

R 5453

R-104 -018 V



**A Guide to Appropriate Technologies
for Small-Scale Storage of Grain
in Sub-Saharan Africa**

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ACKNOWLEDGEMENTS

This study was conducted under an Adaptive Research Project entitled 'Support to Small-Scale Grain Handling and Storage in Southern Africa' (R5453). It forms part of the NRI Cereals and Pulses Food Security Programme and was funded by the Overseas Development Administration.

The authors are most grateful to those who responded to questionnaires, those who assisted the authors during field visits, and colleagues who have contributed to the guide.

SUMMARY

Appropriate technologies for small-scale, on-farm grain storage in sub-Saharan Africa are reviewed and assessed in the light of the current pressures resulting from the liberalisation of grain markets. The study was based on a literature survey of recent storage innovations, visits to countries in the SADC region and replies to questionnaires sent to agriculture ministries and other organisations to ascertain the extent to which improved procedures were being promoted and adopted.

The reasons for storage, and the factors which may affect the choice of a particular storage system, are noted. The construction, uses, cost and efficiency of the six main storage methods (drying/storage crib, basket, metal tank, mud block/brick silo, pit and grain bag) are compared and contrasted; some suggestions for improvements are included.

The problems with high-yielding, improved varieties of maize are assessed with reference to their retention on the farm. It is concluded that support for small-scale, post-harvest storage projects is justified and necessary, but recommendations should reflect social, agro-climatic and economic issues as well as individual need. In most cases, grain bags would be adequate for supplementing storage capacity.

CHAPTER 1. INTRODUCTION

Challenge of grain market liberalisation

1. During the last 25 years or so, government parastatals have been promoted as the principal means of ensuring national food security. They have been used to:
 - (a) provide a market within easy reach of grain producers (frequently acting as the buyer of last resort);
 - (b) subsidise transport costs;
 - (c) apply pan-territorial pricing;
 - (d) hold the nation's reserve stocks (for the assurance of government); and
 - (e) release subsidised grain to millers or consumers.
2. The parastatals have also exercised control over the quality of purchased grain and provided effective storage management. These issues have been fully discussed by Coulter and Compton (1991).
3. Issues of grain storage have tended to be included under donor-funded projects aimed at strengthening central storage facilities, developing co-operative unions, and providing communal storage facilities at the village level. These investments have been partly justified by generalised claims of high post-harvest losses at farm level which may be alleviated by the provision of support for off-farm storage (Nordic Consulting Group, 1993). However, communal storage (at village level) has not been widely adopted primarily because of technical and social problems (Coulter, 1994).
4. Close scrutiny of losses at the producer level, particularly among small-scale farmers, would show that the present grain storage capability is effective and widely used, and losses are generally kept below 5% (Tyler and Boxall, 1984). Exceptions may occur if the equilibrium of the traditional post-harvest system is disrupted. For example, new varieties may be introduced that mature earlier in the season and do not possess the robust storage characteristics of the traditional types (Compton *et al.*, 1993). The newer, high-yielding varieties grown by the more progressive small farmers may also produce grain in quantities which exceed the traditional handling capacity. These farmers, and large-scale

commercial farmers, are therefore dependent on the parastatal and the grain trader to take their surplus grain soon after harvest.

5. The introduction of structural adjustment policies, and grain market liberalisation in particular, has challenged the continuing role of the subsidised parastatals (Coulter and Compton, 1991). Their monopolistic influence over the price of marketed grain is declining and the private sector is being encouraged and enabled to participate in procurement and distribution. The effects of this change on small-scale producers with surplus grain are mixed. The opening of alternative marketing opportunities, and the chance to take advantage of seasonal price rises, has been accompanied by technical difficulties. Of particular significance is the loss of the guaranteed market for surplus grain shortly after harvest, which had previously relieved the producer of storage and quality maintenance problems (Tyler and Bennett, 1993). As this storage problem increases, methods of conserving grain safely on the farm take on a new importance and there is a need for appropriate advice.

Study approach

6. This guide is part of a wider study aimed at increasing the efficiency and effectiveness of grain stock management. It is focused on the Southern Africa Development Community (SADC) region where grain market liberalisation needs to be supported by identifying and adopting appropriate post-harvest technologies, especially storage at the small-scale level. The major grain crop grown in the region is maize, but sorghum and millet predominate in the more arid areas.

7. The study had three components, as follows.

(a) A literature survey was carried out of publications relating to the introduction of innovations in small-scale storage during the last 20 years. These were critically assessed and narrowed down to those which had contributed significantly to storage technology, had been successfully adopted by farmers, and had potential for use in a liberalising grain economy; very few met these criteria.

(b) Visits to seven countries in the SADC region were made in 1993 (some were visited more than once) to assess the process of grain market liberalisation, the consequences for small-scale producers and local post-harvest research and development activities (Tyler and Bennett, 1993). The countries visited were Botswana, Malawi, Mozambique, Namibia, Swaziland, Zambia and Zimbabwe. A

further two visits to Zambia were made (during July 1994 and in October / November 1994) to determine small-scale producer experiences under active grain market liberalisation and to formulate a support programme.

(c) A questionnaire was sent to ministries of agriculture and researchers in 35 countries in southern Africa and elsewhere to ascertain whether or not improved grain storage procedures were being actively promoted and adopted. Responses to the questionnaires contributed very little and were rather disappointing, but they did serve to confirm that, certainly in southern Africa, relatively few resources are being devoted to the improvement of small-scale storage.

Intended readership

8. Comparative information on small-scale storage technologies is not widely available. Such as there is has been reviewed with the object of assisting those who may wish to select improved methods. The guide is also intended to provide guidance for research priorities, extension initiatives and areas for donor support, and to provide resource material for post-harvest training courses.

CHAPTER 2. ROLE OF ON-FARM STORAGE

9. The prime objectives of small-scale storage are:
- (a) to provide assurance for the producer that the seasonal abundance of grain at harvest will remain available for seed, and for consumption, over the following year; and
 - (b) to support the timely and profitable disposal of the surplus.
10. These objectives can be represented by the equation:

$$\begin{array}{ccc} & \textit{storage} & \\ \text{Production} & \longleftrightarrow & \text{Consumption + surplus (if any)} \\ \text{(seasonal)} & & \text{(continuous)} \end{array}$$

11. However, this over-simplistic statement must be qualified and stratified to accommodate very different patterns of storage and marketing activity. In sub-Saharan Africa, the underlying motivation for the small-scale production of grain crops, and their subsequent storage, is one of risk aversion before financial gain. With a subsidised price system, selling all the grain at harvest in the knowledge that maize meal can be bought back later (often at a subsidised price) is an attractive proposition. Selling grain may be the only opportunity for the farmer to obtain cash for which there is usually a pressing need at harvest. However, stored grain can also provide a convenient and generally reliable source of capital. Assuming market demand at acceptable prices, the grain can be sold in any amount to provide cash when needed, or it can be used directly as a medium of exchange. Nevertheless, the prudent farmer will resist the temptation to sell too much of his grain as the disastrous consequences of running out of food have been experienced only too frequently during the droughts of recent years.

Stratification of farmers

12. None of the surveys and classifications of farmers carried out in the past have attempted to link the motivation for storage with the scale of requirement, and current and future needs. Specific store types have been well documented (Bengtsson and Whitaker, 1988; Bodholt and Diop, 1987; Bodholt, 1985; Dichter, 1978; Giga and Katere, 1986) and, although post-harvest losses have also been surveyed extensively (e.g. Tyler and

Boxall, 1984; Visser, 1993), long-term quality/value studies of storage improvement investment in relation to the grain price obtained over many seasons are singularly lacking.

13. For the purpose of this study, producers are broadly classified according to the productivity of their farming enterprise and their dependence on storage. It should be emphasised that medium and large commercial farmers are not included.

(a) Subsistence and less (180 kg of maize or less per person per year)

Farmers who rely entirely on their own production to feed their family are the most vulnerable and the most dependent on storage. Total food requirements for the family may not be met through production. The shortfall will be made up by labouring for others and receiving payment in grain. This group adopts the simplest and cheapest possible storage methods consistent with reliability. They are unable to participate in any serious grain marketing.

(b) Subsistence + cash cropping (up to 2000 kg in excess of the food requirements of the family)

In this category, the farmer depends on his own production to feed his family and in good years, may have a surplus to sell (beyond that which is provided as payment in kind for casual labour). If the surplus is not sold immediately after harvest, some provision for storage has to be made. The cost of providing the extra storage capacity is a limiting factor.

(c) Cash cropping + consumption (over 2000 kg surplus)

Only a minor part of the grain produced is retained for family consumption in this group. Although the surplus may be sold at harvest, there are advantages to be gained from retaining it for later sale. Investment in storage facilities may therefore give a good return.

(d) Double cropping + alternative staples (root crops)

In favourable climates, the prospect of more than one grain harvest, and the opportunity for growing staple root crops (such as cassava and sweet potato), both spreads production across the crop year and reduces the total dependence on grains and pulses and consequently, the requirement for inter-annual storage. Multiple

cropping, however, may lead to handling and drying problems when crops have to be conditioned for market or inter-seasonal storage under adverse weather conditions. This is a particular problem in West Africa as well as in some East African countries where multiple cropping is under development.

(e) Semi-commercial and commercial production (well over 2000 kg)

Although numerically in the minority, the contribution of this group of farmers to the grain economy is disproportionately significant. They own land and can afford to invest in labour, equipment and transport. The study does not focus on their specific operations.

14. The manual aims to benefit primarily those producers in categories (b) and (c).

Purpose of storage

15. The categories described above indicate the role of storage in meeting basic food and cash requirements, but there are many other reasons why storage is important.

16. The size of the harvest is unpredictable but critical to food security. If bumper harvests exceed the capacity of available labour and resources, particularly in terms of transport from the harvest field, drying, and storage operations, waste and loss can occur. It may be impossible either to cope with the volume of grain produced, or to find a satisfactory market for it; temporary drying/storage facilities are therefore required. Conversely, drought and crop failure can lead to shortage and hunger. The traditional, inter-seasonal storage system provides a buffer against this latter extreme, particularly in semi-arid areas where millets and sorghum are grown (Guggenheim, 1978); it is less apparent where harvests are more consistent and reliable.

17. From a strictly practical point of view, a storage system can provide a holding place for harvested crops while the land is being cleared for the next crop. It can also provide an area protected from the rain where the harvested crop can be dried. The storage method usually permits segregation of different types of grain and may afford some degree of protection from fire, insects, birds, rodents and theft.

18. Strong, society-related traditions may dictate storage practices; many of these are associated with deep-seated beliefs. The Dogon tribe of Mali provides the classic example: sorghum and millet are viewed with reverence and they may be conserved in large, ornate

granaries for more than five years (Guggenheim, 1978). The status and success of a farmer may be manifested by the number and size of his grain stores and reflect his social standing within the family and the village. Although cash remittances from wage-earning members of the family, and the occasional dependence on allocations of food aid, have tended to erode this custom, many societies still consider it essential to maintain stocks of grain for feasts, funerals, festivals and obligatory gifts.

19. At the subsistence level, a full granary is more important as a source of food security than as a symbol of wealth. However, for those who wish to pursue the opportunity of selling or bartering surplus grain, there is a vital need for a temporary place in which to store it without loss of quality or quantity.

20. The female members of the family usually play a leading role in storage operations. Traditionally, women take responsibility for post-harvest activities such as de-husking, threshing, shelling and winnowing; they may also be in charge of store maintenance and the safe-keeping and removal of the grain. Subsequent grain processing activities at the household level may be exclusively female prerogatives. As the number of female-headed households is increasing due either to economic circumstances which force the men to take other employment, or to the consequences of AIDS amongst the male population, storage methods must be compatible with the other demands on women's labour.

Agro-climatic considerations

21. The adoption of a particular storage method depends on a complex of factors including the farming system, social and economic pressures, and practical constraints. An over-riding factor is the climate. The mature grain must be harvested when it reaches maximum quality and the chosen storage system must enable it to be conserved in that state. This may involve the following series of procedures: harvesting, temporary storage in the field, transportation from field to homestead, drying, threshing or shelling, winnowing and, finally, storage. The timing and duration of the conditioning process is dependent upon the weather pattern. In semi-arid areas where the rainy season ends before the harvest, drying problems are minimal, particularly if the crop can remain in the field until moisture has been reduced to a safe level. By contrast, if grain is harvested before it is mature and during continuing rains, artificial drying and/or a covered crop drying structure will need to be provided; such a structure may also be used as a place for storage.

22. The inherent unpredictability of the seasons, and the possible long-term change in weather patterns, can severely test post-harvest capability during the critical harvesting and

drying period. Well-adapted farming systems have sufficient flexibility to cope, but special problems may arise if new crop varieties are introduced which are less compatible, and if the quantity of grain increases, during bumper harvests for example.

CHAPTER 3. ON-FARM STORAGE TECHNOLOGIES

23. Traditional post-harvest technologies have evolved from the basic resources and skills available in the farming community. Many are ingenious and perform to the satisfaction of their users, but they have been variously criticised by outsiders for causing high losses, and being inefficient, inflexible and insecure compared with modern structures. However, the use of these technologies has enabled a major portion of the African rural population to be provided with food for many centuries. Detailed examination has also shown that grain losses are much lower than had previously been thought (Tyler and Boxall, 1984).

24. Although farmers recognise the limitations of traditional structures, they are often unwilling to improve their stores. This may be partly due to a lack of access to capital, but it may also reflect their satisfaction with the quality of grain produced by the existing system; a loss of about 5% using the traditional system is acceptable and they will be reluctant to spend time or money on reducing loss below this level. By contrast, the expectations of commercial farmers are much higher, so they are more interested in reducing loss and maximising returns on investment.

Pressure for change

25. Overall, the demand for food grain is rising with the increase in population. As suitable cropping land is limited, an alternative solution is to increase yield by using improved varieties and fertilizers. However, this alters the equilibrium of the farming system so that drying methods and storage capacities which were devised for unimproved grain varieties may show deficiencies when high-yielding types are introduced. There are several reasons for this:

- The improved variety may mature at a different time of the season (for example, before the end of the rainy season), and this may lead to drying difficulties.
- Due to homogeneity, all the grain may mature at the same time.
- The higher yield may impose a greater demand on labour to harvest and transport it to the homestead.

- During storage, post-harvest characteristics of the grain (such as softness) may render it more susceptible to insect damage. Therefore, in order to retain the advantages of the higher yield, some investment is necessary to minimise losses.
- Storage capacity may be inadequate.
- The shortage of storage space was formerly offset by the rapid disposal of surplus grain into a subsidised marketing system but the policy changes which have accompanied grain market liberalisation have virtually removed this option. The reduction in purchasing activities of the grain marketing board means that the farmer can no longer deliver to a convenient local reception point and receive cash. The alternative system, which involves emergent grain traders, has a lower initial capacity for procurement; off-take from the farm is slower, and the net result is that more grain remains on the farm for longer, particularly in more inaccessible areas. This increases the burden on the on-farm storage system and, if it is to cope, additional and suitable capacity has to be provided. Other inadequacies of traditional storage systems are detailed below by store type.

Traditional and improved storage methods

26. A basic classification of storage structures was provided by Hall (1970). The choice of construction materials for traditional storage structures is limited to a few materials. These include:

- clay plaster and bricks
- stones
- timber poles and sticks
- woven plant material
- thatching grasses
- gourd (Cucurbitaceae) containers.

27. The ingenious use of these materials combines function with strength and often results in an aesthetically satisfying design. There is high dependence on obtaining the building materials, particularly poles and thatching grasses, very locally. As a result of the increasing population pressure and the intense use of farmland in many African countries, traditional construction materials have either been exhausted or are becoming scarce and expensive (Giga and Katere, 1986). Alternative new products are becoming available to the small farmer, at a cost, and in some areas store design is evolving to incorporate these

materials (Visser, 1993). For example, plastic sheets are being used for waterproofing, and re-openable plastic or tin containers are providing convenient outlet spouts for many structures used to store shelled grains. Iron sheets and woven polypropylene (wpp) sacks are examples of other commonly used materials.

28. The uses of various types of store for major grain crops are summarised in Table 1. An example of a cost-benefit analysis for a selection of Ghanaian store types is given in Table 2.

Table 1. Commonly used on-farm storage methods for the major grain crops.

Grain crop	Generic type of storage method						
	drying/ storage crib/ basket	mud granary	mudded basket	metal tank	brick granary	pit	grain bags
cob maize	+						
shelled maize		+	+	+	+	+	+
unthreshed sorghum	+	+	+				
grain sorghum		+	+	+	+	+	+
unthreshed millet	+	+	+				
grain millet		+	+				+

Note: Once crib drying is complete, the grains are sometimes shelled and stored in the crib in sacks.

Table 2. Example of cost-benefit analysis for store types: Ghana maize storage.

Cost in cedis ^{ab}	Store type						
	Ashanti crib	Ashanti crib with insecticide	Ewe barn	Northern basket	Northern mud bin	Improve d crib	Sacks in house
Capital cost							
Materials	1000	1000	1000	2000	0	18500	400
Labour	3500	3500	1000	1000	1500	3000	0
Total	4500	4500	2000	3000	1500	21500	400
Capacity (shelled bags)	10	10	20	10	10	17	1
Cost/bag	450	450	200	300	150	1265	400
Life of structure (years)	4	4	3	4	10	4	2
Annual cost (real interest + capital)							
at 10%	142	142	80	95	24	399	230
at 20%	174	174	95	116	36	488	262
Operating cost (C/bag)							
Actellic dust ^c		150				150	150
Labour to shell, treat and fill sack ^d		100				100	100
Sacks		100				100	0
Actellic EC to spray cobs ^e		113				113	
Total	0	463	0	0	0	463	250
Opportunity cost of stored grain ^f	600	600	600	600	600	600	600
Losses (value ^g)	400	80	400	80	80	40	80
Total storage cost							
at 10%	1142	1284	1080	775	704	1501	1160
at 20%	1174	1316	1095	796	716	1591	1192
Cost of grain prior to storage	4000	4000	4000	4000	4000	4000	4000
Break-even price							
at 10%	5142	5284	5080	4775	4704	5501	5160
at 20%	5174	5316	5095	4796	4716	5591	5192

a Real interest rates account for inflation over the period of storage;

b labour shadow prices = 250;

c actellic dust C1500/500g;

d 2.5 bags in one man-day;

e actellic EC C7500/litre can treat 200 bags of cobs;

f product of value of maize and current annual savings rate (15%);

g farmgate price of one bag of maize in September 1991 (C4000).

29. In the following section, examples of the basic types of store suitable for 1-2 t are compared and contrasted, and improvements are suggested. Small containers (gourds, tins, pots, etc.) are excluded because of their limited capacity. The data are derived from the published literature, reports, extension material and returned questionnaires. Information is summarised under 10 headings. Caution is urged where data on costs are included. Costs are difficult to compare, and the current and local prices for construction materials and grain affect economic viability. A worked example from Ghana is given in Compton *et al.* (1993). A seasonal price rise of between 18 and 40 per cent is required to justify the investment in storage and it is assumed that the store is filled every year.

Drying/storage crib

30. **Construction** Traditional cribs are circular or rectangular structures with a framework of wooden poles. The crib is usually 0.6-2.0 m wide and oriented across the prevailing wind. A narrow crib will offer less resistance to air flow and give an improved drying rate. Walls can be made from raffia, bamboo, wire netting, poles or sawn timber; at least 50% of the wall area should be openings to aid ventilation. Roofs are either thatched or made from corrugated iron. The base of the store should be at least 0.7 m above ground level and the legs can be fitted with rat guards. When drying is complete, the walls can be covered with mats to provide further protection from driving rain.

31. **Ease of use** The drying crib has many advantages. It can accommodate early harvested cob maize so losses during field drying are lower. It also enables the land to be cleared and prepared in plenty of time for the next crop (Visser, 1993). Loading and emptying of the crib is facilitated by the open top of the framework; doors or removable poles may also be incorporated. The open structure allows for simple cleaning and for periodic inspections of grain quality. Segregation of different lots of grain is not practicable.

32. **Cost** Traditional cribs may be made entirely from local materials at minimal cost if these are available. If building materials are bought and a builder is employed, costs will rise accordingly. Some costs for the construction of an improved crib in 1992 were given by Visser (1993) as 10,000-15,000 CFA (\$36-55)/t stored. A 1.35 m wide crib which had a corrugated iron roof and used a minimum of local materials cost US\$ 250 to build in 1993 (55% of which represented the cost of the roof).

33. **Grain quality assurance** The effectiveness of different improved storage cribs is difficult to compare or quantify. Local climate and pest infestation pressure, and the standard of design and construction, influence the quality of the stored grain. Quantitative losses are reported to range from less than 5% to more than 20%. Insecticide treatment is normally required. Insect damage is location specific. It also depends on the grain variety being stored and whether, for example, maize cobs are de-sheathed or not.

34. **Security** As stored produce is on display in a crib, the simple wooden structure would be difficult to protect against theft. As a deterrent, doors and other entrance points can be fitted with padlocks. The use of wire netting walls also decreases the risk of theft.

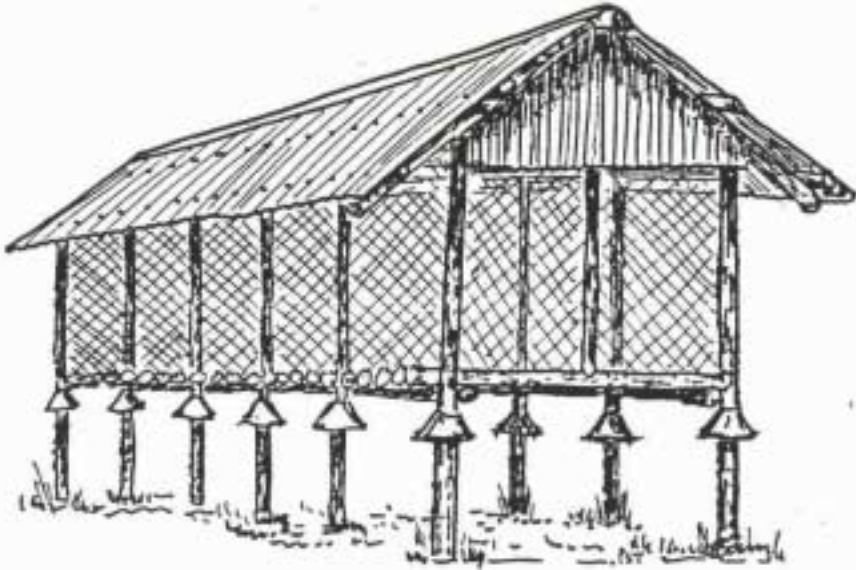
35. **Durability and maintenance** An improved traditional crib will have a life-span of approximately 10 years with maintenance limited to one or two days each year. It may be necessary to renew a thatched roof every three to five years. Greater durability would be obtained by using more permanent building materials.

36. **Social factors** The crib clearly reveals the size of the producer's harvest. While in some areas this may be considered to be a positive sign of affluence and success, in others (e.g. in some West African countries) it may be considered improper or indiscrete.

37. **Flexibility** Cribs can be used for drying cob maize or storing shelled grain in sacks. They can easily be modified for storing other commodities such as root crops and melons.

38. **Overall adoption and potential** The improved crib has similarities with many traditional open storage structures. As small improvements can be incorporated at low cost, and crib storage is not a new concept for many small farmers, this technology is easily extendible and has gained widespread acceptance. The high costs of major improvements to design are usually prohibitive. Improved cribs have been developed, introduced and extended, with varying degrees of success, in Nigeria, Swaziland, Kenya, Benin, Cameroon, Ghana, Tanzania, Uganda and Zambia. In some areas, the adoption of cribs will be constrained by the diminishing local supply of wood and thatching grass, unless alternative and sustainable sources of materials can be found.

Figure 1. Examples of drying/storage cribs.



Basket storage

39. **Construction** For post-harvest grain drying, baskets are of an open-weave construction to allow air to circulate through the grain. Dry shelled grain is often stored in baskets which have mudded walls usually consisting of a cow dung/soil mixture. As well as providing additional protection from the rain, the mudded walls can have a number of other advantages; these include strengthening the structure, preventing uptake of moisture by dry grain, and inhibiting the oxidation and breakdown of insecticides by restricting air movement (Golob, 1984). Baskets are sometimes used for both drying and storage; they are used without mud plaster for the drying phase and then the outside is plastered for the storage period. Most baskets have a tightly fitting lid and some may also have an additional access hatch or exit port. Insects are deterred from entering the store once the mudded basket is filled if the lid is sealed with clay and plastered over. To prevent uptake of ground moisture, basket stores stand on stone or brick foundations, or on a wooden platform. If the baskets are stored outside, an extended thatched roof is used to keep the store shaded from the sun and sheltered from rain. Alternatively, baskets may be permanently stored within a house.

40. **Ease of use** Open weave baskets are used for drying cob maize, and mudded baskets for storing dry shelled grains. Traditional basket granaries are built in different shapes and sizes which variously combine strength, portability, security, ease of filling, ease of emptying and ease of inspection.

41. **Costs** As basket stores are constructed entirely from local natural materials, these building material costs are low. However, basket making is often limited to village specialists who may charge considerably for their skills.

42. **Grain quality assurance** Golob (1984) reports that in Malawi, approximately 35% of some improved varieties of maize may be lost during a six-month storage period compared to about 1-3% by weight of untreated "local" maize. Application of insecticide to improved varieties of shelled grain in basket stores is therefore essential since the basket weave presents no barrier to insect entry.

43. **Security** The simple woven structure makes basket stores vulnerable to theft. When used for storing shelled grain, they are often mudded or plastered, and the filling/emptying ports sealed over. This may deter opportunistic theft and may help to impede goats, birds and rats.

44. **Durability and maintenance** A mudded basket kept outside will need replastering annually whereas a cement plastered basket may last for several seasons. When kept in the house, a well-made grass basket can be used repeatedly for grain storage for 10 or even 20 years (Tyler, 1978). Maintenance includes repairing the thatched roof, and mending cracks in the plastered walls and holes or splits in the basket weaving. Before loading, the store should be cleaned using a stiff brush and sprinkled with insecticide dust if the local infestation pressure is high.

45. **Social factors** In areas where the community can be trusted, basket stores may be left open with their contents accessible; they cannot be locked and many do not have lids to deter potential thieves. However, if theft is a risk, basket stores may be inappropriate unless they can be secured inside a building.

46. **Flexibility** Storage baskets can be constructed to different styles and capacities, and they can be used for both threshed and unthreshed grain.

47. **Overall adoption and potential** Traditional basket storage is widespread in Africa. However, surprisingly little effort has been made to extend the appeal of the basket as a method of storage, perhaps because the emphasis has been on developing structures of greater permanence.

Figure 2. Examples of basket storage



Metal storage tanks

48. **Construction** Metal storage tanks are made from sheet steel which is usually corrugated or fitted with external metal straps to improve rigidity. Most have doors or spouts for loading and emptying. The steel should preferably be galvanised to protect it against corrosion. To protect against corrosion from ground moisture, the metal bins should be fitted with legs, or they should stand on an elevated platform with gaps or channels to allow air circulation around the base. A wide roof often overhangs the storage bin to provide shade, and this will help to reduce moisture migration and heating in the stored grain. A coat of white paint to reflect the sunlight is a useful additional measure.

49. **Ease of use** Before storage the grain must be very well dried, threshed or shelled, and winnowed or sieved. Prerequisites may therefore include a drying crib and a sheller or threshing machine. Apart from the removal of the final residue, filling and emptying is easy. Maintenance is generally simple, but repair of a punctured or badly corroded tank requires the services of a skilled metalworker.

50. **Costs** The cost of a purpose-built bin varies with size. Some recent manufacturing costs for Swaziland are given by Walker (1994) and shown in Table 3. Oil drums can

Table 3. Manufacturing costs of grain tanks in Swaziland.

Capacity (kg)	Capacity (70 kg bags)	Cost (E*)	Cost / kg (E*)
350	5	263	0.75
700	10	359	0.51
2100	30	718	0.34

* 3.33 Swazi Emalangeneni = 1US\$

easily be adapted for grain storage and in some countries they are available at reasonable cost. However, transportation costs from the supplier to distant storage sites may be prohibitive.

51. **Grain quality assurance** If used correctly, a well-made, well-sealed metal bin can provide good protection against insects, moulds and rodents. In most storage environments, insect control using insecticide dusts or fumigation is essential. Phosphine fumigation, using aluminium phosphide tablets, is widely used, although the frequent

misuse of this potentially lethal product is a cause for grave concern. Many metal storage tanks use the hermetic principle to prevent excessive damage from pre-harvest infestation.

52. **Security** Padlocks can be fitted to the filling port and emptying spouts for maximum protection and security.

53. **Durability and maintenance** With routine maintenance and careful use, a metal storage tank can remain serviceable for more than 30 years (Breth, 1976) although 12-15 years is the realistic estimate for Swaziland. Maintenance includes cleaning out residues, protecting against corrosion and repairing the roof.

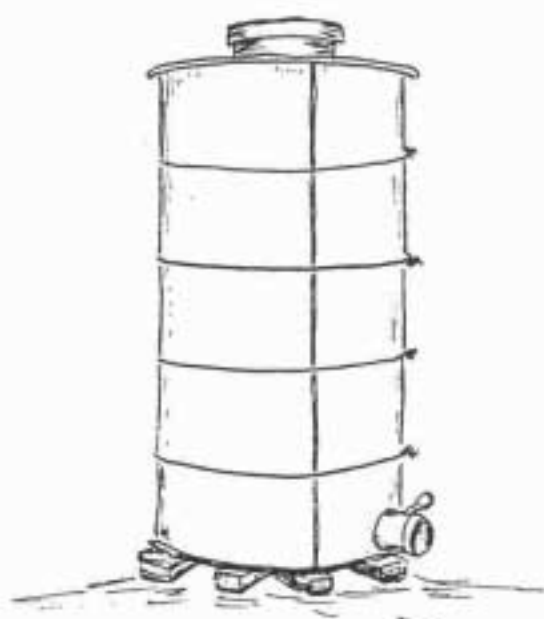
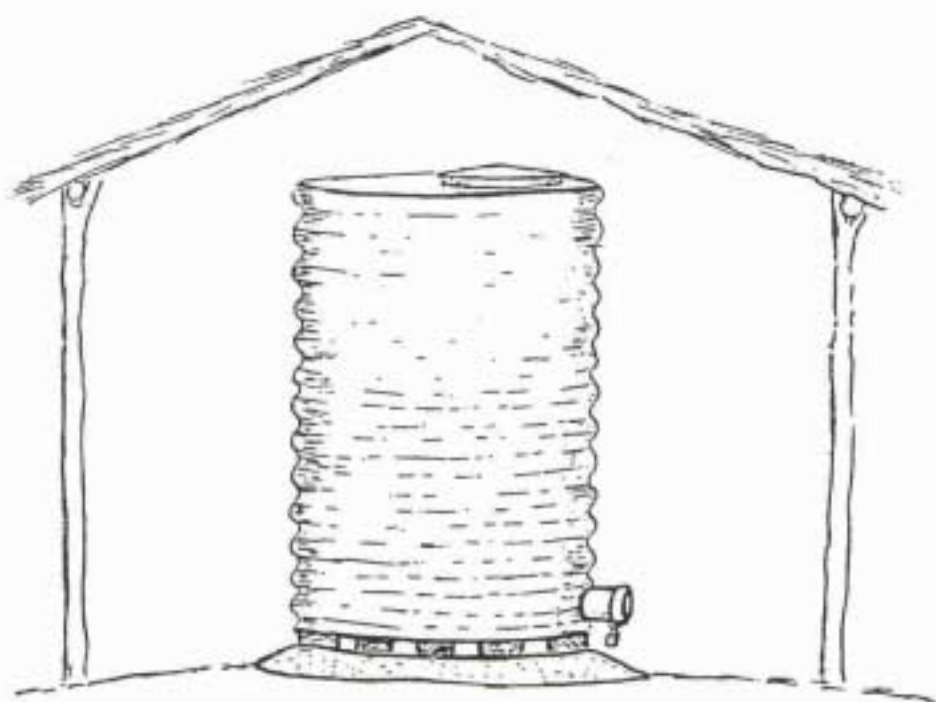
54. **Social factors** The need for secure food-storage structures is increasing in many parts of Africa and the adoption of modern materials is becoming more widespread. The metal bin fulfils the storage requirement in Swaziland and some neighbouring countries (Walker, 1994).

55. **Flexibility** Although food and seed grains can be stored successfully in metal tanks, they cannot be kept separate.

56. **Overall adoption and potential** In Swaziland, grain storage in metal containers has been practised for many years and is now widespread. Walker (1994) reports a Government of Swaziland (1991) survey which found that 36 per cent of homesteads in rural development areas had grain tanks. By extrapolation, a figure of 30,000 tanks are estimated to be installed nationally though this figure, based as it is on limited surveys, should be viewed with caution.

57. However, in many areas of Africa, metal storage tanks are unknown. The durability and security offered by this system could appeal to the more affluent small farmer. It is more likely to be adopted if metal containers are already used for holding water and can be made locally by sheet-metal workers. Large metal tanks are difficult and expensive to transport into rural areas as they are susceptible to damage on poor roads. Ancillary drying and threshing/shelling equipment may also be required. Metal tanks are well suited to a situation where the staple crop is harvested during a distinct dry season followed by storage of grain through a rainy season where good protection is desirable.

Figure 3. Examples of metal storage tanks



Mud block/brick silo storage

58. **Construction** Mud block silos may be cylindrical (with an internal diameter of 1.0-1.5 m and a height of up to 2.5 m) or rectangular (with wall lengths of up to 2.5 m). Thin-walled structures are used for storing unthreshed millet, sorghum and maize cobs; those with thicker walls are used to support the greater internal pressure and total weight of threshed grains. The foundation is often laid into a shallow pit and built up to about 0.25m above ground level using large stones or bricks (burnt or mud). Alternatively, and depending on the availability of strong timber, wooden pillars supporting an elevated platform can be used as a base for the store. The floor slab can be made from bricks or concrete. The gaps in a brick floor should be filled with mortar. Concrete mortar is stronger and offers more protection from rodents and termites than mud mortar. Plastic sheeting or tar paper can be used between the foundation and floor slab to prevent the uptake of ground moisture. A floor slanted in the direction of the emptying spout assists grain removal. The walls can be built with sun-dried mud blocks, burnt bricks or dressed stones which are held in place with mortar. Some variations include dividing walls to create multi-compartments. Mud-block silo walls are usually plastered both inside and out with mud, cement-sand, or soil-cow dung mixtures. Small silos with parallel sides may have a concrete top slab with a built-in manhole. Dome-top structures sometimes have wooden lids which can be sealed in place with soil-cow dung plaster. Most mud-block silos are protected from the sun and rain by a thatched shelter. Additional surface treatments such as whitewashing, or painting with coal-tar, can give further protection.

59. The cement silo has been the subject of much research to enable the advantages of strength and durability to be applied to the construction of small bulk-grain containers. Structures vary from woven frames of sticks or wire mesh (chicken wire) plastered with cement to those built from precast concrete (stave) panels.

60. **Ease of use** Most mud-block silos are used for storing dry shelled grains so, in some regions, they would have to be used in conjunction with a drying method. Ease of access, strength and security can be built into the design of the store.

61. **Costs** Costs rise proportionally with the incorporation of amounts of cement and so does the benefit in terms of increased size, strength and durability. The comparative costs of a brick bin, a cement bin (Ferrumbu), a cement-plastered basket and a mud-plastered basket are compared in Table 4 (data from Tyler, 1994). Depreciated costs per bag are based on the cost of cement, wire mesh, bricks and plastic as appropriate, plus 25 per cent for transport. Construction costs are spread over twenty years for the brick bin

and the Ferrumbu and ten years for the cement-plastered basket. The mudded basket does not incur costs for materials. Insecticide is a recurring annual cost for all types of store.

Table 4. Comparative costs of improved on-farm storage (Kwacha* per bag stored)

Type of store	Store capacity (90 kg bags)					
	10	20	30	40	60	80
Brick bin	355	292	270	253	235	220
Ferrumbu	437	356	329	321	301	28
Cement plastered basket	350	325	266			
Mudded basket	150	150	150			

* 670 Zambian Kwacha = 1US\$

62. **Grain quality assurance** The effectiveness of different mud block silos is difficult to compare or quantify. The quality of the stored grain may be affected by the local climate, the local pest infestation pressure, and the standard of design and construction of the silo. Most mud-block silos offer significantly better durability and grain protection than traditional systems, but all mud-based structures are susceptible to termite attack. Infestations in mud silos may be readily controlled using fumigants (providing the structure is air-tight) and insecticide dusts.

63. **Security** Improved mud brick structures are strong and their contents are not displayed to the potential thief. If theft is a problem, the top manhole cover and the emptying spout may be secured with a lock.

64. **Durability and maintenance** The life of a solid-wall silo will depend on its construction and on the local climatic conditions. With routine maintenance and careful use, a sun-dried mud-block silo may last for 20 years and a burnt-brick silo for up to 30 years. Subsidence and rodent damage are common causes of structural failure. The area around the silo should be kept clean, and the silo should be thoroughly swept out at the end of the storage period. The smoke and heat from a small grass fire lit inside the silo will kill insects and their eggs. Cracks that occur in the plastered walls should be repaired quickly.

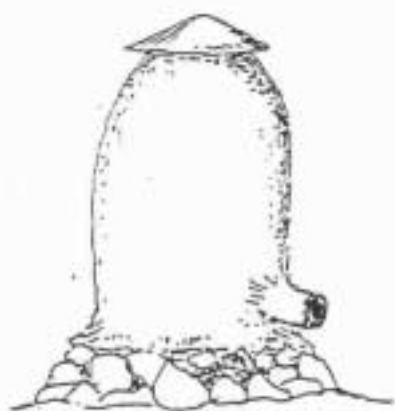
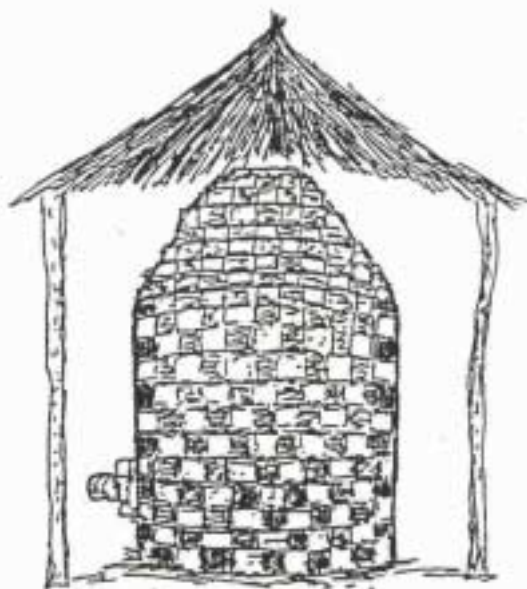
The thatched shelter should be well maintained to prevent heavy rains from washing the mud plaster from the silo walls.

65. **Social factors** Design is often highly characteristic of communities or localities and the stores may be decorated. The improved durability and security offered by the mud-block silo is likely to appeal to the more progressive small farmer who is hoping to benefit from a liberalised grain market.

66. **Flexibility** Different varieties and quantities of food and seed grains can be stored in the compartments of mud silos.

67. **Overall adoption and potential** As traditional African granaries have formed the basis of the design for many of the improved mud-block silos, their construction and external appearance is often similar. Various forms of improved mud-block silo have been developed in many African countries and it appears that they are best suited to the small farmer's need for cheap and reliable permanent storage.

Figure 4. Examples of mud block/brick silos



Underground storage

68. **Construction** Farm-level pit stores have capacities ranging from 0.5 t to more than 20 t (Gilman and Boxall, 1974). Pits are sometimes constructed in a shape that resembles a laboratory conical flask; others are straight-sided, square or circular. Pits should always be dug above the water table. Preference is often given to sites where sandstone and limestone occur together near the surface as these rock formations offer more stability than ordinary subsoil. Clay soils tend to develop cracks as they dry out and these provide channels which allow rainwater to enter the pit.

69. In some areas, it is common to light a fire in a freshly-dug pit to dry out the walls and kill micro-organisms. An absorbent pit lining made from grass matting and straw, or grain husks and chaff, will help to reduce damage from moisture seeping through the pit walls. These stores are usually lined and filled simultaneously. In order to enhance the efficacy of pit storage, modifications are required to make the pits more waterproof and airtight. Reduced moisture ingress and hermetic sealing can both be achieved by lining the pit with plastic sheets. Pits are sometimes filled with grain stored in plastic sacks. A single-layer concrete lining will restrict water ingress and termite access, and prevent the intermixing of soil and grain. More sophisticated concrete or ferrocement pits are constructed in layers and lined with a coating of bitumen or similar waterproof material. An airtight locking manhole is often built into the roof of concrete-lined pits. These improved structures are truly hermetic and can be used to store grain for several years with negligible losses.

70. **Ease of use** Although filling of pit stores is easy, emptying and inspection are not. Frequent opening for regular removal of grain for consumption will destroy the hermetic effect.

71. **Costs** Different linings have been used to improve the effectiveness of traditional, unlined pit stores; of these, matting and straw, plastic sheeting, and concrete or ferrocement are the most common. Boxall (1974) reported that a matting and straw lining was the cheapest possible method of improving a pit store; it is therefore to be recommended, at least to the poorest groups of farmers. Gough (personal communication) has found that there are advantages in using sorghum chaff as a lining. Plastic sheeting is now being produced in a number of African countries and is becoming cheaper and more widely available. Materials for the manufacture of ferrocement are also widely available and, in some countries, lining pit stores with ferrocement would be cheaper than buying metal storage tanks, for example.

72. **Grain quality assurance** A hermetically-sealed ferrocement underground pit can be used to store grains successfully for several seasons (Birewar, 1986). Grain from pit stores often has a characteristic taint and associated flavour deterioration, which is thought to result from localised mould growth. Reduced oxygen levels arising from initial mould growth after filling can asphyxiate insects and serve to inhibit further mould growth. Sealed pits will effectively prevent the entry of insects. Boxall (1974) reported reductions in insect population density of more than 70% in both mat and straw, and plastic-lined pits, over a 13-week storage period. Plastic sheets are easily damaged during loading and emptying of stores. The sealed tops may also be damaged by animals attempting to dig down to the grain. Water can funnel through a punctured sheet and cause areas of mould growth. Better results are obtained if grain is stored in the pits in polythene sacks. Wood ash is sometimes used to cover the grain after filling. This practice would inhibit insect penetration. The use of synthetic insecticides in underground pits has not been reported; pest control is usually accomplished by the hermetic principle. In some pit stores, termites can cause substantial damage to the grains.

73. **Security** Pit storage is popular in some parts of Africa because the entire store can be completely concealed underground and the grain is unlikely to be stolen. In other traditional pit store designs, the top cover forms a mound above ground level. The entrances to modern ferrocement or concrete-lined pit stores are sometimes above ground, but this type of structure is strong and the top cover can be fitted with a lock. There is no risk of damage by fire.

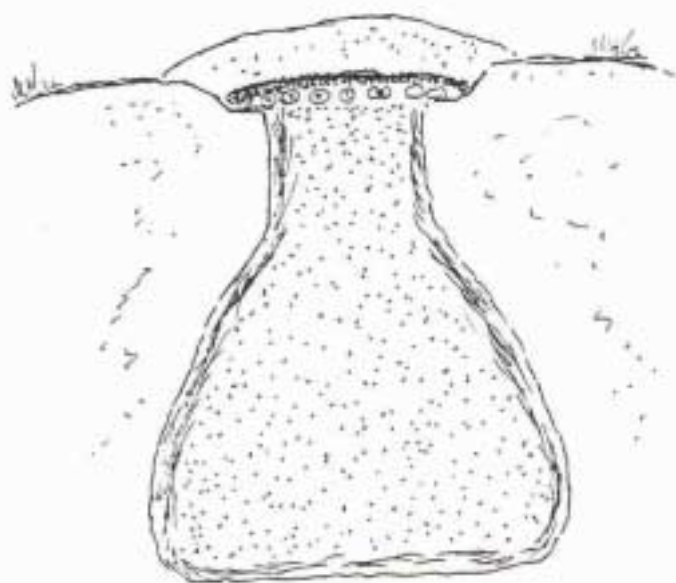
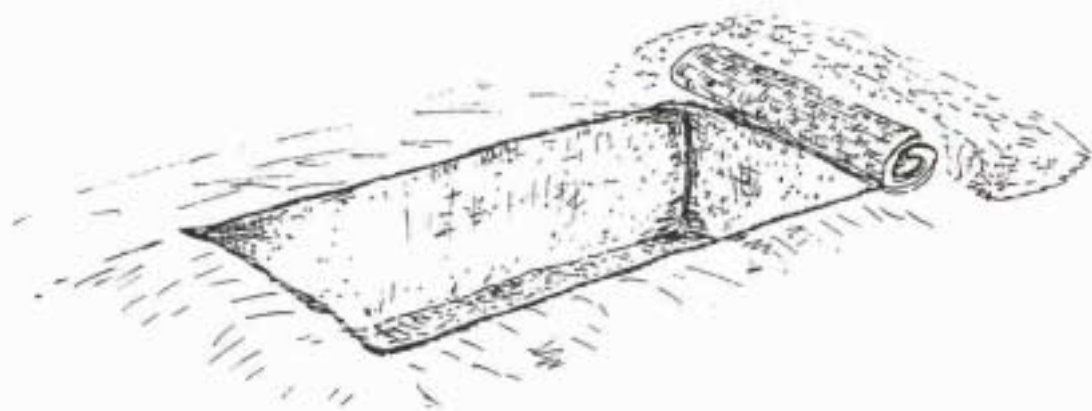
74. **Durability and maintenance** The life of an underground storage structure very much depends on its location. Pit stores in the Maiduguri area of Nigeria were only considered to be temporary structures but, by contrast, Hall (1956) reported that some pits on the north coast of Cyprus are thought to date from the Byzantine Empire. Mat and straw linings may need replacement every year. Concrete linings should be inspected, and any cracks should be repaired, well before the start of each storage period.

75. **Social factors** The best pit stores offer a reliable, hermetic, long-term storage environment. The need to secure stored grain, and the increasing availability of modern materials for improving the structure of pit stores, will probably ensure their continued use in selected parts of Africa. There is no evidence for the adoption of pit storage in areas other than those in which it has long been the custom. However, from an environmental standpoint, where timber for store building is in short supply, the pit may offer an economical alternative.

76. **Flexibility** Shelled maize and sorghum are the main commodities stored in pits. In addition, the comprehensive review by Gilman and Boxall (1974) reported underground storage of cob maize, millets, wheat, barley, beans and paddy.

77. **Overall adoption and potential** The extent to which improved linings for pit stores have been adopted has not been reported. As improved pit stores are adaptable and can be used to meet the new requirements for on-farm grain storage, they are likely to remain popular in areas where they have been used traditionally.

Figure 5. Examples of underground pit stores



Grain bag storage

78. **Construction** Grain bag storage involves both the grain bags themselves and the place in which they are stored. The bags are usually made from jute or woven polypropylene (wpp), but hemp, sisal, grass, rice straw, cotton and polythene sacks are also available. Small numbers of sacks may be kept in the farmer's house or in a separate store. The design of these stores ranges from simple pole and mud thatched shelters (Giga and Katere, 1986) to more modern and expensive buildings incorporating non-traditional materials such as cement (Compton *et al.*, 1993). Small storage platforms for use inside store rooms or houses are usually made from wooden poles. The dunnage and small platforms are important to allow air to flow under the sacks of grain and prevent uptake of ground moisture. If no wood is available, the ground beneath the sacks should be covered with plastic sheets. In order to economise on bags, two or three can be opened up and sewn together to form a small bulk container. The stack should be secure and situated well away from the kitchen, fire place and inflammable goods.

79. Larger numbers of bags can be stacked outdoors, on a plinth or hardstanding, on raised ground where rainwater cannot accumulate. If concrete hardstandings cannot be constructed, earth-filled bags or wooden poles can be plastered with mud to form a similar structure (FAO/Zambia Ministry of Agriculture, Food and Fisheries, 1993). Plinths of this type should be covered with plastic sheets or even unserviceable tarpaulins to prevent erosion. The bag stacks are built on dunnage and covered with waterproof tarpaulins.

80. **Ease of use** Grain bags provide the most convenient way of handling and storing grain (Tyler, 1978) and their use is growing in popularity in rural areas (Giga and Katere, 1986). If ample storage sacks and insecticide dusts are available, small farmers should have little difficulty in adopting the system. The grain can easily be removed for consumption or routine inspection. It can also easily be moved in and out of the store room during periods of sun-drying. Successful bag storage depends more on good store management practice than on the construction and operation of a specialised storage structure.

81. **Costs** The initial capital outlay required to create a storage place for a few bags is minimal, but there is a recurring cost for sacks and insecticide treatment. Although the cost of constructing a separate secure store room could be considerable, it could also have other uses.

82. **Grain quality assurance** Grain can be kept in good condition for many months using a well-managed bag storage system. Sacks do not provide much protection against

insects, rodents and moisture. Penetration by termites can be a problem and a storage platform should always be used. If infestation pressure by storage insects is high, the grain should be treated with insecticide dust. Although burnt cow dung or wood ash may be used instead of insecticide, grain treated this way may meet market resistance. The sacks may be emptied periodically and heat-treated to remove pest infestation. Damage to sacks and contamination of grain by rodents can be a problem. The risk of grain loss is high unless appropriate preventative measures are taken.

83. **Security** Bags stored in a farmer's house or shed are fairly secure, particularly if the further precautions of barred windows and a locked door are taken. Sacks can easily be marked or labelled; this is especially useful for identification during communal transportation and storage.

84. **Durability and maintenance** Durability depends on the quality of bags and the way that they are handled. With careful use they should last for several seasons, or longer if they are carefully repaired. Jute bags are usually two-to-three times more expensive than wpp types which wear out quicker. The farmer's store room should be well maintained and weather-proof. All sacks should be brushed clean and, if possible, immersed in boiling water to kill any residual insects at the start of each storage season. The store room should be kept clean and tidy to reduce harbourage for rodents. Regular inspection and maintenance of the building structure is also recommended.

85. **Social factors** Storing grain in sacks (originally made from animal skins) is a very old method used in many parts of Africa. Familiarity with modern storage sacks has increased as they have been used commercially for seed and fertilizer, for example, and as food aid containers.

86. **Flexibility** A bag storage system is only suitable for dried shelled maize or threshed sorghum and millet. The capacity of a bag stack is limited only by the size of the store room; the farmer can store any number of sacks to fulfil his requirements. Different varieties of grains and beans can be stored separately in sacks and this allows maximum flexibility. If necessary, various compartments can be built into a store room. Store rooms can also be converted into living quarters when required.

87. **Overall adoption and potential** Bag storage systems are used in commerce and are familiar to most small farmers. The low initial capital outlay and inherent flexibility of these systems will probably appeal to small farmers needing more storage because of the liberalised market.

88. Grain bags combine the following advantages:

- ease of use
- flexibility
- wide use in trade
- wide availability, both new and second-hand
- social acceptance
- technically proven
- lowest cost (in the short-term only)

89. The disadvantages are:

- lack of durability, particularly with the newer wpp bags
- easy to steal from
- need for an insecticide input
- need for dunnage
- suitability limited to storing dried shelled grains

90. The need to thresh or shell grain prior to storage can be a serious constraint at harvest time if labour is in short supply or needed elsewhere. Therefore, the introduction of bag storage may necessitate the acquisition of shellers for maize or threshers for sorghum (Visser, 1993).

Figure 6. Examples of storage in grain bags



CHAPTER 4. ADOPTION OF IMPROVED METHODS

91. Research on the improvement of small-scale storage has followed two lines of approach:

- (a) modifying existing structures; and
- (b) developing completely new methods.

92. An alternative approach might be to evaluate those methods already being used successfully by some farmers and transfer them to other farmers through extension programmes. This would probably lead to the formulation of the most effective and acceptable advice.

93. The literature shows that a disproportionate amount of effort, usually donor-funded, has gone into designing and testing modified and new storage methods on research stations. Little enthusiasm has been shown for pilot schemes aimed at introducing new methods to farmers and evaluating their appropriateness, and much less effort has gone into sustained support to extension projects designed to introduce already proven technologies. Extension and training activities have concentrated mainly on the pre-harvest crop production cycle and only minimal attention has been given to post-harvest operations at the smallholder level (Golob and Tyler, 1994). Collaboration between research and extension services within ministries of agriculture has been poor, and budgetary support for post-harvest extension has been lacking.

94. Traditional storage methods are generally well suited to agro-climatic regions and social needs. They are therefore the obvious choice for farmers, where practicable. The advantages of using traditional methods, with or without small modifications, probably outweigh the benefits of new storage systems, particularly in view of the cost of new investment.

95. With the liberalisation of the market, farmers have the option of storing grain on-farm to take advantage of rising off-season prices. However, it is not the tradition for many small farmers to store more than their family requires and, wherever hybrid maize varieties are grown, technical difficulties and input costs associated with maintaining quality during storage have to be overcome.

96. Many small farmers rely on the sale of maize as their principal means of obtaining cash. Hybrid maize varieties are higher yielding than traditional varieties and are therefore generally grown as a cash crop. However, as these varieties may also have poor storage characteristics, losses can be high. For most small farmers, the concept of improving storage systems to reduce losses is not yet engrained for a variety of reasons including the following:

- as the economic advantages of adopting improved storage methods for high-yielding varieties are not immediately apparent, the financial risk may be considered too high;
- the cost of installing improved storage systems may also be too high;
- the necessary technical expertise for installing the systems may not be available; and
- the opportunities and risks of a liberalised market may not be properly understood.

97. In Zambia, it is evident that few small farmers understand the concept of the free market and they are therefore ill-prepared to interact within it (Tyler, 1994). Consequently, they are likely to sell their grain to visiting traders at low and unfavourable prices (distress sales) in order to remove the uncertainties associated with its retention.

98. In more remote districts, small farmers are unlikely to be visited by traders at harvest time. As most of them will be unable to transport their grain to market, they will need more on-farm storage capacity. The pressure for change is highest amongst these farmers and some may be well advised to switch to an alternative cash crop.

99. In Zambia interest rates on loans are high. The newly-liberalised market has therefore led to a rapid turnover of stocks, preferably to supply identified markets, in order to avoid all interest, storage and double handling costs (Tyler, 1994). Traders do not appear to have been attracted by the prospect of speculative storage. These observations provide further evidence that the responsibility for preservation of stocks has been transferred to the farmer.

100. The development of an effective liberalised market and the adoption of improved storage systems will both undoubtedly take time. Farmers will need to acquire a better understanding and trust in the emerging marketing system.

101. Recommendations for improved storage technology depend on the locality and on a wide range of other factors. It is therefore most important for extension workers to ensure that any proposed improvements are economical, technically suitable and socially acceptable in their region.

102. Recommendations may be required for increasing storage capacity. If the extra quantity to be accommodated is small (up to 10 bags) and if the traditional storage system cannot be expanded any further, the cheapest and most flexible option may be to use grain bags for additional capacity. If the quantity of grain to be stored is regularly exceeding storage capacity, investment in a bigger grain bag store room or a brick/cement silo would probably be a better option. The success of any storage method depends on the care and attention devoted by the user to the details of correct construction and use.

Recommendations and advice should therefore be promoted and supported by an informed extension service.

Annex 1. THE POTENTIAL FOR NEW DEVELOPMENTS

In the following section, some current research into storage technology, particularly for the conservation of grain quality in the small-scale farming sector, is summarised.

Many small farmers rely on synthetic insecticides to prevent insect damage to grain. This presents several problems including health risks due to improper usage, development of pest resistance, difficulties in obtaining supplies, and cost. Therefore, research is currently underway to develop physical and biological methods of control for use in small farm grain stores. The neem tree provides a cheap alternative to the use of synthetic insecticides. The leaves are widely used in Asia and sub-Saharan Africa to reduce insect attack on grain and prevent damage by termites during storage. This use of neem for insect control is gaining popularity in Africa (Compton *et al.*, 1993).

The larger grain borer, *Prostephanus truncatus*, poses an ever increasing threat to on-farm stored grain. This beetle, which was accidentally introduced into Tanzania almost 20 years ago, has spread and become established in many adjacent countries and also in West Africa. With the liberalisation of grain markets, particular care must be taken to protect against *P. truncatus* as loss of grain caused by this insect in store can be more serious than that caused by the normal pest species. Biological control using the predatory beetle, *Teretriusoma nigrescens*, is showing promise in reducing damage levels.

Solar energy is available in abundance in tropical regions and its use for drying grains and controlling infestations is well known. Although the efficacy of the method can be enhanced, earlier technologies often required constant attention and involved costs and materials which were inappropriate for most rural producers. Kitch *et al.* (1992) have recently reported successful disinfestation using simple heating pouches made from solar radiation-absorbing black plastic with a sheet of clear plastic spread over the pouch to provide a "greenhouse effect". If a large enough flat surface is available to enable the grain to be spread in a thin layer within the pouch, these "flexible solacutors" can be used for disinfestation. The technology could provide an economical, safe and effective alternative to insecticides where limited volumes of grain are stored, and could offset the common susceptibility of hybrid grain varieties to insects. The pouches are re-usable if handled carefully.

Some types of plastic storage sack can provide a near hermetic enclosure. The "Joseph Sack" (ACIAR, 1988) uses the principle of hermetic storage for insect pest control. It is a resealable plastic laminate bag, with a capacity of about 40 kg, which is used at subsistence

farmer level. The sack was designed and tested by CSIRO for the Australian International Development Assistance Bureau (AIDAB). It has successfully eliminated insect pests and protected the grain from reinfestation for a 12-month storage period.

Traditionally, farmers have used a variety of local materials, including minerals, oils and plant products, to protect their stores against insect and other pest infestations (Golob and Webley, 1980). A number of institutions have initiated projects on the production of these insecticidal materials at farm or village level (Stoll, 1988). Compton *et al.* (1993) discuss the practical issues involved and outline a range of potential problems.

An alternative strategy would be to improve the storage characteristics of maize so that small-scale producers could conserve their surplus until it could be sold profitably. High-yielding varieties (HYVs) with an inherent pest resistance similar to that of traditional varieties would need to be selected. Plant breeders are beginning to recognise this need, and it is likely that HYVs which are less susceptible to insects will become more widely available over the next few years.

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