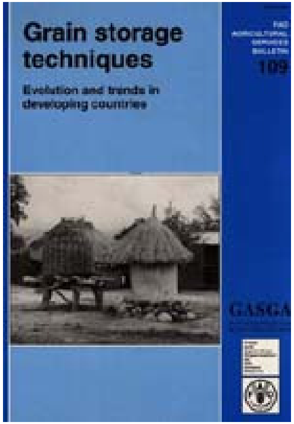

Grain storage techniques

Evolution and trends in developing countries

Table of contents

Edited by **D.L. Proctor**, FAO Consultant

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Contents

Chapter 2 - The biodeterioration of grain and the risk of mycotoxins

Chapter 3 - Quality and grading of grain

Chapter 4 - Grain harvesting, threshing and cleaning

Chapter 5 - Drying methods

Chapter 6 - Storage at farm/village level and in warehouses

Chapter 7 - Bulk storage

Chapter 8 - Insect control

Chapter 9 - Rodent control

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Foreword

Contents - **Next**

With an annual worldwide production estimated at more than two billion tons in 1992, grain crops provide the world's primary staple food. The FAO's Agricultural Engineering Service recognizes that dissemination of knowledge on appropriate grain storage facilities and techniques to its developing member nations remains very important. Therefore AGSE decided to update and revise the FAO Manual No. 60 "Handling and Storage of Food Grains" prepared by Mr. D.W. Hall in 1970, and which was subsequently reprinted three times.

The importance of grain storage as part of the marketing, distribution and food security system is well recognized. As early as 1971, the Group for Assistance on Systems relating to Grain After-harvest (GASGA), in which FAO participates, brought together experts and coordinated activities on research and development. In 1978, following the resolution of the UN General Assembly which called for the reduction of post-harvest losses, FAO launched the Special Action Programme for Prevention of Food Losses (PFL). Since then more than 250 projects have been implemented world wide under this programme.

During recent years, as a result of privatization and liberalization of trade, the organization and management of grain storage has changed in many developing countries. This restructuring of the grain storage sector has created a demand for information and knowledge from the emerging private entrepreneurs operating in the storage sector. In the previous storage and distribution systems, functions such as collection, storage, regulation of supplies, food security and price control, were often entrusted to parastatal marketing boards. Skills have been developed, facilities have been installed and methods taught to their staff, often at high cost. These skills have now to be acquired by the new "actors" of the privatized storage and distribution system. The purpose of the Bulletin is to contribute to the transfer of knowledge on grain storage to persons involved in the storage of grain. This joint production FAO-GASGA Bulletin is aimed at private and public sector storage operators, extension workers, students and researchers. However, the varied topics covered in the chapters are intended for persons each having different interests in the subject.

The preparation of this document has resulted from the contribution of several GASGA Members and Consultants working under contract for FAO. More specifically our thanks go to **J.P. Coulter**, Head of Marketing Research and Systems Action, Social Sciences Group,

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Chief, Agricultural Engineering Service
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Contents - Next

The role of storage in the economy

Contents - Previous - Next

In most countries grains are among the most important staple foods. However they are produced on a seasonal basis, and in many places there is only one harvest a year, which itself may be subject to failure. This means that in order to feed the world's population, most of the global production of maize, wheat, rice, sorghum and millet must be held in storage for periods varying from one month up to more than a year. Grain storage therefore occupies a vital place in the economies of developed and developing countries alike.

The market for food grains is characterized by fairly stable demand throughout the year, and widely fluctuating supply. Generally speaking people's consumption of basic foods such as grains does not vary greatly from one season to another or from year to year. The demand for grain is 'inelastic', which means that large changes in the market price lead to relatively small changes in the amount of grains which people purchase.

Market supply, on the other hand, depends on the harvest of grains which is concentrated within a few months of the year in any one area, and can fluctuate widely from one year to the next depending on climatic conditions. New varieties that have shorter growing periods, and variation in climatic conditions and farming systems in different regions of a country, can help to even out the fluctuations in market supply. But even in a country such as Indonesia, which has diverse climatic and farming conditions and where 90 per cent of rice land is under short duration high yielding varieties, about 60 per cent of production is harvested within a three month period (Ellis et al. 1992).

The main function of storage in the economy is to even out fluctuations in market supply, both from one season to the next and from one year to the next, by taking produce off the market in surplus seasons, and releasing it back onto the market in lean seasons. This in turn smooths out out fluctuations in market prices. The desire to stabilise prices of basic foods is one of the major reasons why governments try to influence the amount of storage occurring, and often undertake storage themselves.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Costs and incentives to store

Contents - Previous - Next

Both producers and consumers benefit from stable prices, which reduce the uncertainties associated with planning farm investment and household expenditure. However storage involves costs, and the only way in which these costs can be recuperated is through a price spread. If storage is to be profitable, people who store grain must receive a price on sale which at least covers the costs of storing the grain since harvest. These include:

- The cost of the store itself (often a rental cost);
- Labour and supervision;
- Pest control;
- Storage and spillage losses; and
- Cost of capital invested in the grain.

In practice, the costs of storage depend on the commodity stored, on the type of storage system, and on unpredictable and variable factors such as pest incidence and climatic conditions. Storage costs also depend on the circumstances of the person, the business or the institution who is storing. The most variable component of storage costs is the cost of capital. For a small farmer or trader, capital may be scarce and costly, and their only access to loans may be from money lenders charging rates of 10% or more per month. On the other hand a Government Marketing Board may have preferential access to loans at low interest, at rates of as low as 10% per annum. There is, therefore, no single cost of storage.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Who stores and why?

Contents - Previous - Next

Farmers, traders and governments all have reasons for storage other than the profitability of the storage enterprise itself. Storage is a component within a farming system, a trading enterprise, or a government policy, and may be undertaken because of its contribution to other activities or objectives within these broader contexts.

Farm Storage

For **small farmers** the main purpose in storing grains is to ensure household food supplies.

Farm storage also provides a form of saving, to cover future cash need through sale, or for barter exchange or gift-giving. Grain is also stored for seed and as inputs into household enterprises such as beer brewing, or the preparation of cooked food. When there are significant inter-seasonal price variations, small farmers often store for speculative gain, that is to say they 'play the market'. This is most common in more prosperous areas, such as the Southern Highlands of Tanzania and southern Mali, which produce a mixture of cash and food crops, and where farmers' financial circumstance make it easier for them to sell when the price is best. Speculative considerations are even more important in the storage decisions of large-scale commercial farmers.

Despite the desire to store grain in order to cover food requirements and future cash needs, farmers often sell a large proportion of their produce at harvest, when prices are low. This is frequently the case with deficit producers, who must satisfy cash needs immediately after the harvest, only to buy in food later in the season.

There is an ongoing debate about whether farmers are forced to sell because of debt and economic dependence on others, or whether they sell because they regard storage as too costly (in terms of time), or too risky (given the risk of losses and unpredictability of future prices), or unprofitable in relation to other investments such as cattle. There is no single answer to the debate, since there is much variation in the circumstances under which individual farmers operate, both within and between nations. The 'forced sales' situation has been documented by some authors in South Asia (e.g. Crow, 1987), while the 'wise farmer' been found to apply in South-East Asia by Mears (1980) and Ellis et al. (1992). In the Sahelian countries of Africa, conflicting findings have been reported. Carefully documented work by Dione (1989) has shown head taxes in Mali to have resulted in forced sales, but Berg and Kent (1991) report several authors who have reached opposite conclusions.

Another reason for not storing is the unpredictability of future prices, which often makes storage a risky business. This is particularly the case in countries such as Mali where prices vary widely from year to year, and do not follow a steady monthly trend. From Figure 1.1 (see Figure 1.1. Retail Prices of Millet in Mali, 1986 - 1991 Annual Monthly Averages compared with Monthly Averages combined over 5 years), it can be seen that Malian prices normally rise between harvest time and the lean season, but farmers who engaged in speculative storage in 1989 suffered significant losses. Storage was particularly risky as Mali was passing from a period of scarcity, when prices levels were related to the cost of imports, to a period of surplus, when they were related to the price at which Mali could export. Movement between surplus and deficit in the Sahelian countries probably explains the wide variation in Mali's prices from year to year.

Farmers may sell their grain at any time from maturity (sale of the standing crop) onwards. Sale at or before harvest has the advantage that the farmer is saved the cost and time involved in preparing the crop for storage. Transport, threshing, winnowing and drying are all passed on to other levels in the marketing chain, leaving the farmer free to attend to the next crop, or to other farm or off-farm activities. It has been estimated that post-harvest activities account for one quarter of the total cost of production even for small farmers in poor countries (Greeley, 1991 p.5). Early sale also reduces the risks of losses in postharvest activities, and this is particularly advantageous in cases where the harvest occurs in the wet season.

Trader Storage

The role of **traders** in cereal storage varies enormously between different parts of the world and between different crops. In most African countries traders carry out very little interseasonal storage of coarse grains, but buy and sell quickly, earning a moderate profit on each transaction. Most storage is carried out by farmers, and to a lesser degree by Government marketing boards and consumers who buy in anticipation of future household needs. Given a general situation of capital shortage, long-term storage of staple grains is insufficiently profitable to attract the interest of traders, who can earn more money by investing in fast moving consumer goods.

However the opposite is often true with rice in Africa. This crop is generally produced as a cash crop for the urban markets, but does not have a major demand for use as a staple in rural areas. Often much of the rice is imported and this has encouraged the emergence of large traders able to obtain finance major shipments and to negotiate advantageously with the authorities. Even when sourcing supplies from local producers, traders and millers must hold stocks to cover the needs of their urban clientele, and cannot rely on steady supplies arriving from rural areas.

In Asian countries, traders have a much larger role in interseasonal storage. The two major cereals are rice and wheat and both of these must be milled before reaching the consumer. This is unlike the situation in most of Africa where coarse grains such as maize, millet and sorghum are the main staples. Typically African consumers buy these grains whole, and either grind them at home or take them to be ground at small custom-mills.

Large millers who become involved in the marketing chain tend to have good banking connections and can obtain capital at reasonable cost. Studies by the Natural Resources Institute (NRI) in Indonesia and Pakistan indicate, that wherever Government policy is conducive, millers enter the storage business on a large scale. In Indonesia, traders and millers store about 50% of that part of the rice crop which is carried over from the first harvest (Ellis et al., 1992). Indeed it is common for them to store beyond the point when storage is profitable in its own right. This is because storage is only part of a business activity which involves milling and distribution of milled rice; millers must store in order to keep the mills running out of season, and to maintain supplies to regular customers. Losses on storage are more than compensated for by the gains on other operations.

In Pakistan, the millers' role in wheat storage has been limited by Government subsidies to public sector institutions, which procure about 60% of the marketed portion of the wheat crop. Rather than procuring wheat themselves, millers found it cheaper to procure from these Government institutions which carried out most of the long-term storage. However, when the Government raised their selling price in 1989 and thereby improved the incentives for millers to store, these responded promptly by buying up more stock.

In the future, storage behaviour in African countries will probably evolve towards the Asian pattern. The liberalisation of cereal markets will encourage the development of the private trade, the reform of banking systems should gradually increase traders' access to capital markets, and increased urbanisation and sophistication of tastes will favour the emergence of large milling enterprises.

Government Storage

As already mentioned, **Government** may become involved in storage for the purpose of stabilising prices and revenues to farmers. Related to this is Governments' overriding concern for national food security, which is fundamental to political stability. Governments therefore use storage to balance national supply and demand over time, and to minimise the risk of politically embarrassing shortages. They are thus attempting to supplement, and in some cases to replace, market mechanisms, on the assumption that the market can only achieve the balance with an unacceptable degree of supply and price fluctuation.

Governments do not involve themselves in the grain market only for reasons of national interest: they are often concerned with rewarding or placating particular lobbies or sectional interests. In developed countries farmers' interests often receive a high priority in Government decisions, out of proportion to their numbers. High 'support prices' encourage production in excess of demand, and surpluses have to be stockpiled at the taxpayers' expense. In many developing countries, the interests of the civil service and ruling party often take priority. Large national food reserves tend to be supported by the civil servants whose job it is to manage them, and by politicians who sometimes use their procurement and distribution as a means of dispensing patronage.

Governments may keep different types of storage reserve, depending on how much they wish to intervene in the grain market. Some of the options are:

a. **a food security reserve** to be sold or distributed for free at times of extraordinary shortage or famine. Such reserves can be found in Sahelian countries like Mali and Chad. They are of limited size (e.g. 10% of the normal volume of grain marketed crop), and are usually limited to the amount thought necessary to tide the country over until the arrival of food aid or imports. They are not designed for the purpose of stabilising prices to producers and consumers. This is reflected in Figure 1.1 which shows that, since a reserve was created in Mali, monthly average retail prices have fluctuated by up to 260% of the lowest figure.

b. **a price stabilisation stock**, as in the case of Indonesia. Here the Government has no monopoly role in grain procurement and distribution but buys and sells grains in competition with private operators. Average interseasonal retail price increases in Java are only 11% of the lowest monthly figure (Ellis et al, 1992). How much this extraordinary low figure is due to Government stockholding and how much to the stockholding activities of millers is a matter of debate.
c. **national storage reserves** designed to supply most or all consumer needs in urban areas, and in rural deficit areas. In this case the Government has either a statutory trading monopoly, or a monopoly of all interregional shipments, and is the only party allowed to store significant quantities of grain. Between the 1960s and the early 1980s, such systems were the norm in many African countries, before the onset of liberalisation. Even now, the grain marketing systems in some countries, including Zimbabwe and Kenya, are still partially structured in this way.

Such Government operations usually benefit from public subsidy (intended or de facto) and capital investments are largely financed by overseas aid. Indeed subsidies are necessary if the public sector is to carry out functions which would not be profitable to the private sector. However, in some countries subsidies have allowed the State to 'crowd out' private sector competition. In the case of Pakistan for example, this phenomenon has resulted in the State handling about 60% of the marketable surplus. In many countries, such competitive advantages are outweighed by the high cost of fulfilling Government requirements (e.g. to buy and sell at fixed politically-determined prices, and to supply civil servants' consumption needs), overstaffing and slow decision-making processes. In such countries e.g. Tanzania in the 1980s, the official marketing agency may become insolvent and be gradually displaced by private sector competition.

Even relatively efficient Government trading operations face the problem that the more grain they buy, and the more they succeed in stabilising prices throughout the year, the less the incentive for private sector storage'. The responsibility for storage then falls very heavily on Government, and the private traders and millers concentrate on buying and selling quickly. Consequently, the Government finds that it has very high storage costs which it cannot recover through sale prices which have been politically determined. In the end the Treasury or Government banks must bale out the Government enterprise, thereby increasing the budgetary deficit.

Since 1981, there has been a major move to liberalise grain marketing systems in developing countries, and this has been stimulated by both donor pressure and the massive budgetary deficits stemming from the operation of Government marketing boards. Many African Governments are opting for the first of the above options i.e. a limited food security reserve.

Some countries do not appear to need any reserve stocks but can rely on international trade to assure food security and to stabilise prices. This is particularly the case with some deficit countries in Africa, such as Swaziland and Namibia, who have good communications with the world market and are close to major grain suppliers.

Lastly there are some countries where it would seem most appropriate for Government to maintain some sort of price stabilisation role. Such is the case in landlocked countries like Zimbabwe and Malawi, whose production fluctuates between surplus and deficit. If the Governments of these countries totally withdraw from price stabilisation, prices are likely to be subject to very wide interannual fluctuations, with adverse effects on production incentives and consumer welfare (Pinkney, 1993). Nevertheless these countries still have major scope for liberalisation. By improving port facilities and communications with the outside world, and by developing intra-regional trade, they can greatly reduce the required level of stockholding.

The move towards liberalisation in developing countries contrasts with the situation of the developed countries, where Governments are still heavily involved in the grain trade. Developing country officials often ask why they should be asked to liberalise while rich countries fail to do so. The answer is simply that these countries have the wealth to support their farmers at the expense of their non-farming majorities.

Farmers, traders and governments all have reasons to store grain, but they also have reasons for limiting the amount of storage. The unit costs of storage tend to be constant (or to decrease slowly) as larger quantities are stored, but the benefits fall off as more is stored. In deciding how much to store, the benefits must be balanced with the costs involved (see Figure 1.2: Balancing the Supply and Demand for Storage.).

Contents - **Previous** - **Next**

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Improvements in large-scale storage and handling

Contents - **Previous** - **Next**

How improvements have taken place

Until now, most large-scale storage of cereals in developing countries has been carried out by Government marketing boards, which have developed their activities with the technical and financial assistance of donors and international financial institutions. This has resulted in the building of large numbers of grain stores and mills, with a gradual increase in scale and the degree of technical sophistication. In some countries this has helped maintain food security and feed urban populations growing at 5% or more per annum. However there has also been much wastage, with stores often being inadequately located, inappropriately designed, and poorly managed and maintained. Stores have been built to support Government monopolies, on the assumption that no storage would be carried out by the private sector, but in the event of liberalisation, much of the capacity has been found unneeded and poorly located. Thus the National Milling Corporation in Tanzania has over 400,000 tonnes of storage capacity for which it must find new uses, to which must be added the large storage capacity of the State-sponsored cooperative unions.

Most grain stores have been designed for bag handling, reflecting the low cost of manual labour and the lack of spare parts and maintenance support needed for mechanical handling equipment. However bulk handling has been introduced throughout the developing world, with results which leave much to be desired. Too often, Marketing Boards have been unable to make good use of these facilities and they have become rusting monuments to inappropriate development assistance.

In international development assistance programmes, there is often much support for 'modern' capital-intensive systems. This was observed in a study commissioned by the Pakistan Agricultural Research Council (Courter, 1991). Between 1983 and 1987 no less than five feasibility studies advanced the case for investments in bulk handling. All the studies had used questionable assumptions, and four out of the five studies had assumed reductions in storage losses of 5% or more simply by switching from bag to bulk handling.

Given that loss surveys have revealed storage losses of between 1.5% and 3.9% such reductions would have been impossible.

The case for bulk handling

There are, however, instances when bulk handling is economically justified in developing countries. This is usually at bottle-necks in the marketing chain, and where grain has to be handled in large volumes and at great speed, for example at port facilities, railway terminals or at mills. In such cases, investment in bulk handling facilities will often result in major cost savings, due to reduction in demurrage charges and down-time. The investment in one capital asset (bulk-handling equipment) produces major savings in the use of other capital assets (ships, trains, mills etc.). In most developing countries, labour costs are unlikely to be significant in the calculations, but bulk handling will reduce the risk that labour problems, strikes etc. will slow operations or bring them to a halt.

Bulk handling tends to be least viable for the long-term storage of grain, where stocks are only turned over once a year or less. In such cases the savings in labour and bags are unlikely to cover the high capital cost in silos, handling equipment etc. With well-run bulk storage complexes it may be possible to achieve a marginal reduction in storage losses but, due to poor operation and maintenance, losses are sometimes increased.

Bulk handling may also result from changes in farming methods. The introduction of combine harvesters in certain countries provides an incentive to start handling the grain in bulk. From the tank of the harvester the grain can be transferred mechanically to a bulk truck, from there to a bulk store or silo, and from there to a mill. This completely eliminates the use of the bags in the system, and overcomes problems of labour shortage and congestion which sometimes occur with a bag handling system. However in irrigated or high rainfall areas, the main benefit to the farmer may be by making it easier for him/her to plant a second crop on the same land.

Even where the economics of bulk handling are favourable, there are other reasons for caution. Most notably one should carefully assess whether the operating company or Marketing Board can obtain power, fuel, spare parts and qualified staff at all times and in sufficient quantities to operate and maintain bulk handling machinery. It should also be noted that some commodities, including milled rice and small grains, are difficult to handle in bulk. Paddy rice and wheat varieties such as Mexipak are abrasive, and require the use of special equipment such as rubber bucket elevators. Bulk handling also poses problems for commodities which must be handled in many different grades or small lots. For further guidance on how to decide between bag and bulk systems readers are referred to a useful bulletin published on this subject by NRI (Friendship and Compton, 1991).

Appraising the case for improvements

Technical improvements must be appraised within the context of a **total commodity system**. This includes the chain of activities linking farmers and consumers, suppliers of goods and services to the participants in that chain (banks, equipment suppliers etc.) and Government policy and regulatory activity. A four step approach is recommended based on an appraisal of the case for bulk handling in Pakistan (Courter, 1991):

Step 1: Fully understand the policy environment

As Governments gradually move towards more liberalised systems, public policies towards grain marketing are in a state of flux. If planning is possible at all, it is important to plan for tomorrow's system and not for today's. One needs to ask the following questions:

- What types of reserves does the Government wish to hold?
- Where?
- What is the level of stockholding considered desirable?
- What pricing regime will the Government operate?
- Will the system be subsidised and by how much?
- What will be the role of the private sector?
- Is this system sustainable?

- Can it be financed, managed and maintained?
- How is the system likely to change in the future?

Step 2: Understand the operating company (e.g. Marketing Board! which is supposed to implement the project

Here one needs to carry out an institutional appraisal, with a view to understanding the way in which the company operates, the capability of staff and their perceptions of the current situation and any proposed changes. This will involve interviewing Directors and company staff from Chief Executive down to the level of store attendant.

Step 3: Identify possible improvement scenarios

In the Pakistan study, there were various alternatives to consider, involving different logistics, storage technologies, and mechanising different stages in the marketing chain, as follows:

(a) Alternative logistical arrangements:

The public sector handling system at the time of the study was more complicated than the system illustrated in Figure 1.3 (see Figure 1.3: Alternative Logistical Arrangements), having additional handling and storage operations which might be eliminated by rationalisation. It would be unwise to convert this existing system to bulk handling as this would compound logistical inefficiencies. For this reason it was assumed that bulk handling would be introduced within a rationalised system of the type illustrated above. The economics of bag and bulk alternatives are compared along this logistically efficient system.

(b) Various alternative storage technologies:

Bag systems	Standard warehouses ('house-type godowns'); Permanent plinths (outdoor storage with bags stacked on plinths and covered by tarpaulins).
Bulk systems	Concrete silos; Steel silos; Bulk warehouses; Open bulkheads (grain held outdoors between pre-fabricated steel walls and covered with PVC sheeting).
Bag-cum-bulk	Using standard warehouses, with grain stored in bulk within bag walls.

(c) Mechanisation of different stages in the marketing chain, as follows:

Converting only the mills for reception and handling grain in bulk (preliminary

calculations showed this to be the most obvious place to start conversion);

Bulk handling from reclaim (i.e. unloading of grain for dispatch) at the storage centre to the mill;

Bulk handling from reception of grain at the storage centre to the mill;

Bulk handling from the market to the mill;

Bulk handling throughout the whole chain, from harvest to mill.

Step 4: Appraise the improvement scenarios and draw conclusions

The scenarios considered involved various permutations and combinations of logistics, storage technology, and the stages of the chain to be converted to bulk. For each scenario, the case for bulk handling was appraised alongside the bag handling alternative, using costbenefit analysis (CBA). Only those costs likely to differ between the two alternatives were included in the calculations. The methodology of CBA and its application in the Pakistan project are discussed in Annex 1.

Table 1.1 shows the results obtained for just one of the scenarios considered, i.e. deciding which type of store should be used when building new long-term storage

facilities. The cheapest technology is the permanent plinth, cost per tonne estimated at US$6. 1 per tonne, compared to warehouses $13.9, concrete silos $14.8 and bulk warehouses $9.4. The cost of the open bulkhead system ($6.8) is similar to the permanent plinths, but this technology is unproven under Pakistani conditions, and effective pest control is likely to prove difficult.

This finding was interesting because investment programmes had concentrated on funding the construction of warehouses and to a lesser extent bulk storage, but had completely ignored the possibility of building permanent plinths, which were suitable in the dry conditions of Pakistan. To store the same quantity of grain, plinths require a capital investment of less than one sixth that for standard warehouses and about one eighth that for concrete silos.

The other analyses did however confirm that there was a good case for using bulk handling in port facilities, in the intake and handling of wheat at flour mills and (subject to thoroughgoing reform of the railways) for long-haul shipment by rail.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Improvement to storage on the farm

Contents - Previous - Next

The case for improvements in storage

As indicated previously, storage involves substantial costs and risks as well as potential benefits for farmers. Storage competes with other activities valued by farm family members, and it is necessary to understand where storage fits in to the entire farming system and household economy in order to assess the need for interventions and the probability of their uptake.

Over the past two decades the need for economic and social analysis in the planning and design of storage interventions has become more widely recognized. This stems from the realization that any 'improvements' in storage will only be attractive to farmers, traders or governments if the perceived benefits substantially outweigh the costs. Technical superiority is generally insufficient (although it can be attractive for its prestige value), and farmers and traders are likely to tolerate quite high storage losses before undertaking complex or expensive changes to their storage systems. An understanding of the reasons why people store, and the systems within which storage occurs, is necessary in order to estimate how the benefits and costs of innovations are

likely to be assessed by the intended users of the technology.

Rates of adoption of new storage technologies at the farm level have often been disappointing (Phillips 1981; Compton, 1992). In some cases, projects have failed because they were promoted on the basis of assumptions which turned out to be false. Sometimes it was incorrectly assumed that storage ranked high among farmers' lists of priorities. From such experiences it can be concluded that, before storage projects are implemented, there is a general need for more research into the economic and social factors involved.

Table 1.1. Comparison of costs for new permanent storage facilities, using different storage types, for long-term storage of grain (cost US$ per tonne of wheat)

It is also now generally accepted that local, established storage systems are usually well adapted to local conditions, and losses from grain storage are already low and acceptable to farmers (Greeley 1987, Compton 1992). This is not to say that improvements cannot be made. Indeed, the following factors point to an increased need for improvements in the handling and storage of grain at various levels in the system.

(i) Increasing urban demand

Due to demographic changes urban population in most developing countries is growing at 5 % or more per annum. In addition many countries, particularly those in Asia, are experiencing massive increases in intensive animal production, creating large markets for feed grains. For example, Indian poultry production grew by about 9% per annum in the 1980s. Consequently an increasing proportion of grain production is destined for the market rather than subsistence use, increasing storage requirements on the farm and elsewhere in the marketing chain.

(ii) Changes in government policy

Structural adjustment programmes and market liberalization in a number of African and Asian countries are increasing the role of the private sector in storing produce which is surplus to subsistence requirements. It was noted previously that in most African countries, traders and millers are not heavily engaged in storage, and this means that farmers in surplus producing areas are having to greatly increase their storage activity.

(iii) Changes in the farming system

On-farm and off-farm storage systems have been affected by technical change in other aspects of the farming system. The *green revolution* has involved the adoption of new

varieties which are often more susceptible to storage losses (Golob and Muwalo, 1984). It has proved difficult for plant breeders to combine higher yields with storage durability, since the very qualities which lead to higher yields, and therefore (potentially) increased income also make the grain more attractive to pests. Thus, high yielding varieties of maize tend to give large, soft grains with less husk cover than traditional varieties.

Short duration varieties have allowed for increased cropping intensity. This can give rise to further storage problems when one of the harvests occurs in the wet season, making it difficult for farmers to dry the grain sufficiently for storage. Farmers in some areas have responded to the situation by growing high yielding varieties for immediate sale, and traditional varieties for storage and on-farm consumption (Giga and Katarere, 1986).

High yields also imply that farmers may need to manage the storage or sale of larger quantities of grain within a shorter space of time, which in itself may cause problems and encourage farmers to sell at harvest, in order to free up the labour for field preparation of the next crop. In some cases labour constraints at harvest lead to early or late harvesting of the crop, with consequent losses (Compton, 1992).

(iv) Changes in the pest population

A major change in the incidence of pests can prompt farmers to seek new storage technologies. In Tanzania the larger grain borer, a destructive pest of stored maize and cassava, was introduced from its native habitat in Central America in the early 1980s. Farmers were reported to have suffered up to 30 per cent losses from the new pest. In response to their demands the government, with donor assistance, implemented a successful extension programme to control the pest.

The larger grain borer has now spread to a number of other East and West African countries, including Kenya, Togo and Ghana, but losses in these countries have not yet reached the levels recorded in Tanzania.

What factors must one consider in assessing the potential for on-farm improvements?

The first step in the identification of appropriate technology is the assessment of the needs of potential users. In the case of post-harvest technology, claims of high losses and of the potential for reducing them have provided a major justification for the promotion of new technologies. The issue is discussed below in the next sub-section.

Whether or not there are good quality data on losses, it is also important to investigate

the potential demand for the technology by its intended users. Even if losses appear quite high, it may be that post-harvest problems do not rank high among farmers' priorities. It may also be that they are more concerned to reduce labour or other costs than they are to reduce losses. Mechanical threshers and mills have been widely adopted in Bangladesh even though they tend to increase losses, because of the savings in labour costs (Greeley, 1987). As a result women labourers from poor households have lost a source of income from hand threshing and milling.

Even where there is a demand for loss reducing technical changes, farmers may find it difficult to adopt recommended technologies, because of cash flow problems, labour constraints, lack of materials, or storage chemicals. Small farmers and traders often find it difficult to obtain credit at reasonable interest rates, since formal financial institutions consider loans to them be too risky.

If it is decided that some form of intervention is both desirable and feasible, then the full range of options should be considered. For example, if storage losses are high, then, in addition to investigating storage technologies, the potential for altering cultivation and postharvest activities (e.g. shelling maize instead of storing it on the cob), for introducing varieties with improved storage characteristics, or for experimenting with biological control methods can also be examined. A discussion of a wide range of options is given in Compton (1992).

Notwithstanding these options, the most successful storage technology to date appears to be the use of insecticides. They can easily be integrated into existing storage systems, and often give high returns. The main constraints on increased insecticide use are: availability of appropriate insecticides at the right time; stability of the formulations used; farmer training in the correct types and correct use of insecticide; cost, which sometimes renders their usage uneconomical.

In view of the latter, it may be appropriate to use locally available materials, such as woodash, sand or certain plant materials which control the growth of insect populations. Use of such materials is most likely to be viable where small quantities of grain are involved, for example in storing locally produced seeds. When farmers have to store larger amounts of grain (e.g. a tonne), usage of such materials may prove tedious and cumbersome, and sufficient quantities of them may not be available. At the same time some of these materials may have toxicological effects which have yet to be investigated. Research in the coming years should throw more light on the usability of a range of these materials.

Introducing new store types has often proved difficult. The main reason is that the capital cost of new stores is too high, and often fails to offset the reduction in the value of losses, especially where stores are not used to full capacity. There have been notable successes in the introduction of metal bins in Swaziland, Central America and the

Punjab area of India and neighbouring Pakistan, but no such cases are known of in poorer areas of Africa. For similar reasons, mechanical driers have also been difficult to promote. Unless there are severe drying problems, sun drying tends to be preferred since it is cheaper. The improved quality of mechanically dried grain is rarely reflected in a higher price, and therefore provides no incentives for farmer adoption.

As well as assessing the level of losses and the demand for the new technology, one must also appraise the cost-benefit or financial viability of the improvement to the individual farmer. The next three sub-sections discuss the assessment of the three factors highlighted above, i.e. losses, demand and financial viability.

(i) Assessment of storage losses

Losses can occur at several stages of the post-harvest chain, including threshing, storage, transport, milling, wholesale and retail distribution. In order to decide whether it is worth taking action over losses of any sort, one should obtain information on losses at all these stages.

There has been a tendency to overestimate storage losses, and to base estimates on extreme cases or guess-work rather than on sound empirical testing. Figures of 30 per cent or more are not uncommon (Greeley, 1987, p. 13ff). By contrast, the results of

detailed field studies suggest that under traditional storage systems in tropical countries losses are typically around 5 per cent over a storage season (Tyler and Boxall, 1984), depending upon the crop, the ambient conditions, the period of storage and other factors. Somewhat higher levels have been encountered in the wetter parts of West Africa and Central America.

Loss figures around the 5% level should not however be considered insignificant. Firstly it should be noted that physical losses are usually accompanied by qualitative losses affecting the mass of the grain in store. Secondly the losses are mainly experienced during the lean season before the new harvest is ripe, thereby having an adverse effect on the food security of farming families at a particularly critical period. In Honduras, farmers' feelings of insecurity about this period have been an important motive for adopting metal storage bins.

Even where detailed studies are undertaken, there are a number of methodological difficulties involved in estimating losses (Greeley, 1991). Loss assessment methods tend to be slow and to require skilled field and laboratory staff. They are often undertaken on experimental sites, making it difficult to relate the results to on-farm situations.

There are a number of factors which tend to lead to an upward bias in the loss estimates. Firstly, extremes may be taken rather than averages. Ideally the sample size

and standard deviation should be quoted with the loss estimate to avoid this. Secondly, removals from store over the season are not always accounted for. Where removals do occur, percentage losses calculated on the basis of grain remaining in store will be overestimates. Another source of overestimates lies in treating partial damage as a total loss, when in fact the damaged grain would be used by farmers for home consumption or animal feed. A fourth source of upward bias lies in the potential for double counting losses at different stages in the post-harvest system. Losses at one level are related to those at other levels.

Another difficulty in using estimates of losses to justify technical change is the problem of assigning to the losses a value which makes sense to the potential user of the technology. The most common form in which losses are expressed is as a percentage weight loss. But what is important from the farmer's point of view is the use that the grain can be put to, or the market price that will be received. Grain intended for sale may be consumed, or that intended for consumption used as animal feed.

A rapid loss assessment method for estimating storage losses in maize and cassava has recently been developed in Togo (Compton et al. 1992). The method attempts to incorporate farmer criteria in defining categories of loss, and since the measurement occurs in the field, rather than at a laboratory, results can be discussed with farmers on the spot. Such methods could usefully be integrated into post-harvest technology

projects.

(ii) Assessment of demand

As in all market research one should start with desk research, including the interviewing of key informants, to gain whatever data are readily available about storage systems, the uptake of improvements introduced in the past and other relevant information.

One should then visit representative villages in the area of interest to analyse the farming system together with the farmers (i.e. carry out a participatory rural appraisal or PRA) to identify opportunities for improvements, taking care to interview a representative sample of farmers and womenfolk, including significant minority groups likely to have an important role in crop storage (e.g. larger mechanised farmers). Out of this activity should come: (a) an assessment of whether any improvements are worth considering in greater depth; (b) a list and description of these ideas or concepts suited to particular groups of farmers.

Selection of technologies may be aided by means of matrix analysis. This involves tabulating the alternative technologies (on a horizontal axis) against the full range of criteria used in their selection (on a vertical axis). Each technology can be scored or

ranked in terms of the respondents' perception of its performance against each criterion. The different steps to be considered in matrix analysis are outlined in the shaded box on the next page, using the appraisal of alternative storage structures as an example. Typical results are displayed in Figure 1.4.

The same approach could be used in assessing pest control systems, or other technologies.

Figure 1.4. Matrix Scoring for three grain storage structures

	Metal bin	Improved crib	Traditional crib
Durability of structure	*****	*****	**
	***		
Ease of handling	*****	*****	****
	*	*	
Peace of mind	*****	***	***
Low construction costs	*	***	*****
			*****

Does not attract pests	*****	****	**
	**		
Total Score:	27	21	21

HOW TO DO MATRIX SCORING

1. **Find a group of key informants who are knowledgeable and willing to discuss. Hold an open-ended discussion with them about on-farm storage. This should be along the lines of a 'focus-group interview', with the moderator guiding the discussion in a non-directional manner, with occasional prompts, and asking for clarification of points of interest.**
2. **As the discussion proceeds, ask the participants to consider a range of alternative storage structures. Ask them which are of interest, and the pros and cons are for each. Probe for further criteria.**
3. **Based on the discussion, make a short list of (a) storage structures worthy of further consideration, and (b) the most important criteria by which the informants appraise their suitability. Then construct a matrix with the storage structures**

displayed on the horizontal axis, and the criteria on the vertical axis. This can be done on a large sheet of paper, or on the ground (using seeds, stones etc. for scoring).

4. **Make negative criteria positive (e.g. 'attracts pests' is written on the chart as 'does not attract pests').**
5. **Convene a group of villagers to assess each storage structure following the list of criteria. Structures may be scored on a scale of, say, ten points. If many items have to be compared, a smaller scale with less points can be used. The highest total score will indicate the most preferred.**
6. **Ask which criteria are most important? If it emerges that some criteria are far more important for the villagers than others then give them more weight by multiplying their scores by a weight factor (e.g. 2).**

Adapted from: J. Mascarenhas, Participatory rural appraisal and participatory learning methods, recent experience from MYRADA and South India; Forests, Trees and People Newsletter No. 15/16.

This exercise can be carried out with people representing different social groups.

In this case the metal bin has the highest score. However, if 'low construction costs' were of leading importance to the villagers, resulting in the multiplication of its scores by two, then the traditional bin would come out top, with 31 points, compared to 28 and 24 respectively for the other two constructions.

As an alternative to scoring, data may be ranked against each criterion, 1 = best, 2 = next best, etc.. Ranking can be used for up to 7 items. The method is straightforward and rapidly elicits much information on why participants give priority to certain criteria. However ranked data for different criteria cannot be added up. Ranking only conveys an order of preference, but not the degree of liking or disliking.

By this stage it may be concluded that certain technologies are affordable and can be field tested without further research. Where this is not the case however, or where one is approaching a number of villages with different characteristics, one may proceed to appraise the different options through concept testing. This market research technique was introduced by NRI into Swiss-funded storage projects in Central America, and is now used for the rapid appraisal of storage concepts, without going to the expense of constructing prototypes.

In a concept test, respondents (chosen from the target population) are shown a picture or mock-up of the new storage structure with a list of their key attributes, and then

answer questions about likes and dislikes, how and when he/she would use the store, willingness to invest in one, preference between alternative concepts and so on. The tests can be carried out in individual depth interviews or in group interviews, or in a combination of both.

The tests can yield some quantitative information e.g. about the percentage of respondents wishing to invest in the structure, about their ranking of technologies etc., but above all it produces in a short space of time a lot of qualitative insights into farmers' thinking about storage and its place in the farming system and the household economy.

(iii) Assessment of financial viability in on-farm storage and handling

On-farm improvements offer the potential for an increase in net benefits through a reduction in variable costs, such as labour, a reduction in the value of grain losses, or an increase in the market value of the grain as a result of using the technology.

An example of the use of cost-benefit analysis (CBA) on farm-storage projects is that undertaken by Boxall and Bickersteth (1991). They compared seven different storage technologies in terms of the break-even price which the farmer must obtain on one bag of maize to cover storage costs, at two different discount rates. Their findings are

presented in Table 1.2, and details of the methodology used are shown in Annex 1.

They found that traditional systems with lower capital costs and no operating costs achieve lower break-even prices in spite of higher losses. Various development programmes had favoured the improved storage crib, but this technology proved the least favourable on account of its high capital costs. Only in areas with particularly high losses would the improved crib be financially viable. The mud bin was the most cost-effective structure because of its durability, cheap construction cost and low losses.

The conclusion reached was that storage technologies currently being recommended under certain development programmes would not, under normal circumstances, be profitable for farmers. Similar findings were encountered in two other West African studies (Al Hassan, 1989; Stabrawa, 1992).

Marketing of new on-farm technology

Having established that a given concept is desired and financially viable, one can then proceed to test-market the technology, by persuading farmers in a given locality to build or install prototypes. As with any other marketing exercises, the test-market will

need to be supported by a delivery structure (involving artisans, trainers etc.), after-sales service and maybe credit. The demand for the technology should be monitored through the growth of sales in the target area, and the level of market penetration i.e. the number of units installed/potential number installed. Reasons for non-adoption should be analysed, with a view to either changing the product or the marketing strategy, or revising downward one's view of market potential. Figure 5 (see Figure 1.5. Schematic presentation of Technology Dissemination) summarises NRI's approach to technology assessment and dissemination in Guatemala.

Table 1 2. GHANA - Maize STORAGE COSTS (In Cedis; Cedis 360 = US$ 1)

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

References

Contents - Previous - Next

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Biodeterioration

Contents - Previous - Next

The condition of stored grain is determined (Lacey, 1988) by a complex interaction between the grain, the macro- and micro-environment and a variety of organisms (including microorganisms, insects, mites, rodents and birds) which may attack it.

Grain provides an abundant source of nutrients, and the natural consequence of the type of stable ecosystem described above will normally be spoilage (biodeterioration) of the grain, caused by the organisms.

The extent of contamination by moulds is largely determined by the temperature of the grain and the availability of water and oxygen. Moulds can grow over a wide range of temperatures, from below freezing to temperatures in excess of 50C. In general, for a given substrate, the rate of mould growth will decrease with decreasing temperature and water availability. Moulds utilise intergranular water vapour, the concentration of which is determined by the state of the equilibrium between free water within the grain (the grain moisture content) and water in the vapour phase immediately surrounding the granular particle. The intergranular water concentration is described either in terms of the equilibrium relative humidity (ERM, %) or water activity (aw). The latter describes the ratio of the vapour pressure of water in the grain to that of pure water at the same temperature and pressure, while the ERH is equivalent to the water activity expressed as a percentage. For a given moisture content, different grains afford a variety of water activities and, consequently, support differing rates and type of mould growth. Typical water activities which are necessary for mould growth range from 0.70 to 0.90.

The interaction between grain temperature and moisture content also affects the extent of mould colonisation. The passage of water from the grain into the vapour phase is encouraged by an increase in temperature. Consequently, for a given moisture content, the water activity, and the propensity for mould growth, will increase with temperature. Maize, for example, can be relatively safely stored for one year at a

moisture level of 15 per cent and a temperature of 15C. However, the same maize stored at 30C will be substantially damaged by moulds within three months.

Insects and mites (arthropods) can, of course, make a significant contribution towards the biodeterioration of grain, through the physical damage and nutrient losses caused by their activity. They are also important, however, because of their complex interaction with moulds and, consequently, their influence on mould colonisation.

In general, grain is not infested by insects below a temperature of 17C whereas mite infestations can occur between 3 and 30C and above 12 per cent moisture content. The metabolic activity of insects and mites causes an increase in both the moisture content and temperature of the infested grain. Arthropods also act as carriers of mould spores and their faecal material can be utilised as a food source by moulds. Furthermore, moulds can provide food for insects and mites but, in some cases, may may also act as pathogens.

Another important factor that can affect mould growth is the proportion of broken kernels in a consignment of grain. Broken kernels, caused by general handling and/or insect damage, are predisposed to mould invasion of the exposed endosperm. It has been estimated, for example, that increasing the proportion of broken grains by five per cent will reduce the storage-life of that consignment by approximately one order of

magnitude; that is from, say, 150 to 15 days.

Mould growth is also regulated by the proportions of oxygen, nitrogen and carbon dioxide in the intergranular atmosphere. Many moulds will grow at very low oxygen concentrations; a halving of linear growth, for example, will only be achieved if the oxygen content is reduced to less than 0.14 per cent. Interactions between the gases and the prevailing water activity also influence mould growth.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Moulds and mycotoxins

Contents - Previous - Next

The interactions described above, within granular ecosystems, will support the growth of a succession of micro-organisms as the nutrient availability and microenvironment changes with time. In the field, grains are predominantly contaminated by those moulds requiring high water activities (at least 0.88 aw) for growth, whereas stored grains will

support moulds which grow at lower moisture levels. The rate of mould growth is also determined by the ability of the micro-organism to compete with other species. Some species, including those of Aspergillus, Penicillium and Fusarium, can occur both in the field and in storage.

Secondary metabolites are those compounds, produced by living organisms, which are not essential for growth. Some secondary metabolites produced by moulds are highly toxic to animals, humans and plants. These so-called 'mycotoxins' have been extensively studied since 1961, when a group of highly toxic Aspergillus flavus toxins - the aflatoxins - were isolated from a consignment of groundnut meal which had been imported into the UK (Coker, 1979).

Any activity which disturbs the stability of an ecosystem will increase the production of secondary metabolites, including mycotoxins. Such activities include the widespread use of fertilizers and pesticides, high yielding plant varieties and the cultivation of a limited number of plant species with restricted genetic variation. The normal practices of harvesting, drying and storage also, of course, significantly disturb the ecosystems of grains established before harvest.

The major mycotoxin-producing moulds include (Miller, 1991) certain Aspergillus, Fusarium and Penicillium species. Toxigenic (mycotoxin-producing) Aspergillus moulds

can occur both before and after harvest, whereas Fusarium and Penicillium moulds occur predominantly before and after harvest respectively. In general, Aspergillus is associated with the tropics and Penicillium with temperate climates, whereas Fusarium moulds occur world wide. However, because of the complexity and variety of ecosystems supporting mould growth in grains, the nature and extent of the worldwide occurrence of moulds and mycotoxins cannot, as yet, be confidently defined. About 300 mycotoxins have been reported, produced by a wide variety of moulds. A few of the major moulds and mycotoxins are listed in Table 2.1 and discussed in the following sections of this Chapter.

Table 2.1. The major moulds and mycotoxins.

Mould species	**Mycotoxins produced**
Aspergillus parasiticus	Aflatoxins B1, B2, G1, G2
A. flavus	Aflatoxins B1, B2
Fusarium sporotrichioides	T-2 toxin
F. graminearum	deoxynivalenol (vomitoxin) zearalenone
F. moniliforme	fumonisins

Penicillium verrucosum	ochratoxin A

The significance of mycotoxins

Mycotoxins have been implicated in a range of human and/or animal diseases and occur in a variety of grains. The ingestion of mycotoxins can produce both acute (short-term) and chronic (medium/long-term) toxicities ranging from death to chronic interferences with the function of the central nervous, cardiovascular and pulmonary systems, and of the alimentary tract. Some mycotoxins are carcinogenic, mutagenic, teratogenic and immunosuppressive. Aflatoxin B. (Figure 2.1. Chemical structures of the Aflatoxin group of mycotoxins.), for example, is one of the most potent hepatocarcinogens known.

The mycotoxins have attracted worldwide attention, over the past 30 years, firstly because of their perceived impact on human health, secondly because of the economic losses accruing from condemned foods/feeds and decreased animal productivity and,

thirdly, because of the serious impact of mycotoxin contamination on internationally traded commodities. It is estimated, for example, that the cost of managing the mycotoxin problem on the North American continent is approximately $5 billion.

The Aflatoxins

The aflatoxin-producing moulds *Aspergillus flavus* and *A. parasiticus* occur widely, on inadequately dried food and feed grains, in sub-tropical and tropical climates throughout the world. Pre-harvest mould growth, and aflatoxin production, is encouraged by insect damage, mechanical damage, drought stress and excessive rainfall. The aflatoxins may occur, both before and after harvest, on virtually any food or feed which supports fungal growth, including cereals, oilseeds and edible nuts. Maize, groundnuts, cottonseed, oil-palm kernels and copra are particularly associated with the occurrence of the aflatoxins. The very substantial international trade in these commodities serves to amplify the worldwide nature of the aflatoxin problem.

The ingestion of aflatoxin B1-contaminated animal feed, by dairy cattle, can result in the presence of aflatoxin M1 (Figure 2. 1e) - a metabolite of aflatoxin B1 - in milk. This is an issue of considerable importance to public health, given the frequent consumption

of milk and dairy products by infants.

Aflatoxin B. has been confirmed as a highly potent human carcinogen, whereas the carcinogenicity of the aflatoxins G1 (Figure 2.1c) and M, has been confirmed only in experimental animals.

The acute toxicity of the aflatoxins has been demonstrated in both animals and man. The outbreak of 'Turkey X' disease in the UK, in the early 1960s, was associated with the death of thousands of turkeys, ducklings and other domestic animals which had received a diet containing aflatoxin-contaminated groundnut meal. Many human fatalities occurred (Anon, 1993(a)) in India, in 1974, when unseasonal rains and a scarcity of food prompted the consumption of heavily aflatoxin-contaminated maize. Acute aflatoxicosis, also caused by the consumption of contaminated maize, caused fatalities in Kenya in 1982.

The chronic effects, caused by the consumption of low dietary levels (parts per billion) of the aflatoxins, on the health and productivity of domestic animals are well established. Reduced weight gain has been reported (Anon, 1989), for example, in cattle, pigs and poultry; reduced milk yield in cows; and reduced feed conversion in pigs and poultry. Low levels of aflatoxin have been associated with an increased susceptibility to disease in poultry, pigs and cattle. Vaccine failures have also been

reported. If similar immunosuppressive effects are manifested in humans, it is possible that the aflatoxins (and other mycotoxins) could be significantly enhancing the incidence of human disease in developing countries.

The Trichothecenes

The trichothecenes comprise a large group of mycotoxins, produced by a variety of Fusarium moulds. The current discussion will be limited to the two trichothecenes - T-2 toxin and deoxynivalenol - which occur naturally, in significant quantities, in cereal grains.

(i) T-2 toxin (Figure 2.2. Chemical structures of the Trichothecene group of mycotoxins.)

***F. sporotrichioides*, the major producer of T-2 toxin, occurs mainly in temperate to cold areas and is associated with cereals which have been allowed to overwinter in the field (Anon, 1993(b)). T-2 toxin has been implicated in two outbreaks of acute human mycotoxicoses. The first occurred in Siberia (in the former USSR), during the Second World War, producing a disease known as 'alimentary toxic aleukia' (ATA). Thousands**

of people, who had been forced to eat grain which had overwintered in the field, were affected and entire villages were eliminated. The symptoms of ATA included fever, vomiting, acute inflammation of the alimentary tract, anaemia, circulatory failure and convulsions. Trichothecene poisoning also occurred in Kashmir, India, in 1987 and was attributed to the consumption of bread made from mouldy flour. The major symptom was abdominal pain together with inflammation of the throat, diarrhoca, bloody stools and vomiting. T-2 toxin was isolated from the flour together with other trichothecenes, namely deoxynivalenol, nivalenol and deoxynivalenol monoacetate (Figures 2.2b, 2.2c and 2.2d respectively).

T-2 toxin has been implicated with the occurrence of haemorrhagic toxicoses (mouldy maize toxicoses) in farm animals. Oral lesions, severe oedema of the body cavity, neurotoxic effects and, finally, death have been reported in poultry, after the ingestion of feed contaminated with T-2.

The most significant effect of T-2 toxin, and other trichothecenes, may be the immunosuppressive activity, which has been clearly demonstrated in experimental animals. The effect of T-2 toxin on the immune system is probably linked to the inhibitory effect of this toxin on the biosynthesis of macromolecules.

There is limited evidence that T-2 toxin may be carcinogenic in animals.

(ii) Deoxynivalenol (Figure 2.2b)

F. graminearum occurs worldwide and is the most important producer of deoxynivalenol (DON) (Anon, 1993(c)). The outbreaks of emetic (and feed refusal) syndromes in farm animals, produced by the presence of DON in their diets, has resulted in the trivial name, vomitoxin, being attributed to this mycotoxin.

DON is probably the most widely distributed *Fusarium* mycotoxin occurring in a variety of cereals, particularly maize and wheat. As stated above, DON has been implicated in a human mycotoxicosis, in India, in combination with T-2 toxin and other trichothecenes. Other outbreaks of acute human mycotoxicoses, caused by the ingestion of DON and involving large numbers of people, have occurred in rural Japan and China. The Chinese outbreak, in 1984-85, resulted from the ingestion of mouldy maize and wheat. The onset of symptoms occurred within five to thirty minutes and included nausea, vomiting, abdominal pain, diarrhoea, dizziness and headache. Another *F. graminearum* toxin, zearalenone (see below), was also isolated from the mouldy foodstuff.

The immunosuppressive effect, of those concentrations of DON which are naturally ocurring, has been reported. There is inadequate evidence in humans and experimental animals, however, for the carcinogenicity of DON. DON is not transferred into milk,

meat or eggs.

Zearalenone ([Figure 2.3. Chemical structure of Zearalenone])

F. graminearum is also the most important producer of zearalenone, a widely-occurring mycotoxin which is responsible for many outbreaks of oestrogenic syndromes amongst farm animals (Maracas, 1991).

The occurrence of zearalenone in maize has been responsible for outbreaks of hyperestrogenism in animals, particularly pigs, characterised by vulvar and mammary swelling, uterine hypertrophy and infertility.

As described above, zearalenone was isolated from mouldy cereals involved in an outbreak of acute human mycotoxicosis in China.

There is limited evidence in experimental animals, and inadequate evidence in humans, for the carcinogenicity of zearalenone. It is not transmitted from feed to milk to any significant extent.

The Fumonisins ([Figure 2.4. Chemical structures of the Fumonisin group of toxins.])

The fumonisins are a group of mycotoxins which have been characterised comparatively recently (Anon, 1993(d). They are produced by *F. moniliforme* which occurs worldwide and is one of the most prevalent fungi associated with maize.

To date, only the fumonisins FB1 and FB2 appear to be toxicologically significant. The occurrence of FB1 in cereals, primarily maize, has been associated with serious outbreaks of leukoencephalomalacia (LEM) in horses and pulmonary oedema in pigs. LEM is characterised by liquefactive necrotic lesions of the white matter of the cerebral hemispheres and has been reported in many countries, including the USA, Argentina, Brazil, Egypt, South Africa and China. FB1 is also toxic to the central nervous system, liver, pancreas, kidney and lung in a number of animal species. FB2 is hepatotoxic in rats.

The incidence of *F. moniliforme* in domestically-produced maize has been correlated with human oesophageal cancer rates in the Transkei, southern Africa and in China. The levels of fumonisins in domestically-produced maize have been reported as similar to those levels which produced LEM and hepatotoxicity in animals.

Currently, there is inadequate evidence for the confirmation of the carcinogenicity of

the fumonisins in humans. There is limited evidence, in animals, for the carcinogenicity of FB1 but inadequate evidence for the carcinogenicity of FB2. Data are not available for the transmission of these toxins into milk, meat and eggs.

Ochratoxin A (Figure 2.5. Chemical structure of Ochratoxin A.)

Ochratoxin A is produced (Pitt and Leistner, 1991) by only one species of *Penicillium*, *P. verrucosum*, probably the major producer of this mycotoxin in cooler regions. Amongst the aspergilli, *Aspergillus ochraceus* is the main source of ochratoxin A.

Ochratoxin A has been mainly reported in wheat and barley growing areas in temperate zones of the northern hemisphere. It does, however, occur in other commodities including maize, rice, peas, beans and cowpeas; developing country origins of ochratoxin A include Brazil, Chile, Egypt, Senegal, Tunisia, India and Indonesia.

A correlation between human exposure to Ochratoxin endemic'nephropathy (a fatal, chronic renal disease occurring in limited areas of Bulgaria, the former Yugoslavia and Romania) has been suggested. A causative link, however, has yet to be confirmed.

Ochratoxin A produces renal toxicity, nephropathy and immunosuppression in several animal species.

Although there is currently inadequate evidence in humans for the carcinogenicity of ochratoxin A, there is sufficient evidence in experimental animals. Ochratoxin A has been found in significant quantities in pig meat, as a result of its transfer from feedingstuffs.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

The interaction of mycotoxins

Contents - Previous - Next

The complex ecology of mould growth and mycotoxin production can produce mixtures of mycotoxins in food and feed grains, particularly in cereals. The co-occurrence of mycotoxins can arise through a single mould producing more than one toxin and simultaneous contamination by two or more moulds, from the same or different species.

The co-occurrence of the *Fusarium graminearum* toxins deoxynivalenol and zearalenone with the *F. moniliforme* toxins fumonisin B1 and B2, for example, has been reported (Miller, 1991) in southern Africa. Other naturally occurring combinations of *Fusarium* mycotoxins include T-2/diacet-oxyscirpenol (DAS) (Figure 2.6. Chemical structures of Diacetoxyscirpenol, Fusarenone and Cyclopiazonic acid.), deoxynivalenol/DAS and DAS/fusarenone (Figure 2.6b). Naturally occurring combinations of mycotoxins produced by more than one genus include aflatoxins/trichothecenes (Argentina), aflatoxins/zearalenone (Brazil, Indonesia), aflatoxins/ Ochratoxin A and aflatoxins/cyclopiazonic acid (Figure 2.6c)/zearalenone (Indonesia), afla-toxins/fumonisins (USA). Given the worldwide distribution of the *Fusarium* moulds, the presence of combinations of *Fusarium* mycotoxins and aflatoxins in food and feeds of developing country origin should be expected.

The co-occurrence of mycotoxins can affect both the level of mycotoxin production and the toxicology of the contaminated grain. The presence of trichothecenes may increase the production of aflatoxin in stored grain, for example, whereas some naturally occurring combinations of *Fusarium* toxins are synergistic in laboratory animals. To date, little is known about this particularly important area of mycotoxicology. The significance of mycotoxins in human disease will become more clearly defined through the continued identification of biomarkers, present in blood and/or urine, which reflect the levels of recent dietary exposure to mycotoxins. Aflatoxin, covalently bound to

albumin in peripheral blood, and the urinary aflatoxin B1-guanine adduct have both been used, for example, to monitor aflatoxin ingestion.

Studies using the aflatoxin-albumin adduct have demonstrated the significantly higher exposure that occurs in Gambia, Kenya and the Guangxi region of China, compared with Thailand and Europe. In Europe, the levels of biomarker were below the detection limit.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

The control of mycotoxins

Contents - Previous - Next

Since the occurrence of mycotoxins is a consequence of biodeterioration, it follows that the mycotoxin problem is best addressed by controlling those agents - temperature, moisture and pests - which encourage spoilage.

The pre-harvest control of the agents of biodeterioration is somewhat compromised by Man's inability to control the climate! Both insufficient and excessive rainfall during critical phases of crop development can, for example, lead to mould contamination and mycotoxin production. The very substantial economic losses attributed to mycotoxins, on the North American continent, clearly illustrates the difficulties associated with the prevention of contamination, even in wealthy, developed nations.

Considerable effort has been expended on the development of crop strains which are resistant to mould growth and/or mycotoxin production. Breeding programmes have focused, for example, on the development of Aspergillus/aflatoxin resistant varieties of maize and groundnuts, with limited success. It has been suggested that wheat has three types of resistance to Fusarium graminearum; resistance to the initial infection, resistance to the spread of the infection and resistance to mycotoxin (deoxynivalenol) production. Attempts to exploit the resistance to mycotoxin production (through either the inhibition of synthesis or chemical degradation) may hold the most potential because of the limited number of genes which control this process.

The post-harvest handling of grains does, however, present many more opportunities for controlling mycotoxin production. Although many small farmers will not have access to artificial drying equipment, the importance of the utilisation of effective drying, and storage regimes cannot be overemphasised, and is covered extensively in later

chapters. Drying to moisture levels which will ensure safe storage in tropical climates is especially important when grains are shipped from temperate to tropical climates.

However, despite the best efforts of the agricultural community, mycotoxins will continue to be present in a wide range of foods and feeds. Consequently, strategies are required for the removal of mycotoxins from grains. Currently, two approaches are utilised; namely, the identification and segregation of contaminated material and, secondly, the destruction (detoxification) of the mycotoxin(s).

The Segregation of Contaminated Grains

In the first instance, the identification and segregation of contaminated consigments is pursued through the implementation of quality control procedures by exporters, importers, processors and regulators. The consignment is accepted or rejected on the basis of the analysis of representative samples of the food or feed. Acceptable levels of mycotoxin contamination are specified by individual customers, commercial agreements and regulators. Currently, over 50 countries now regulate against the aflatoxins; 5 parts per billion (g/kg) is the most common maximum acceptable level. Aflatoxin M1 in dairy products is regulated in at least 14 countries, the tolerances for infant diets being

0.05-0.Sppb milk. Regulations exist for other mycotoxins including, for example, zearalenone (1mg/kg in grains; the former USSR), T-2 toxin (0.1mg/kg in grains; the former USSR) and ochratoxin A (150ppb food, 100-1000ppb feed; numerous countries). Guidelines, advisory levels and 'official tolerance levels' for deoxynivalenol also exist in some countries. The guideline in Canada, for example, refers to 2mg/kg in uncleaned soft wheat, 1mg/kg in infant foods and 1.2mg/kg in uncleaned staple foods calculated on the basis of flour or bran. In the USA, 4mg/kg is advised for wheat and wheat products used as animal feeds.

The mycotoxin content of grains can be further reduced during processing. Automatic colour sorting, often in combination with manual sorting, is widely used to segregate kernels of abnormal appearance (which are considered more likely to contain aflatoxin) during the processing of edible grade groundnuts. Mycotoxins can also be concentrated in various fractions produced during the milling process. Zearalenone and deoxynivalenol, for example, are reportedly concentrated in the bran fraction during the milling of cereals. It can be argued, however, that all fractions will contain mycotoxins if the original grain is heavily contaminated. Ochratoxin A appears to be reasonably stable to most food processes. In general, the stability of mycotoxins during processing will depend upon a number of factors including grain type, level of contamination, moisture content, temperature and other processing agents.

A further segregation process involves the removal of aflatoxin, from animal feeds, after ingestion. Here, mycotoxin binding agents - hydrated sodium calcium aluminosilicate, zeolite, bentonite, kaolin, spent canola oil bleaching clays - included in the diet formulation, reportedly remove aflatoxin, by adsorption from the gut.

The Detoxification of Mycotoxins

Ammonia, as both an anhydrous vapour and an aqueous solution, is the detoxification reagent which has attracted (Park et al, 1988) the widest interest and which has been exploited commercially, by the feed industry, for the destruction of aflatoxin. Commercial ammonia detoxification (ammoniation) facilities exist in the USA, Senegal, France and the UK, primarily for the treatment of groundnut cake and meal. In the USA, cottonseed products are treated in Arizona and California whilst maize is ammoniated in Georgia, Alabama and North Carolina. Commercial ammoniation involves the treatment of the feed, with ammonia, at elevated temperatures and pressures over a period of approximately 30 minutes. Onfarm procedures, as practiced with cottonseed in Arizona, involve spraying with aqueous ammonia followed by storage at ambient temperature, for approximately two weeks, in large silage bags.

The nature of the reaction products of the ammoniation of aflatoxin is still poorly understood. However, many studies have been performed, on both isolated ammoniation reaction products and treated feedingstuffs, in an attempt to define the toxicological implications of ammoniation. Very extensive feeding trials have been performed with a variety of animals including trout, rats, poultry, pigs and beef and dairy cattle. The effect of diets containing ammoniated feed has been determined by monitoring animal growth and organ weights together with haematological, histopathological and biochemical parameters. The results of these studies, combined with the practical experience of commercial detoxification processes, strongly indicate that the ammonia detoxification of aflatoxin is a safe process. However, the formal approval of the ammoniation process by the USA Food and Drug Administration is still awaited.

Commercial processes have not been developed for the detoxification mycotoxins.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Sampling and analysis

Contents - Previous - Next

The control of the mycotoxin problem comprises (a) the identification of the nature and extent of the problem (by the implementation of surveillance studies), (b) the introduction of improved handling procedures, which address the identified problems, and (c) the regular monitoring of foods and feeds as part of a quality control programme.

The operation of both surveillance studies and quality control programmes requires efficient sampling and analysis methods.

Since the distribution of aflatoxins (and, presumably, other mycotoxins) in grains is highly skewed, it is important that great care is taken to collect a representative sample (Coker and Jones, 1988). There is still considerable debate as to the appropriate size of such samples. In general, the sample size should increase with increasing particle size; samples of whole groundnuts, maize and rice, for example, should be of the order of 20, 10 and 5kg respectively. Samples of oilseed cake and meal should be approximately 10kg in weight. For whole grains, each sample should be composed of about 100 incremental samples, collected sytematically from throughout

the batch, whereas samples of cake and meal require approximately 50 increments. It is important to remember that the collection of samples from the surface of a large, mature stack of grains will only reflect the quality of the outer layers. The mycotoxin content of the grain in the interior of the stack can only be monitored during the break-down of the stack. Needless to say, an incorrectly collected sample will invalidate the final analysis result.

The sampling of grain shipments, normally involving tens of thousands of tonnes of material, poses a particularly difficult sampling problem. Representative samples should be collected from carefully defined 500 tonne batches, using the methods described above. Potential sampling points include weighing towers, conveyor belts, and trucks and barges receiving the discharged material. The sampling of fast moving grain is a hazardous operation; automatic, on-line sampling equipment should be used wherever possible.

The reduction of the sample, for analysis, should also be performed so as to ensure the representative nature of the laboratory sample. It is imperative that the complete sample is comminuted prior to subdivision. Ideally, the comminution and subdivision of whole grains should be performed simultaneously, using a subsampling mill. Alternatively, the comminuted sample should be subdivided using a mechanical riffle. Manual coning and quartering procedures should only be used as a last resort.

Equipment available for the collection of representative samples is discussed in detail in Chapter 3.

High performance liquid chromatography (HPLC) has been used for the analysis of a wide range of mycotoxins including the aflatoxins, ochratoxin A, zearalenone, deoxynivalenol (DON) and the fumonisins. To date, high performance thin layer chromatography (HPTLC) has been applied mainly to the aflatoxins whereas gas liquid chromatography (GLC) has been utilised for the quantification of DON, T-2 toxin and zearalenone. Enzyme-linked immunosorbent assays (ELISA) have also been applied to many mycotoxins including the aflatoxins, ochratoxin A, deoxynivalenol, T-2 toxin and zearalenone. Despite the utilisation of sophisticated, expensive HPLC, HPTLC, GLC and ELISA procedures, agreement between laboratories is invariably poor, when identical samples are analysed (Coker, 1984)!

Quality control programmes require simple, rapid, efficient analysis methods which can be handled by relatively unskilled operators (Coker, 1991). Recently developed rapid methods include those that utilise immunochemistry technology or selective adsorption agents. A rapid ELISA method for estimating aflatoxin in groundnuts, cottonseed, maize, rice and mixed feeds has been subjected to a collaborative study and recommended for First Action Approval by the Association of Official Analytical Chemists (AOAC). Solid phase ELISA kits have been developed for the aflatoxins,

ochratoxin A, zearalenone and T-2 toxin in a variety of commodities. An 'immunodot' cup test, where the antibody is immobilised on a disk in the centre of a small plastic cup, has been approved by the AOAC as an Official First Action screen for aflatoxin in groundnuts, maize and cottonseed. Card tests have also been developed where the antibody is immobilised within a small indentation on a card similar in size to a credit card. Such tests have been developed for the aflatoxins, ochratoxin A, T-2 toxin and zearalenone in maize. The reported analysis (extraction, filtration and estimation) time for solid phase ELISA kits is 5-10 minutes. ELISA kits, however, are relatively expensive and suffer reduced shelf-lives at elevated temperatures.

Minicolumns (small glass columns) containing selective adsorption agents have been developed for aflatoxin/zearalenone (single test) and deoxynivalenol.

There is an urgent need for simple, robust, low-cost analysis methods, for the major mycotoxins, which can be routinely used in developing country laboratories.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Conclusions

The mycotoxins described in this chapter, as symptoms of biodeterioration, are acutely toxic, carcinogenic, immunosuppressive and oestrogenic; and have been the cause of serious human and/or animal diseases. The potential immunosuppressive role of mycotoxins in the aetiology of human disease is an especially important issue which requires further careful study. Every effort must be made to minimise the occurrence of mycotoxins in food and feed grains.

Undoubtedly, the implementation of improved handling and quality control procedures will have a significant effect on the incidence of mycotoxins in important foods and feeds throughout the world.

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Contents - Previous - Next

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Introduction

Contents - Previous - Next

Most countries have developed national standards for their main grain crops. These have evolved to facilitate the movement of grain, providing both sellers and purchasers with guidelines to support financial transactions, and ensuring that quality will meet up with enduse requirements.

Where trading involves direct choice and price negotiation in front of the commodity, grading standards are rarely employed; quality is assessed visually and is influenced by enduse, and the price is determined more by local rather than national factors. For transactions that involve the movement of large volumes of grain over long distances, the buyer may never meet the seller or be able to examine the whole consignment. The standard will provide an unambiguous description of the quality of the consignment and

assist in the formation of a legally-binding contract. Standards can also be seen to protect consumers rights through setting limits to the amount of unsuitable or noxious material.

The use of grading standards can send a clear indication of quality requirements to both producer and end-user. Although some countries have sought to support small farmers through purchase of all grain at the same price without regard to quality: under these circumstances grading standards cease to be operative by default. This may stimulate productivity but creates problems for end-users such as millers who require uniformity and consistency in quality to ensure efficient and cost-effective processing.

Whilst establishment of standards can set the guide-lines and rules for sale and purchase of grains, there has to be an institutional framework for their implementation. This is much easier to establish at centres of aggregation of grain e.g. ports, parastatal grain depots, than in the more diffuse rural areas and markets, where control and supervision of regulations is difficult.

Notwithstanding these problems, the establishment of quality and grading standards for producers and users can be beneficial in the following ways:

- **Graded grains are likely to be more equably priced than non-standardised grains.**

This will bring stability not only to market prices but also to the quality offered.

- **Prices quoted against a recognised grade assist producers and traders to market their products. This will also benefit net consumers of grain in more stable prices with assured quality.**
- **Greater conformity in quality through standardisation will provide the millers, bakers and other processors with the consistency necessary for optimum performance.**
- **Standards reveal clear variations in quality and indicate the opportunities for improvement and the potential rewards to be obtained.**
- **The sanitary hazards associated with the inter-country movement of grain can be reduced if clearly-defined standards are enforced, particularly in relation to the prevention of spread of serious storage pests like the Larger Grain Borer.**

However, the use of standards can have its disadvantages, namely:

- **National standards may reflect local end-uses and hinder export to areas that have differing requirements. Whilst restricting opportunities for commercial trade, this can also be detrimental for regional food security. The stimulation of regional trade would require inter-country conformity in export standards. These may have to be more stringent in relation to physical conditions such as moisture content,** defective grains and insect infestation, than that for national use.

- The establishment of standards and the quality assurance practices to regulate and enforce them carries costs which have to be carefully considered to avoid imposing unnecessary expense for little improvement in quality.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Quality characteristics of grains

Contents - Previous - Next

Consumers have become accustomed over the years to demanding grain with particular qualities. Where consumers are close to the source of the grain, e.g. in local markets, their own preferences and the laws of supply and demand will control the quality of the grain. However, where grain is traded over large distances, particularly internationally, the consumer will have no direct influence over quality, and regulatory standards must be established and imposed to protect consumer rights. Therefore criteria of grain

quality must be established and accepted by all parties in the grain trade. The criteria assigned to grain are the intrinsic varietal qualities and those which are environment- or processinduced. The more important quality criteria as they relate to grading of grain are described in the following sections.

Intrinsic Qualities

(i) Colour

Cereal grains are pigmented and range through the colour spectrum from very light tan or almost white, to black. Where extractive milling is required, highly-pigmented varieties may give low yields of white flour.

(ii) Composition

Composition, e.g. protein, carbohydrate, lipids and their breakdown products, qualitatively influences product acceptability, by affecting texture and taste. Quality changes evolve slowly in stored grain and more rapidly in milled or processed intermediary products.

Some grain components, for example husk, are inedible and quantitatively influence product yield and gross nutrient available to the consumer.

(iii) Bulk Density

Each type or variety of grain when in optimum health, fully mature, etc. has a characteristic bulk density. This is defined as the weight per standard volume measured in a standard manner. The same characteristic is variously known as 'test weight', 'bushel weight' or 'specific weight'. For details of how bulk density is measured see page 62.

If the bulk density varies the trend is usually downwards and indicative of reduced overall quality of the grain. Hence it is often measured in the grain trade. Factors which commonly affect bulk density are insect infestation, excessive foreign matter and high percentage moisture content. In wheat, bulk density is considered to be a reasonable indicator of milling yield.

Bulk density should not be confused with 'specific volume' as defined in the context of Chapter 6 of this bulletin. The terms are related, but the distinction is necessary because it is an established fact that the 'bulk density' of grain increases when it is stored in large quantities, bag or bulk, due to compaction.

(iv) Odour, aroma

Most grain types, when fresh, have a distinctive natural odour or aroma. This is generally accepted as an indicator of good quality, although some people prefer grain which smells 'old' or even fermented.

As with most natural produce, some grain varieties are better-liked than others because of their odour. Certain cultivars of rice, for example, possess aromatic qualities which are considered desirable by some consumers.

See also mixed variety.

(v) Size, shape

Rice, as a whole-grain food, is classified by size (length) and shape (length:breadth ratio). Other grains also have size considered in their specification. In general a small range in size assists with processing and handling.

Induced Qualities

(i) Age

During the post-harvest phase, grain undergoes complex biochemical changes termed 'aging'. Changes to carbohydrate, lipids and protein fractions result in, for example, firming of texture in rice on cooking, and increased gas-retention capability in wheat flour. For most consumers, the effects of these changes are considered to be desirable. When plotting consumer acceptability of a grain product against its age since harvesting, generally it is considered to be maturing during the upward curve of the graph, and deteriorates only when the curve changes direction downwards.

(ii) Broken grain

Grain is marketed normally in whole grain form and is considered to be of inferior quality if broken. Breakage may occur from fissures as a result of excessive drying/weathering conditions in the field or during handling. Breakage reduces quality by reducing acceptability and by increasing susceptibility to infestation during storage. This affects milling yield by contributing to weight loss.

(iii) Chalky or immature grain

Empty grains result from sterility and pre-harvest infections and insect attack.

Immature grain content is affected by time of harvest. In rice, immature grains are greenish in colour. Thin white (usually opaque) grains are caused by incomplete grain filling and may result from pests or disease. Chalkiness is caused by incompletely filled starchy endosperm which disrupts light transmission, causing opaque regions. In most cereals, chalky areas have lower mechanical strength on crush tests and may break during handling. The broken portion is more easily invaded by certain storage pests.

(iv) Foreign matter

Dilution of the prime product by foreign matter reduces the value, and also may affect handling and processing. Foreign matter may be subclassified as:

animal origin - insects and their products, rodent excrete, etc;
vegetable origin - straw, weeds, seeds, dust, micro-organisms/toxins;
mineral origin - stones, mud, dust, glass, metals, oil products, pesticide residues.

Elements from all three subclasses may render the grain unfit for consumption. Potentially the greatest threat to health probably is from micro-contamination with the bacterial products of poor sanitation, and with toxins and chemical pesticide residues.

(v) Infested, infected grain

Grain mass, and therefore yield, is reduced by infestation. Contamination not only has direct food hygiene implications but also indirect ones, as invading micro-organisms may produce toxins under certain conditions which may lead to acute or chronic illness.

(vi) Mixed varieties

A mixture is an indication of poor pre- and post-harvest management and supervision, e.g. seed selection, lot segregation and treatment, contamination, etc. Grains differing in size and other characteristics affect processing potential. Whilst preference for a particular variety may be influential nationally or regionally, internationally-traded grain is recognised usually by grain type rather than by variety e.g. yellow or white maize. Exceptions do occur, e.g. basmati rice, (see odour, aroma).

(vii) Moisture content

Moisture content (me) of grain plays a crucial role in post-harvest processing and is associated with most of the induced characteristics. Water vapour will diffuse throughout a bulk of grain and the mc will tend to equalise. 'Hot spots' may occur at a site of increased respiration (caused by sprouting, infestation or microbial activity), and condensation may occur on cold grain or containers.

Grain standards

Contents - Previous - Next

The term 'standard' used in the present context refers to the measures that serve as a basis for making comparisons or judging the accuracy of unknown samples. Three types of standard will be covered in this chapter:

- standard *specification* which define and specify a subject,
- standard *test method* by which a specification is tested,
- *grading* standard which allow a subject to be classified into more than one category.

Standards are established for a variety of purposes but mainly: a) for produce grading in agricultural marketing, or, increasingly, b) for the protection of consumers. The requirements of the two groups are not necessarily compatible.

Standard Specification for Grain

There are at least 330 specifications for cereals and cereal products at national and international level (over 50 countries or regions) of which at least 12 are applicable globally. Standard specifications provide criteria to characterize the nature of a commodity, usually on a pass or fail basis.

Most countries have a national standards institution which may issue specifications for commodities as well as methods of testing. Many countries adopt or modify international standards, e.g. International Organization for Standardization (ISO) standards, into their national system. Another source is the Codex Alimentarius Commission (Codex) which operates a committee to formulate standards on cereals, pulses and legumes.

Tables 3.1 (see Table 3.1. European Community Intervention Regulations on Minimum Quality Standards.) and 3.2 (see Table 3.2. Ethiopia - Grain Grading Standards.) show examples of trading-bloc and national standards, and Tables 3.3 and 3.4, examples of international standards.

Table 3.3 shows the ISO standard specification for wheat: a sample is judged against the standard, and may be referred to as wheat if it passes all the criteria listed.

One notable feature of the standards in Tables 3.1 to 3.4 is the difference in tolerance of mc. Both of the quoted international standards allow 15.5%, whereas the European Community (EC) and Ethiopian standards have lower values, 14.5 and 14.0% respectively.

In the cited examples, not only do we have the potential for mix-interpretation but also, more seriously, the basis for deterioration of the product. For example, take the case of maize with 15.0% mc loaded into a ship in northern latitudes at 4C. Calculated from data presented by Foster (1982), such grain would have an inter-grain equilibrium relative humidity (ERM) of approximately 65 % which is normally regarded as safe. However, if the grain is unloaded in a tropical country with an ambient temperature of 32C, its inter-grain ERH becomes 75% - too high for safe storage.

Boxall and Gough (1992a and b) monitored shipments of food-aid maize grain from north America to southern Africa. They reported that heating and mould-damage took place when the grain was stacked at port of discharge, and confirmed that the standard mc of 15.5% at loading was too high for the conditions at the destination. A second shipment of grain dried specifically to approximately 14.5% mc suffered damage as

well. In comparison, an intraAfrican importation with 12.2% mc did not suffer heating or deterioration on storage. Studies are continuing at NRI on the importance of integrating quality standards between suppliers and consumers.

The problems associated with moisture content may be harmful to international trade in grain and need to be addressed adequately by the standardisation institutions. ISO 7979 (Table 3.3) goes some way towards this by acknowledging the principle of destinationspecific mc though without defining appropriate action.

Standard Test Methods

There are at least 420 standard test methods for cereals and cereal products at national and international level (over 50 countries or regions) of which at least 75 are applicable globally.

As with the specification of cereals, many countries modify or adopt international standards, e.g. International Organization for Standardization (ISO) standards, into their national system. Another important organisation, particularly for the development of testing methods, is the International Association for Cereal Science and Technology

(ICC). Other organisations issuing standard test methods include the Association of Official Analytical Chemists (AOAC) and the American Association of Cereal Chemists (AACC).

Table 3.3. International Standard - Wheat - Specification ISO 7970: 1989

Maximum tolerances (% m/m):	
Foreign or deteriorated odour, additives, toxic substances	0
Pesticide residues, other contaminants	National limit or Codex limit
Living insects	0
Moisture content	15.5*
Bulk density, minimum (kg/hl)	70
Damaged grain	15
of which:	
Broken grain	7
Shrivelled grain	8
Unsound grain	1

Grain attacked by pests	2
Other cereals	3
Extraneous matter	2
Inorganic material	0.5
Harmful and/or toxic seeds, bunted grains and ergot	0.5
Ergot	0.05
Falling number, minimum	160

'Lower moisture contents are required for certain destinations, in relation to the climate, and duration of transport and of storage. For further information, see ISO 6322, parts 1, 2 and 3.
Source: International Organisation for Standardisation

Table 3.4. Codex Standard for Maize (Corn) Codex Stan 153-1985

Maximum tolerances (% m/m):	
Abnormal or foreign odour	0

Moisture content	15.5
Blemished grain	7
of which:	
diseased grain	0.5
Broken kernels	6
Other grains	2
Foreign matter	2
of which:	
inorganic matter	0.5
Filth	0.1
Toxic or noxious seed, heavy metals,	free from
microorganisms or poisonous or	amounts hazardous
deleterious substances	to health

Source: Codex Alimentarius Commission

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Grain trade

Contents - Previous - Next

Table 3.5 shows the world production and trade figures for grain for the year 1990. Total grain movement across national borders was approximately 225 million tonnes, representing some 12% of grain production. This large trade in grain highlights the need for both national and international standards to ensure uniformity in quality and quantity of grain.

Table 3.5. World Grain Statistics.

Year: 1990	Production '000 t	Imports '000 t	Exports 7000 t
Africa	87751	27785	2725
N + C America	402095	16270	115770

S America	68503	8517	11227
Asia	859650	98878	15808
Europe	283238	40078	62527
Oceania	24587	787	14802
USSR	228854	32862	1641
World	1954678	225177	224500

Source: FAO Trade and Production Year-book

National requirements

It could be argued that a commodity standard should be country-specific, containing factors such as percentage brokers, foreign matter, moisture content that reflect the types of end-use, be it for commercial or domestic purposes. Government policy on the liberalization of the grain market may reduce the significance of domestic quality standards, and it is up to the buyer and seller to decide on quality and price. Although a government may retain the use of standards under particular circumstances e.g. for national food reserves, where quality control will be important.

Regional requirements

End-usage, and hence standards, may vary from one country to the next. Where standards vary considerably between countries, the movement of grain may be hindered. A country may have a single standard that covers both internal and external grain movement. This may not facilitate the trade of a commodity between countries, particularly if the standard permits a greater degree of defective grains than its potential trading partner.

Regional food security may be impaired if the quality of the commodity is not acceptable by some of the countries in the region. Therefore a quality grading standard, acceptable by all users would be necessary for a commodity stored as part of a regional food security programme.

International trade

International trade of grain may be possible without a standard, if buyer and seller are aware of each others' requirements. However when country-specific information and

requirements are not known, a standard will provide the guide-lines that ensure the maintenance of quality, and safeguard consumers' rights. The need for detailed standards may be lessened if a country adopts the "fair average quality" system of assessing quality and price of grain consignments (see below).

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Standard grading of grain quality

Contents - Previous - Next

It was noted above that there is more than one reason to establish standards. Consumerorientated standards tend to specify the nature of a commodity on a pass or fail basis, particularly in relation to wholesomeness or fitness for consumption. Producer or marketorientated standards tend to grade grain into one of several classes based usually on inherent quality and projected market value.

Fair average quality (FAQ)

The selling and buying of produce on a Fair Average Quality (FAQ) basis, as practiced by many national and international marketing agencies, is essentially subjective. Normally, samples from different parts of the available stock of produce offered for sale (which may be scattered on farms or in warehouses throughout the producing area) and submit them under seal to independent assessors (public analysts or the like) for appraisal. After examining the samples by sight, smell, taste and (perhaps) touch, the assessors will eslect those samples which they consider representative of the bulk of the samples, mix them together and reduce the lot to a single reference sample which is declared to represent the Fair Average Quality of the seller's stock. Parts of this sample may be used for certain objective tests, e.g. determination of percentage moisture content, oil content, free fatty acid content, or bulk density, if requested by the sellers, buyers or both. In any event, the main part of the reference sample is retained by an independent agency such as the Grains and Feeds Trade Association (GAFTA) for a specified period, during which any transactions involving the produce should be completed. If there is a dispute over quality the independent agency can be referred to for arbitration, and the reference sample may be used as evidence.

It is important to appreciate that the results of the FAQ assessment relate only to the crop which has been sampled, and only for the period agreed upon between the sellers

and buyers. If consecutive FAQ same from the same crop, or FAQ samples from the same growing area in consecutive years, or FAQ samples of the same commodity grown concurrently in different areas are compared objectively significant differences in quality may be revealed. Thus FAQ has a loose definition, and can only be applied when fairly wide variations in quality can be tolerated.

The main advantage of FAQ is, of course, that it enables producers to dispose of most of their crop with the minimum of trouble and expense. At the same time the buyer can expect to gain by paying only a moderate price for the crop, although he does run the risk of having to bear the cost of additional processing is quality is some way short of optimal.

Grain specification

Table 3.1 includes the EC minimum quality intervention standard for wheat. There is a series of Articles in the Commission Regulations, in which relaxations of these grading standards are noted at individual national level. The Articles also allow a deduction or premium to be made according to changes in individual characteristics, e.g. increased prices paid for lower mc and grain defects, and for higher specific weights (bulk

densities).

In comparison, ISO 7970 allows lighter grain with higher mc higher damaged grain, but lower extraneous matter. 'Wheat' as specified must contain a low amount of non-wheat matter, but tolerates higher levels of grain defects, whereas 'wheat' as graded incorporates an element of processing value for the purchaser by rewarding desirable properties.

Conway et al (1992) studied quality/value relationships in milled rice. In a system with wellorganised grain quality inspection, they found that qualities apparent at acceptance were only partially reflected in the wholesale price. More cryptic qualities, manifested as change in 'colour' during storage, formed the greater part of the valuation. It is a measure of the success of the application of the acceptance standard that these qualities did not feature largely in the valuation; also, of the valuers' reliance on, or habituation to, the standard. It shows that the acceptance system should not be relaxed, rather that it may need supplementing to cover the newly-identified qualities.

Sampling, equipment and methods

Contents - Previous - Next

Table 3.6 (see Table 3.6. National and International Standards - Sampling.) shows a number of standard test methods dedicated to sampling. There are at least 30 methods, of which 5 or more are applicable internationally. The remainder are national or regional standards.

The need for sampling

Batches of grain are rarely uniform in quality even when regarded as acceptable. Pests usually occur non-randomly in stored grain. Consequently the only sure way of obtaining complete and accurate information about the grain is to carry out a total examination. This may be possible if the quantity to be examined is small, but is usually neither practical nor economical when a large quantity is involved. The choice is either not to examine the consignment at all or to take samples to obtain some information, acknowledging that anything less than a total examination is bound to affect the accuracy of the results.

Principles of representative sampling

The results of sample analyses can be expressed in precise terms. However, precise analytical results may be of little practical value, and may be misleading if the samples are obtained without taking into account the non-random or aggregated distributions of foreign matter, damaged grains, insects, etc.

Certain principles of representative sampling must be observed:

- **The cnnsignment should be divided into primary units of equal size or status, which may be sampled. For bagged grain, each bag may be regarded as a primary unit. For bulk grain, the primary unit may be expressed in terms of weight, if the grain is being moved, or volume, when it is static - as in a truck or bin.**
- **All primary units should have an equal opportunity of being sampled. This is possible only during the construction or dismantling of a stack, the loading or off loading of a truck, or when bulk grain is being moved.**
- **The method should select, without bias, a representative number of primary units from the consignment.**

Many countries adopt the recommendations of ISO 950 "Cereals - Sampling (as grain)". Its recommendation for selecting a proportion of bags is shown in Table 3.7, and for grain in road and rail trucks in Figure 3.1 (see Figure 3.1. Sampling Points in Bulk Grain Carriers.).

Working sample size

In practice, it is necessary to compromise between what is theoretically attainable and the natural desire to obtain results of analyses as quickly as possible. Providing the associated margins of error are recognised and accepted, it is generally suggested that working samples of between 500 and 1000 grains should be used for the determination of common defects such as insect damage, broken grains and discoloured grains. Equivalent minimum working sample weights are:

Maize (small grain)	200g
Maize (large grain)	250g
Sorghum	25g
Black-eyed cowpeas	150g

Wheat	25g
Bulrush millet	10g
Paddy	15g

Samples of these sizes can be analysed in 10 to 20 minutes, depending upon the skill of the inspector and available equipment.

Table 3.7. Selection of Bags for Sampling.

Number of bags in consignment	Number of bags to be sampled
Up to 10	Every bag
11 to 100	10, drawn at random
More than 100	Square root (approximately) of the total number of bags drawn at random according to a suitable scheme.

In the USA, minimum working sample weights of 250g and 1000g are required for the determination of ergot and garlic respectively in wheat, while 250g samples are recommended for the determination of smut in both wheat and sorghum. Such 10 to 40 fold increases on the basic working sample weight illustrate what is meant by 'large'

and 'small' sample sizes.

There is a need for sampling awareness when dealing with grain contaminated with mycotoxins. As analytical techniques improve, so detectable and tolerance levels are being lowered. To emphasise the link between the standard test method and specification, Jewers et al. (1989) conclude, "When aflatoxin levels are controlled by legislation it is important that sampling procedures and sample sizes are specified."

For the determination of foreign matter and live infestation, samples should be as large as possible. If bagged grain is being tested, the best results are obtained by passing the entire contents of sample bags over a suitable sieve.

Equipment for obtaining primary samples from bagged grain

(i) Simple bag sampling spears

These are the most commonly-used instruments for taking samples from bags, being relatively cheap, simple and quick. The main variations in design are illustrated in Figure 3.2 (see Figure 3.2. Typical Spears for sampling Bagged Grain.). Generally, sampling spears having a maximum external diameter of about 12mm are designed for

small grains such as wheat, while 25mm diameter spears are suitable for larger grains. To obtain a good cross-sectional sample the spear should be 40 to 45cm in length.

The tapered type of sampling spear penetrates bags easily. However, it takes unequal portions of grain from along the line of penetration, which could lead to distorted assessments of grain quality. More even sampling is achieved with the cylindrical type of sampling spear.

The main disadvantage of obtaining samples with these instruments is that it does not conform to the basic principles of representative sampling. If foreign matter or defective grain happens to be very unevenly distributed in the bag, the haphazard nature of spear sampling could lead to a distorted quality assessment (Figure 3.3. Inadequacy of Spear Sampling. Black dots represent grain defects).

(ii) Double-tube sampling spears

These spears (Figure 3.2D) comprise two metal tubes, one fitting closely inside the other and each with several common slots. Spears may vary in length from 45cm to 3.5m, and in width from 12mm to 50mm. Turning the inner tube through 180 opens or closes the intake apertures, and so collects grain from a transverse section of the bag.

Double-tube sampling spears are designed primarily for obtaining samples from vertical lines of penetration in bulk grain, although small versions may be used for sampling bagged grain. They are superior in many ways to the simple bag sampling spear, but are still instruments of haphazard rather than representative sampling.

(iii) The Produce-Flow sampler

This sampler (Figure 3.4. Vertical section of Produce-flow Sampler.) was designed at the Tropical Products Institute, now a part of NRI, as a representative sampling device for bagged grain. Grain is tipped into the hopper and falls through onto a cone, which is positioned to ensure that the flow is evenly distributed. Some of the grain is trapped by four vents arranged equidistantly around the base of the cone, and directed via a separate spout into a sample collector. The size of the sample depends upon the dimensions of the vents, which are interchangeable. Sampling of a 100kg bag of grain is complete within 20 seconds of starting the flow.

Equipment for obtaining primary samples from bulk grain

Bulk grain is sampled either when it is static, i.e. when it is contained in a truck, barge

or storage bin, or when it is on the move, i.e. when it is being discharged through a spout or on a conveyor belt. A wide range of sampling equipment has been developed to meet the special requirements of these various situations, some for small-scale operations and other items for situations where grain is handled in very large quantities.

(i) Equipment for sampling static bulk grain

<u>Double-tube sampling spears</u> (see also above)

Spears 1.8m long and 3.5cm outer diameter are commonly used, but longer 3.7m double-tube spears are available for sampling grain in exceptionally deep trucks and barges.

The sampling spear should always be inserted into bulk grain at a slight angle from the vertical, with the slots facing upward. The slots must be opened only when the spear has reached the sampling position, and must be closed before it is removed.

<u>Manually-operated deep bin probes</u>

The simplest probe of this type consists of a hollow spear head, which serves as a sample cup, with a spring-loaded cap attached to a metal or wooden rod about 1 metre long. Extension rods are attached to increase the depth of penetration. When the

sampling point has been reached a slight upward pull on the rod lifts the cap of the spear head, allowing grain to fill the cup. The probe is then withdrawn completely and the sample removed. A single probe yields up to 300g of sample material.

The deep bin fin-probe consists of a double-tube sampler with a set of extension rods. When the sampling position is reached a twist of the extension rod opens the sample intakes. This action is facilitated by the fin which prevents the outer tube from turning. A reverse twist closes the sample intakes before the probe is withdrawn from the grain. Up to 600g of sample representing a 1.5m long vertical 'cut' may be obtained.

A considerable amount of physical effort is required to push any of these probes into grain. None can be expected to penetrate more than approximately 5 metres.

Pneumatic grain samplers

Pneumatic grain samplers overcome the main disadvantages of manual operation by using powered-suction to penetrate the static bulk of grain, and by taking a continuous sample. They are quicker to operate than manual samplers, and can be used easily to obtain samples from the sides and floors of bulk grain containers. An example is shown in Figure 3.5 (see Figure 3.5: Pneumatic Sampler.).

Auger-type sampler

The sampler consists of a tube approximately 1.4m long and 5cm wide, open at the bottom end and housing a motor-powered auger. Grain lifted by the screw is collected in a bag at the outlet spout. It is necessary to insert the device into the grain at an angle in order to obtain sample material. There are no extension pieces which would permit sampling deeper than the half metre or so the sampler penetrates. The sampler is therefore of limited usefulness.

(ii) Equipment for sampling moving grain.

The Pelican sampler

The Pelican sampler (see Figure 3.6: Manual sampling of moving grain. A Pelican sampler. B Ellis Cup sampler.) consists of a cowhide pouch attached to a metal frame at the end of a hardwood or tubular metal handle. It is used to obtain samples from freefalling grain, e.g. from a spout discharge to the hold of a ship.

If the spout is sloping, the components of the grain stream are likely to be stratified. It is important, therefore, to cut the sampler through the stream from one side to the other in a single motion to obtain a good sample.

The force behind a stream of grain may be very great. It is essential to observe appropriate safety measures when sampling in this manner.

The Ellis Cup sampler

This is a hand-held scoop (Figure 3.6B), designed for obtaining small samples from bulk grain on moving conveyor belts. When properly used, the cup will obtain a vertical section of the flowing grain at the point where it is inserted into the stream. Samples taken in this way are used for making spot checks on the condition of grain and are not intended as substitutes for representative samples obtained elsewhere in the system.

Sampling with the Ellis cup is hazardous. Extra safety precautions are necessary, as with the Pelican sampler.

Limpet-type sampler

This type of sampler is clamped or bolted to the outside of the delivery spout. A tube is inserted through a hole drilled into the spout wall. The tube usually is open at both ends and has an inlet slot in the upper side projecting into the grain stream. Sampled material is removed either by means of a motorised worm screw, or a plunger operated by compressed air. Worm screw extractors can be made to operate continuously or at

intervals. Plunger sample extractors remove samples of fixed size at intervals.

The limpet sampler is capable only of extracting material from part of a grain stream. Figure 3.7 (see Figure 3.7. Limpet sampler.) shows the auger principle in operation. If there is any appreciable stratification of material in the stream, samples cannot be regarded as representative.

The diverter-type sampler

The diverter-type sampler is probably the best device yet invented for obtaining representative samples from bulk grain. The sampler (Figure 3.8. Principle of operation of the Diverter sampler.) is designed to take a complete cross-section of a stream of grain, by means of a powered diverter head which takes a cut through the stream, on a preset schedule. During periods of inactivity the aperture of the diverter head is sealed to prevent it collecting dust.

Grain extracted from the main stream by the sampler may be fed directly into a secondary sampler, which reduces the sample to a manageable size before it is delivered via spouting to the grain inspection laboratory. Figure 3.8 shows the principle of operation.

Quality determination, equipment and methods

Contents - Previous - Next

The term 'quality' has different meanings for those who are concerned with the handling, storage, processing and utilisation of grain, even though all will be looking for grain of 'good quality'. For example, grain-handling agencies will want dry, insect-free, undamaged grain which will store well; millers will want a grain which will yield a high percentage of finished produce; and consumers will be concerned with flavour, appearance or cooking qualities of grain.

Grain quality may vary with the variety or type of grain selected by the farmer. It will be influenced by climatic and soil conditions during the growing season, cultivation practices, weather conditions at harvest, and by harvesting techniques. Apart from short-term aging or maturation immediately after harvest, quality cannot be improved during storage, handling and processing - on the contrary, it is easily lost.

Every type of grain can be said to possess properties which contribute to its overall quality. A consideration of the various properties or qualities, either alone or together, allows the grain to be graded and valued, and enables the design and development of optimum methods for handling, storing and processing.

Research work into methods for the identification of varieties may hold the key to grain grading systems of the future. Consumers are becoming accustomed to buying fruit and vegetables by variety, so why not grain? Most cereal crops have been studied; polyacrylamide gel electrophoresis (PAGE) techniques have been used to discriminate between wheat varieties, and reversed-phase high-performance liquid chromatography (RPHPLC) techniques may be applicable to wheat and rice.

Assessment of grain quality

With over 420 standard test methods, including at least 75 internationally-applicable, it is apparent that there is a large diversity in grain character. This is obvious when considering the range of uses for grain: paddy to produce milled rice, barley for malting, durum wheat for pasta production etc.

Many assessments are commodity-, product- or end user-specific. Of the wide range of properties, bulk density and foreign matter are commonly assessed for most types of grain. In addition, the influence of moisture content on other grain qualities, as well as the simple economic fact, make it important for quantification.

(i) Bulk Density

All equipment for the determination of bulk density have features of (a) causing the sample material to fall from a standard container through a standard height into a standard volume weighing bucket, (b) levelling the surface of the material in the weighing bucket in such a way as not to influence its packing and (c) weighing the loaded bucket. However, differences in equipment design and procedural detail can result in very different values for bulk density, even when the same grain sample is used. It is essential, therefore, that only one type of apparatus is used for determining bulk density. ISO 7971 is a standard reference method with results expressed as mass per hectolitre.

The bulk density of a sample of grain can also be affected by the presence of foreign matter, and varies with mc Consequently it is standard practice to remove as much foreign matter as possible by sieving samples before carrying out bulk density determinations, and also to measure the mc of the sieved material.

(ii) Foreign Matter

Most grain quality standards state that the screens in sieves used for the assessment of foreign matter content should consist of perforated metal plate conforming to specifications laid down by national or international standards organisations. Such specifications cover the composition and thickness of the metal plate, the shape and dimensions of the perforations, and the arrangement of the perforations on the plate. Table 3.8 (see Table 3.8. Sieve Perforations for Grain.) shows some examples of perforation specifications for some grain types.

Operating Capacity of Sieves

The efficiency of a sieve is dependent upon two factors: the dimensions of the apertures in the screen, and the proportional volume of material which will not pass through the apertures. As a general rule, the percentage sieving area' of a screen with small perforations is less than that of a screen with larger holes, and its capacity for sieving efficiently is correspondingly reduced. Also, for a perforated metal screen of fixed specifications the sieving efficiency falls off markedly if the volume of material which will not pass through the apertures exceeds a certain quantity. Table 3.9 shows the recommended volume of grain that should be placed on a screen, to maintain its sieving efficiency.

Table 3.9. Grain Sieves, 200mm Diameter, Maximum Loadings.

Nominal aperture mm	Recommended volume of load cm	Typical grain equivalent
8.0	500	300g Maize
4.0	350	250g Sorghum
2.0	200	150g Wheat
1.0	140	100g Millet

Source: International Standard ISO 2591-1973

(iii) Moisture Content

The standard test method (ISO 712) for the determination of mc in cereals is by mass loss in a hot-air oven. The method is time-consuming and a variety of rapid methods have been developed for day-to-day use. These range through accelerated heating by infra-red source gravimetric tests to almost instantaneous readout by electronic moisture meter. Of the latter, two types are common; resistance and capacitance meters.

It is recommended that grain-handling agencies avoid using a mixture of meter types, because this can lead to conflicting results. Instead, the meter best suited to their particular requirements should be selected. The following factors should be considered when selecting a meter to determine moisture content:

<u>Resolution</u> **- the ability of the meter to differentiate between moisture contents which are very close in value. Some meters have the ends of the scale compressed i.e. the scale is not linear. The resolution of the meter is therefore relatively poor for high and low readings.**

<u>Repeatability</u> **- a measure of the meter's ability to give a constant reading when the same sample is tested several times. Capacitance meters, due to variations in grain packing, may not produce such accurate results as resistance meters, which normally use a more homogeneous ground or compressed sample.**

<u>Reliability</u> **- a measure of variation between meters when measuring the moisture content of the same sample. Meters should be regularly checked and calibrated to ensure reliability.**

<u>Stability/drift of measurements</u> **- affects the frequency of the need to calibrate the meter against the standard test method.**

Range of commodity - calibrations will be necessary for all the commodities of interest, and the meter must be capable of accommodating them.

Range of mc - in general, resistance meters cannot measure low mc i.e. lower than approximately 9%, whereas capacitance meters can - to 1 or 2% in some cases.

Sample size - meters use differing size of test samples: larger samples give more accurate results, and require fewer replications.

Sample weighing - most capacitance meters require the sample to be weighed, thus introducing an extra variable (and extra cost).

Ambient effect - meter readings vary with temperature, and correction is required. Some meters automatically display the corrected moisture content.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

The role of standards in local trade

Contents - Previous - Next

Producers of grain will have a number of uses for their produce; as food for the family or livestock, for seed, or for sale. The trade of grains can cover a large area entailing a variety of end usages. A number of end-users would benefit from the uniformity of supply associated with the use of grain standards, such as the commercial producers of food products e.g. beverages, baked products and animal feed, or the procurers for food security reserves. It is difficult to judge whether the setting of standards for these varied uses can best be carried out by the relevant industry rather than a government regulatory body, or a combination of the two. Whatever method is used to formulate the standards, it gives a clear message of quality requirements to producers, and it should provide a more uniform and regular supply for the end users.

Given that the formulation of standards is the best system for providing information to grain producers and end-users, they should be based on factors which both consider important and which are easily recognisable and unambiguous. The selection of grades must allow clear steps which can be easily differentiated and represent a clear change in value and end-use. Standards should be built on those characters that can be accurately and uniformly measured, and interpreted. To assist this process, terminology must not be difficult to understand.

Above all standards should be sources of information intelligible to all and serving a clear function in the production and utilisation of grain.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

References

Contents - Previous - Next

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Technical alternatives

Contents - Previous - Next

Harvest constitutes a major operation among agricultural activities. Considered for a long time as the last step in production, it must rather be approached as the first one in the postproduction system, because of its influence on subsequent processing and preservation of the products.

Harvesting methods differ according to the part of the plant to be used. As regards forage crops, the whole plant is cut, but for underground crops (eg, groundnuts, roots and tubers), the crop is lifted while the soil sticking to it is removed. With cereals, the crop is first cut either as a whole or partially (ears), and then threshed and cleaned to separate the grain from the ears and straw.

In the latter case two main alternatives exist: separate harvesting and threshing, or combined harvesting and threshing.

In developing countries the first alternative is generally the most widely applied. Although harvesting and threshing are still frequently done by hand, their mechanization has begun to develop during recent years, especially where the crop is produced not for self-consumption but rather for commercial purpose. Nevertheless, such mechanization has not developed everywhere to the same extent but according to the type of crop concerned, because labour requirements remain high for handling the produce before threshing.

In industrialized countries, attempts have been made since the beginning of the 20th century to devise machines which would both harvest and thresh grain, so as to reduce the labour requirements involved. Combine harvesters ('combines') which can cut, convey, separate and thresh the grain were the product of this development work. They are in widespread use, and have been used already on large grain production schemes in a number of developing countries.

Rice Harvesting and Threshing

(i) Harvesting methods

Manual harvesting

In many countries rice ears are cut by hand. A special knife is frequently used in SouthEast Asia ("ani-ani"), Latin America ("cuchillo") and Africa. For instance, in the Casamance region of Senegal rice is cut stem by stem with a knife, 10 cm below the panicle so as to leave straw in the field in amounts large enough to produce grazing for cattle. Nevertheless such practice is labour intensive.

To harvest denser varieties (500 stems/sq metre instead of 100) a sickle is used mainly

on a generally wetter produce. But work times remain high: 100 to 200 man-hours per ha for cutting and stooking.

Mechanized harvesting

During past decades the mechanization of rice harvesting has rapidly evolved. It first developed in Japan, then in Europe and has now reached many tropical countries.

The first machines used were simple animal-drawn (horses in Europe, oxen in the tropics) or tractor-driven mowing machines fitted with a cutter bar. The improvements made on this equipment have first resulted in the development of swathers (Figure 4.1. Swather.). These drop the crop in a continuous windrow to the side of the machine making it easy to pick up the panicles and manually tie them into bundles. The next step forward has been the reaper that forms unbound sheaves; and finally the reaper/binder which has a tying device to produce sheaves bound with a twine. However the supply, cost and quality of the twine are the main problems associated with the use of such equipment.

The output of these machines varies between 4 and 10 hours per hectare, which is slow. However, they may be usefully introduced into tropical rice growing areas, where hand harvesting results in great labour problems. In temperate countries they have been

gradually replaced by combine harvesters.

(ii) Threshing methods

After being harvested paddy bunches may be stacked on the plot. This in-field storage method results in a pre-drying of the rice ears before threshing, the purpose of which is to separate seeds from panicles.

Traditional threshing

The traditional threshing of rice is generally made by hand: bunches of panicles are beaten against a hard element (eg, a wooden bar, bamboo table or stone) or with a flail. The outputs are 10g to 30kg of grain per man-hour according to the variety of rice and the method applied. Grain losses amount to 1-2%, or up to 4% when threshing is performed excessively late; some unthreshed grains can also be lost around the threshing area.

In many countries in Asia and Africa, and in Madagascar, the crop is threshed by being trodden underfoot (by humans or animals); the output is 30kg to 50kg of grain per manhour. The same method, but using a vehicle (tractor or lorry) is also commonly applied. The vehicle is driven in circles over the paddy bunches as these are thrown on

to the threshing area (15m to 20m in diameter around the stack). The output is a few hundred kg per hour. This method results in some losses due to the grain being broken or buried in the earth.

In south-east Asia, total losses induced by traditional harvesting and threshing methods are estimated between 5 and 15%.

Mechanized threshing

From a historical viewpoint, threshing operations were mechanized earlier than harvesting methods, and were studied throughout the 18th century.

Two main types of stationary threshing machines have been developed.

The machines of Western design are known as 'through-flow' threshers because stalks and ears pass through the machine. They consist of a threshing device with pegs, teeth or loops, and (in more complex models) a cleaning-winnowing mechanism based upon shakers, sieves and centrifugal fan (Figure 4.2. 'Through-flow' Thresher.). The capacities of the models from European manufacturers (eg, Alvan Blanch, Vicon, Borga) or tropical countries (Brazil, India, etc.) range from 500 to 2000kg per hour.

In the 70s, IRRI developed an axial flow thresher which has been widely manufactured

at local level. Such is the case in Thailand where several thousands of these units have been put into use. They are generally mounted on lorries and belong to contractors working about 500 hours per year.

More recently, a Dutch company (Votex) has developed a small mobile thresher provided with either one or two threshers (Figure 4.3). The machine has been widely adopted in many rice growing areas. The simple design and work rates of these machines (about 500kg per hour) seem to meet the requirements of rural communities.

The 'hold-on' thresher of Japanese design (Figure 4.4. 'Hold on' thresher - Japanese design.), is so-called because the bundles are held by a chain conveyor which carries them and presents only the panicles to the threshing cylinder, keeping the straw out. According to the condition of the crop, work rates can range between 300kg and 700kg per hour (Iseki model). The main disadvantage of these machines is their fragility.

(iii) Combined harvesting and threshing methods

Combine-harvesters, as the name implies, combine the actions of reaping and threshing. Either the 'through-flow' or the 'hold-on' principle of threshing may be employed, but the reaping action is basically the same. The main difference is that combine-harvesters of the Western ('through-flow') type are equipped with a wide cutting bar (4-5m) while the working width of the Japanese ('hold-on') units is small (1m). According to the type of machine used, and specially to their working width, capacities range from 2 to 15 hours per hectare.

Such machines are being increasingly used in some tropical countries. In the Senegal river delta region, private contractors or farmers' organizations have recently acquired combine harvesters, mainly of the Western type (Massey Ferguson, Laverda, etc.). So, almost 40% of the Delta surface area is harvested with a pool of about 50 units. Between 200 and 300 hectares of winter rice are mechanically harvested. In this region the popularity of combine harvesters is high despite their poor suitability for some small-sized fields.

In Brazil, several manufacturers have adapted machines to rice growing conditions by substituting tracks for wheels; some machines are simple mobile threshers equipped with cutter bars.

In Thailand, local manufacturers have recently transformed the IRRI thresher into a combine harvester so as to reduce the labour requirement. The unit can harvest 5ha per day and seems to have been rapidly adopted.

(iv) Strippers

Because of their size, conventional harvesters and combine harvesters prove unsuitable for many rice growing areas with small family farm holdings. In response to this problem, research services, during the last ten years, have developed small-sized machines for harvesting the panicles without cutting the straw. Such machines are known as strippers.

In the UK, the Silsoe Research Institute (SRI) has developed a rotor equipped with special teeth for strip-harvesting spikes or panicles. IRRI recently adopted this technology and has developed a 10hp self-propelled 'stripper gatherer' with a capacity of about 0.1ha per hour. However, the harvested grain has to be threshed and cleaned in a separate thresher. Since harvesting unthreshed produce results in frequent stoppages for emptying the machine, this constitutes the main drawback to the progress of the prototype.

In France, CIRAD-SAR has designed and developed a machine which strips panicles from the plants and threshes them in only one pass (Figure 4.5). The stripper has been specially designed for harvesting paddy rice on small plots. The essential component is a wire looped in line with the direction of movement of the machine, which is mounted on a three-wheeled carriage and powered by a 9hp engine. With a 30 cm working width the stripper capacity is about 1 ha per day.

Maize Harvesting and Threshing

(i) Harvesting methods

Manual harvesting

In village farming systems the crop is often harvested by hand, and cobs are stored in traditional structures. Quite often, the crop is left standing in the field long after the cobs have matured, so that the cobs may lose moisture and store more safely after harvest.

During this period the crop can suffer infestation by moulds and insects and be attacked by birds and rodents. To reduce such risks, an old practice (called "el doblado") is sometimes applied in South and Central America. This involves hand-bending the ears in the standing crop without removing them from the stalks. It helps mainly to prevent rainwater from entering the cobs, and also limits bird attacks; but, because of the high labour requirements involved, the practice is gradually falling into disuse.

Manual harvesting of maize does not require any specific tool; it simply involves removing the cob from the standing stalk. The work time averages 25 to 30 days per

ha. Traditionally, maize cobs are commonly stored in their unhusked form. To improve their drying, it is often recommended to remove the husks from the cobs. Maize husking is usually a manual task carried out by groups of women. Some machine manufacturers (e.g. Bourgoin in France) have developed stationary maize huskers, such as the "Tonga" unit.

Mechanized harvesting

The first mechanized harvester to detach ears of maize from the standing stalks, the 'corn snapper', was built in North America in the middle of the 19th century. This was followed by the development of 'corn pickers', which incorporated a mechanism for removing the husks from the harvested ears. The first animal-drawn maize pickers were replaced by tractor-drawn units (l or 2 rows) and then tractor-mounted units (1 row). Finally came the development of self-propelled units capable of harvesting from up to 4 rows. A specific feature in maize harvesters is the header which leaves the stalks standing as it removes the ears.

The rates of work can vary from 2 hours per hectare with a 3-row self-propelled harvester to 5 hours per hectare with a tractor-drawn or -mounted single row unit. Generally speaking, harvest losses range from 3% to 5%, but they may be up to 10%-15% under adverse conditions. Depending on the situation, a single-row harvester can

be employed effectively on up to 20 hectares or more; but the use of a multi-row machine demands several tens of hectares to be economically effective.

Specially designed for harvesting maize as grain, the corn-sheller was initially a cornhusker in which the husking mechanism was replaced by a threshing one (usually of the axial type). Corn-shellers are self-propelled machines of the 3 to 6-row type with capacities of 1 to 2 hours per hectare (Figure 4.6. Maize sheller.). The surface areas harvested during a 180-hour campaign range between 100ha (with a 3-row unit) and 200ha (with a 6-row one).

Another alternative consists of equipping a conventional combine with a number of headers corresponding to the machine horsepower. However, although widely used, such a method requires many adjustments to the threshing and cleaning mechanisms.

(ii) Threshing methods

Shelling and threshing

Traditional maize shelling is carried out as a manual operation: maize kernels are separated from the cob by pressing on the grains with the thumbs. According to the operator's ability the work rate is about 10kg per hour. Outputs up to 20kg per hour

can be achieved with hand-held tools (wooden or slotted metal cylinders). To increase output, small disk shellers such as those marketed by many manufacturers can be recommended (Figure 4.7. Maize hand shellers.). These are hand-driven or powered machines which commonly require 2 operators to obtain 150kg to 300kg per hour. Another threshing method, sometimes applied in tropical countries, involves putting cobs in bags and beating them with sticks; outputs achieved prove attractive but bags deteriorate rapidly.

Motorized threshing

Nowadays many small maize shellers, equipped with a rotating cylinder of the peg or bar type, are available on the market. Their output ranges between 500 and 2000kg per hour, and they may be driven from a tractor power take off or have their own engine; power requirements vary between 5 and 15hp according to the equipment involved. For instance the French Bourgoin "Bamba" model (Figure 4.8. "Bamba" motorized maize sheller.) seems well-suited to rural areas in developing countries because of its simple design, easy handling and versatility (maize, millet sorghum, etc.).

Millet and Sorghum Harvesting and Threshing

(i) Manual harvesting

In Africa, and especially in the Sudano-Sahelian area, these cereals constitute the staple food in the human diet. They are harvested almost exclusively by hand, with a knife (Figure 4.9. Knife ("ngobane") for harvesting millet.) after unroofing or bending the taller stems to reach the spikes. Harvesting and removal from the field takes 10 to 20 days per hectare, according to yields. Harvested ears are stored in traditional granaries while the straw is used as feed for cattle or for other purposes (e.g. thatching).

(ii) Gradual mechanization of threshing

Women separate the grain from the ears with a mortar and pestle, as it is needed for consumption or for marketing purpose (Figure 4.10). The threshed grain is cleaned by tossing it in the air using gourds or shallow baskets.

This traditional method is arduous and slow (10kg per woman-day). Consequently, research has been conducted for some years on how to mechanize it.

The mechanical threshing of sorghum ears does not raise any special problems: conventional grain threshers can be used with some modifications; such as adjustment

of the cylinder speed, size of the slots in the cleaning screens, etc. On the other hand, the dense arrangement of spikelets on the rachis and the shape of millet ears (especially pearl millet), make their mechanical threshing excessively difficult.

The first millet and sorghum threshers were developed in Senegal in the 1960-70s: the Siscoma BS 1000 and the Marot DAK II. Giving relatively high outputs (about 1000kg per hour) they have been intended for village farmers' groups, cooperatives or private contractors going from village to village to work on big threshing layouts. The multipurpose "Bamba" thresher, better suited to rural communities, has a capacity of about 300kg per hour. The

Senegalese pool of millet and sorghum threshers currently amounts to 120-150 units.

As regards mechanized harvesting at family level, some hand-operated threshers (Champenois) were developed and tested experimentally but they did not prove very successful. CIRAD is currently working on the design of powered millet threshers of low capacities (50 to 100kg per hour).

Grain Cleaning

Threshing operations leave all kinds of trash mixed with the grain; they comprise both vegetable (e.g. foreign seeds or kernels, chaff, stalk, empty grains, etc.) and mineral materials (e.g. earth, stones, sand, metal particles, etc.), and can adversely affect subsequent storage and processing conditions. The cleaning operation aims at removing as much trash as possible from the threshed grain.

The simplest traditional cleaning method is winnowing, which uses the wind to remove light elements from the grain (Figure 4. 11).

(i) Mechanized cleaning

The most rustic equipment is the winnower (Figure 4.12. Cereals winnower.): a fan-originated current of air passes through several superposed reciprocating sieves or screens. This type of machine was widely used in the past for on-farm cleaning of seed in Europe. It can be either manually powered or motorised; capacities range from a few hundred kilogrammes to several tonnes per hour.

In Europe, with the use of combine harvesters and the development of centralized gathering, cereal winnowers have been progressively replaced by seed cleaners in the big storage centres. These machines, also equipped with a system of vibrating sieves, are generally capable of very high outputs (several tens of tonnes per hour).

In developing countries, mechanizing the cleaning operation at village level has seldom been felt as a necessity, because of the lack of quality standards in grain trading. However, because of the current trend towards privatization of marketing networks, the demand for cleaning machines will probably increase. The local manufacture and popularization of simple and easily portable equipment, such as winnowers or screen graders suited to cereal crops, need to be encouraged. CIRAD/SAR has recently developed cleaning machines of the rotary type with outputs of a few hundred kilogrammes per hour.

Contents - **Previous** - **Next**

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Constraints

Contents - **Previous** - **Next**

Because there is a wide choice of equipment available for both harvesting and threshing, it is not easy to select the machinery most appropriate to a particular

situation. It is very important, therefore, to identify the constraints specific to each situation before selecting equipment.

Technical Constraints

(i) Cropping and Farming Systems

Previous analyses of the cropping and farming systems are required to determine the actual needs regarding mechanization: location of the land under cultivation, intensification level, prices of products, etc.

The mechanization of the harvesting operation for crops - mainly food crops - with yields ranging between 0.5 and 2 tonnes per ha rarely justifies itself economically.

On the other hand, mechanizing the harvesting operation will be more easily justified on an intensified irrigated area of several hectares with paddy rice as main crop, where small farmers can group together, and the sale price for paddy is sufficiently attractive.

(ii) Cropping Conditions

The constraints affecting harvesting and threshing operations which influence the quality of the product are: the moisture content of the grain at harvest time, the maturity of the crop, the type of plant involved and the way it stands in the field.

The moisture content of the grain must be between 18 and 23% at harvest time, or between 12 and 20% at the threshing stage. These guidelines determine the start of operations. Below such values, losses (in the case of rice) from shattering during harvest and breakage during threshing are excessively high and bad for the subsequent processing. Above such values, problems arise at storage level: risks of moulds developing and germination of the grain in stooks, drying cribs or granaries.

Crop maturity and type directly affect mechanization and vice versa. The introduction of mechanized technology has reduced the tendency to plant mixed varieties of grain: single variety crops ripen uniformly thus making it easier to harvest or thresh them mechanically. With crops which do not mature at one time, the choice of the date for performing the harvesting operation will determine the results: for paddy an earlier harvest will generally result in low yields and high percentage of unripe grain; on the other hand, delayed harvesting will lead to shattering losses, higher percentage of broken grain at the processing level, etc. In addition, the weed infestation level will affect the use of machines and also the cleanliness of the harvested and threshed materials.

The type of plant influences both the choice of machines and their performance:

- **the grain-straw ratio must be as high as possible to limit the volume of straw entering the machine;**
- **the attachment of the grains to the panicles or spikes must allow relatively easy stripping at maturity;**
- **erect and short stemmed varieties are preferred (paddy varieties with very curved grain ears make it necessary to cut high proportions of straw, and tall varieties of maize, millet and sorghum prove difficult to mechanize);**
- **the abrasive property of certain seeds (eg, paddy) makes it necessary to use high quality materials in the manufacture of machines.**

To meet these objectives, it is necessary to observe a very strict work schedule, especially for wetland paddy. Accordingly, machines must be able to work under particularly difficult conditions: in the mud with special attachments (tracks, cage-wheels, etc.) before the complete drainage of rice fields, at low working speeds, on a produce difficult to cut because still partially green, and handling of a product often soiled with mud.

Social and Labour Constraints

Harvesting is a labour-intensive operation but is less arduous than threshing. Because most of the rural population consider threshing as a particularly tedious operation (especially in the case of millet), grain producers accept the relatively high cost of mechanical threshing.

The skills and experience of farmers, and the interests of traditional systems, must necessarily be taken into account when mechanizing certain operations. It will be easier to extend the use of harvesting machines where farmers are already employing other powered equipment such as tractors, motor pumps or processing units. The availability of workers skilled in the operation, maintenance and repair of engine-powered equipment favours the adoption of new machines.

Lastly, in developing countries harvesting and threshing operations are traditionally carried out by women. However, in most situations, as these operations become mechanized, they are taken over by men and the role of women is reduced to winnowing and the gleaning of grain scattered during harvesting and threshing. The mechanization of post-harvest operations frequently means the transfer of activities from women to men.

Economic Constraints

Economic constraints are a drawback to the purchase of farm machinery. The high costs involved, above individual farmers' resources, allow the acquisition of such equipment only if credit and the possibility of farmers grouping together exist. Alternatively, if private individuals are interested in equipping themselves, they can hire out their services to the rest of the community.

To justify and encourage the purchase of machines, technical versatility can be an incentive (e.g. a rice thresher which can also be used for threshing millet and maize), even if the equipment proves less efficient with certain crops than a specific single-purpose one. In such a case, the choice of the equipment should be made according to the crop which is mechanized first.

In practice, the costs of machines and services vary from one country to another. By way of example, the following 1992 tax-free prices for some machines in Senegal are given for comparison:

Thresher, Votex Ricefan	1,100,000 Fcfa

Thresher, SISMAR, Borga type	7,700,000 Fcfa
120hp rice combine harvester	24,000,000 Fcfa
Millet thresher, SISMAR (without tractor)	7,700,000 Fcfa
Multipurpose Bamba thresher, Bourgoin	2,200,000 Fcfa

Supplied services are generally paid a percentage of the crop: 5 to 10% for threshing and 15 to 20% for combine harvesting.

In Mali, the cost of using the Votex thresher is estimated to be between 3 and 5% of the grain produced (paddy at about 70 Fcfa per kg); assuming that the useful life is 10 years for the thresher (7 years for the engine), and that the working parts will need replacing after processing every (a) 80t for the thresher teeth, (b) 800t for the crimp screen and (c) 1000t for the thresher unit (toothed shaft and fan).

These figures must be considered as basic, because the profit margins of manufacturers and retailers of spare parts are not taken into account, and also because prices can be higher in other countries (as in Senegal).

Organization of the Distribution System

The introduction and extension of new machines is easier if distribution systems for machines and spare parts, and local industrial or artisan manufacturing facilities exist already.

Compared with animal-drawn implements, powered harvesting and threshing machines are difficult to manufacture. Research has been conducted into the design of simplified equipment which can be manufactured locally, e.g. the IRRI and Votex threshers.

Support from technological transfer projects has often been needed for the local production of some machines: the Votex Ricefan thresher in Mali and Senegal, for example. This thresher has been designed to cope with transport problems and allow local assembly or even partial manufacture.

Local construction will develop in several steps:

1. **The assembly of imported kits;**
2. **Partial manufacture, except cylinder and gear case, by using cutting, punching, drilling and welding jigs; and**
3. **Total manufacture, except some elements made of high-quality steel.**

Theoretically, local manufacturing offers various advantages such as reduced profit margins to retailers and transport costs (100 kits in one container instead of 22 Votex threshers, etc.), but also some drawbacks (quality of construction and employed materials, adverse taxation and customs regulations, etc.).

Training Needs

In most developing countries, mechanization is far removed from traditional practices and its acceptance is a delicate matter for many farmers. Accordingly, training is a key element in the successful adoption of engine-powered machines by farmers.

Appropriate training of several types is required:

- **farmers need to be informed about how credit schemes to purchase equipment function;**
- **then they need to be made aware of the conditions suitable for harvesting and threshing which will reduce the costs of these operations and improve the quality of the product obtained;**
- **farmers require training on the management of equipment: while operators and**

mechanics need to learn about the maintenance and running of equipment;
- management staff will need training in work organization, projecting running costs, and maintaining operational accounts;

This training should be complemented by supplying information on, and demonstrating, new harvesting, threshing and cleaning equipment to farmers so as to increase their awareness of the range of machines available.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Evaluation of costs

Contents - Previous - Next

Size of Investments

Agricultural practices in industrialized countries have become complex and almost completely mechanized. In contrast, in developing countries, only some operations are

mechanized while others continue to be manual or use animal-drawn implements.

The scale of mechanisation depends on the type of farm and working methods. Thus, the size of investment varies greatly from one situation to another: assuming a given value of 1 for a pedal-operated thresher, it is between 10 and 60 for a power-driven unit and between 60 and 300 for a combine harvester.

Accordingly, if a pedal-operated thresher can be purchased by a farmer with a 2 to 3 hectare farm, a powered unit or a combine harvester can be purchased only by groups of farmers or private contractors provided that financial means (agricultural credit, technical aid, etc.) are made available. Lastly, the choice of equipment must be justified economically, cost-effective, and capable of increasing work productivity.

The same consideration applies to the different harvesting and cleaning machines. In addition, prior to any investment the total operating cost of the equipment must be estimated.

Calculation of Operating Costs

Theoretically, the costs of mechanized operations are easily calculated when all the

expenses involved are known. This is not always the case in developing countries.

(i) Estimated operating cost

The cost of using farm machinery is generally calculated as a cost per hour. This provides useful information for deciding whether to purchase equipment, the type of machine to be selected and the renting rates to be applied in case of collective use of the equipment.

Such estimates are necessary for loan companies, dealers selling on a credit basis or agencies funding large-scale investment operations.

Fixed costs

These are independent of how much the equipment is used per year. They include the interest on capital (generally at the rate applied by local companies on medium-term loans to farmers), possible taxes, levies and shelter charges, and also insurance premiums if any.

In developing countries, only interest on the capital invested (return on tied-up capital) is considered. Insurance is taken into account only for the purchase of large equipment on a credit basis (a requirement of the loan company). There are very few farmers or

farmers' groups who invest in buildings to shelter their equipment.

Rates usually applied are as follows:

- **capital interest (half of the average rate applied by the loan company),**
- **insurances: fire, third-party claim (0.5 to 1% of the purchase price),**
- **shelter (0.5 to 1% of the purchase price),**
- **sales tax, duty, vehicle licence, etc.**

Costs variable under certain conditions

These include depreciation, and repair charges for the equipment.

The cost of depreciation is the original cost distributed over the estimated useful life of the equipment in order to recover the capital required for its replacement.

When the expected annual hours of use are higher than the ratio of depreciation period in hours to the number of years of use, depreciation must be charged to variable costs. Below this value, it is charged to fixed costs.

In developing countries, depreciation as regards the purchase price (resale value supposed nil) also includes transport, handling, installation and starting up costs.

The depreciation period is expressed as a quantity of work (hours or hectares) and as a number of years. For a loan company such value must never be below the life of the loan granted.

Repair charges include the costs of labour and spare parts. They are generally related to the purchase value using coefficients calculated from surveys among manufacturers and repairers in industrialized countries. The same coefficients are used in developing countries, because relevant information concerning them is rather scarce: the costs of spare parts may be higher, but this is compensated for by the lower cost of labour.

Table 4.1. Estimated useful life and repair coefficients for some agricultural machines.

Equipment	Depreciation		Repair coefficients
	Years	Hours	
Wheeled tractor	6	6000	0.5
Harvester	5	2000	0.5
Thresher	10	5000	0.7
Combine harvester	6	3500	1

Note: These figures are only indicative and are subject to high variation

depending upon how the equipment is used.

Actually variable costs

These costs are proportional to the annual working time; they include the costs of fuel, lubricants, operation and maintenance.

Fuel consumption is expressed as: O.191/hp/hour for petrol engines and 0.121/hp/hour for diesel engines.

Coefficients must be adjusted according to the nature of the work undertaken by the equipment when in operation. For example, in Senegal an average consumption of 101/h, travel time included, has been recorded for 123hp combine harvesters (i.e. 0.081/hp/hr) and 101/hr for 100hp tractors (i.e. 0.101/hp/hr) with offset attachments for tillage. Such values must be used with care because they vary according to the work performed (engine power required) and the method of recording work time - see (ii) below. For more accuracy they can be easily verified in the field for different types of work.

Lubricant consumption is calculated from the engine consumption. For tractors and combine harvesters, oil changes for the gearbox, axle and hydraulic system must be

taken into account. Average values can be given as follows:

- **2.51/1001 of fuel for engines,**
- **4.51/1001 of fuel for tractors and combines**

Labour costs (operator. mechanic 'equipment manager' etc.! and supplementary expenses are estimated according to local wages (on an hourly, monthly or piece-work basis) to which must be added travel costs and sundry expenses (transport, maintenance supplies, close support vehicle, etc.).

In many developing countries labour costs and sundry expenses may be high: e.g. in the Senegal river valley 5 workers (1 operator, 1 apprentice, 1 'pointeur', 1 mechanic and 1 manager) plus one permanent support car are required for a combine harvester.

(ii) Observation on some elements of calculation

Depreciation is the key factor which determines whether mechanization projects can be repeated or sustained. Many such projects have disappeared because they were unable to incorporate sufficient reserves for amortizement.

Efforts to evade such problems include:

- **systematically borrowing the capital required for replacing the equipment and repaying the loan plus interest; that is coping with amortization without taking account of technical depreciation;**
- **settling the loan and partially allowing for technical depreciation; thus making part downpayment possible when the equipment is replaced.**

Estimating the annual working time is of upmost importance. For a tractor one generally allows 1000 working hours. The basic factors used for calculating the expected working time are (a) the time required for each operation with the equipment concerned, and (b) the area worked.

The stock of spare parts must be carefully examined because it corresponds to locked-up funds. It is composed according to the distance from suppliers, the size and features of the equipment pool, and the working conditions of the machines. Suppliers' lists must be adapted to local requirements.

The operating cost per hour of farm machinery permits the cost of the corresponding cultural operation to be determined. This will vary according to the time required for the operation, equipment used, working conditions, skill of the work force, and the distance of the working site.

The efficiency of the equipment is the time required for carrying out the work with it. The 'theoretical' efficiency is the capacity per hour derived from the technical specifications of the machine concerned; the 'actual' efficiency is expressed as working time in the field; and the 'practical' efficiency is the working time which also includes time for stoppages, turning, making adjustments, etc.

In the Senegal delta region, for example, the theoretical efficiency of a combine harvester is 1 hour per hectare (4t/hr for a 4t/ha crop); with a travelling speed of 2.2km per hour for an actual working width of 3.9m (cutter bar 4.2m wide), its actual output is 1 hour and 30 minutes per hectare, while its practical output is 2 hours and 30 minutes per hectare when time for travel, hopper emptying, etc., are included.

(iii) Actual operating cost

The actual operating cost can be determined after an operation, a campaign or at the conclusion of the pay out period. Some aspects must not be omitted, such as repair costs increasing as the equipment gets older, and the market value of actual expenses when the currency used is not stable.

The actual operating cost determined at the start of actual expenditure assumes value only in terms of the references in which it was established. The method of calculation is

the same as that used for estimating costs (see above), but employs data actually recorded during the reference period. Such data must be written down in the log-book and 'monitoring book'.

The log-book is kept with the equipment everywhere it goes; it is used to record the following data:

- **operations performed, i.e. type and features (surface area, weight, distance, etc.), work duration;**
- **lubricant and fuel consumptions;**
- **repairs and maintenance (time and products required).**

The monitoring book is kept at the farm and records the history of the machine; it must comprise:

- **general data such as the purchase date and price, commissioning costs, value of the stock of spare parts, supplier address, etc.,**
- **the work performed per campaign (or per year) and working hours;**
- **the expenses and receipts per campaign (or per year) ie, repairs, fuels, lubricants, labour, sundries, receipts from custom services, etc.**

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

References

Contents - Previous - Next

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Introduction

Contents - Previous - Next

There is an essential need to dry grain quickly and effectively after harvest and before storage to retain maximum quality, to attain a moisture content sufficiently low to minimise infestation by insects and microorganisms (bacteria, fungi, etc.), and to prevent germination.

Wherever possible, it is traditional to harvest most grain crops during a dry period or season and simple drying methods such as sun drying are adequate. However, maturity of the crop does not always coincide with a suitably dry period. Furthermore, the introduction of high-yielding varieties, irrigation, and improved farming practices has led to the need for alternative drying practices to cope with the increased production, and grain harvested during the wet season as a result of multi-cropping.

Natural methods of drying make use of exposure of the wet grain to the sun and wind. Artificial dryers employ the application of heat from combustion of fossil fuels and biomass resources, directly or indirectly, and in both natural and forced convection systems. Mechanical dryers, long used in developed countries, are finding increased application as farming and grain handling systems develop.

Contents - Previous - Next

Drying principles and general considerations

Drying Mechanisms

In the process of drying heat is necessary to evaporate moisture from the grain and a flow of air is needed to carry away the evaporated moisture. There are two basic mechanisms involved in the drying process; the migration of moisture from the interior of an individual grain to the surface, and the evaporation of moisture from the surface to the surrounding air. The rate of drying is determined by the moisture content and the temperature of the grain and the temperature, the (relative) humidity and the velocity of the air in contact with the grain.

Figure 5.1 (see Figure 5.1. Drying and Drying Rate Curves.) demonstrates the drying of a single layer of grain exposed to a constant flow of air. The moisture content falls rapidly at first but as the grain loses moisture the rate of drying slows. In general the drying rate decreases with moisture content, increases with increase in air temperature

or decreases with increase in air humidity. At very low air flows increasing the velocity causes faster drying but at greater velocities the effect is minimal indicating that moisture diffusion within the grain is the controlling mechanism.

Grains are hydroscopic and will lose or gain moisture until equilibrium is reached with the surrounding air. The equilibrium moisture content (EMC) is dependent on the relative humidity and the temperature of the air; EMCs for a range of grains are shown in Table 5.1 (see Table 5.1 Grain Equilibrium Moisture Contents).

The relationship between EMC, relative humidity and temperature for many grains has been modelled by numerous researchers; the results of which have been summarized by Brooker et al. (1974).

It is very important to appreciate the practical significance of the EMC. Under no circumstances is it possible to dry to a moisture content lower than the EMC associated with the temperature and humidity of the drying air; for example, the data in Table 5.1 show that paddy can only dry to a moisture content of 16.7% when exposed to air at 25C and 90% relative humidity. If paddy at a moisture content less than 16.7% is required then either the temperature of the drying air has to be increased or its humidity reduced.

The drying of grains in thin layers where each and every kernel is fully exposed to the drying air can be represented in the form:

MR = f(T, h, t); (1)

where $MR = \frac{MC - MC_e}{MC_o - MC_e}$ **(the moisture ratio);**

MC is the moisture content of the grain at any level and at any time, % dry basis (%db);

MC_e is the equilibrium moisture content (%db);

MC_o is the initial moisture content of the wet grain (%db);

T is the air temperature (C);

h is the air relative humidity; and

t is the drying time.

Empirical data have been used to determine mathematical approximations of the relationship between drying rate and air conditions. Relationships for many grains have been summarized by Brook & Foster (1981). For example, a thin layer equation for paddy (Teter 1987) is:

$MR = \exp.(-X * t^{Y})$; (2)

where $X = 0.026 - 0.0045h + 0.01215T$; and

$Y = 0.013362 + 0.194h - 0.000177h^2 + 0.009468T$,

with h expressed as a percentage, and T in C.

In the drying of grain in a deep bed, whilst individual kernels may all be losing moisture at different rates, the overall drying rate will remain constant for a long period. The air absorbs moisture as it moves through the bed until it becomes effectively saturated and moves through the remaining layers of grain without effecting further drying. Figure 5.2A (see Figure 5.2. Drying Zone in Fixed-bed Drying.) shows the three zones present within a thick drying bed at an intermediate time within the drying operation. Drying takes place within a discrete zone, the size of which depends on the moisture content of the grain and the temperature, humidity and velocity of the air. Below the drying zone

is the dried zone where the grain is in equilibrium with the air. Above the drying zone is the un-dried zone wherein the grain remains unchanged from its initial condition. In a shallow bed as in Figure 5.2B the drying zone is thicker than the bed depth and drying would occur initially throughout the bed.

The change in temperature and humidity of air as it moves through a bed of grain depends on the rate at which moisture is being evaporated from each kernel as an individually exposed element. Knowledge of the effect of grain moisture content, other grain properties, the temperature, humidity and flow rate of the air upon fully exposed kernels is essential to an understanding of how drying would proceed within a bed.

Unfortunately no theory has been developed that accurately and practically describes the thin layer drying rate. As described above many empirical relationships have been established and these have to be used in prediction of drying time (see below). Accurate prediction of drying time is further inhibited by the variability of key factors encountered in practice, particularly so for the simple drying systems that are the most appropriate for use in developing countries. For example the moisture content of individual grains is likely to vary considerably within a batch and in the case of drying with a heater of constant heat output the temperature of the drying air will vary with changes in ambient air temperature.

Air Properties

The properties of the air flowing around the drying grain are a major factor in determining the rate of removal of moisture. The capacity of air to remove moisture is principally dependent upon its initial temperature and humidity; the greater the temperature and lower the humidity the greater the moisture removal capacity of the air.

The relationship between temperature, humidity and other thermodynamic properties is represented by a psychrometric chart as shown in Figure 5.3 (see Figure 5.3. CIBS Psychrometric Chart.). It is important to appreciate the difference between the absolute humidity and relative humidity of air. The absolute humidity is the moisture content of the air (mass of water per unit mass of air) whereas the relative humidity is the ratio, expressed as a percentage, of the moisture content of the air at a specified temperature to the moisture content of air if it were saturated at that temperature.

The changes in air conditions when air is heated and then passed through a bed of moist grain are shown in Figure 5.4 (see Figure 5.4. Representation of Drying process.). The heating of air from temperature TA to TB is represented by the line AB. During

heating the absolute humidity remains constant at HA whereas the relative humidity falls from hA to hB. As air moves through the grain bed it absorbs moisture. Under (hypothetical) adiabatic drying sensible heat in the air is converted to latent head and the change in air conditions is represented along a line of constant enthalpy, BC. The air will have increased in both absolute humidity, Hc, and relative humidity, hc, but fallen in temperature, Tc. The absorption of moisture by the air would be the difference between the absolute humidities at C and B. (HC-HA)

If unheated air was passed through the bed the drying process would be represented along the line AD. Assuming that the air at D was at the same relative humidity, hc, as the heated air at C then the absorbed moisture would be (HD-HA), considerably less than that absorbed by the heated air (HC-HA)

Physical Properties of Grain

Comprehensive data on the numerous physical and thermal properties of grain are available in texts such as Brooker et al. (1974) and Brook & Foster (1981).

Moisture Content.

Convention dictates that moisture contents of grains are usually measured on a wet basis, ie the mass of moisture per unit mass of wet grain and written as X % (wb). The alternative measure refers to the measurement on a dry basis (X%(db)) which is the mass of moisture per unit mass of completely dry grain. Conversion between the two measurements is shown in Table 5.2. All moisture contents given in the text are on a wet weight basis, unless otherwise stated. Table 5.3 (see Table 5.3. Moisture loss during drying.) shows the mass of water lost from wet grain during drying for a range of initial and final moisture contents.

Table 5.2. Conversion of Moisture Contents.

Wet Basis %	Dry Basis %
10.0	11.0
11.0	12.3
12.0	13.6
13.0	15.0
14.0	16.3
15.0	17.6
16.0	19.0

17.0	20.5
18.0	21.9
19.0	23.5
20.0	25.0
21.0	26.5
22.0	28.2
23.0	29.9
24.0	31.6
25.0	33.3
26.0	35.1
27.0	37.0
28.0	38.9
29.0	40.8
30.0	42.8

Bulk Density.

The bulk density of grain is the weight per unit volume. Moisture content has an appreciable effect on the bulk density (see Chapter 3 for more detail).

Resistance to Air Flow.

The energy required to force air through a bed of grain is dependent on the air flow, the grain depth and physical properties of the grain such as surface and shape factors, the kernel size distribution, moisture content, and the quantity and nature of contamination, stones, straw, weeds etc. The relation between air flow and the pressure drop generated across the bed for selected grains is illustrated in Figure 5.5 (see Figure 5.5. Resistance of Grains and Seeds to Air Flow.). The data generally refer to clean and dry grain and correction factors of up to 1.4 are used for very wet and dirty grain (Teter 1987).

Latent Heat of Vaporization. Energy in the form of heat must be supplied to evaporate moisture from the grain. The latent heat of vaporization, Lh, for a grain depends on its moisture content and temperature and is appreciably greater than the latent heat of evaporation of water. The latent heat of vaporization for paddy at selected moisture contents and temperatures is shown in Table 5.4 (see Table 5.4. Latent Heat of Vaporization of Paddy.). Data for other grains have been reported by Brooker et al. (1974)

Estimation of Drying Time

A basic design procedure for the field worker is best illustrated for the design of a batch type dryer although the principles can be applied to a certain extent in the design of continuous multi-stage systems.

Assumed ambient air conditions are a dry bulb temperature of Ta and a relative humidity of RHa; from the psychrometric chart the wet bulb temperature, Twa, the enthalpy, Ha, and the absolute humidity ha can be derived. The air is heated to a selected safe drying temperature, Tb, thereby raising the enthalpy of the air to Hb.

The wet grain of equivalent bone-dry mass G has a moisture content of MCw%(db) and is to be dried to a moisture content of MCd%. A mass air flow of V is available.

The moisture, M, to be removed,

$$M = G * (MC_w - MC_d); (3)$$

It is assumed that throughout the drying period the air will exhaust from the bed at a constant wet bulb temperature and in equilibrium with the uppermost layers of grain.

Initially the exhaust air will be in equilibrium with grain at MCw moisture and finally in equilibrium with grain at MCd moisture. By superimposing equilibrium moisture content data on to the psychrometric chart for the initial and final moisture contents the humidity of the exhaust air at the beginning and end of drying can be found. An average of the initial and final exhaust air relative humidities, hea is taken for calculation of drying time, td:

$$t_d = \frac{M}{V * (h_a - h_{ea})} \text{; (4)}$$

An alternative, more complex but more accurate method for the estimation of drying performance is the technique based on dimensionless drying curves as initially developed by Hukill (1947). The methodology permits the estimation of the moisture content of grain at any level within the bed at any time after initiation of drying. It can be used for any grain for which EMC and thin layer drying data are available as is the case for most cereal grains.

The methodology involves the use of bulk drying curves as depicted in Figure 5.6 and calculation of three parameters, moisture ratio, time unit and depth factor.

The moisture ratio, MR is calculated from Equation 1:

$$MR = \frac{MC - MC_e}{MC_o - MC_e}$$

The time unit, Y, is calculated using the equation:

$$Y = \frac{t_d}{t_{0.5}}$$

where t0.5 is the half-response time, the time required for fully exposed grain to reach a moisture ratio of 0.5 under the drying air conditions employed. It can be calculated from the thin layer drying equations as in Equation 1 with MR assigned a value of 0.5.

The depth factor, D, is defined as the depth of the bed that contains the mass of grain, DM, that can be dried from the initial moisture ratio MR = 1 to a final moisture ratio MR = 0 with the sensible heat available over the period of one half-response time as the air cools to its wet bulb temperature. DM is calculated thus:

$$DM = \frac{V * C_p * t_{0.5} * (T_{dh} - T_{wa})}{L_h * (MC_o - MC_e)}$$ **; (6)**

where C_p is the specific heat of air. The number of depth factors within the bed is found from the expression:

$$D = d * \frac{G}{DM}$$ **; (7)**

where d is the bed depth.

The curves in Figure 5.6 are represented by the equation:

$$MR = \frac{2^D}{2^D + 2^Y - 1}$$ **; (8)**

By transposing the drying conditions to these units and using either Figure 5.6 (see Figure 5.6. Dimensionless Drying Rate Curves.) or Equation 8 it is possible to predict when any layer within the bed reaches a desired moisture content.

More rigorous approaches to the design of drying systems have been developed. These include the methods based on thin layer drying equations described by Brook & Foster (1981) and Brooker et al. (1974). Many of these have been developed into sophisticated

simulation techniques (Brooker et al. 1974).

The drying conditions for specific grains and situations are many and varied. Drying will take place under any conditions where grain is exposed to a flow of unsaturated air. Very fast drying can be accomplished using large volumes of high temperature air but, if carried through to completion, is likely to be inefficient in energy use and liable to damage the grain by over-heating and/or over-drying. Conversely slow drying, as in sun drying in inclement weather, provides conditions for continued respiration and deterioration of the grain leading to both quantitative and qualitative losses and the growth of moulds.

Drying Efficiency

The efficiency of the drying operation is an important factor in the assessment and selection of the optimum dryer for a particular task. There are three groups of factors affecting drying efficiency:

* those related to the environment, in particular, ambient air conditions;
* those specific to the crop;

*** those specific to the design and operation of the dryer.**

There are several different ways of expressing the efficiency of drying, of which the sensible heat utilization efficiency (SHUE), the fuel efficiency, and the drying efficiency are the most useful.

The SHUE takes into account the sensible heat attributable to the condition of the ambient air and any heat added to the air by the fan as well as the heat supplied by combustion of the fuel. It is defined as:

$$SHUE = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Total Sensible Heat in the Drying Air}}$$

The fuel efficiency is based only on the heat available from the fuel:

$$\text{Fuel Efficiency} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Heat Supplied from Fuel}}$$

It can be appreciated that the fuel efficiency would be significantly different for the operation of the same dryer at two locations with widely different ambient conditions. With low temperature drying, particularly in dry climates, the heat supplied from the

fuel may be less than half of the total sensible heat and the fuel efficiency may exceed 100%. Direct comparison of the performance of dryers at separate locations is not possible using the fuel efficiency.

The drying efficiency, defined as:

$$\text{Drying Efficiency} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Heat Available for Moisture Removal}}$$

is the expression to be used for evaluation of dryer designs or comparison between dryers, since it is a measurement of the degree of utilization of the sensible heat in the drying air.

Foster (1973) evaluated the fuel and drying efficiencies of several types of dryers used with maize. Over a wide range of conditions, continuous-flow dryers were found to have a fuel efficiency of 38% and a drying efficiency of 51%, batch dryers 42% and 58%, dryeration 61% and 78%, and two-stage drying, 60% and 79%, respectively.

Effect of Drying on Grain Quality

The drying operation must not be considered as merely the removal of moisture since there are many quality factors that can be adversely affected by incorrect selection of drying conditions and equipment. The desirable properties of high-quality grains include:

- **low and uniform moisture content;**
- **minimal proportion of broken and damaged grains;**
- **low susceptibility to subsequent breakage;**
- **high viability;**
- **low mould counts;**
- **high nutritive value;**
- **consumer acceptability of appearance and organoleptic properties.**

Moisture Content. It is essential that the grain after drying is at a moisture content suitable for storage. As discussed the desired moisture content will depend on the type of grain, duration of storage, and the storage conditions available. It is also important that the drying operation is carried out to minimize the range of moisture levels in a batch of dried grain. Portions of under-dried grain can lead to heating and deterioration.

Stress Cracking and Broken Grains. Drying with heated air or excessive exposure to sun

can raise the internal kernel temperature to such a level that the endosperm cracks. The extent of stress cracking is related to the rate of drying. Rapid cooling of grain can also contribute to stress crack development.

Nutritive Value. **Grain constituents such as proteins, sugars and gluten may be adversely affected when the grain attains excessive temperatures. The feeding value of grains can be lowered if inadequately dried.**

Grain Viability. **Seed grain requires a high proportion of individual grains with germination properties. The viability of grain is directly linked to the temperature attained by grains during drying (Kreyger 1972).**

Mould Growth. **Many changes in grain quality are linked to the growth of moulds and other microorganisms. The rate of development of microorganism is dependent on the grain moisture content, grain temperature, and the degree of physical damage to individual grains. Mould growth causes damage to individual grains resulting in a reduction in value. Under certain circumstances mycotoxin development can be a particular hazard.**

Appearance and Organoleptic Properties. **The colour and appearance as perceived by the customer and/or consumer. For example, the colour of milled rice can be adversely**

affected if the paddy is dried with direct heated dryers with poorly maintained or operated burners or furnaces.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Natural and solar drying

Contents - Previous - Next

Sun Drying

The traditional practice of grain drying is to spread crop on the ground, thus exposing it to the effects of sun, wind and rain. The logic of this is inescapable; the sun supplies an appreciable and inexhaustible source of heat to evaporate moisture from the grain, and the velocity of the wind to remove the evaporated moisture is, in many locations, at least the equivalent of the airflow produced in a mechanical dryer. In tropical countries, for at least several months of the year, the mean level of insolation upon the ground is more than 0.5 kW/m (measured as a mean over the hours of daylight). The heat

available therefore, assuming a 12 hour day, is 21.6 MJ/m, a quantity theoretically sufficient to evaporate 9 kg of water.

Even today, sun drying of grain remains the most common drying method in tropical developing countries. It is first employed when the crop is standing in the field prior to harvest; maize cobs may be left on the standing plant for several weeks after attaining maturity. Although not requiring labour or other inputs field drying may render the grain subject to insect infestation and mould growth, prevent the land being prepared for the next crop and is vulnerable to theft and damage from animals. Drying in the field may also be carried out after harvest with the harvested plants laid in stacks with the grain, maize cobs or panicles raised above the ground and exposed directly to the sun. Data on the drying of paddy in the field has been gathered by Angledette (1962) and Mendoza et al. (1982).

Drying on flat exposed surfaces is the most common way of drying grain after harvesting and threshing. For drying small amounts on the farm grain may be spread on any convenient area of land. Contamination with dirt cannot be easily avoided with this method and cleaner dried grain can be obtained by drying the grain on plastic sheets, preferably black.

Purpose-constructed drying floors are commonly used where there is a need to dry

large quantities of grain during the season, e.g. at most rice mills. The floors are usually made of concrete or brick, these materials presenting a relatively smooth and hardwearing surface. Floors should be constructed to withstand the movement of vehicles and sloped or channelled to hasten the runoff of rainwater. The paddy is spread in a thin layer on the floors and raked at intervals, preferably 7-8 times daily, to facilitate even drying. At night the paddy is heaped into rows and covered with sheeting.

Work by Chancellor (1965) and Soetoyo & Soemardi (1979) has demonstrated that paddy can be dried from 24-26% moisture to 14% moisture at depths of 50-100 mm at a rate of 3.3 kg/m.h for stirred paddy and 1.9 kg/m.h for unstirred paddy. The grain can reach temperatures as high as 60C under clear skies and the rate of drying can be extremely high. Under these circumstances kernel cracking and loss of head rice can be appreciable, particularly if paddy is dried to below 14% moisture. Covering the paddy around midday may be beneficial under particularly hot and sunny conditions. Experiments at IRRI have shown that cracking can be reduced by 25% if paddy is dried in the shade but the benefit from the improved quality is generally more than offset by the longer drying times and hence reduced throughput and increased costs.

In rainy weather, even though drying will be slow, every effort should be made to prevent wet freshly-harvested paddy from over-heating with deterioration in quality by

spreading on floors rather than let it remain in heaps and sacks. Under these conditions or when there is great demand for drying space paddy can be dried to 17-18% moisture and then temporarily stored for 15-30 days before final drying.

Crib Drying

Compared with paddy, cob maize can remain at relatively high moisture contents, in excess of 20% with natural ventilation for considerably longer periods, from one to three months. The maize crib in its many forms acts as both a dryer and a storage structure. The rate and uniformity of drying are controlled by the relative humidity of the air and the ease with which air can pass through the bed of cobs. The degree of movement of air through the loaded crib is largely attributable to the width of the crib; research in West Africa has shown that crib widths should not exceed 0.6 m (Anon 1980). Guide-lines on crib design, construction and operation have been prepared by Bodholt (1985). Further information on crib design is available in Chapter 6.

Solar Dryers

An improved technology in utilizing solar energy for drying grain is the use of solar dryers where the air is heated in a solar collector and then passed through beds of grain. There are two basic types of solar dryer appropriate for use with grain: natural convection dryers where the air flow is induced by thermal gradients; and forced convection dryers wherein air is forced through a solar collector and the grain bed by a fan (Brenndorfer et al. 1985).

Natural convection dryers are generally of a size appropriate for on-farm use. A design that has undergone considerable development by the Asian Institute of Technology (AIT) in Bangkok, Thailand (Boothumjinda et al. 1983; Exell 1980) is shown in Figure 5.7 (see [Figure 5.7. Natural Convection Solar Dryer.]). The dryer consists of three components, a solar collector, the drying bin and a solar chimney. For a one tonne capacity dryer the collector is 4.5 m long and 7.0 m wide with the solar absorber base of burnt rice husks or black plastic sheet covered with clear plastic sheet. The drying bin is 1.0 m long and 7.0 m wide with a base of perforated steel or bamboo matting.

The solar chimney provides a column of warm air that increases the thermal draught of air through the dryer. It is made of a bamboo frame covered with black plastic sheet. In Thailand paddy was dried from 20% moisture to 13% moisture in 1-2 days and the rice quality was appreciably greater than that from sun dried paddy. A disadvantage of the dryer is its high structural profile which poses stability problems in windy conditions,

and the need to replace the plastic sheet every 1-2 years. A smaller (100 kg capacity) and simpler version of this type of dryer has also been developed (Exell & Kornsakoo 1978; Oosthuizen & Sheriff 1988) as shown in Figure 5.8 (see Figure 5.8. Small scale Solar Paddy Dryer.).

The forced convection solar dryer can be considered as a conventional mechanical drying system in which air is forced through a bed of grain but the air is heated by a flat plate solar collector rather than by more conventional means. Several types of flat plate collector are shown in Figure 5.9 (see Figure 5.9. Flat Plate Collectors.).

The performance of a flat plate collector can be quantified by calculation of the collection efficiency; the ratio of the heat gathered by the collector to the insolation incident on its surface. The collection efficiency is a function of the air velocity through the collector, the geometry of the air duct, the absorptivity of the absorption surface, and the transmissivity of the cover(s).

Considerable work has been undertaken in developing low-cost and efficient solar collectors for crop drying applications (Brenndorfer et al. 1985; Davidson 1980). The simplest type of collector is the bare plate (Figure 5.9) which consists simply of an air duct the uppermost surface of which acts as the absorber plate. The covered plate collector in its many forms utilises a translucent cover above the absorber plate; four

versions of this type are also shown in Figure 5.9. Compared with the bare plate collector higher collection efficiencies are obtainable with covered plate collectors but at the expense of increased complexity and cost.

The optimum design suitable for use at farms and mills in developing countries is probably the bare plate collector which is capable of operating at a collection efficiency of 40-50% with an airflow of 0.10 kg/s.m. With typical insolation levels in many tropical countries of the order of 0.5 kW/m such collectors are capable of providing mean daily elevations in air temperature of 5-10C with heat outputs of 0.20-0.25 kW/m of collector area. Covered plate collectors, operating at efficiencies of 60-70%, are capable of providing air temperature elevations of 10-30C but at a lower airflow.

A major advantage of the bare plate collector is that it can be easily incorporated into the roof of a dryer or storage building. Corrugated iron is a popular and inexpensive roofing material in many areas and when painted black forms an excellent solar absorber. A false ceiling can be fixed to the roof joists so forming a shallow duct running the length of the building and easily connected to a fan via ducting at one end of the building. The heat available from the collector is weather dependent and consideration should therefore be given as to whether solar energy should be the sole source for heating the air or a supplement to more conventional heating systems.

Research and performance studies on forced convection solar dryers have been reported by Bose (1978), Muthuveerappan et al. (1978) and Soponronnarit et al. (1986). Damardjati et al. (1991) have described the performance in Indonesia of a 10 tonne/day paddy dryer (Figure 5.10. Forced Convection Solar Paddy Dryer.) that incorporated a 225 m2 roof-type collector together with a moisture extraction unit (MEW, see below). Heat output from the collector averaged 60 kW over daylight hours and that from the MEU 35 kW with a mean daily elevation in air temperature of 7-9C.

Mechanical dryers

Batch-in-Bin Dryers

The small capacity version of the batch-in-bin dryer, otherwise known as the flat-bed dryer, has been developed for farm- or village-level use. Its capacity is of the order of

1-3 tonnes/day with drying times of 6-12 hours.

As represented in Figure 5.11 (see [Figure 5. 11. Flat Bed Dryer.]) the flat-bed dryer is simple to construct using easily available and inexpensive materials and easy to operate with unskilled labour. The walls of the drying bin can be constructed of wood, brick or metal. The floor of the drying chamber is preferably made from fine wire mesh, suitably supported, or perforated metal. If these are not available then sacking spread over a coarser but stronger wire mesh can be used. To facilitate an even airflow through the bed the length of the drying chamber should be 2-3 times the width. The height of the plenum chamber is of the order of 0.3 m. Unloading ports can be fitted at intervals in the walls of the drying chamber.

In order to prevent excessive moisture gradients through the bed, the depth of grain in the bin is relatively shallow, 0.4-0.7 m. and the air velocity is usually of the order of 0.08-0.15 m/s for maize and 0.15-0.25 m/s for paddy. The temperature of the air is selected according to the desired safe storage moisture content of the grain. For the drying of paddy in tropical areas an air temperature of 40-45C is usually used, with a heater capable of raising the air temperature by 10-15C. With such bed depths and air velocities the pressure drop over the bed is relatively low, 250-500 Pa, and therefore simple and inexpensive axial-flow fans can be used. Typically power requirements are 1.5-2.5 kW per tonne of grain for a belt-driven fan powered by a petrol or diesel

engine.

Operation of flat-bed dryers invariably results in a moisture gradient between the lower layers and the higher layers of the bed (Soemangat et al. 1973). This problem can be reduced by careful selection of drying temperature and airflow conditions but, even so, gradients of 34% moisture are to be expected. Turning of the grain in flat-bed dryers at intervals can alleviate the problem but this extends the drying time and requires additional labour.

The flat-bed dryer is easily loaded from sacks by hand. However, unloading the dried grain into sacks can be time- and labour-consuming; placement of the drying bin on a tilting frame has been investigated (Wimberly 1983) but this incurs additional costs.

Dryers of this type have been developed in many countries and designs are available from the University of the Philippines at Los Baos (UPLB), Los Baos, Philippines and the International Rice Research Institute (IRRI), Manila, Philippines.

IRRI have also developed a vertical batch-in-bin dryer which operates more efficiently than the flat-bed dryer. It differs from the latter in that the airflows horizontally through the bed on either side of the plenum chamber and exhausts through slatted sides. The bin is easily unloaded by removing the slats. Details are available from IRRI.

Both direct and indirect heaters can be used with the flat-bed dryer (see below). Solar air heating (see above) can also be an option. The waste heat from the engine used to power the fan can be used (Esmay & Hall 1973; Soemangat e' al. 1973; Teter 1987). Heating of the air by 5-10C using waste engine heat is possible but the engine exhaust gases should not be drawn through the grain; the exhaust gases should be ducted outside the housing around the engine. A development of this principle is the moisture extraction unit (MEW) in which the fan is directly driven by the engine and the air is drawn over and around the engine block and exhaust pipe.

Large capacity batch-in-bin (or in-store) dryers can be used in cooler dryer areas. The advantage of this technique is that the bin is used for both drying and storage with savings in both capital and operating costs. With heated air at a temperature of 40-45 C, bed depths of 2-3 m can be used with air velocities through the bed not exceeding 0.08 m/s. Since drying times to achieve reductions in moisture content of 5-10% can be of the order of 20-40 days, this method should not be used in humid areas with grain of moisture contents greater than 18% because of the risks of sprouting and mould growth in the upper layers of the bed.

Large batch-in-bin dryers are usually round or rectangular and range in capacity from ten to several hundred tonnes. With large bins, air distribution ducts at the base of the bin are used rather than a plenum chamber. The ducts can be semi-circular, rectangular

or triangular as shown in Figure 5.12 (see <u>Figure 5.12. Air ducts for large Batch-in-Bin Dryer.</u>). To ensure good air distribution through the bed, ducts should be spaced from each other at a distance of half the depth of grain and one quarter the depth from the end and side walls. Air velocity through the ducts should not exceed 5 m/s because of pressure drop factors. More than one fan can be used to provide the airflow required. Detailed information on duct design and airflow distribution is presented by Brooker et al. (1974).

In-bin layered drying with ambient air can be performed with confidence in locations where the relative humidity of the air is less than about 70%. An initial layer of grain, 0.6-0.9 m deep, is loaded into a storage bin, 5-10 m deep, and further layers are added as drying proceeds. Over-drying of the grain is minimized because of the low air temperature. In the USA an airflow of 0.025-0.06 m3/s per tonne was used to dry paddy from 20% moisture to 16% moisture within 14 days when ambient temperature ranged from 18-24C (Houston 1972). Careful and skilled management is required to ensure that each layer is dried before the succeeding layer is loaded into the bin.

View showing three different forms of Air Duct: Rectangular, Triangular, and SemiCircular. Dimensions are in relationship to grain depth D.

Some success has been reported in Indonesia for the drying of paddy from 18%

moisture to 13% moisture (Gracey 1978; Renwick & Zubaidy 1983). The latter also demonstrated that field-wet paddy (24% moisture) could be dried safely in bulk to 18 % moisture by continuous aeration (24 in/day) with ambient air, regardless of the humidity of the air. Subsequent drying to 14% moisture or less was accomplished by drying at times of lesser humidity and with the addition of waste engine heat.

There can be a need to dry grain in sacks in certain instances: for example, at central drying facilities where farmers wish to retain access to their own grain. Stacks of sacks are laid over air distribution ducts with no need for a conventional drying bin. Drying proceeds in much the same manner as for bin drying. After use, the air distribution ducts can be dismantled easily to allow use of the building for other purposes.

Re-circulating Batch Dryers

This type of dryer avoids the problems of moisture gradients experienced with bin dryers by re-circulating the grain during drying. One version of a re-circulating batch dryer is shown in Figure 5.13 (see [Figure 5.13. Re-circulating Batch Dryer.]). The dryer is a self-contained unit with an annular drying chamber, 500 mm thick, around a central plenum chamber, a fan and heater, and a central auger for transporting the grain from

the bottom to the top. When drying is complete the grain is discharged from the top. Most dryers of this type are portable and can be moved relatively easily from farm to farm.

Air temperatures of 60-80C are employed with air flowrates of 0.9-1.6 m3/s per tonne of grain, twice that used in flat-bed dryers (Wimberly 1983). However, since the grain is only exposed to the flow of hot air for relatively short times within each cycle, too rapid drying rates are avoided and moisture distribution within individual grains is equalised during the period the grain remains in the non-drying sections at the top and bottom of the dryer. Control of the drying rate can be effected by adjusting the auger speed to regulate the flow of grain through the dryer.

Another version of a re-circulating batch dryer is rectangular with drying chambers on either side of the heater, fan and plenum chamber. Under each drying chamber are horizontal screw conveyors that collect the grain and return it to a screw auger at one end that lifts the grain to a holding section at the top. A screw conveyor in the holding section distributes the grain evenly along each drying chamber.

The capital cost of re-circulating batch dryers is considerably greater than batch-in-bin dryers (<u>Table 5.5. Dryer Specifications, Estimated Performance, and Cost for drying Freshly Harvested Field Paddy (Raw Paddy) from 20% to 14% Moisture</u>) because of

their greater complexity and incorporation of handling and conveying devices. However, throughput is greater due to the shorter drying times and the quality of the dried grain is likely to be higher. Re-circulating batch dryers require specialist skills for construction and trained operators for successful operation and therefore are not generally suitable for operation by small-scale farmers or enterprises.

Continuous-flow Dryers

Continuous-flow dryers can be considered as an extension of re-circulating batch dryers. However, rather than the grain re-circulating from bottom to top, as in the latter, the grain is removed from the bottom, in some systems, cooled, and then conveyed to tempering or storage bins. In their simplest form continuous-flow dryers have a garner (or holding) bin on top of a tall drying compartment. With some dryers a cooling section is employed below the drying compartment in which ambient air is blown through the grain. At the bottom of the dryer is the flow control section that regulates both the circulation of grain through the dryer and its discharge.

There are three categories of continuous-flow dryers based on the way in which grain is exposed to the drying air:

- **crossflow, in which the grain moves downward in a column between two perforated metal sheets while the air is forced through the grain horizontally. Dryers of this type are relatively simple and inexpensive, but, unless mixing systems are incorporated, moisture gradients are set up across the bed;**
- **counterflow, which employs a round bin with an unloading system at the base and an upward air flow. These dryers are relatively efficient since the air exhausts through the wettest grain. Bed depths of up to 3-4 m can be used;**
- **concurrent flow, which is the reverse of counterflow drying in that the air moves down through the bed. High air temperatures can be used since the air first comes into contact with wet, and sometimes cold, grain. Drying is rapid in the upper layers but slower at the bottom with some tempering action. Bed depths of at least a metre are used;**

Probably the most commonly used continuous-flow dryer is the crossflow columnar dryer, which can be classified as non-mixing and mixing types.

In one version of a non-mixing dryer (Figure 5.14. Continuous Flow Dryers.), drying takes place between two parallel screens, 150-250 mm apart on either side of the plenum chamber. The air escapes from the dryer through louvres on either side of the dryer. The flow rate of grain through the dryer is controlled by a regulator gate at the

base of the drying column. Since the grain flows plug-like through the drying section the layer of grain closer to the plenum chamber is dried by hotter and drier air than is the grain on the outside. However, mixing is effected to a fair degree when the grain is discharged and conveyed to tempering and storage bins. Air temperatures of 45-55C and airflows of 2-4 m3/s per tonne of grain are used. Flow problems can be encountered with very wet and dirty grain as the grain may clog. Teter (1987) notes that if very wet paddy is to be dried then the grain should be cleaned and also pre-dried to at least 22% moisture before a non-mixing dryer can be used.

In one design of the mixing type of continuous-flow dryer, as also shown in Figure 5.14, a baffle system facilitates the mixing of grain and avoids the development of moisture gradients across the drying bed. Higher air temperatures, 60-70C, can therefore be used without damaging the grain. Unless screens are fitted on the outside of the drying section lower airflows, 1-1.5 m3/s per tonne of grain, have to be used to avoid grain being blown out of the dryer.

Another design of this type is the LSU (Louisiana State University) dryer (Figure 5.15. Louisiana State University (LSU) Continuous Flow Dryer.). In this version the drying section consists of a vertical compartment across which rows of air channels are installed. One end of each channel is open and the other closed. Alternative rows are open to the plenum chamber and intervening rows to the exhaust section. Alternate

rows are also offset such that the channel tops divide the moving stream of grain as it descends providing considerable mixing.

Further information on continuous-flow dryers has been presented by Bakker-Arkema et al. (1982), Fontana et al. (1982) and Houston (1972). As can be appreciated from Figure 5.14 many of these dryers are large and complex structures and are usually designed and constructed by specialist firms.

Compared with batch-in-bin dryers and re-circulating batch dryers, continuous-flow dryers offer the largest drying capacity. When large volumes of wet grain are to be dried in a single site these are the types to be considered first. They are most commonly used in a multi-pass drying operation as shown in Figure 5.16 (see Figure 5.16. Large drying system using Continuous-flow Dryer, Conveying Equipment, and Tempering Bins.). Investment costs are high (Table 5.5) but because of the large throughputs operating costs per tonne can be lower than the larger batch-in-bin dryers and re-circulating dryers.

In a multi-pass drying system, continuous-flow dryers are used in association with tempering bins. During each pass through the dryer the grain is dried for 15-30 minutes with a reduction in moisture content of 1-3%. Drying at this rate sets up moisture gradients within the individual grains. After each pass the grain is held in a tempering

bin where the moisture within the kernel equalises as moisture diffuses from the interior of each kernel to the surface. The combination of rapid drying and tempering is repeated until the desired moisture content is attained. Using this procedure the actual residence time of the grain within the continuous-flow dryer is of the order of 2-3 hours to effect a 10% reduction in moisture. Selection of the number of passes is a compromise between the dryer efficiency, ie fewer passes, and grain quality, ie longer drying time. Tempering periods are usually 424 hours in duration. The tempering bins may be aerated with ambient air to cool the grain with some slight moisture removal.

It is vital that the operation of drying with tempering is carefully planned and managed to ensure maximum throughput and efficiency. This usually means that the plant is operated 24 hours a day with two or more batches of grain being dried at a time. Well trained management and staff are essential.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Drying operations

Contents - Previous - Next

Dryeration

Originally developed for use with maize, dryeration is a combination of heated air drying and aeration cooling. In this process a tempering period is employed between a high temperature drying phase and a cooling phase. Whereas less than 1% moisture is removed if cooling is carried out immediately after drying, as much as 2% moisture can be removed if the grain is cooled slowly after tempering. Damage to the grain is reduced and drying efficiency is improved through better utilization of the residual heat in the grain for moisture removal during cooling. Higher air temperatures can be used in the drying phase since the grain is not dried to such a low moisture content.

Two-Stage Drying

Two-stage or combination drying can be used to relieve pressure on drying facilities during peak periods. For example, paddy at moisture contents of less than 18% can be stored for up to 20 days without significant losses either in quantity or quality. In two-stage drying, grain is dried to an intermediate moisture content, 20% moisture for

maize, 18% moisture for paddy, as soon as possible using any of the methods described above and then dried instore to the desired final moisture content over several days or weeks with intermittent use of ambient air or air heated by 3-5C. Research with paddy in the Philippines (Tumambing & Bulaong 1986; Adamczak et al. 1986) has shown that, in addition to increasing throughput of the first stage dryers, there were substantial overall energy savings and no loss of quality compared to drying to 14% moisture in the conventional manner.

Pre-drying Aeration

Work in the Philippines has shown that wet paddy can be maintained in reasonable condition for 3-7 days when aerated with ambient air (Raspusas et al. 1978; de Castro et al. 1980). By aerating stacks of sacked paddy at a rate of 0.5 m3/s per tonne for eight hours a day, quality could be maintained for nine days during the dry season and two days during the wet season. Aerating in bulk with similar airflows maintained quality for 14 days and three days respectively (Raspusas et al. 1978). The length of time that paddy can remain in aerated storage without deterioration is dependent on the moisture content of the grain and ambient air conditions.

Drying of Parboiled Paddy

After parboiling, paddy contains about 35% moisture. During the parboiling process the starch is gelatinized which confers quite different drying properties to that of field paddy. It has been shown (Bhattacharya & Indudhara Swamy 1967) that in the drying of parboiled paddy, significant damage (ie kernel cracking) does not occur until the moisture content falls to 16%, regardless of the drying method or the rate of drying,. Cracking then occurs some time after the grain has cooled. The recommended drying procedure is to dry the parboiled paddy to 16-18% moisture as fast as facilities permit, temper it for four hours if warm or eight hours if cooled, and then dry in a second operation to 14% moisture. Air temperatures of 100-120C can be used for parboiled paddy in continuous-flow dryers.

Drying of Seed Grain

If grain is destined for use as seed then it must be dried in a manner that preserves the viability of the seed. Seed embryos are killed by temperatures greater than 40-42C and

therefore low temperature drying regimes must be used. Seed grain may be dried in any type of dryer provided that it is operated at a low temperature and preferably with greater air flowrates than generally used. It is essential that batches of grain of different varieties are not mixed in any way and therefore the dryers and associated equipment used must be designed for easy cleaning. In this respect simple flat-bed dryers are more suitable than continuous-flow dryers.

Teter (1987) noted that seed paddy can be sun dried at depths of up to 30 mm but that the final stages of drying to 12% moisture should be conducted in the shade to avoid overheating and kernel cracking. Flat-bed dryers can be used with bed depths of up to 0.3 m, air temperatures not exceeding 40C, and airflows of 1.3-1.7 m3/s per tonne of grain.

Cross-mixing between batches of different varieties can be avoided by drying in sacks in a flat-bed dryer although care must be taken in packing the loaded sacks in the dryer to ensure reasonably even distribution of airflow. Specialised tunnel dryers in which sacks or portable bins are individually placed over openings in the top of the tunnel have been developed (Teter 1987).

Contents - Previous - Next

Novel dryers and recent developments

Contents - Previous - Next

Fluid Bed Drying

This type of dryer in which individual grains are suspended and sometimes transported by air moving at high velocity, 2-3 m/s, can produce very evenly dried grain. Recent research in the Philippines (Sutherland & Ghaly 1990; Tumambing & Driscoll 1991) has indicated that the fluid bed dryer has promising potential for the rapid first-stage drying of paddy to 18% moisture in two-stage drying (see above). Paddy at a bed depth of 100 mm can be dried from 24% to 18% moisture in 15 minutes with air at 100C and a velocity of 2 m/s, with no adverse effects on quality. However, due to the high air velocities required to fluidise the paddy, power requirements for the fan are high and the thermal efficiency is low compared to conventional (fixed bed) drying. Re-cycling of the exhaust air was identified as a potential means to improve the thermal efficiency.

Conduction Drying

Work at IRRI (Stickney et al. 1983) has investigated the use of a heated floor dryer. This consisted of a metal floor heated to 50-90C by circulation of water heated by a furnace burning agricultural wastes. Paddy at depths of up to 60 mm could be dried from 22-26% moisture to 18% moisture in 1-2 hours depending on the floor temperature. Frequent raking was necessary but no parboiling effects were recorded and grain breakage was generally lower than that of sun dried paddy. This method is also considered as an option for the first (rapid-drying) stage of two-stage drying.

The Warehouse Dryer

This dryer has been developed (Jeon et al. 1984) for use with a wide range of crops including maize and paddy. Its particular feature is the use of a wind-powered vortex flow inducer as an alternative to conventionally powered fans for generating increased airflow over and around the drying grain. The flow inducer is mounted centrally on the roof of the dryer building and draws air, heated by a furnace and heat exchanger, through the drying bins or trays positioned in the middle of the dryer. The performance is governed by the velocity of the prevailing wind.

Rotary Drying

This method of drying has been researched at the IRRI in Philippines and also at the AIT in Thailand. Small dryers for farm use were developed at the IRRI as reported by Espanto et al. (1985). A directly-heated version consists of a perforated iron drum (0.6 m in diameter and 0.9 m long) mounted over a portable stove. The interior of the drum is fitted with flights to facilitate mixing and uniform heat transfer. The drum is rotated manually.

An indirect-heated dryer is constructed from a 2001 oil drum also mounted over a stove. Air is passed through the drum by a fan.

The performance of both dryers was very similar. Batches of 25 kg of paddy at 28% moisture can be dried to 18% moisture in 50-60 minutes and batches of maize from 33% moisture to 18% moisture in 80 minutes. Larger versions of the indirectly- heated dryer have been built (Jeon et al. 1990). With paddy, milling quality was improved relative to sun drying but the viability of the grain was greatly reduced due to the high temperatures attained at the drum surface. Similar results were obtained with the AIT dryer as reported by Jindal & Obaldo (1986).

Microwave and Infrared Dryers

When grain is irradiated by electromagnetic energy high temperature potentials are generated between the interior and surface of individual grains. Moisture therefore migrates to the surface where it evaporates to the surrounding air. The rate of airflow necessary is that required to absorb the moisture and not as the provider of latent heat. This reduction in airflow would minimize the dust and other pollutants discharged to atmosphere. More uniform drying is possible compared with conventional heated-air drying. However the capital cost and energy consumption of the microwave equipment necessary is considerable. Radajewski et al. (1988), in Australia investigated, using simulation techniques, the use of microwave heating as a means of pre-heating wheat before drying and concluded that the reduction in drying time could not offset the power consumption required for microwave heating. Infrared heating systems are similarly expensive, and since infrared radiation only penetrates superficially it is necessary to agitate the grain thereby exposing all the surface area to the radiation, thereby incurring additional cost.

Contents - Previous - Next

Ancillary equipment

Air Movement

The selection and sizing of a fan to move air through a dryer is very important. The major resistance to the flow of air comes from the grain bed; the pressure drop through the bed support and ducting is of lesser effect, particularly for deep beds. The pressure drop across a grain bed is a function of the depth, the air velocity and the grain itself. Data such as those in Figure 5.4 should be used to evaluate the pressure drop across the grain bed for a given application. It is important to note the major effect of dockage upon the pressure drop generated.

For most situations either axial-flow or centrifugal fans are used. The axial-flow fan moves air parallel to its axis and at right angles to the field of rotation of its blades. With the centrifugal fan the air enters parallel to the drive shaft, moves radially through the blades and is discharged tangentially from the housing surrounding the

impeller. Axial-flow fans can be easily mounted in-line in the ducting and are relatively inexpensive but are only capable of operation against pressure drops of less than 1,500 Pa. Compared with axial-flow fans centrifugal fans can operate against higher pressure drops and are quieter in use but are more expensive.

Brooker et al. (1974) provide comprehensive information on the selection and operation of fans. It should be noted, particularly for large-scale dryers containing perhaps hundreds of tonnes of grain, that the risks of mechanical or electrical failure of the fan is likely to result in considerable losses if the fan cannot be repaired within a day or two. Consideration should be given therefore to installation of a back-up fan, particularly in locations where repair facilities are limited.

Air Heating

Heaters can be divided into two types, direct and indirect. In direct heaters the fuel is burnt in situ with the drying air so that the products of combustion pass through the drying bed with the air. Heaters of this type are less expensive and more energy efficient; however, the quality of the grain may be lowered due to contamination with combustion products, particularly if the heater is poorly maintained. In indirect heaters

the combustion air does not come into contact with the drying air and a heat exchanger is used to raise the temperature of the latter. Depending on the type of heat exchanger as much as 25 % of the heat may be lost; however, there is no danger of contamination of the grain.

Air for drying can be heated by gas and oil and also solid fuels such as coal, wood and biomass residues. Oil-fired heaters are the most common for use with small on-farm dryers. Oil-fired and gas-fired heaters for all sizes of dryers are commercially available as described by Araullo et al. (1976), Brookeret et al. (1974) and Wimberly (1983). Small heaters are usually transportable and are easily positioned on the suction side of the fan so that the hot air from the heater is drawn into the plenum chamber by the fan together with ambient air.

Use of Biomass

Oil and gas are the conventional fuels employed in heated-air dryers, particularly so for small-scale operations such as the batch-in-bin dryer. The use of these fossil fuels is increasingly expensive and environmentally undesirable. The use of alternative and renewable energy sources is likely become increasingly common as new combustion

technologies are developed and conventional fuels increase in cost. In many areas the residues available from grain crops, such as maize cobs and rice husks, are available in large quantities, but are generally under-utilized and present problems of disposal. Depending on the crop production systems employed other agricultural residues may be produced in the vicinity of grain drying plants and may offer alternative fuel options.

Few comprehensive measurements have been made of biomass residue availability. However, estimates have been made from the ratio of crop yield to the residue, data for which is shown in Table 5.6. The estimated world-wide production of agricultural residues (calculated from the crop to residue ratio) is given in Table 5.7. Much of this material has current or potential use for a wide range of applications, but in many places there are underutilized resources that could be used as fuel for grain drying. Table 5.8 provides details of calorific values of a selection of agricultural residues and wood.

There are many different combustion systems that are currently or potentially suitable for combustion of biomass residues. The broad classification of types of combustion systems and their status of development is outlined below (Page 126 et seq.).

Table 5.6. Conversion Ratios for the estimation of Crop Residues.

Crop	Residue	Crop: Residue Ratio	Source
Barley	Straw	1: 1.2	1
Coconut	Shell	1: 0.15	2
Cotton	Stalk	1: 4.25	3
Groundnut	Shell	1: 0.5	3
	Straw	1: 2.3	3
Jute	Stick	1: 2.0	3
Maize	Straw	1: 1.0	1
	Cob	1: 0.18	4
Millet	Straw	1: 1.4	1
Oats	Straw	1: 1.3	1
Palm Kernel	Shell	1: 0.35	6
Rice Paddy	Husk	1: 0.22	5
Rye	Straw	1: 1.6	1
Sorghum	Straw	1: 1.4	1
Soya beans	Straw	1: 1.1	5

Sugar Cane	Bagasse	1: 0.2	5
Wheat	Straw	1: 1.3	1

Sources: 1: Hall & Overend (1987); 2: NRI (unpublished data); 3: Kristoferson & Bokalders (1986); 4: Watson & Ranstad (1987); 5: FAO (1982); 6: Cornelius (1983).

Table 5.7. Estimated Crop Residue Production of Developing Countries (1989).

Crop	Production '000,000 tonnes	Residue	Production '000,000 tonnes
Barley	24.4	Straw	29.3
Coconut	42.1	Shell	6.3
Cotton	11.7	Stalk	49.8
Groundnut	21.2	Shell	10.6
		Straw	40.5
Jute	3.6	Stick	7.2
Maize	197.7	Straw	197.7

		Cob	35.6
Millet	25.9	Straw	36.2
Oats	2.3	Straw	3.0
Palm Kernel	3.5	Shell	1.2
Rice Paddy	492.6	Husk	108.4
Rye	1.3	Straw	2.1
Sorghum	41.6	Straw	58.6
Soya beans	50.5	Straw	55.6
Sugar cane	962.9	Bagasse	192.6
Wheat	230.7	Straw	299.9

Residue Production from Table 5.6. Source: FAO (1990)

Table 5.8. Alternative uses of Crop Residues.

Material	**Gross Calorific Value (daf*) MJ/kg**

Alfalfa straw	18.4
Cotton seed husks	19.4
Cotton stalks	17.4
Groundnut shells	19.7
Maize stalks	18.2
Maize cobs	18.9
Rice straw	15.2
Rice husks	15.5
Soybean stalks	19.4
Sugar cane bagasse	19.0
Sorghum bagasse	18.9
Wheat straw	18.9
Wood	20.0

*** dry ash free. Sources: various**

Grate Furnaces. The use of grates is probably the most commonly used method world-wide. There are grate systems suitable for burning a wide range of biomass materials,

including many particulate residues and straw. The grate is designed to support the biomass fuel and allow air to circulate freely through it. There are many types of this system: flat grates, both static and moving; cone grates; step grates and sloping grates (Sarwar et al., 1992). Flat grates (Figure 5.17. Flat Grate Furnace.) are the simplest type and are found in the majority of log and straw burning systems. Step grates (Figure 5.18. Step Grate Furnace.) are often used to burn rice husks.

Suspension Burners. These are suitable to burn particulate agricultural residues of regular size and shape. The systems typically comprise a cylindrical chamber where the combustion air is introduced tangentially as illustrated in Figure 5.19. These systems have great potential for application in developing countries. A small number of commercial and piloted systems exist (Mahin 1991; Robinson 1991).

Figure 5.19. Sawdust fed Suspension Burner, showing connection between furnace and table feeder.

Fluidized Bed Systems. These systems are especially suited for burning both large and small particulate agricultural residues of relatively high moisture contents. The fluidized bed furnace comprises a combustion chamber containing a sand bed acting as the heat transfer medium. Commercial units are generally large-scale and capital intensive and as such are less suited for application in developing countries.

Under-fed Stokers. These systems are also suitable for particulate biomass residues of relatively high moisture content. The biomass is transported by a screw-feeder through a specially constructed trough into the middle of the furnace. From the sides of the trough primary air is forced through the biomass mound. Secondary air is introduced near the top of the mound allowing complete fuel combustion. There has been relatively little application of under-fed stokers in developing countries.

Gasification Systems. These systems can be designed to burn wood in the form of logs (Figure 5.20. Gasifier.) and also particulate fuels. The biomass is pyrolysed to produce combustible gases and wood tars. These products of pyrolysis are then used as a fuel. Since good combustion control can be obtained with gasifiers the hot gases of combustion can be employed to direct-fired dryers. Gasifications systems are typically at the experimental or adaptive research and development stage although there has been some limited commercial success with wood and charcoal gasifiers (Breag & Chittenden 1979; Hollingdale 1983; Sarwar et al. 1992).

There are handling and combustion advantages in compressing particulate materials into a more compact form, briquettes, for use in existing furnace systems (Smith et al. 1983). Various techniques can be used for converting residues to briquettes; the piston press, the screw press, the pellet press and the manual press. The experience of briquetting agricultural residues has been mixed. Various technical problems have been

encountered but the main difficulty has been the fact that, in many places, briquettes are too high in cost to compete with existing woodfuel (Eriksson & Prior 1990).

Details of the commercial availability of equipment for combustion and handling of biomass materials can be found in publications by Eriksson & Prior (1990), Sarwar et al. (1992), and the Biomass Energy Directory (Anon. 1992). A great deal of information and consideration is needed to arrive at any reasonable conclusion on the suitability of a particular combustion system for use in grain drying systems in developing countries. A list of principal organizations involved in research activities on biomass residue combustion is given in Annex 2.

Contents - Previous - Next