers with stored grain were selected to ensure that not less than four samples were taken per village. A final sample was taken in January 1998 to examine the quality of the 1997 rabi crop just before the new harvest.

Selection of farmers and assessment of farmers' perceptions

During the initial village visit, group meetings were used to gain an understanding of the storage practices of farmers, their store types and usual storage periods. From these discussions it was apparent that storage of grain from one season to another was uncommon apart from the case of a limited number of rich households. Subsequent wealth ranking exercises were used to classify households into 'rich', 'medium' and 'poor' and, in a number of cases, into an additional category of 'very poor'. These categories broadly correlate with the area of landholding. Rich farmers harvested sufficient grain to retain some in store for the entire period between harvests. Generally, farmers were storing grain for up to 6 months and in the case of poor households perhaps only 2–3 months.

Farmers were selected across the range of storage periods, but with more chosen from the shorter storage periods. It was hoped this would capture the poor households, but for a number of reasons this was not entirely successful. Despite these efforts to select households predominantly from the poor category, subsequent wealth ranking exercises indicated that the selection was biased towards farmers from the richer wealth categories (Table 2). It is also the case that the poorest of the poor are landless labourers and as such, unless they are paid in grain, have no need to store grain. Farmers' perceptions concerning grain and quality losses were assessed as part of a wider participatory rural appraisal survey that examined aspects of both production and utilisation. Wealth ranking exercises were used to stratify farmers and a series of ranking, scoring and diagramming exercises were used to gain an understanding of the sorghum economy in the context of the farming and livelihood systems. Farmers chosen for grain sampling were the subjects of in-depth interviews. Additional households from the poor wealth categories were used to supplement these case studies to provide a more balanced picture, correctly weighted for the socioeconomic profile of the selected villages. The findings of these in-depth interviews form the basis of the discussion presented in this report.

Sampling from farm stores

Samples of 5 kg were extracted from farm stores using sampling probes of appropriate dimensions and then placed in a double layer plastic bag for return to the laboratory. Multiple sub-samples were taken from across the width and depth of each store to provide the best possible representative sample. Where there was open access to the grain bulk, such as in mudded baskets or loose grain piles, a five-compartment probe (80 cm long by 2.5 cm diameter) was used. Where access was more difficult, such as in bag stacks of gunny (jute) bags, a short probe (27 cm by 1.5 cm diameter) was employed. A total of 73 samples was collected in June 1997, 68 in October and 13 in January 1998. Farmers were paid for their grain at the current market rate. Care was taken not to mention to farmers that a further sample would be taken at a later stage. This was done to ensure that their subsequent behaviour would not be influenced by the opportunity to sell grain to the researchers.

General grain quality assessment

On return to the laboratory the grain was fumigated with phosphine to kill all infesting insects. Each 5 kg sample was then separated using a Boerner divider into three 1 kg portions for general quality analysis, mould and mycotoxin analysis. The remaining 2 kg, plus about 1 kg remaining after general analysis, was recombined and stored in a cool, dry place pending any further requirement for analysis.

One of the 1 kg samples was subdivided to give a sub-sample of 600 g. From this, three 30 g sub-samples were taken to determine moisture content (MC) using a ventilated oven (3 h at 130°C) and a 200 g sample taken to estimate insect numbers. The remainder of the sample was weighed and then carefully sorted to give the following quality refractions by weight: % discoloured grain, % shrivelled grain, % mould damaged grain, % insect damaged grain, % foreign matter and % sound grain.

To provide a convenient means of comparing samples a quality index (QI) was developed. The QI was calculated as the sum of the percentage value of each of those quality characteristics listed above (except % sound grain) and weighted for the more important characteristics by multiplying insect damaged by two and mould damaged by three (as shown in Equation 1). The reciprocal of this value was taken so that a fall in grain quality would be registered by a fall in QI.

$$QI = \frac{1}{\begin{array}{c}\%\text{ discoloured} + \%\text{ shrivelled} + \%\text{ foreign matter}\\ + (\%\text{ insect damage} \times 2) + (\%\text{ mould damage} \times 3)\end{array}} \times 100 \qquad (1)$$

Weight lost as a result of insect infestation was estimated for 10 samples of rabi grain (variety 'Maldandi'), using the count and weigh method (Adams and Schulten 1978) on two 50 g sub-samples. These data were used to prepare a calibration so that an estimate of weight loss could be made of all samples for which an estimate had been made of the % insect damage. Since there was little difference in grain size between crops and varieties, it was assumed that this rough estimate would be applicable to all the samples taken during the current study.

Table 2. Mean percentage (%) ± standard deviation (s.d.) of sampled farmers in various wealth categories compared with the village communities from which the samples were drawn.

	Socioeconomic profile of sample			
	Rich	Medium	Poor	Very Poor
Farmer sample	40 ± 19	46 ± 16	14 ± 13	0
Village sample	16 ± 8	38 ± 9	37 ± 14	9 ± 9

Mycotoxin analysis

Mycotoxin analysis was undertaken for the June and October samples. The 1 kg samples from each of these two occasions were combined by village. Flour was prepared from these bulk samples using a hand-mill. This flour was thoroughly mixed and a 1 kg subsample scooped from this mixture, placed in a plastic bag and air-freighted to the United Kingdom (UK) for mycotoxin analysis. In the UK, 500 g portions of the June or October mycotoxin samples were combined according to their similarities, giving a total of 7 samples in June and 13 samples in October. Each sample was checked for *Alternaria* toxins, T-2 toxin and deoxynivalenol, fumonisin B_1 and a number of aflatoxins—B_1, B_2, G_1, and G_2. As all mycotoxin concentrations appeared to be very low it was decided that analysis of grain from individual stores was unnecessary. The analytical methods used are described in Hodges et al. (1999).

Data analysis

Data were subjected to Pearson's correlation analysis, linear regression or analysis of variance. Where necessary, data were transformed to ln(count + 1) or to arcsine prior to analysis in order to meet the assumptions underlying analysis of variance.

Results

Farmers' perceptions on grain variety and store type

While farmers clearly differentiated between the storage characteristics of rabi versus kharif grain (rabi better and kharif worse) and between varieties (hybrid varieties noticeably worse), these characteristics were not necessarily used in selection of varieties or store type. The choice of rabi versus kharif was generally predetermined by climatic conditions and prevailing soil types in a specific location. In the case of kharif varieties, despite the clear dissatisfaction of farmers concerning both storage and eating characteristics of hybrid varieties, these still dominated in most of the kharif-producing areas. Yield outweighed all of these factors, which partly reflects the fact that kharif varieties are produced for sale as well as home consumption, indeed in one district kharif grain was produced exclusively for sale. However, during crop decision-making exercises with farmers, it was noticeable that sorghum scored highly for its value as a source of food (less so as a source of cash), but storage and postharvest characteristics were not considered of sufficient importance to be mentioned by farmers.

Farmers' discussions concerning choice of store type indicated that a range of issues was important. These included cost of the storage structure, ease of use, amount of grain to be stored and the availability of appropriate store construction skills. Production season also played a role in the choice of store type since, compared to rabi, kharif yields are higher, so larger storage structures are required. The use of underground pits—which had once been prevalent in both rabi and kharif areas—had been largely abandoned. Underground water seepage had become a problem, although it was not clear why it had arisen. In such pits, checking the grain for insect attack is difficult and time consuming and the smaller quantities of grain produced by individual farmers caused them to seek smaller, more convenient above-ground structures, usually in the home. In the kharif areas, traditional mudded baskets (kangis) were preferred over gunny (jute) bags. Although they were more expensive to construct, these structures were perceived to last longer—up to twenty years, whereas a gunny bag may only last 5–6 months if it suffers rat damage. However, households from the poor wealth category, with little to store, often relied on gunny bags because of the low initial investment.

It was apparent from discussion with farmers that both underground stores and mudded woven baskets (despite their advantages) were declining in use, due to the difficulty of finding skilled artisans for their construction. Increasingly, metal bins were being used because of their low cost, availability and durability.

Direct observation of store types and grain varieties

In June 1997, 73 grain samples were taken, comprising 33 samples of kharif grain harvested in October–November 1996 and 40 samples of rabi grain harvested in February–March 1997. Generally, villages had either a rabi or a kharif crop, but in one case, grain from both harvests was in store in June, though only the rabi crop remained in October (village No. 6 in Table 4). In a few cases, some rabi grain was in underground pits in June but none was sampled as the grain being consumed at that time was in gunny bags and the pits were not due to be opened for several weeks. The grain in these pits, which would subsequently be transferred to gunny bags, was sampled as a matter of course in October. In October, samples were obtained from 30 of 40 farmers who had contributed rabi grain samples in June 1997 and 23 of the 33 farmers who had contributed kharif samples. At the time of sampling, most farmers still had some grain in store, although stocks were lower than we had expected from farmers' June estimates for time to stock exhaustion. Of the 40 original farmers storing rabi grain, 6 (15%) no longer held any grain and a further 9 (26%) had less than 10% of the grain observed in June. Only 10 of the sampled farmers (29%) thought that they still had enough rabi sorghum to last until the next harvest, although 13 still actually had rabi sorghum in January 1998.

From the frequencies of store types and grain varieties observed in June, it is clear that the rabi farmers have a strong convergence of practice (Figure 1). Nearly all were growing the improved variety, 'Maldandi', and storing it in gunny bags. In contrast, farmers harvesting sorghum in the kharif season grew a wider range of varieties and used a more diverse selection of storage structures; gunny bags, polypropylene bags and mudded baskets were about equally common (Figure 1). The varieties grown and the store types used by the sampled farmers are consistent with the prevailing practices of farmers as indicated in the participatory rural appraisal survey.

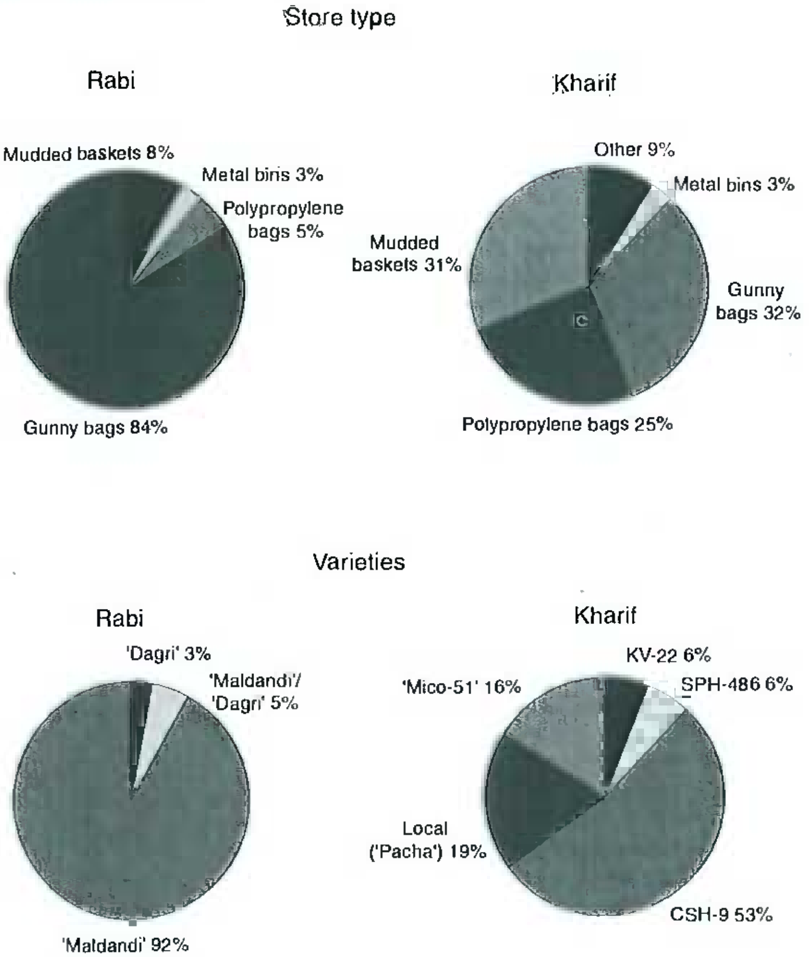

Figure 1. Store types and grain varieties of the rabi and kharif sorghum harvests (June 1997).

Postharvest handling practices

Farmers indicated that the postharvest handling practices for rabi and kharif grain are similar. After threshing and drying, at the home or other convenient place, the grain is placed in the chosen storage container. Neem leaves and ash may be admixed and Gammexane (benzene hexachloride or lindane) powder sprinkled on store surfaces, particularly on gunny bags. Insect infestation is noticed after 4–5 months in kharif grain and 6–7 months in rabi grain. Frequent sun-drying and cleaning by picking and winnowing (every 2–3 months) is used to control insect infestation. Farmers said that, by using this method, rabi sorghum could be stored safely for up to one year after harvest.

Women were responsible for the management of household grain stores in all the case-study villages. The usual period of storage is determined mainly by farmers' wealth category and by whether the grain is of the kharif or rabi harvest. Discussions with farmers suggest that only those from the rich wealth category were able to store from one harvest to the next. Households from the medium and particularly the poor wealth category often had insufficient land resources (both quantity and soil types) to produce enough grain for household consumption throughout the year. The usual storage period was 2–6 months depending on the land available for individual farmers. It was apparent that for most of the poorer households the length of grain storage was such that insect infestation and mould damage was rarely a problem (grain blackening being the exception as discussed below).

Grain quality analysis

The June rabi sample, which had been stored for 3–4 months, had a significantly higher QI than the kharif grain which by June had been in store 8–9 months (Table 3) ($F_{(1,72)} = 101.2, p < 0.0001$). The difference seemed to be due to the kharif crop having significantly more mouldy grains ($F_{(1,72)} = 8.6, p < 0.0001$), as no insect damage was apparent as at this time.

The grain samples from both harvests were equally dry, the highest MC was only 10.7% and the average 8.9%, and there was no evidence of any significant difference between the moisture values for the two crops. Thus with neither harvest was there any obvious correlation between MC and mould damage at the time of sampling. It therefore seems likely that the conditions promoting mould growth on the kharif grain occurred preharvest and/or early in the storage season. Farmers' responses lead us to believe that this damage was the 'grain blackening' that occurs on kharif sorghum, especially hybrids, dampened by unseasonal rain in the field. The degree of blackening varies from year to year and occurs to a significant extent at least once in every three years, depending on the amount of rainfall. Despite the blackening, much of this grain is used for home consumption; farmers from the medium and poor wealth categories indicated that they have little choice but to eat it. For this purpose it is washed and sun-dried. Despite this, farmers did suggest that the blackened grain is associated with health problems. Blackened grain has a low market price and the worst affected is used for animal feed (both on farm and by those purchasing it in the market).

Grain sampled in October had been stored through the monsoon period and, as expected, this had resulted in a rise in grain MC. Both crops exceeded 11% (Table 3) and the small difference between them, only 0.3%, was significant ($F_{(1,62)} = 4.48, p < 0.038$). This suggests that the kharif crops were grown in areas where the monsoon is more prolonged. The difference in QI between crops was large and statistically significant ($F_{(1,65)} = 85.7, p < 0.0001$). For both crops there was a large October fall in QI, both because insect damage was apparent for the first time (Table 3) and because there was an increase in % mouldy grain. For the crops combined, there was a strong significant correlation between the incidence of mould damage and insect damage ($r = 0.539, p < 0.01$), suggesting that either mould attack facilitates insect attack or the same factor(s) may predispose the grain to both types of damage. The overall differences between the two crops are reflected in the average values for mould damage and insect damage observed in the villages (Table 4). There was no evidence of significant differences between store types in the incidence of mould, insect damage or for values of the QI (Table 5); however, the small numbers of observations on most of the store types precludes any firm conclusions on this matter.

Table 3. Mean quality parameters for the 1996 kharif and 1997 rabi harvests of sorghum grain for samples taken in June and October 1997.

	Moisture content	Discoloured grain	Mould damage	Insect damage	Foreign matter	Shrivelled grains	Sound grain	Quality index
	Percentage							
June								
Kharif	8.90	1.74	9.61	0.00	4.64	2.13	80.75	2.67
Rabi	8.93	1.08	1.10	0.00	1.88	0.78	95.15	14.20
October								
Kharif	11.49	8.25	15.11	8.62	1.60	0.65	62.98	1.36
Rabi	11.16	1.83	1.44	2.86	1.22	0.51	92.30	7.30

Table 4. Village averages for the incidence (%) (± standard deviation) of insect and mould damage to grain in the rabi and kharif harvests sampled in October 1997.

Village no.	Rabi			Village no.	Kharif		
	Insect damage (%)	Mould damage (%)	Quality index		Insect damage (%)	Mould damage (%)	Quality index
1	4.0 ± 2.7	0.3 ± 0.3	10.9 ± 5.1	6	Kharif crop all consumed		
2	4.2 ± 4.3	1.4 ± 1.0	16.0 ± 7.7	7	11.9 ± 12.6	22.3 ± 16.8	2.3 ± 1.0
3	2.0 ± 1.0	0.6 ± 0.5	9.9 ± 2.8	8	4.5 ± 2.8	13.2 ± 3.8	3.5 ± 2.3
4	3.0 ± 2.5	1.7 ± 0.9	15.3 ± 2.0	9	11.5 ± 5.1	14.6 ± 8.9	3.36 ±1.7
5	2.8 ± 1.1	5.0 ± 4.7	24.9 ± 14.5	10	8.4 ± 3.4	15.4 ± 3.1	5.3 ± 5.7
6	3.2 ± 2.3	0.7 ± 0.6	12.2 ± 7.4	11	7.6 ± 5.6	8.2 ± 5.7	3.7 ± 1.5
12	5.4 ± 5.8	0.6 ± 0.4	6.9 ± 4.9				

Table 5. Store type averages for the incidence (%) (± standard deviation) of insect and mould damage to grain in the rabi and kharif harvests sampled in October 1997.

Crop	Store	No. in sample	Insect damage (%)	Mould damage (%)	Quality index
Rabi	Gunny bag	34	2.9 ± 2.4	1.45 ± 2.3	10.5 ± 6.7
	Metal bin	1	2.0	0.9	7.1
Kharif	Gunny bag	8	6.9 ± 3.8	16.0 ± 12.6	1.6 ± 0.7
	Metal bin	1	6.6	17.4	1.4
	Polypropylene bag	5	4.7 ± 3.5	7.7 ± 5.6	2.6 ± 1.0
	Mudded basket	9	9.7 ± 6.0	17.8 ± 10.3	1.4 ± 0.6
	Box store[a]	1	33.7	20.8	0.7
	Corner of house	2	9.6 ± 11.8	12.4 ± 1.9	0.7 ± 1.1

[a] Brickwork box built in house

Insect infestation and associated grain weight loss

The primary pests *Rhyzopertha dominica* (Fabricius) and *Sitophilus oryzae* (L.) were the most numerous insects and the most likely to cause damage and weight loss in the rabi and kharif grain samples taken in October 1997 (Table 6). The percentages of rabi and kharif samples infested by *R. dominica* were very similar (about 84%) but the numbers of this species were about three times greater on kharif grain. In contrast, *S. oryzae* clearly preferred rabi grain, since about 20% more rabi samples were infested and numbers of this species were about six times greater than on kharif grain. The secondary pest *Cryptolestes ferrugineus* (Stephens) was considerably more numerous on kharif samples while the two harvests were similar in the extent of infestation by *Tribolium castaneum* (Herbst) (Table 6). Sorghum grain weight losses due to insect damage were determined for 10 samples of 'Maldandi' grain taken in October 1997. The regression of these weight losses with their corresponding percentages of insect damaged grain was statistically significant ($r^2 = 0.79$, $df = 8$, $p < 0.001$). The regression equation from this relationship was used to estimate what the likely weight losses were for other grain samples for which only estimates of % grain damage had been made. The mean values of these estimates were weight losses of 0.88 ± 0.30% for the rabi crop and 1.71 ± 1.17% for the kharif.

Quality decline in rabi sorghum through to January 1998

Only 13 of the rabi stocks first sampled in June 1997 were still available for sampling in January 1998. The quality assessment of these samples showed evidence of continued quality decline (Table 7). In the 3 months between June and October 1997, through the monsoon, the QI fell by about 63% and in the following 3 months to January 1998 it fell again by 15% of its June value. Although the major reduction in quality occurred during the period of the monsoon, thereafter there were increases in mould and insect damage and a noticeable increase in the proportion of discoloured grain (Table 7).

Table 6. Percentage of rabi and kharif sorghum samples infested by insects and mean numbers of live and dead insects/kg (± standard deviation), from samples taken in October 1997.

Harvest	*Rhyzopertha dominica*	*Sitophilus oryzae*	*Tribolium castaneum*	*Cryptolestes ferrugineus*
Rabi	% samples infested			
	83	70	36	3
	Mean no./kg			
	135 ± 245	170 ± 300	10 ± 20	0.5 ± 40
Kharif	% samples infested			
	84	50	31	13
	Mean no./kg			
	365 ± 470	30 ± 45	15 ± 25	30 ± 85

Table 7. Mean values for quality factors of rabi season grain from the same 13 stores sampled on 3 occasions during a storage period of about 11 months.

Quality factor	June 1997	October 1997	January 1998
% discoloured	1.0	1.9	2.8
% mouldy	0.9	1.1	1.7
% insect damage	0	3.1	4.9
% foreign matter	1.5	1.4	2.7
% shrivelled	0.8	0.6	0.8
Quality index	26.6	9.6	5.7

There was also an increase in foreign matter by January 1998, possibly due to contamination with stones, soil etc. as farmers re-dried their sorghum stocks after the monsoon. Insect damage increased to the extent that the stocks remaining in January had probably suffered a weight loss of about 1.25%, an increase of 42% on the mean loss estimated for all the rabi samples (30) taken in October 1997.

Mycotoxin contamination

Mycotoxin contamination in June and October (Table 8) was low and certainly below the levels that would be expected to constitute a health risk. There was no evidence of any increase in contamination rates as a result of the monsoon period, i.e. no increase between June and October. Low levels of aflatoxin contamination were typical of both the rabi and kharif harvests and although four toxins were tested for, only aflatoxin B_1 was evident. Contamination with fumonisin B_1 was almost exclusive to the kharif crop; of the 11 rabi bulk samples only 1 showed any signs of fumonisin B_1, whereas all 8 kharif bulk samples were contaminated. *Aflatoxin* and *Alternaria* toxin contamination was very low and differed little between the two harvests.

Farmers' perceptions of grain losses

In the context of wider concerns in the farming and food systems, farmers did not generally perceive losses of grain quantity or quality during storage to be of major importance. The exception to this was the issue of grain blackening. Although a preharvest problem, mould formation appears to continue during storage (Table 3). This is not to say that farmers did not recognise that grain and quality losses occur during storage. Insect damage illustrates this point. Farmers knew when it began to occur and had adopted sun-drying and neem and ash admixture as a means of combating it. Estimates of the extent of losses varied widely, but 3–5% for rabi grain and 5–10% for kharif, over a year in storage, were the commonly perceived levels.

Kharif-producing farmers did, however, indicate that losses could be as high as 20% in years of severe grain blackening. It was also indicated that poor households took extra care of the little stored grain that they had. As a result, actual losses during the few months in which this group stored grain is probably even lower than the figure of 5–10% they quoted.

Farmers did not specifically mention mould damage (except in the context of grain blackening discussed above). However, they did discuss changes that took place to the grain over time in storage. They indicated that the 'lustre' of grain was lost during storage. Of most significance were the changes in the cooking and eating qualities. It was indicated that the stickiness of dough made from grain was lost over time. This change took place after about 6 months and was more pronounced in kharif grain, particularly hybrid varieties. This was also associated with a loss of taste. The relative importance of these issues needs to judged in the light of the fact that these changes are taking place after 6 months. Since this is the limit of storage for most households, most will only rarely experience such problems. This suggests that while these problems are undoubtedly impacting on consumers of sorghum (particularly for kharif consumers), they are not responsible for changes in the relative proportion of sorghum in cropping patterns.

Table 8. Maximum observed mycotoxin contamination (parts per billion—ppb) in sorghum samples taken from the rabi and kharif harvests in southern India in June and October 1997. Numbers given in brackets = number of store samples contributing to the bulk sample analysed for mycotoxins.

	Total number of stores	Aflatoxin B_1	*Alternaria* toxins			*Fusarium* toxins
			AtlOH	AltOMe	Altenuene	Fumonisin B_1
June						
Kharif	27	2.7 (12)	23 (15)	33 (15)	36 (15)	87 (12)
Rabi	45	1.5 (17)	11 (16)	9 (16)	0 (16)	25 (16)
October						
Kharif	27	0.5 (4)	33 (4)	40 (4)	55 (6)	177 (2)
Rabi	35	0.6 (5)	12 (5)	6 (5)	8 (5)	0 (35)

Note: health risk—aflatoxin >5 ppb, *Alternaria* toxins >1,000 ppb, fumonisin B_1 >1,000 ppb

Conclusions

It is clear that rabi sorghum enters storage with better quality characteristics than its kharif counterpart, which may suffer some moulding prior to storage. The monsoon period is associated with a major decline in quality for both crops, in particular a rise in mould damage and the start of insect attack. Both these factors were somewhat greater for kharif sorghum, presumably due to the rather lower quality of kharif grain at the onset of the monsoon. However, an intrinsically greater susceptibility of kharif varieties to mould and insect attack cannot be ruled out. Both grain types are of rather poor quality by the end of the storage season, whether it be October in the case of the kharif crop or January in the case of the rabi.

Although farmers of kharif sorghum appeared to use a wider range of storage methods, this appeared not to be a factor affecting the grain quality, since QI values for kharif grain in gunny bags, the storage technique of most rabi farmers, differed little from the grain stored by other methods. It appears that choice of storage method is dependent on a wider set of factors than storage efficiency alone. Differences between rabi and kharif can be explained to some extent by the amount of grain to be stored, particularly the larger kharif crop. Ease of use, availability of appropriate artisanal skills and costs are among the issues mentioned by farmers. Regional preferences also undoubtedly play a role.

In the period under study, grain weight losses due to insect attack were relatively low and in October, at the end of the kharif storage season, amounted to an average of only 1.7%, while at the same time the rabi crop appeared to have lost only 0.9%. The losses in the kharif crop due to insect damage were low considering that the estimate was made on grain that was close to the end of the storage period. It might be considered that the technique used to estimate the grain weight loss, the count and weigh method, could have resulted in an underestimate of loss. This tends to happen if grains are removed completely from the store, e.g. when they are reduced to dust, as may be the case with some of the kharif or rabi grain. However, applying the end-of-season loss figure to the whole stock is likely to give an overestimate of loss since much of the grain is sold or consumed long before the monsoon, i.e. before the time when insect attack becomes prevalent. Thus the weight losses of the entire stock were probably somewhat smaller than our estimate.

The two crops differed with respect to the predominant insect pests, with *R. dominica* and *S. oryzae* equally common on rabi but *R. dominica* predominant on the kharif. Although the two species differ in their abilities to tolerate dry conditions (Haines 1991), with *S. oryzae* being seriously limited on grain with MC below 11%, it seems that this is not a major consideration in this case as *S. oryzae* was more common on the drier crop. The predominance of *R. dominica* on the kharif crop is presumably a reflection of the susceptibility of the different grain varieties to the two species. In connection with this, it is interesting to note that Reddy and Nusrath (1988), studying insect infestation and mycotoxin production in kharif sorghum varieties, list *R. dominica* as a major pest of this grain and make no mention of any *Sitophilus* spp. Furthermore, Kishore et al. (1977) noted that in high-yielding kharif varieties the percentage damage caused by *R. dominica* was many times greater than that caused by *S. oryzae*.

Mycotoxin contamination generally remained below levels that would represent a human health hazard. Similar low contamination rates were reported from earlier surveys in southern India (Bhat and Rukmini 1978; Sashidhar et al. 1992). In the current study, there was no notable increase in prevalence of mycotoxins after the monsoon season even though mould attack rose significantly during this period. Fumonisin B_1 was almost exclusively restricted to the kharif crop where it was found in all samples, even prior to the monsoon. It seems likely that this mycotoxin is associated with preharvest mould damage. The picture given here, of relatively slight mycotoxin contamination, should not be taken to imply that there are no potential problems with mycotoxicosis, as other researchers have reported significant aflatoxin (Mall et al. 1986), *Alternaria* toxin (Anasari and Shrivastava 1990) and fumonisin (Bhat et al. 1997) contamination in kharif crops in India. In the case of fumonisin, a disease outbreak was reported in a few villages on the Deccan Plain in households where rain-damaged mouldy grain was being consumed (Bhat et al. 1997). In the storage system we investigated, mycotoxin contamination rates may sometimes be higher in those years where weather conditions are less favourable or otherwise due to poor storage by individual farmers. Preharvest grain blackening, therefore, remains an issue of concern both for reasons of health and for the marketing of kharif grain. Research on 'hard' varieties of sorghum with a high degree of resistance to fungal attack, particularly to *Fusarium moniliforme*, show that specific anti-fungal proteins are involved (Kumari and Chandrashekar 1994). The possibility of transferring this characteristic to sorghum varieties, that otherwise already have good agronomic characteristics, presents one possible approach to the problem of grain blackening. This may be particularly successful when transferred to varieties whose morphology does not favour mould growth, e.g. those with panicles that hang downwards which are less prone to moisture accumulation.

Overall, the grain storage practices of farmers in southern India do not appear to be a constraint to the production and consumption of sorghum. Mycotoxin contamination and grain losses due to insect attack appear to remain low, although towards the end of their respective storage seasons the kharif and rabi crops have suffered a considerable decline in quality. This appears not to be a significant problem as this decline was limited to only a small portion of the remaining stock. However, if farmers wish to retain stocks between seasons, to market grain strategically, then their current practices are likely to be inappropriate. By all accounts the major issue facing sorghum grain would appear to be the preharvest mould damage sustained by kharif varieties.

Farmers' perceptions of the nature and extent of grain weight and quality losses are entirely consistent with the findings of the technical study. Farmers are certainly aware that quantitative and qualitative changes take place. They have developed practices to keep these changes within acceptable limits and what changes do occur apparently do not influence farmers' choice of crop or variety. This reflects to a certain extent the fact that, for many households, the ability to store grain for periods of more than 6 months is constrained by production resources rather than postharvest practice. To be more specific, those farmers who might be significantly affected by serious grain quality deterioration towards the end of the harvest are those without grain at this time. There are undoubtedly characteristics of hybrid sorghum grain which cause it to store poorly and its qualities to decline, although this is clearly not an important issue in the current scenario of farm practice. This does not mean that these traits are not impacting on the wider sorghum economy (and therefore on farmers), but only that they are not impacting on the components of the sorghum production and utilisation system examined. Storage by wholesale traders and industrial users shows a different picture—this has been highlighted by other parts of this study (Kleih et al. 1998). So while the current study has certainly laid to rest many concerns relating to farm storage, it is clear that components of the utilisation chain need more detailed study.

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