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Quality Changes in Farm-Stored Sorghum Grain Grown in the Wet or Dry Season in South India - A Technical and Social Study

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Summary

In the last 20 years there has been a steady decline in both the production and consumption of sorghum in parts of south India. To understand the factors responsible for this, a survey of postharvest practices was undertaken which included sampling for grain quality in farmers' stores and a participatory rural appraisal (PRA) of the same farmers. Twelve villages, across the states of Maharashtra, Karnataka and Andhra Pradesh, were surveyed. The study areas chosen were divided roughly evenly between those where sorghum is grown during the monsoon rains (kharif season) or after the rains (rabi season). The first grain samples were taken from stores before the onset of the monsoon, in June 1997. The second set of samples, largely from the same harvests and same stores, was taken after the monsoon in October 1997. A third sample, of what remained of the rabi stocks, was taken in January 1998. Grain samples were assessed for quality and tested for mould and mycotoxin contamination.

Nearly all rabi farmers grew the improved variety Maldandi and stored their grain in jute bags. Kharif farmers used a much wider range of storage techniques and grain varieties than did the rabi farmers. In June, the quality of kharif samples was considerably below that of the rabi grain due to mould damage attributable to preharvest infection. No insect attack was evident in either harvest which both had mean moisture contents of about 8%. After the monsoon, in October, the moisture content of the crops had risen to about 11% and insect attack was evident with the primary pests *Sitophilus oryzae* and *Rhyzopertha dominica* equally common on rabi, but *R. dominica* was particularly abundant on kharif grain. Overall the quality of both crops had fallen substantially although grain weight losses were low, averaging only 1.7% for kharif and 0.88% for the rabi crop.

Numerous mould species were identified from the sorghum samples with eight species affecting 5% or more of grains. Mould colonisation was more evident in the kharif crop than the rabi. Internal colonisation, as opposed to surface contamination with spores, was evident in the kharif grain due to *Fusarium moniliforme*, *Alternaria alternata*, *Curvularia lunata* and *C. lunata* var. *aeria* while in the rabi crop only *A. alternata* caused any significant internal colonisation. Colonisation rates for typical field fungi appeared to decrease between June and October. However, the number of mould-infected grains actually increased in this period, so it is presumed that there was a rise in typical storage fungi that may not have been detected by the culture methods used in this study. Mycotoxin contamination was observed in both crops, and included aflatoxin B1, *Alternaria* toxins and *Fusarium* toxins. However, these were all below limits likely to represent a hazard to human health. *Fusarium* toxins were almost exclusively limited to the kharif crop, as expected by the high rate of internal colonisation by the mould that produces it, *F. moniliforme*. This is a typical field mould and it is assumed that the accumulation of *Fusarium* toxins is linked to the pre-harvest grain blackening of the kharif crop. Serious mycotoxicosis has been recorded from time to time in India due to the consumption of contaminated sorghum, and the current results should be interpreted with caution since there may be considerable year to year variation in the climatic factors affecting mycotoxin production.

Farmers indicated that while there were postharvest losses and quality deterioration, these were not a major concern. The exception was grain blackening which affects the kharif crop in some years due to unseasonal rainfall on the mature crop. It was also apparent that the majority of farmers stored grain for a relatively short period (less than 6 months). This was due to the limited quantities produced by land-scarce households from the medium and poor wealth categories.

Overall, the grain storage practices of farmers in south India do not appear to be a disincentive to sorghum cultivation. Hybrid sorghum varieties by virtue either of the time of year that they are grown, or intrinsic characteristics, suffered considerable quality decline in storage, although this is clearly not an 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 may have shown a different picture – as has been highlighted by related projects on sorghum utilisation and marketing. So, while this 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 their current practices are likely to be inappropriate since grain quality at the end of the storage season was poor. By all accounts the current major issue facing sorghum grain would appear to be the preharvest mould damage sustained by kharif varieties.

Introduction

Sorghum production and consumption has either stagnated or declined in many areas of south India over the last 20 years (Dayakar, *et al* 1996; Hall and Brough, 1997; Marsland, 1998). Factors responsible for this changing pattern of production and consumption include: displacement by recently introduced cash crops (Kelley and Rao 1993); changes in food habits (Marsland 1998); and the apparently poor storage characteristics of the crop, particularly the kharif season hybrids. 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 (PRA). The study was undertaken in twelve selected villages in the states of Karnataka, Maharashtra and Andhra Pradesh. The farmers had either sorghum grain produced during the monsoon rains (kharif season) or after the rains (rabi season) although one village produced both rabi and kharif crops, one of a number of grain varieties and one of several store types. In addition to assessing the visible grain quality characteristics, further insights into postharvest problems were gained by an analysis of mould and mycotoxin contamination which 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. On both these occasions, the 1996 kharif and 1997 rabi harvests would be found in store although by October the kharif crop would be nearly exhausted and soon to be replaced by the new crop. A third sampling occasion was added, in January 1998, so that samples of the 1997 rabi crop could be collected just before it too was replaced by a new harvest. The storage period of the grain collected by this sampling regime is summarised in Table 1.

Table 1: Summary of season of origin and storage period of grain sampled

	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 months

The working hypotheses identified during the rapid rural appraisal were

- 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)
- Farmers' perception was that losses occurred in storage but that these were low and not a major constraint in production and utilisation systems.

These hypotheses contrast strongly 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 PRA 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 two villages for each district and 12 villages in all (Table 2).

A small team of socio-economists together with two grain survey staff visited villages in June 1997 just before the start of the monsoon. Their objectives were to

- ensure that the villages selected met the criteria of the project,
- select farmers from whom the samples would be taken, attempting to ensure a good cross section of the different socio-economic groups within the village, including a selection of the major store types and grain varieties (Table 2), and
- take samples of the 1996 kharif crop and 1997 rabi crop as described below.

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 this time, the 1996 kharif crop was at the end of its storage period and the new harvest was imminent. In some cases, 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 (Table 2). 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' perception.
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 additional category of very poor. These categories broadly correlate with the area of land holding. Rich farmers harvested sufficient grain to retain some in store for the entire period between harvests. Generally farmers

Table 2: Crop types, store types, grain varieties and numbers of samples taken from twelve villages in south India

State	District	Sub-district	Village	Numbers of samples taken June '97	Oct. '97 (+replacements)	Jan.'98	Sorghum harvest	Main store types*	Main varieties*
Mahar-ashtra	Pune	Bhor	1. Kurangwadi	6	4 (+1)	-	rabi	GB	Mal.
		Dhaud	2. Kauthadi	5	4 (+1)	-	rabi	GB	Mal.
	Solapur	Solapur South	3. Ingalgi	6	5	3	rabi	GB	Mal.
		Akkalkot	4. Kegaon Khurd	6	4 (+1)	3	rabi	GB	Mal./Dag.
Karnataka	Bijapur	Sindgi	5. Chattarki	6	5	1	rabi	GB	Mal.
		Bagalkot	6. Ingalgi	7	5	5	rabi/kharif	GB	Mal./Mic.
Mahar-ashtra	Akola	Akola	7. Jamokeshwara	6	6	-	kharif	GB/PB/MB	CSH/SPH
		Balapur	8. Kolasa	7	7	-	kharif	GB/PB/MB	CSH
	Nanded	Nanded	9. Moregaon	6	4 (+1)	-	kharif	MB/PB	Mic./JK
		Hadgaon	10. Khambala	6	3 (+2)	-	kharif	MB/GB/PB	CSH
Andra Pradesh	Mahabub-nagar	Koilkonda	11. Khazipur	6	3 (+2)	-	kharif	GB/PB	Local
		Kodangal	12. Pyalamaddi	6	3 (+2)	2	rabi	GB/PB	Mal.

* Store types GB - gunny bag, PB - polypropylene bags, MB - mudded basket

Varieties Mal. - Maldandi, Dag. - Dagri, Mic. - Mico-51, JK - JK-22, CSH - CSH-9, SPH - SPH468

Table 3: Comparison of socio-economic profile of sample farmers and the socio-economic profile of the communities from which they were drawn (proportions based on wealth ranking exercises)

State	District	Village	Socio-economic profile of sample						
			Farmer sample (%)			Village (%)			
			Rich	Medium	Poor	Rich	Medium	Poor	Very Poor
Mahar-ashtra	Pune	Kurungwadi	33	50	17	19	44	26	11
		Kauthadi	20	40	40	13	37	37	13
	Solapur	Ingalgi	67	33	0	26	31	24	19
		Kegaon Khurd	50	33	17	10	36	39	15
Karnataka	Bijapur	Ingalgi	57	43	0	19	48	33	0
		Chattarki	17	66	16	9	32	40	19
Mahar-ashtra	Akola	Jamakeshwar	17	83	0	6	52	42	0
		Kolasa	29	43	28	5	21	75	0
	Nanded	Khambala	50	33	17	21	43	36	0
Andhra Pradesh	Mahabub-nagar	Pyalamaddi	67	33	0	31	31	37	0
		Khazipur	33	50	17	13	40	20	27
Mean %			40	46	14	16	38	37	9

were storing grain for up to six months and in the case of poor households perhaps only 2-3 months. The group meetings were used to determine the usual period of storage and the proportion of farmers storing for longer or shorter periods. This raised a dilemma for grain sampling. While it was desirable to examine grain quality over time, there was also a need to relate these measurements to the actual storage period of most households, particularly to those from the predominantly poor and very poor wealth categories. As a compromise, 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 from the predominant poor category, subsequent wealth ranking exercises indicated that the selection has still been biased towards farmers from the richer wealth categories. This undoubtedly occurred due to the higher "visibility" of this category of farmer in group meetings etc. and their ability to manoeuvre themselves into position for grain sampling, for whatever reason they perceived this to be advantageous. 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. Table 3 summarises the socio-economic stratification of farmers chosen and compares this with the socio-economic profile of the communities from which these samples were drawn. This illustrates the predominance of richer farmers in the sample.

Farmers' perceptions concerning grain and quality losses were assessed as part of a wider PRA survey which 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 subject 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 socio-economic profile of the selected villages. The findings of these in-depth interviews forms 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. 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 diam.) was used (Figure 1). Where access was more difficult such as in bag stacks of gunny (jute) bags, a short probe (27 cm by 1.5 cm diam.) was employed (Figure 2). 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.

Each sample was placed in a double layer plastic bag and returned from the field to the Indian Grain Storage Research and Management Institute (IGMRI) for sample division and analysis.

Figure 1: Sorghum samples being taken from a loose grain pile using a long compartmentalised probe

Figure 2: Sorghum samples being taken from gunny bags using a short probe

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 a give a sub-sample of 600 g. From this, three 30 g sub-samples were taken to determine moisture content 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
% sound grain

This general grain-quality analysis was used to develop a Quality Index (Q.I.). This was done to provide a convenient means of comparing samples. Q.I. 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 below). The reciprocal of this value was taken so that a fall in grain quality would be registered by a fall in Q.I.

Q.I. = (1/(% discoloured + % shrivelled + % foreign matter + (% insect damage x 2) + (% mould damage x 3)) x 100

Weight lost as a result of insect infestation was estimated for ten samples of rabi grain (variety Maldandi), using the count and weigh method (Adams and Schulten, 1978) on two 50g 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 grain sizes between crops and varieties differed little, it was assumed that this rough estimate would be applicable to all the samples taken during the current study.

Mould analysis

Mould analysis was undertaken at ICRISAT. Only about half of the samples collected in June and October were subjected to mould analysis. None of those in January 1998 were analysed. Samples were chosen to give a representative selection of crop, variety and store type.

Four hundred grains were taken from each sample and sub-samples of 100 grains were subjected to one of four treatments, a) grains surface-sterilised in 1% NaOCl, prepared from Clorox® (Clorox Company, Oakland, CA 94612, USA) containing 5.25% sodium hypochlorite, b) grains surface-sterilised in NaOCl and also treated with the fungicide, benomyl (0.05%) [Benofit® 50 WP (benomyl 50% WP) EID Parry (India)], c) grains neither surface sterilised, nor treated with benomyl, or d) grains not surface sterilised, but treated with benomyl (0.05%).

Grain was incubated for five days at 28±1°C in pre-sterilised Petri dishes (glass, 9cm diameter) holding a layer of absorbent cotton, and two layers of blotting paper, to which 10 cm^3 of distilled water had been added. Four replicate dishes, each with 25 grains, were prepared for each treatment. Each grain in all the four treatments was examined under a stereo microscope (Olympus CO1®) for grain colonisation and a compound microscope (Olympus BH 2®) for proper identification of moulds using the Scotch-tape method. This method was used mainly to preserve attachment of conidia to conidiophores. It was particularly useful for those organisms in which the conidia readily break up under normal procedures for slide preparation. Photomicrographs were made of individual moulds or groups of moulds, using both the microscopes. Mould identification was achieved by comparison and confirmation using information available in the literature, (Barnett and Hunter 1972; Barron, 1968; Champ *et al.* 1991; Ellis, 1971, 1976; Hawksworth, *et al.* 1995; Sivanesan, 1987; Sutton, 1980).

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 to give bulk samples that were then milled using a hand-mill. The resulting flour was thoroughly mixed. A 1 kg sub-sample was scooped from this mixture, placed in a plastic bag and air-freighted to the UK for mycotoxin analysis.

In the UK, 500g portions of the June or October mycotoxin samples were combined according to their similarities (see Tables 11 and 12) giving a total of seven samples in June and thirteen samples in October. Each sample was checked for *Alternaria* and *Fusarium* toxins and a number of aflatoxins. As all mycotoxin concentrations appeared to be very low it was decided that analysis of grain from individual stores was unnecessary.

The following analytical methods were used.

i. **Aflatoxins B_1, B_2, G_1, and G_2.**

The NRI in-house HPLC method, based on Tomlins *et al.* 1998 and Bradburn *et al.* 1995 was used. An acetone-water (80:20) extract was cleaned-up using a reverse phase phenyl solid phase extraction (SPE) column and quantification was by HPLC (JASCO) using a spherisorb ODS1 column, water/ acetonitrile/ methanol (6: 3: 1) at a flow rate of 0.8 ml/min. Post column derivatisation using a KOBRA electrochemical cell enabled fluorescence detection using excitation wavelength of 365 nm and emission wavelength of 440 nm. Perkin Elmer 'PCINT' data handling software with four level calibration gave results directly in µg/kg (ppb). Full quality assurance protocols were implemented involving recovery experiments, proficiency testing (FAPAS) and confirmatory tests.

ii **Fumonisin B_1**

The method used was based closely on a published HPLC method (Sydenham *et al.*, 1993). The pH of a methanol/ water (75:25) extract was adjusted to 6.2 and then applied to a strong anion exchange (SAX) SPE column. After washing the column with methanol/water the fumonisin was eluted with 1% acetic acid in methanol. HPLC quantification of the freshly prepared o-phthaldialdehyde (OPA) derivative was achieved using: an ultracarb 7 ODS30 column; methanol/ 0.1M sodium dihydrogen phosphate (76:24) mobile phase at 1 ml/min.; fluorescence detection using excitation at 335 nm and emission at 440 nm; and PCINT data acquisition software. Recovery studies were carried out for each batch of analyses to provide quality assurance.

iii. T-2 Toxin and Deoxynivalenol

A validated NRI method using SPE (Romer #225 Myco-Sep trichothecene columns) clean-up and quantification by HPTLC. Acetonitrile/ water (84:16) extracts were filtered and cleaned-up using the Myco-Sep columns. The extracts were taken to dryness and analysed separately for the two toxins.

For T-2 toxin the extracts were spotted onto an HPTLC plate, developed using chloroform/ acetone (9:1) for 22 minutes and then visualised by dipping briefly in a solution of 3% sulphuric acid in methanol. After drying for 2 minutes in a fume cupboard and 5 minutes in an oven at 100°C the spots were quantified using a scanning fluorodensitometer (CAMAG II) set for an excitation wavelength of 365 nm and a 400 nm emission filter. Single-level calibration and data acquisition software (CATS 3) were used to give the result directly in µg/kg. Recovery experiments were performed on each batch of samples.

For deoxynivalenol a similar procedure was used, but the development solvent was toluene/ acetone (3:1). After 16 minutes the plate was dried and dipped into 3% aluminium chloride/ methanol and dried for 2 min in a fume cupboard and 5 min in an oven at 120°C to visualise the spots. Quantification by HPTLC was similar to that described for T-2 toxin, except that the excitation wavelength was 313 nm.

iv Alternaria toxins.

An NRI in-house method employing phenyl SPE column clean-up and quantification by both HPTLC and HPLC was used. Methanol/ water acidified with 0.1 N hydrochloric acid was used for extraction. The crude extract was de-fatted by partitioning with hexane and then further clean-up was achieved using a phenyl SPE column. After washing the column with water, the alternaria toxins were eluted in chloroform. The extracts were taken to dryness and re-dissolved in benzene/ acetonitrile (9:1), and then spotted onto an aluminium backed HPTLC plate (Merck 5547) and developed in toluene/ ethyl acetate/ formic acid/ water (1500:700:198:27) for 12 minutes. The plates were dried for 10 min in a drying box and then for 5 min at 105°C before quantification using an HPTLC scanner. The excitation wavelengths used for altenuene, alternariol and alternariol methyl ether were 313 nm, 265 nm and 255 nm respectively. Recovery experiments were performed on each batch of samples and HPLC was used for confirmation.

Data Analysis

Data were subject 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 vs. 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 vs. kharif was generally predetermined by climatic conditions and prevailing soil types in a specific location. In the case of kharif varieties, despite 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' discussion concerning choice of store type indicated that a range of issues was important. These included cost of storage structure, ease of use, amount of grain to be stored and availability of appropriate store construction skills. Production season (therefore rabi or kharif varieties) also played a role in 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 mud-lined baskets (kangis) were preferred over gunny 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 mud-lined 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, a total of 73 grain samples were taken, comprising 33 samples of kharif grain harvested in Oct./Nov. 1996 and 40 samples of rabi grain harvested in Feb./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 (see Table 2, village No. 6). 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

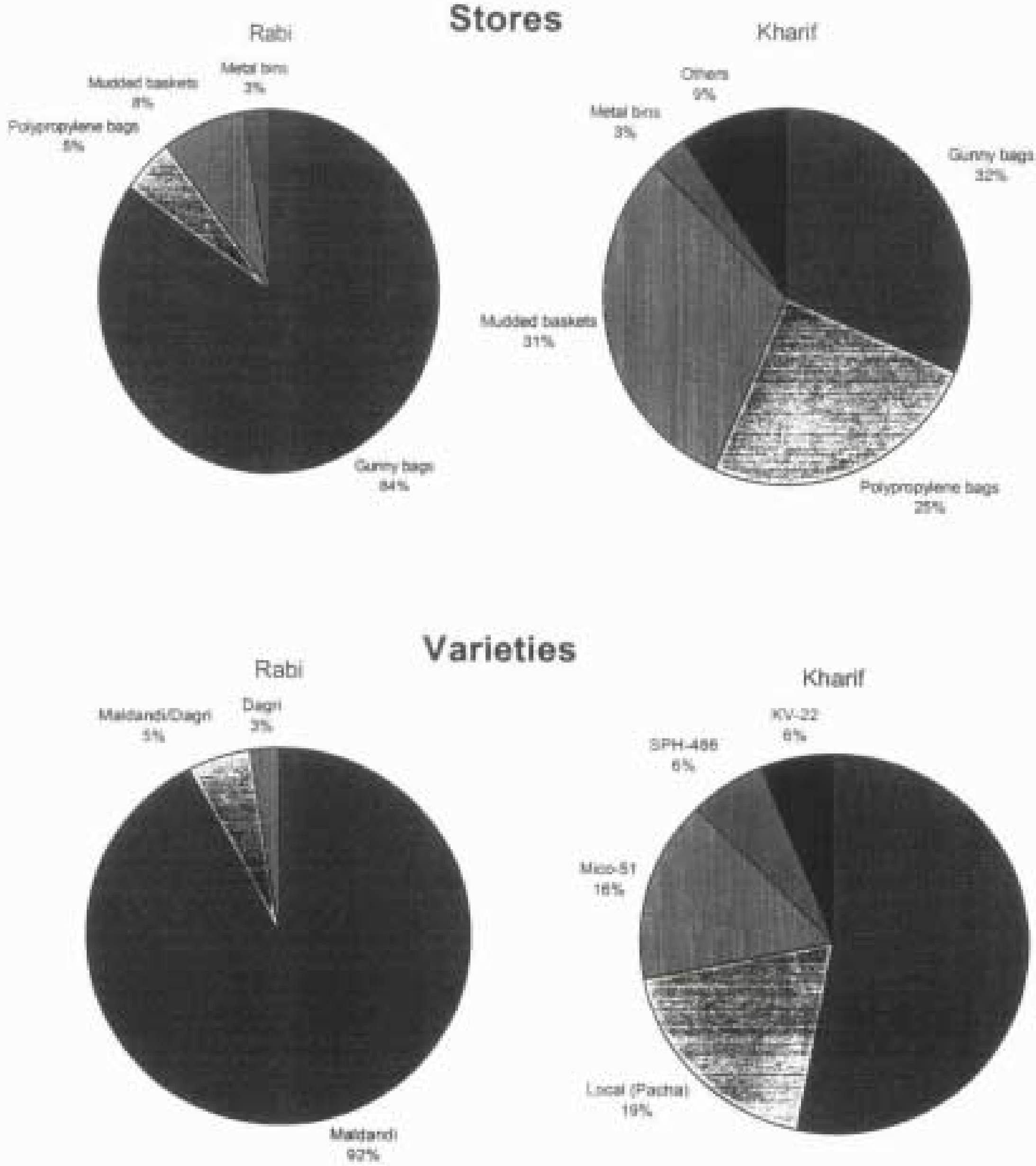

Figure 3: Store types and grain varieties of the rabi and kharif harvests (June 1997)

Figure 4: Sorghum stored in traditional mud-lined baskets

farmers who had contributed kharif samples (Table 2). 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 forty original farmers storing rabi grain, six (15%) no longer held any grain and a further nine (26%) had less than 10% of the grain observed in June. Only ten of the sampled farmers (29%) thought that they still had enough rabi sorghum to last until the next harvest, although in the event 13 still had rabi sorghum in January 1998.
The frequencies of store types and grain varieties observed in June are shown in Figure 3. It is clear that the sampled farmers harvesting rabi grain have a strong convergence of practice, nearly all growing the improved variety, Maldandi, and storing it in gunny bags. The sampled farmers harvesting in the kharif season grew a wider range of varieties and used a more diverse selection of storage structures; gunny bags, polypropylene bags and mud-lined baskets (Figure 4) were equally common. The varieties grown and the store types used by the sampled farmers are consistent with the prevailing practices of farmers as indicated in the PRA survey.

Postharvest handling practices

Discussions with farmers indicated that the postharvest handling practices for both rabi and kharif grain are broadly similar. The panicles are threshed on a village threshing yard, usually by bullock trampling, or in some instances with hired mechanical threshers. Threshed grain is sun-dried for 15 days either at the home or other convenient place such as roads (depending on the quantity). Dried grain may be mixed with *neem* leaves and ash and then placed in the chosen storage structure. Gammaxene (BHC) powder may be used on the outside of storage structures, particularly on gunny bags. Farmers indicated that insect infestation is noticeable 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 indicated that, by using this method, rabi sorghum can be stored safely for up to one year after harvest.

Women are responsible for the management of household grain stores. This was found to be the case across all case-study villages. The usual period of storage is determined mainly by farmers' wealth category and by whether the grain is of the kharif and rabi harvest. Storage periods are summarised in Table 12. 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. Some farmers consumed all 'own-produced' grain first then relied on in-kind wages and then on the market, while others would try to stretch out 'own-produced' grain with in-kind payments and purchases from the market, although this was not as common as the former. However, 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

A summary of the June and October grain quality analysis data is shown in Table 4. The June rabi sample, which had been stored for 3-4 months, had a considerably higher proportion of sound grain than the kharif grain which by June had been in store 8-9 months. This was mostly as a result of the rabi crop having significantly fewer mould damaged grains ($F_{(1,72)} = 8.6$, $p < 0.0001$). There were considerable differences in the profile of Q.I. values between the two harvests (Figure 5). The Q.I. values for the kharif in June were significantly lower than for the rabi ($F_{(1,72)} = 101.2$, $p<0.0001$) which resulted largely from the big difference in mould damage rather than insect damage, as at this time none was detected in either harvest.

Table 4: Mean quality parameters for the 1996 kharif and 1997 rabi harvests of sorghum grain for samples taken in June and October 1997

	% m.c.	% Discoloured grain	% Mould damage	% Insect damaged	% Foreign matter	% Shrivelled grains	% Sound grain	Quality index
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
Oct.								
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

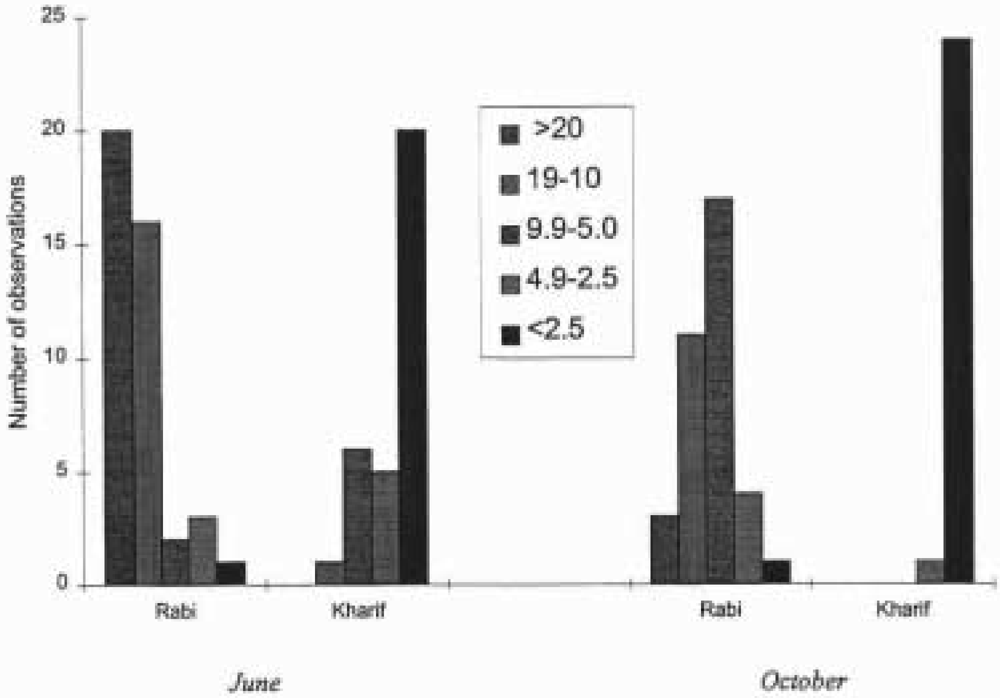

Figure 5: Frequency distribution of Quality Index values for the rabi and kharif sorghum harvests in June and October 1997.

It is clear that in June the kharif samples (in store 7-8 months) were of substantially lower quality than those from the rabi season (in store 3-4 months). The grain samples from both harvests were equally dry, the highest moisture content 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 moisture content 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 to kharif sorghum that is dampened by unseasonal rain whilst still in the field. Farmers indicate that grain blackening occurs in the kharif season and particularly with hybrid kharif sorghum. 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).

In the kharif crop, there was a positive correlation between the presence of foreign matter and mouldy ($r = 0.458$, $p<0.01$) and shrivelled grain ($r = 0.45$, $p<0.01$). As would be expected from this, there was a very strong negative correlation between foreign matter and the % of sound grain ($r = -0.639$, $p<0.01$). Clearly, poorer quality grain samples were associated with higher contamination rates with foreign matter. It is likely that considerably less care was taken in the postharvest handling of poorer quality grain leading to the inclusion of more foreign matter, rather than the presence of more foreign matter actually resulting in greater quality decline. The process of sun drying may have introduced foreign matter. However, farmers did not indicate that there was a difference in care in postharvest handling practices for lower quality grain. In the one district where kharif sorghum is grown exclusively for sale, less care may have been taken, but ultimately this would reflect on the price farmers received for their grain.

Grain sampled in October had been stored through the monsoon period. For both crops, insect damage was apparent for the first time (Table 4) and there was an increase in the % of mouldy grain which led to a fall in the Q.I., particularly so for the kharif crop. The difference in Q.I. between crops was large and statistically significant ($F_{(1,65)} = 85.7$, $p< 0.0001$). The overall differences between the crops are reflected in the average values for mould damage and insect damage observed in the villages (Table 5) and for the individual varieties (Table 6). However, very little can be concluded about the performance of varieties by crop since although Maldandi (rabi) and CSH-9 (kharif) were well represented, there were too few observations on the others. Differences between store types for the two crops are shown in Table 7. Within each crop there was no evidence of significant differences between stores in the incidence of mould, insect damage or for values of the Q.I.; however, the small numbers of observations on most of the store types precludes any firm conclusions on this matter.

As expected, the monsoon conditions resulted in a rise in grain moisture content; both crops exceeded 11%. Although the difference in moisture content between crops was small, only 0.3%, it was significant ($F_{(1,62)} = 4.48$, $p<0.038$). This suggests that the kharif crops were possibly grown in areas where the monsoon is more prolonged. In both crops, grain quality showed a clear decline during the monsoon period (Table 3), although decline was significantly greater for the kharif crop in number of mouldy grains ($F_{(1,61)} = 63.9$, $p<0.0001$), insect damaged grain ($F_{(1,61)} = 20.09$, $p<0.0001$) and discoloured grains ($F_{(1,61)} = 130.9$, $p<0.0001$). In the kharif crop, the increase in mouldy grain during the rains was about sixteen times greater than in the rabi crop. In the case of the rabi crop, there was evidence of farmers re-drying their grain to limit this type of damage. This might account for some of the difference between the crops, although the earlier, high level of mouldy grain in the kharif crop would obviously predispose it to a more rapid increase in damage with the onset of the monsoon. 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.

Insect infestation and associated grain weight loss

The incidence of insect infestation of rabi and kharif grain samples taken in October 1997 is shown in Table 8. Considerable damage and weight loss would be expected from attack by the primary pests *Rhyzopertha dominica* (Fabricius) and *Sitophilus oryzae* (L.). The percentages of rabi and kharif samples infested by *R. dominica* were very similar (about 84%) but the actual numbers of this species were about three times greater on kharif grain. In contrast, *S. oryzae* clearly preferred rabi grain, since about

Table 5: Village averages for the incidence of insect and mould damage to grain in the rabi and kharif harvests sampled in October 1997

Rabi				Kharif			
Village no.	% Insect dam.	% Mouldy	Qual. Index	Village no.	% Insect dam.	% Mouldy	Qual. 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 6: Grain variety averages for the incidence of insect and mould damage to grain in the rabi and kharif harvests sampled in October 1997

Crop	Variety	N	Insect dam.	Mould dam.	Qual. Index
Rabi	Maldandi	33	2.8±2.4	1.5±2.6	14.6±9.0
	Dagri	2	4.4±3.1	0.9±0.4	6.4±1.1
Kharif	CSH-9	16	7.5±7.6	13.6±4.9	1.7±0.6
	Local	4	7.6±5.6	8.2±5.7	2.4±1.1
	Mico-51	2	16.1±2.7	21.2±10.6	0.96±1.4
	SPH-486	2	12.2±12.6	42.2±4.0	0.65±0.06
	JK-22	3	8.5±3.7	10.2±5.5	2.0±0.9

Table 7: Store type averages for the incidence of insect and mould damage to grain in the rabi and kharif harvests sampled in October 1997

Crop	Store	N	Insect dam.	Mould dam.	Qual. 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
	Polyprop. Bag	5	4.7±3.5	7.7±5.6	2.6±1.0
	Mudded bask.	9	9.7±6.0	17.8±10.3	1.4±0.6
	Compart.	1	33.7	20.8	0.7
	Corner	2	9.6±11.8	12.4±1.9	0.7±1.1

Table 8: Percentage rabi and kharif sorghum samples infested by insects and mean numbers of live and dead insects/kg (± s.d.), 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

20% more rabi samples were infested and numbers of this species were about six times greater than on the 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 8). Sorghum grain weight losses due to insect damage were determined for ten samples of Maldandi taken in October 1997. The regression of these weight losses with their corresponding percentages of insect damaged grain is plotted in Figure 6 and is 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.

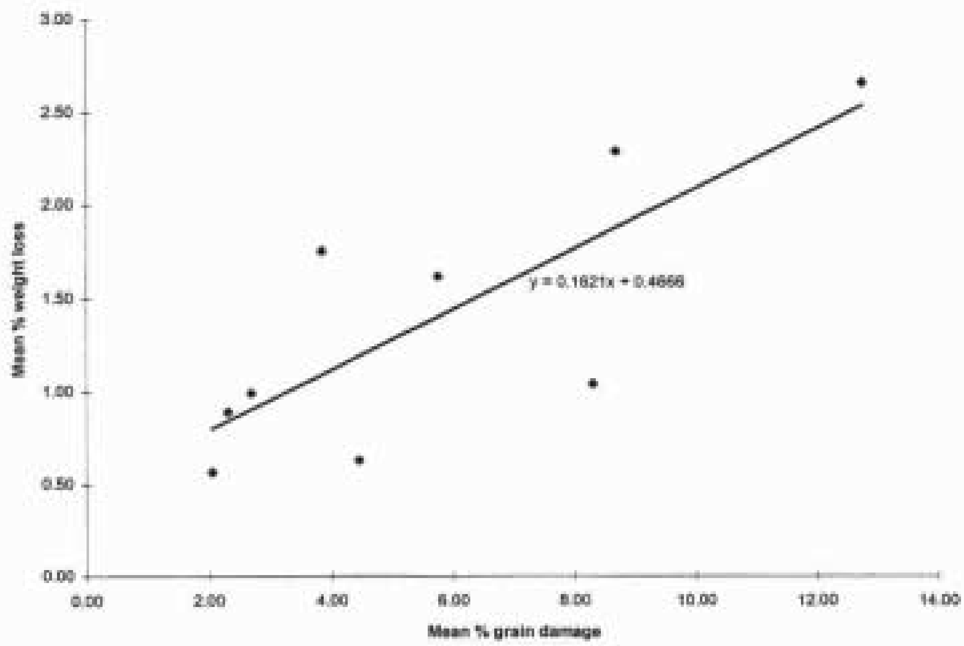

Figure 6: Mean % grain damage of ten Maldandi sorghum samples from October 1997 plotted against the corresponding mean % weight loss, with regression trend line

Quality decline in rabi sorghum through to January 1998
Only thirteen 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 9). In the three months between June and October 1997, through the monsoon, the Q.I. fell by about 63% and in the following three 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 9). There was also an accumulation of foreign matter, possibly due to contamination with stones, soil etc., when farmers have re-dried their sorghum stocks. Insect damage increased to the extent that the stocks remaining in January 1998 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.

Table 9: Mean values for quality factors of rabi season grain from the same 13 stores sampled on three occasions during a storage period of about eleven months

	June 1997	October 1997	January 1998
% Discoloured	1.0	1.9	2.8
% Mouldy	0.9	1.1	1.7
% Insect damaged	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

Fungal contamination
The major fungal species observed on the grain are listed in Table 10. The majority are typical 'field fungi' although two species, *Aspergillus flavus* and *Aspergillus niger*, are considered to be storage fungi. A much greater percentage of kharif than rabi grain had been colonised by fungi but in both crops colonisation was apparently more frequent in June than in October. This was a somewhat surprising observation as the grain quality results showed the percentage of mouldy grains increasing from June to October. The reason for the apparent decline may well be that many of the field fungi have died off in the period and been replaced by storage fungi. Storage fungi are possibly not detected by the techniques used in this study (because the incubation period is rather short and a specific xerophylic medium has not been used). The absence of any detectable *Eurotium* spp, most typical of storage fungi, tends to confirm this interpretation. In addition, the two storage fungi that were detected did both increase in the period when the field fungi generally decreased.

The effects of surface sterilisation and treatment with fungicide (benomyl) are shown in Figures 7 and 8. Comparisons of the sum mould frequency in these two figures shows that there was a far greater % colonisation of surface sterilised kharif grain than rabi grain, indicating that more of the kharif had become colonised internally, rather than just being contaminated with spores externally. Few species achieved internal colonisation of rabi grain, the exception being *Alternaria alternata,* while kharif grain

Table 10: % of sorghum grain colonisation by fungi and frequency of major fungal species in June and in October 1997*.

Season	No. samples	% grain colonised	Frequency of major mould fungi[1]							
			Aa	Af	An	Cl	Cla	Er	Fm	Rs
Field/storage fungus				F	S	S	F	F	F	F
June										
Rabi	11	48.6	13.7	1.1	5.4	3.7	0.9	2.1	4.1	12.6
Kharif	15	86.7	12.9	2.7	6.7	17.5	10.8	9.8	13.3	5.5
October										
Rabi	22	26.5	4.4	1.22	6.5	1.7	1.2	0.9	0.9	8.7
Kharif	19	49.2	2.5	5.5	6.3	6.0	18.7	1.0	3.3	14.0

* Mean of 4 replicates @ 25 grains/plate. [1]Fungal species included in this table if infection of at least 5% of grains observed in one or more instances. Aa: *Alternaria alternata*, Af: *Aspergillus flavus*, An: *A. niger*, Cl: *Curvularia lunata*, Cla: *C. lunata* var. *aeria*, Er: *Exserohilum rostratum*, Fm: *Fusarium moniliforme*, Rs: *Rhizopus stolonifera*.

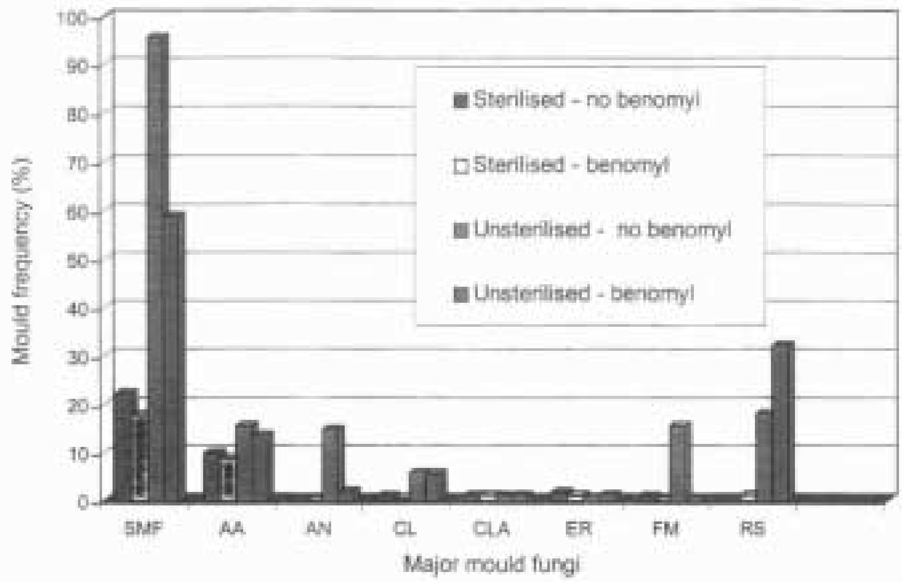

Figure 7: Sum mould frequency (SMF) and frequency of major moulds (%) on rabi sorghum grain sampled in June and October 1997 (abbreviations as for Table 10)

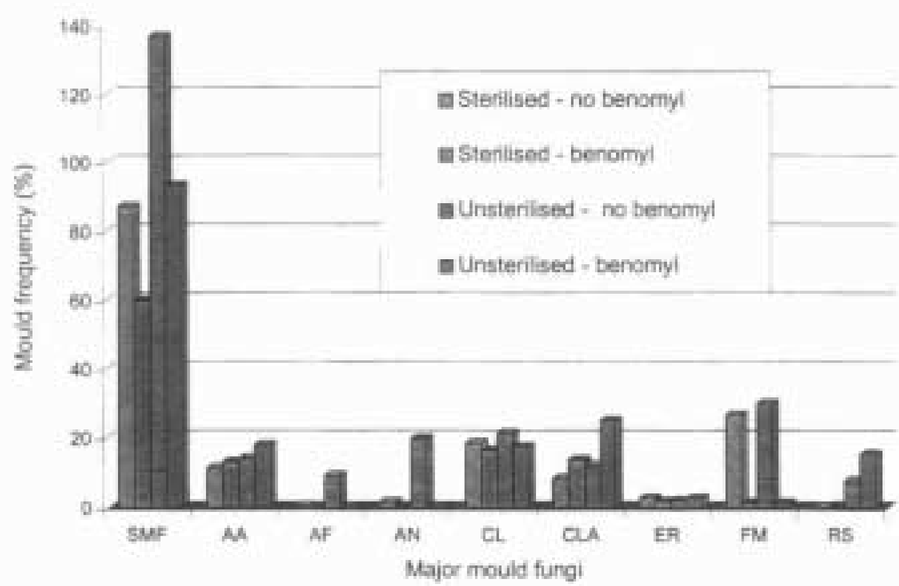

Figure 8: Sum mould frequency (SMF) and frequency of major moulds (%) of kharif sorghum grain sampled in June and October 1997 (abbreviations as for Table 10)

was colonised internally by *Fusarium moniliforme*, *A. alternata*, *Curvularia lunata* and *C. lunata* var. *aeria*.

Mycotoxin contamination

Mycotoxin contamination in June (Table 11) and October (Table 12) 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. Contamination with Fumonisin B1 was almost exclusive to the kharif crop; this is confirmed by the observation in the fungal analysis that only the kharif crop suffered any internal colonisation by *Fusarium moniliforme*. Aflatoxin and *Alternaria* toxin contamination was very low and differed little between the two harvests, this is consistent with the findings of the fungal analysis where there was little difference in the growth and colonisation of the two crops by *Aspergillus flavus* or *Alternaria alternata*.

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 pre-harvest problem, mould formation appears to continue during storage. This is not to say that farmers did not recognise that grain and quality losses did not occur during storage. Insect damage illustrates this point. Farmers knew when it began to occur and had adopted sun drying as a means of combating it. The use of neem and ash treatments also highlights farmers' awareness of these issues. Estimates for 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 are probably even lower than the figure of 5-10% they quoted.

Farmers did not specifically articulate the concept of mould damage (except in the context of grain blackening discussed above). However, they did discuss changes which 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 six 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 are changes taking place after 6 months. Since this is the limit of storage for most households, most will only rarely experience such problems. Furthermore, particularly in the case of hybrid sorghum, farmers seem to have made a conscious trade-off between grain quality and higher yields. This is evidenced by the extent to which these varieties have been adopted in the kharif villages studied. As already discussed, farmers did not include postharvest problems and storage among their crop decision making criteria. This suggests that, while these problems are undoubtedly impacting on consumers of sorghum (particularly for kharif consumers),

Table 11: Mycotoxin contamination (in parts per billion, ppb) in sorghum samples taken from the rabi and kharif harvests in south India in June 1997.

Samples		Aflatoxins ppb					*Alternaria* toxins ppb			*Fusarium* toxins ppb		
	No. stores	B1	B2	G1	G2	Total	AltOH	AltOMe	Altenuene	FumB1	DON	T-2 Toxin
Rabi												
Good qual. Maldandi.	17	1.5	nd*	nd	nd	1.5	Nd	6	nd	0	nd	nd
Good qual. Maldandi/Dagri	16	0.7	Nd	nd	nd	0.7	11	9	nd	25	nd	nd
Good quality Maldandi	6	0.5	Nd	nd	nd	0.5	Nd	nd	15	0	nd	nd
Good/medium qual. Maldandi	6	0	Nd	nd	nd	0	Nd	nd	10	0	nd	nd
Kharif												
Poor qual. CSH 9	12	2.7	Nd	nd	nd	2.7	Nd	nd	22	87	nd	nd
Poor qual. Mixed varieties	15	2.1	Nd	nd	nd	2.1	23	33	36	79	nd	nd

* Not detected *Health risk* Aflatoxin - 5 ppb, *Alternaria* toxins 1000 ppb, FumB1 - 1000 ppb , DON 1000 ppb T2 Toxin 100 ppb

Table 12: Mycotoxin contamination (in parts per billion, ppb) in sorghum samples taken from the rabi and kharif harvests in south India in October 1997

Samples		Aflatoxins ppb					*Alternaria* toxins ppb			*Fusarium* toxins ppb		
	No. stores	B1	B2	G1	G2	Total	AltOH	AltOMe	Altenuene	FumB1	DON	T-2 Toxin
Rabi											nd	nd
Good qual. Maldandi.	5	0	Nd	nd	nd	0	nd	nd	nd	0	nd	nd
Good qual. Maldandi.	5	0.6	Nd	nd	nd	0.6	10	nd	nd	0	nd	nd
Good qual. Maldandi.	6	0	Nd	nd	nd	0	nd	nd	nd	0	nd	nd
Fair qual. Maldandi/Dagri.	5	0	Nd	nd	nd	0	nd	nd	nd	0	nd	nd
Fair qual. Maldandi	5	0	Nd	nd	nd	0	12	6	8	0	nd	nd
Good/fair qual. Maldandi.	5	0.2	Nd	nd	nd	0.2	nd	nd	nd	0	nd	nd
Good qual. Maldandi	4	0.3	Nd	nd	nd	0.3	nd	nd	nd	0	nd	nd
Kharif												
Poor qual. Mico-51, JK 22	3	nd	Nd	nd	nd	nd	nd	nd	nd	125	nd	nd
Poor qual. CSH-9, SPH-468	6	nd	Nd	nd	nd	nd	nd	9	55	93	nd	nd
Poor qual. CSH-9	6	nd	Nd	nd	nd	nd	nd	nd	nd	37	nd	nd
Poor qual CSH-9	6	nd	Nd	nd	nd	nd	nd	nd	nd	89	nd	nd
Poor qual. JK 22	2	nd	Nd	nd	nd	nd	nd	13	nd	177	nd	nd
Fair qual. local var.	4	0.5	Nd	nd	nd	nd	33	40	nd	9	nd	nd

* Not detected *Health risk* Aflatoxin - 5 ppb, *Alternaria* toxins 1000 ppb, FumB1 - 1000 ppb , DON 1000 ppb T2 Toxin 100 ppb

Table 13: Summary of postharvest practices and perceptions

Season	Wealth Category	Usual storage period (months)	Farmers' estimates of annual storage losses	Store types	Postharvest practices	Quality losses	Farmers' perception of relative importance of postharvest constraints
Rabi	Rich	12	3-5% occasionally up to 10%	Gunny bags, metal bins, *hudas* (above ground storage structures), *haggis* (underground stores) bamboo baskets.	Cleaning, frequent sun drying, mixing neem leaves, ash and BHC powder	Dough loses stickiness, taste changes and colour becomes darker.	Price fluctuations and rodent damage of most serious concern
	Medium	2-6	3-5% occasionally up to 10%	Gunny bags, *kangi* (mudded bamboo bins) also metal bins	Cleaning, repeated sun drying and mixing with neem leaves/ash	Dough becomes less sticky and loses its flavour	Relatively unimportant
	Poor	2-6	3-5% occasionally up to 10%	Earthen pots, bamboo baskets and gunny bags	Cleaning and sun drying and occasionally using neem leaves	Don't usually notice changes during the short period in which grain is stored	Relatively unimportant
Kharif	Rich	8-12	8-10 % occasionally up to 20 %	Big rooms plastered with mud and cement, open rooms, gunny bags, metal bins	Cleaning, repeated drying, mixing with neem leaves/ash, using BHC on the gunny bags	Grain becomes grey, dough loses its elasticity, *roti* become hard and tasteless, some off- odours	Price fluctuation, and grain blackening are relatively serious concerns
	Medium	4-6	10% occasionally higher	Gunny bags and bamboo baskets	Cleaning, repeated sun drying, mixing with neem leaves/ash	Dough loses elasticity. *Roti* become hard, tasteless and dry.	Relatively unimportant
	Poor	4-6	5%	Earthen pots and gunny bags	Cleaning and sun drying immediately after threshing	Poor taste of roti	Relatively unimportant

they are not responsible for changes in the relative proportion of the crop in cropping patterns. These patterns and perceptions are summarised in Table 13.

Conclusions

It is clear that rabi sorghum enters storage with better quality characteristics than its kharif produced 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 the start of insect attack and rise in mould damage. 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 Q.I. 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 1.71%, while at the same time the rabi crop appears to have lost only 0.88%. The losses in the kharif crop due to insect damage are low considering that the estimate was made on grain that was close to the end of the storage period. Although the technique used to estimate the grain weight loss, the count and weigh method, will tend to under-estimate losses where grains are removed completely from the store, for example when they are reduced to dust, much of the grain was sold or consumed long before any loss estimate was made. Thus the weight losses of the entire stock will actually have been somewhat smaller than our estimate.

The two crops differed with respect to the predominant insect pest, with *R. dominica* and *S. oryzae* equally common on rabi but *R. dominica* predominant on the kharif. The two species do differ in their abilities to tolerate dry conditions (Haines 1991). *S. oryzae* is more or less unable to develop on grain with moisture contents below 11%, however it seems that moisture is not a major consideration in this case as *S. oryzae* was not less dominant on the dry season 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 but make no mention of any *Sitophilus* spp. In a very brief note on the susceptibility of high-yielding kharif varieties the percentage damage caused by *R. dominica* was many times greater than that caused by *S. oryzae* (Kishore *et al.*, 1977).

Mycotoxin contamination generally remained below levels that would represent a human health hazard. Similar low contamination rates were reported from earlier surveys in south 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 B1 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 investigated in this study, 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, specifically by *F. moniliforme*, show that specific antifungal proteins are involved (Kumari and Chandrashekar, 1994). The possibility of transferring these characteristics to sorghum varieties, which 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; such as those with panicles that hang downwards, which are less prone to moisture accumulation.

Overall, the grain storage practices of farmers in south 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 considerable quality decline. 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 wished 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 six 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.

In addition to the technical conclusions drawn above, this research has raised a number of methodological issues that may provide valuable lessons for others. 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, BalaRavi and Dayakar, 1998). 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 need more detailed study.

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