AGRICULTURAL AND
FOOD ENGINEERING
WORKING DOCUMENT
5

Small mills in Africa
Selection, installation and operation of equipment

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by

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Preface

Small mills are very important machines for many communities in Africa as they eliminate much tedium and time-consuming labour. Various types of small mills are found across Africa. While considerable literature is available on the technologies of medium- and large-scale mills, there is little information on small-scale mill technologies and on how to make the right purchase decision.

This working document includes information on various types of hullers and small mills available in Africa. It advises how to select milling equipment, and how to install, operate and maintain small mills. It includes simple profitability calculations.

This document is designed to be comprehensive and practical. It is addressed to entrepreneurs or communities who want to invest in a mill and to extension workers, national and international development organizations, and rural finance institutions involved in advising potential investors.

List of acronyms

kg	Kilogram
kW	Kilowatt
m	Metre
mm	Millimetre
US$	United States dollar

Glossary

Aspiration:	removal of lighter parts of a grain by air current.
Awn:	spiked part of the husk at the end of a grain.
Endosperm:	energy-rich starchy centre of a grain.
Feed:	part of the grain used for animal feed.
Flour:	a fine powder made from grain.
Grinding:	breakage of coarse grains into smaller pieces.
Hulling:	(dehulling, husking or dehusking) removing the fibrous outer shell and the bran from the surface of a grain.
Husk:	fibrous outer shell of the grain.
Meal:	crushed grain with a coarser texture than flour.
Milling (grinding):	production of flour from cereals, seeds, dried root crops and nuts.
Pericarp:	tough outer layer of grain beneath the husk.
Shelling:	removing maize corns from the cob.
Toxins:	poisonous residues and growths that can contaminate grain.
Winnowing:	separating he chaff from a grain by employing air

Chapter 1
Introduction

BACKGROUND

The earliest records of food production in Africa show that indigenous crops have long been milled to produce coarse flour for cooking. Traditional crops such as yam, sorghum, millet and teff have been ground for centuries either with a crude mortar and pestle fashioned from a tree stump and branch or by using flat stones or rubbing stones (Plate 1). All these types of grinding systems are still in common use throughout Africa today. Newer crops, such as rice, maize and cassava, have been introduced in more recent centuries, and new milling techniques have followed.

Plate 1

FAO/B. CLARKE

Traditional rubbing and hand grinding stones

In the mid-nineteenth century, electric motors were invented and higher speed machines, such as hammer and plate mills, began to replace traditional stone mills. As electricity became available in many parts of Africa, motor-driven mills gained in importance. However, it was not until the introduction of the diesel engine in the early twentieth century that high- speed mills were seen in more significant numbers across the continent. A relatively low-speed, water-cooled diesel engine can, for example, power a hammer mill, producing maize flour of acceptable quality. These mills are in widespread use in rural parts of the world in areas where no electricity grid is available. Diesel-powered grain mills are limited to areas with access to fuel and spare parts.

Plate 2

FAO/B. CLARKE

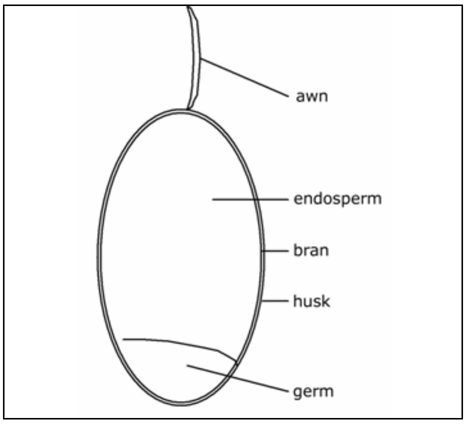
Women at work

Many people still cannot afford paying for commercial grain-milling services and they grind by hand using traditional techniques. Therefore, pounding is a common sight and sound in many areas. It is often a social activity, carried out predominantly by women (Plate 2), and many hours are spent each day in this laborious and time-consuming task. The pestle may weigh up to 4 kg, and pounding requires a lot of effort.

The stone mill or quern, either hand-, animal- or motor-driven, is relatively unknown in Africa despite having given good service in many other countries. This machine operates on the same principle as plate mills but uses large stones instead of plates and is set with a vertical axis. The skills of dressing stones have not been acquired in areas where appropriate stones have not been easily available. However, there are isolated examples of stone mills in Africa that are well designed for using low-speed animal power.

Larger-scale mills are in operation in most African countries today. They mainly supply flour to larger cities and towns. These mills use fluted roller mills that operate to a higher technical standard than small-scale mills do. They can remove bran and wheatgerm, producing refined white flour mainly for bread making. Larger-scale roller mills are also used to mill maize into grits.

FIGURE 1
Typical structure of a cereal grain



Source: FAO/B. Clarke.

OBJECTIVES OF MILLING

The main objective of milling is to improve the digestibility of the grain for human or animal consumption. A typical grain (Figure 1) is surrounded by a hard coat or husk, which protects the germ and the endosperm, the energy-rich starchy centre of the grain. The layer between the husk and the endosperm is called bran. The awn is the spiked part at the end of the grain.

The aim of milling for human consumption is to produce a palatable meal or flour and to expose the starch in the endosperm to the digestion juices of the stomach. The objective is not to produce a very fine flour or paste but rather to mill the grain to a point of coarseness that is acceptable to the consumer.

The main purpose of milling animal feed is to prevent the grain passing straight through the animal without being fully digested. There is little to be gained from producing very fine flour from a digestive point of view. Very dusty animal feed can also cause respiratory problems when fed dry.

Preferences for different types of milled products vary throughout Africa with respect to the fineness of final product. Many people in East Africa prefer a very fine flour to make “nzima” or “ugali”, a smooth gruel, while other people in Central and West Africa prefer coarser, unshelled flour, which gives more texture to the product.

Chapter 2
Hulling

PRINCIPLES OF HULLING

The principle of hulling is to shear the grain between different surfaces of high friction in order to separate the protective and hard outer layer of the grain from the softer starchy centre and the germ. Surfaces for hulling can be knives, stones or perforated plates. Husks are the by-product of hulling. They are of little nutritious value but can be used as a biofuel for running a mill.

Hulling of maize and sorghum removes the hard outer layer or husk and the bran of the grain. Other crops such as cowpeas and various legume crops are hulled to remove the tough outer layer beneath the husk (pericarp). Rice has traditionally been pounded with mortar and pestle to remove the husk. However, this method produces a high percentage of broken grains.

DIFFERENT TYPES OF HULLERS

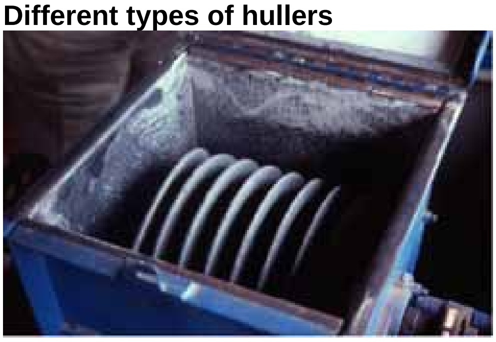
There are four main types of huller: the abrasive disc huller; the abrasive cone huller; the Engelberg huller; and the rubber roll huller (Plate 3). Grains in all hullers are subject to high-speed rasping or abrasion. Stone discs or steel ridges shear the grains against each other as well as against a fixed, perforated plate.

The abrasive disc huller has a row of carborundum discs in a chamber. The discs rotate at high speed as the grains pass over them and are circulated through a series of discs until they emerge with the hulls polished off. The bran is collected separately.

The carborundum cone huller is similar to the abrasive disc huller but has a single large cone that rotates in a closely fitted conical drum made out of perforated steel. The gap between drum and cone can be varied by adjusting the depth of penetration of the cone into the drum. The ridges within the drum also determine the rate of shear. A carborundum cone huller has a horizontal or vertical axis.

The Engelberg huller has a horizontally-ridged cast rotor within a perforated plate cylinder. An adjustable knife controls the width of the gap in which the produce is sheared. The setting of the knife has to be adapted to the grain hulled so that it can slip easily through the gap between the knife and the screen, peeling off the husk without too much

Plate 3
Different types of hullers


FAO/B. CLARKE
(a) disc huller


FAO/B. CLARKE
(b) cone huller


FAO/B. CLARKE
(c) rubber-roll huller


FAO/B. CLARKE
(d) Engelberg huller

damage to the main part of the grain. Coarse breakage of grains is acceptable in hulling as the grain is later to be milled into finer particles.

The rubber-roll huller shears the grains between two rubber rolls that spin in opposite directions. One roll spins about 50 percent faster than the other roll. The grains are carried through a gap about 1 mm wide between the rolls and fall into a trough or onto a conveyor belt for further processing or packing. The rubber-roll huller has a gentler action than the other types and is more common in larger flour mills as it produces high-quality flour.

USE OF DIFFERENT TYPES OF HULLERS

Each type of product needs its special huller. For example, maize can be hulled in an abrasive disc huller but it is more commonly hulled in an Engelberg huller. Before hulling, maize needs to soak in water for several minutes, this softens the outer husk and makes it peel off more easily.

Rice is mainly hulled by an Engelberg machine or by a rubber roll huller. An Engelberg huller is mainly for small-scale use as it is more reliable, needs fewer spares, is less expensive and is easier to maintain. It can also polish and dehusk grains. However, it needs a little more power and produces a higher percentage of broken grains than do other hullers. While broken grains are as nutritious as unbroken ones, they alter the cooking characteristics and, hence, the attractiveness of the product to the consumer.

Spare parts for Engelberg hullers are less expensive than those for other types of hullers and they are more readily available in most parts of Africa. Spare rolls for the rubber roll huller usually need to be imported, and replacement is necessary every few weeks when the machine is used intensively. Spare rubber rolls for hullers are relatively costly compared with the metal components of the Engelberg machine.

Sorghum is a small grain and is processed well by an abrasive disc huller. Another suitable type for sorghum is the abrasive cone huller, which polishes the grains against a perforated plate screen.

Chapter 3
Milling

PRINCIPLES OF MILLING

Some knowledge of the principles of grinding helps to run a mill effectively. Hence, a brief overview of major milling mechanisms is given below.

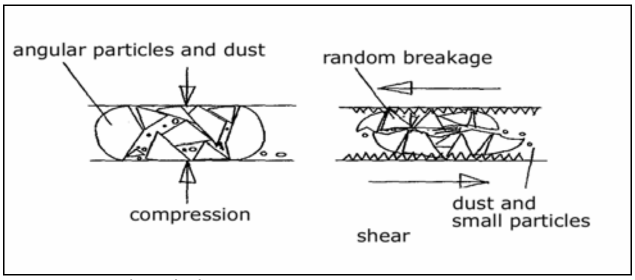
Mechanism of fracture of a grain

Grain subjected to a force responds in three distinct stages. The first stage is called elastic deformation, the second is termed plastic deformation, and the final stage is termed breakage or fracture. Elastic deformation means that the grain deforms under force but returns to its original shape when the force is removed. As the force is increased on a grain, plastic or permanent deformation takes place, even when the force is removed. The grain appears to be flattened or distorted in some way but is still in separate, identifiable units. The grain eventually fractures when forces are increased further.

The chief mechanisms of fracture in milling are compression and shear. Other effects occur, such as cutting, sawing, tearing and abrasion, but they are only a combination of shear and compression. A dry grain shatters in a random matter when compression and shear is applied (Figure 2). The grain then breaks into coarse chunks, some fine particles and very fine dust. Dry grains do not deform when grinding forces are applied, but they produce cracks that eventually lead to grain failure.

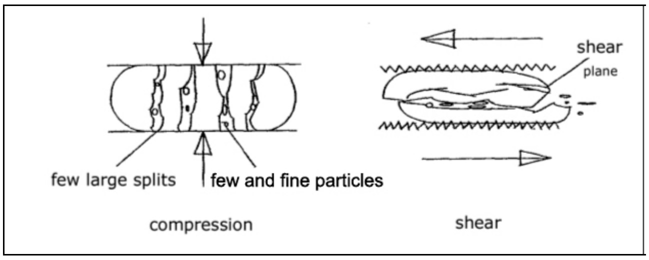
On the other hand, moist grains produce a range of closer-sized particles as well as fewer and finer particles when forces are applied (Figure 3). Through compression, they can be formed into flat discs that are ideal for a wide range of meals for human and animal consumption. Shearing of moister grain tends to tear the grain along defined plains of failure.

FIGURE 2
Compression and shear of dry grains



Source: FAO/B. Clarke.

FIGURE 3
Compression and shear of moist grains



Source: FAO/B. Clarke.

The stages of compression and shear occur in all milling machines between two flat plates, or between a flat plate and a bed of grain. In some mills, the grain is suspended in the air where it is struck by a high-speed plate or hammer. A larger grain has more inertia and, therefore, fractures more easily. As the grain becomes finer, it has less inertia and fractures less.

Effect of moisture content on the fracture of a grain

Grains respond differently to applied forces depending on their moisture content. When a grain is dry, it is hard and brittle, and applied forces break it into angular-shaped pieces and very fine particles. The grain starts to distort in an elastic manner as more force is applied. Further force causes some plastic deformation before the grain fractures or breaks. This is caused by the propagation of cracks from the points of stress, which are normally the points of contact.

On the other hand, a moist grain is relatively soft and deforms to some extent elastically when pressure is applied. As the force on the grain is increased, a moist grain is capable of retaining more plastic deformation than a dry grain before it breaks.

DIFFERENT TYPES OF SMALL MILLING MACHINES

Hammer mills

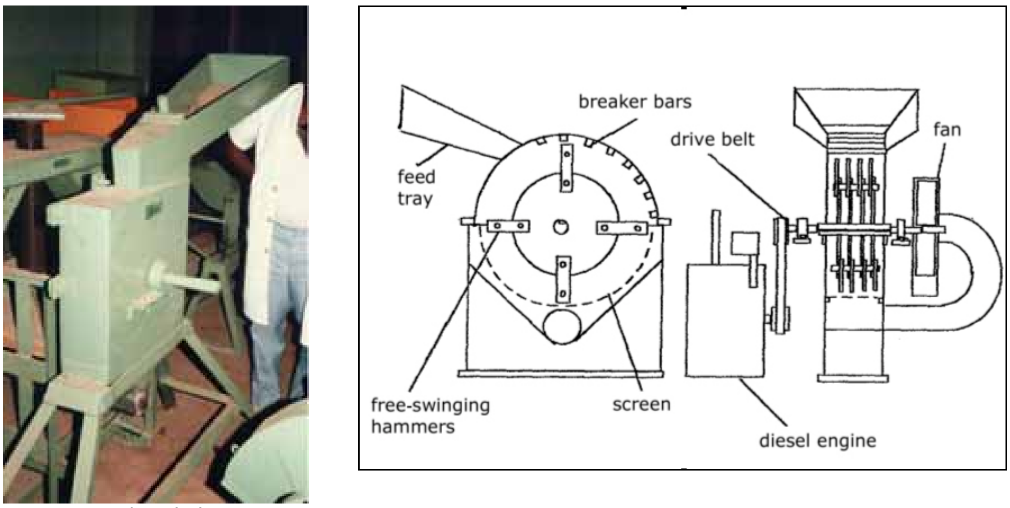
Hammer mills (Figure 4) are very common throughout Africa. As the name implies, hammers in the mill grind grains through impact. The grains are placed into a holding hopper on top of the hammer mill, and a small control gate allows the grains to trickle into the grinding chamber. The grains feed into the path of the hammers either through the centre of the front plate or through the top side of the case. The hammers strike the grains and shatter them before they can pass through the screen surrounding the hammers. The flour produced either falls by gravity into a chamber or sack below, or is propelled by air flow up through a cyclone into a holding container. The airflow is provided by either the fan effect of the hammers or by extra fan blades mounted on the hammer shaft.

A hammer mill consists of a large cylinder with a horizontal shaft that drives a rotor with several rows of free-swinging hammers. The hammers rotate inside a perforated metal screen through which the flour is drawn. The hammers are driven by two or four sets of V-section belts between the engine and the mill. The hammers spin at high speed, usually between 2 000 and 4 000 revolutions per minute to achieve a hammer-tip speed of about 60 m/second. The speed of the mill has to be matched to the size of the mill as a small mill needs to run at higher revolutions than does a larger mill.

Some hammer mills have screens that cover the mill around 360 degrees. More popular designs have screens around 180 degrees of the lower periphery as this allows easily made replacement screens to be used. Beater bars are often incorporated into the upper semi-circle against which the grain impacts.

Screens are made by perforating blank sheets of steel. This is not commonly practised in Africa, and screens have to be imported. Screen replacement represents one of the main running costs of the mill. The rate of screen replacement depends on thickness of the steel. As a rough guide, it is possible to punch a hole through steel of the same thickness as the diameter of the hole. For example, a screen for a hammer mill with 0.5 mm holes would be made from 0.5 mm thick steel. The larger the hole size, and hence the thicker the steel, the longer the screen will last.

FIGURE 4
Locally made hammer mill and its typical construction



Source: FAO/B. Clarke.

There are also simple hammer mills that have no transmission belts and are driven directly by the motor. The base plate of the motor is fixed to the mill chamber, and an accurate alignment of the mill is essential. Mills without transmission belts are well suited for local manufacture. Simple hammer mills can have a small electric engine, but they also work well in petrol and diesel-driven mills.

Hammer mills work well for grains with a minimum moisture content of 12 percent. Drier crops are very dusty when ground and can create health problems for mill operators. However, the drier the crop, the less power is needed for milling. As a rule of thumb, five percent less power is needed for every one percent reduction in moisture content. In most African climates, grain can be sun-dried to have a moisture content of 12 percent or less in dry regions.

Plate mills

Plate mills (Figure 5) are popular in West Africa and the Sudan and operate with a greater component of shear than compression. A plate mill consists of a circular chamber made of cast iron or steel within which two plates with a narrow gap between them are mounted face to face. The plates are grooved in order to provide a shear mechanism.

When grains are introduced into the centre of the mill, the plates shear the grains between them. One of the plates rotates and the grains revolve, working their way to the outer edge of the plate before dropping by gravity into a holding sack below.

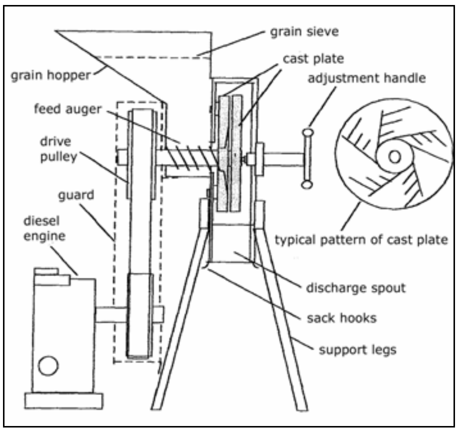
The grains lodge in the rotating plate and are sheared by the grooves in the opposing plate. As the grains move to the edges of the plates, the grooves become shallower and reduce the size of the grains. The design of grooves follows a very old style developed for stone mills several thousand years ago.

Plates are usually about 200–300 mm in diameter. Plates are normally aligned in a vertical direction, but horizontal alignment is more convenient when the mill is run by a diesel engine. Plate mills can run as fast as possible but normally at about 2 500–3 500 revolutions/minute, as overheating of the plates limits the speed of the mill.

Frictional heating imposes power limits. For example, a plate mill with 300 mm plates cannot be driven by an engine with more than 12 kW. However, the speed of mill is not a critical factor to the mechanism of grinding. Plate mills operate more effectively with soft and moist grains that shear easily than with hard and brittle grains. It is common in West Africa to add water at the time of grinding. The milled product has to be used very quickly in order to prevent fermentation.

The fineness of the flour ground is adjusted by increasing the pressure on the grain by narrowing the gap between the plates. This is done with a simple hand wheel connected to the outer plate by a shaft. The mill should not be run empty because grains in the mill are needed in order to lubricate the action and, thus, prevent wear. Excessive wear is caused when the plates come into contact with each other. A fine flour or meal from a plate mill is obtained by re-circulating the product in the mill for a second or third grind.

FIGURE 5
Locally made plate mill and its typical construction



Source: FAO/B. Clarke

When the plates wear out, they have to be replaced with new ones. Cast-iron or steel plates are preferable but old mills can also be refurbished by replacing worn plates with locally made steel plates. Grooves are cut with the help of simple grinding wheels. Such replacement plates provide a short-term emergency solution for grinding cereals and they can be used for softer fruits and vegetables.

COMPARISON OF MILLING MACHINES

Product considerations

A new mill should make a similar product to that made by traditional milling techniques. Traditional crops and cooking methods are deeply entrenched in most societies, and there is little desire for initiating change.

A hammer mill grinds anything brittle including straw, mineral ores and dried roots. Any produce to be ground should flow easily when milled. Very soft produce reduces the throughput of a mill and tends to block up the screens so that the mill eventually ceases to function.

On the other hand, plate mills are a little more versatile. Any fresh or partially dried fruit or vegetables may be ground in plate mills, provided that the product responds to gravity. Plate mills can operate at a lower speed than a hammer mill and can be turned by hand (where small enough), by animals, wind, water or any other variable speed source. The material to be milled may be soft or hard. Water may be added to cereals but the product must then be processed quickly in order to prevent fermentation.

Technical considerations

Hammer mills have a power requirement that ranges between two and 50 kW, while motor-driven plate mills generally demand less power and 0.5–12 kW is sufficient. As a rule of thumb, about 1 kW can mill 25–30 kg of produce per hour

Machines and spares for hammer mills are often made locally at lower prices than imported parts. Some components, such as screens, are rarely made locally and need to be imported, especially those of a very fine size.

Plate mills of 0.5 kW are usually made for grinding soft fruits and vegetables, and the plates can be made from locally produced steel. Plate mills are not popular for grain milling as they have to be manufactured from chilled cast iron, which is rarely available in Africa.

Purchase considerations

Locally available mills first have to be assessed. Local dealers or manufacturers normally offer the most appropriate mill for the area, and spare parts should be easily available. Second-hand mills may be in stock – they are worth considering. The supplier of the mill should be able to visit the processing site in order to provide in full after-sales service, including the provision of spare parts. However, there is very little that can go wrong with most small mills, provided maintenance is carried out on a regular basis.

Chapter 4
Investment considerations

OWNERSHIP CONSIDERATIONS

Both individual and communal ownership of small mills are common throughout Africa. Individual ownership offers greater freedom and flexibility when making decisions. An individual owner is more likely to be careful with the equipment by ensuring regular maintenance of the mill. Members of the owner's family are often employed in running the mill and benefit directly from a successful enterprise.

Communal ownership spreads the risk of failure associated with operating a mill. It may be easier to obtain a loan from a bank or an aid agency where responsibilities and risks are distributed among a number of people. However, communal ownership increases the risk that the mill will not be profitable. Clear responsibilities have to be given and management issues require careful consideration. There is no simple formula for successful ownership of a mill because people behave differently in every situation.

FEASIBILITY CONSIDERATIONS

Before making any investment decision, it is necessary to make sure that the operation of a small mill will be profitable. This can be done by carrying out a feasibility study. Such a study tries to find out:

- whether there is a market for milling services;
- how much it would cost to run a mill;
- what profits can be expected;
- which type of mill would be most suitable in a specific environment;
- whether suitable people are available to run such an enterprise;
- what possibilities there are to finance the mill.

The following checklist gives an outline of key questions to answer before making a decision on investing in a mill:

- How much would people pay for the service of machine milling the grain instead of pounding?
- How much of the food consumed in the locality is currently prepared by pounding?
- Would there be enough customers in the area who are able to pay the milling fee?
- Is there another mill near by that could be in competition?
- What kind of crops could be milled in the area and what type of mill would be the best option?
- Are fuel and spare parts available?
- Are human resources available to handle business management including financial management tasks associated with a mill?
- Is there any possibility of receiving a loan from a bank or other agency, and if so, what are the conditions?
- What costs are associated with milling, how can they be broken down and passed on to the mill user?
- How much grain needs to be milled in order to pay off the mill before it becomes obsolete?

If the answers to the above questions are positive, then investing in a mill has a high probability of success. (see FAO 2003 for further reading)

PROFITABILITY CALCULATIONS

Some information on how to calculate the profitability of a mill can be found in the feasibility study. Milling fees are normally the only source of income, and the fees collected have to be greater than all the costs associated with running a mill. Costs can be broken down into operating costs and capital costs. Operating costs can be further broken down into fixed and variable costs. Fixed costs do not vary with the throughput of the mill. They include items such as general labour costs, the rent paid for hiring the mill room, and flat rates paid on utilities, such as water, electricity and the telephone. Variable costs are those that change when the mill is in use compared with being idle. They include fuel, lubrication oil, repair of worn parts, storage bags, electricity and water (provided there is a meter).

Capital costs are those associated with financing the mill. Finance can be provided by taking out a loan and paying interest on it, by using personal funds, or by a combination of the two. The capital costs depend on the interest rate to be paid. Before embarking on a particular capital investment it is also prudent to look at returns from alternative investments as well as returns from saving deposits.

A very simple example, based on prevailing 2004 prices of how, to calculate the profitability of running a mill is given below. Many assumptions have to be made, and it is wise to include not only optimistic but also pessimistic estimates about income and costs in order to be sure that the mill will become a successful operation.

Income

The potential income from a small mill can be assessed as follows. Setting the milling fee at 10 percent of the value of the crop milled and the prevailing grain price of US$150/tonne, the milling fee earned per tonne of produce is US$15. The hourly output of a 15 kW mill is 400 kg, and if the mill worked 6 hours/day for 250 days/year, it would grind 2 400 kg of flour every day for a total of 600 tonnes of flour per year. With the above assumptions, the annual income from a running a village mill is the annual throughput (in tonnes per year) multiplied by the milling fee charged: 600 tonnes/year × US$15/tonne = US$9 000.

Operational costs

A crude assessment of operating costs is as follows:

- Labour costs: two workers are needed to run the mill, labour costs are US$3/person-day, the total labour costs per year are US$1 500 (assuming 250 working days per year).
- Fuel costs: consumption is about 3 litres/hour; assuming a diesel price of US$ 0.5/litre and a running time of the mill of 6 hours/day and 250 working days per year, total fuel costs amount to US$2 250 per year.
- Maintenance costs: maintenance includes replacing screens, filters and hammers, and costs are estimated at US$500 per year.

Thus, operating costs per year including labour, fuel and maintenance costs add up to: US$1 500 + US$2 250 + US$500 = US$4 250.

Capital costs

The approximate purchase price of a small mill with a diesel engine is US$4 000. The formula for the annuity (a) or the fixed annual capital cost is: $a = K \times i / 1 - (1 + i)^{-n}$, where K is the cost of the mill, i the interest rate, and n the number of years for repayment. Therefore, in this example, assuming that US$4 000 has to be repaid over a five-year loan period and that the average rate of interest is 25 percent, capital costs add up to an annual payment of US$1 487.

Summary of profitability

For the present example, the simple profitability calculation above can be summarized as:

Annual turnover		US$9 000
Minus operating costs	(US$4 250)	
Minus capital costs	(US$1 487)	
Profit margin per year		US$3 263

A profit of US$3 263 is an attractive proposition and it indicates how a small mill can inject prosperity into a region. However, the calculated profit varies when any of the underlying assumptions vary. For example, fluctuating grain prices, droughts affecting food production and income generation, non-paying customers and unexpected breakdowns are all constant threats to the profitability of a mill. The calculated profitability has to be adapted to specific circumstances and must be seen as an approximation. Correct prices, costs, capacities and outputs need to be verified before any decision is taken.

Chapter 5
Mill installation

BUILDING REQUIREMENTS FOR A SMALL MILL

Choosing the location for a small mill in the community is an important task. Most settlements are fairly compact and the mill needs to be close to where people live. Engines make a lot of noise and a location has to be chosen where people are not disturbed. Road access for larger loads of grain needs to be planned. Tarmac roads are rarely found in rural areas, but an access road to the mill is a definite advantage for the installation of the mill, and possibly for transporting raw materials and finished goods to and from the site.

The mill has to be housed in a small building for several reasons:

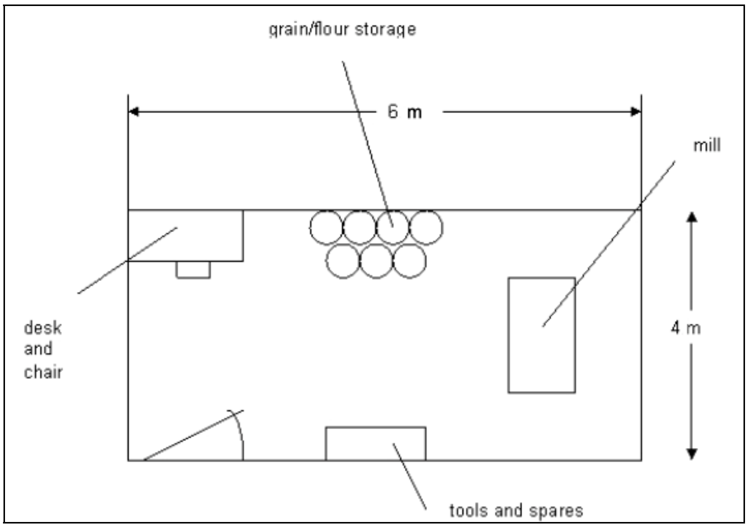
- to protect the machine, the operator, raw materials and products from inclement weather conditions;
- to secure tools, spare parts, fuel, grain and flour against theft;
- to protect the mill from roaming animals, such as chickens and goats as well as vermin;
- to reduce noise levels.

The type of building material used depends on local availability. Common materials are concrete blocks, mud blocks and wood. Open blocks are an attractive solution but are rarely available in more remote areas. Windows with steel bars or slats are also necessary in order to see inside properly without the need for artificial light. Glass windows are not usually necessary.

The size of building depends very much on the required storage space for grains, spare parts and finished products. A typical mill measures about 24 m^2. The mill itself and the motor occupy about 2 m^2 with access space around it. Spare parts, fuel and tools will occupy a further 4 m^2. A further 18 m^2 is necessary for the storage of crops and products and to put up a desk. For security reasons, a strong, usually wooden, door is needed with a good lock. Figure 6 shows a typical mill-room layout.

The roof of the building should be weatherproof and thiefproof. Iron is preferred to local materials, such as grass thatch. It is almost impossible to make a mill verminproof and birdproof. Hence, it is advisable to use metal containers to store raw materials and milled crops. The use of elevated platforms for storage of crops and products with rat-guards on the legs will help to prevent losses.

FIGURE 6
Typical mill-room layout



Source: FAO/B. Clarke.

POWER REQUIREMENTS

Fuel-driven engines

Small mills are driven by two types of engines, using either diesel or petrol for combustion. The engines are similar in operation but have significant differences. Diesel engines consume less fuel and last longer, and they are more robust and designed specifically for harsh conditions. Diesel engines are a little heavier and more expensive than petrol engines. They are normally cast-iron framed, have one, two or possibly four cylinders, and are suitable for driving water pumps, mills and other machines. Petrol engines are available in smaller sizes than diesel engines. They are suitable in areas where petrol is more readily available than diesel. Petrol engines can be up to 50 percent less expensive to buy than diesel engines.

Power-driven engines

The electric-motor-driven mill is preferable to fuel-driven mills in areas where mains electricity is available. It runs quietly, is cheaper to purchase than a diesel-powered mill, and easier to operate than other drive systems. Electric motors require virtually no maintenance, are highly reliable, and easy to start (with the push of a button). Electric motors never run out of fuel but they are subject to power cuts.

Renewable energy sources

Many early stone mills were powered by water or wind. Today, plate mills can still be powered in these ways, provided there is enough wind or water available. Small plate mills powered by water need about 3 kW and a head of water of at least 4 m, with a flow rate of 8.3 litres/second. In mountainous areas, where water is plentiful, a water turbine, which runs at a higher speed than a water-driven wheel, can be an alternative to fuelled engines. A small stream with a head of 5 m is sufficient to operate a water turbine for a 10 kW mill effectively.

A 3 kW windmill requires a wind speed of about 45 km/h across wind sails with a swept area of 10 m^2. Both wind and water sources can only drive a plate mill for which a constant speed is not a critical factor as the power supply from such sources is variable.

Animal power as well as human power can also be used to drive plate mills. Animal-driven mills can supply a small community, but they are normally used as family mills capable of milling up to 2 kg of flour per hour.

Combined use of engines

Engines can be switched from one machine to another. A small mill may be fully occupied grinding maize throughout the day, but if it has spare capacity, the engine can be switched to an alternative duty.

An engine can also be switched over to drive a huller for maize. In this case, a flat belt from the common driveshaft is used to run a pair of “fast and loose pulleys”. The machine in use has the flat belt moved over to the fast, or the drive, pulley, while the unused machine has its pulleys moved from the drive to the free wheel position. Large engines can be used to drive a whole range of machines simultaneously by a set of pulleys.

A generator can also be used to provide power to electric motors of individual machines. However, it is very expensive and needs to run at optimal capacity. Mills can also be driven by tractors, which are a large power source. However, a tractor is used primarily on the field and can only be made available for milling purposes at certain times and seasons.

RECOMMENDATIONS FOR INSTALLATION

The engine and mill must be set up according to the manufacturer’s instructions. This may require the services of a dealer. The floor of the mill building should be flat and free from any flooding risks. The mill and engine need to be aligned accurately so that the belts do not come off or wear prematurely.

The engine and mill can be mounted on a common bed-frame made of rigid steel. This can be attached directly on a mud floor, or preferably on a concrete base. Bolting the mill down to the floor helps to prevent the mill from moving around. Both hammer and plate mills are naturally well-balanced machines when maintained properly. Plate mills are often mounted on legs that are free-standing on any firm floor without any other fixing. However, a larger diesel engine benefits from being bolted securely onto a concrete floor.

Chapter 6
Operation and maintenance

Some maintenance has to be carried out on a daily basis while other tasks need to be done on a regular but less frequent basis. Failure to make checks and to keep records can lead to a drop in the efficiency of a mill and eventually to costly breakdowns. It is very important to make sure that a mill is in good running order and condition at all times.

DAILY MAINTENANCE

The availability of fuel needs to be monitored in order to ensure that the engine does not stop unexpectedly. Planning is necessary in areas with fuel shortages.

The mill room needs sweeping every day. This is best done at the end of the working day in order to prevent rodents and insects from infesting the mill and its surroundings overnight. All such pests leave waste products that contaminate a mill and can pose a health hazard.

The mill interior needs cleaning every day. The condition of hammers and screens has to be checked as they can easily become damaged during a day of milling. Plate mills need less maintenance than hammer mills. However cleaning and routine checks are daily tasks for both mills.

PERIODIC MAINTENANCE

The level of lubricating oil in the engine sump falls gradually and needs topping up as well as replacing from time to time in the same way as in a motor vehicle. The oil filter has to be replaced on a regular basis (about every 300 hours). Instructions from the manufacturer should be followed.

The drive belts grow slack after protracted use and have to be tightened according to the manufacturer's recommendations. It is especially important to keep all the belts at the same tightness. Ideally, when one belt fails, all belts are replaced in order to keep them uniformly tight.

The mounting of the mill needs a periodic check-up. This needs attention to make sure that all holding-down bolts, beater bolts, plate-fixing bolts, etc. are tight. All bearings need periodic lubrication.

The air-intake filter needs cleaning. As a mill environment is usually very dusty, the filter has to be checked periodically. A blocked air filter increases fuel consumption and eventually stops the engine.

The hammers in hammer mills have to be repaired from time to time. Hammers are made from a rectangular-shaped piece of steel with holes at each end. As one corner of the hammer wears, it can be turned over to present the other corner. The hammers can be turned over until all four corners have worn away.

Worn hammers can be repaired by welding on some layers of welding rod until they can be ground back to the original shape. The welded part of the hammer is very hard and has good wear characteristics. Replacement of worn hammers is preferable. This has to be done after a few hundred hours of running. Replacement hammers can be made from the hardened leaf springs of trucks or other high-quality steels. When undertaking replacements, it is necessary to ensure that the tip clearance between hammers and screen is about 5 mm.

It is also important to make sure that all hammers are balanced after repair or replacement. Most small mills do not have more than 16 hammers. Assuming the sets on each side of the mill are referred to as the north, south, east and west, then the east ones should balance with those on the west, and the north ones with those on the south. Otherwise, the mill will vibrate, which places extra load, and increases wear, on the bearings.

Balancing requires that some metal be ground off from each of the heavier set of hammers, and a grindstone needs to be applied to both ends of the hammers. Where there are no accurate scales to balance the hammers, this can be done with the help of a simple pivoted beam. Each set of hammers has to be placed equidistant from the balance point. The repair or replacement of hammers is a very time-consuming task. It is better and cheaper to screen the crop for metal parts before milling rather than risk damaging the hammers.

Screens are very expensive and are rarely made locally. Attempts can be made to revive worn or broken screens by soldering or patching. Screens can also be made by sawing slots into curved sheets of motor bodywork, which gives a slotted screen with slots about 1 mm wide and 20–30 mm long.

MAINTENANCE RECORDS

Maintenance records are vital for profitable mill operations. Records should be kept on:

- fuel or electricity consumption;
- expenses regarding repairs or replacement of filters, belts, hammers, screens, plates or stones;
- any costs associated with hiring labour;
- building rent;
- expenses on items such as storage bags, brushes and stationery;
- expenses for other utilities, e.g. water.

Keeping records and analysing all expenses regarding operation and maintenance are necessary in order to calculate and periodically revise milling fees charged to consumers. Maintenance records are also the only source of information for calculating profits and losses. Last but not least, all records need to be kept in a secure box in a safe place.

SAFETY ISSUES

Accidents are usually caused by the power source or the transmission. Electrically-driven mills need good-quality fixed wiring, secure connection boxes, and correct fuses. Diesel and petrol engines can have fuel leakages, and it is very important to have a secure fuel tank away from the mill in a separate room. Naked flames anywhere near the mill must be avoided. Petrol engines are more dangerous because of the greater flammability of petrol compared with that of diesel.

The transmission components of any mill need to be protected carefully by guards. Belts or driveshafts have to be covered at all times by guards. These are provided by the manufacturer but are frequently removed by mill operators, causing many unnecessary accidents. Mills also need to be kept clean inside and outside as dust in the air can be explosive. Mills must be a no-smoking zone.

Bibliography

Bassey, M.W. & Schmidt, O.G. 1989. *Abrasive disk dehullers in Africa*. Ottawa, IDRC.
Carruthers, I. & Rodriguez, M. 1992. *Tools for agriculture*. 4th edition, London, IT Publications in association with CTA and GRET.
Eastman, P. 1980. *An end to pounding: a new mechanical flour milling system in use in Africa*. Ottawa, IDRC.
FAO. 1983. *Processing and storage of food grains by rural families*. Agricultural Services Bulletin No. 53. Rome.
FAO. 1989. *Utilization of tropical food: cereals.* Food and nutrition series. Rome.
FAO. 2003. *Market research for agroprocessors*. Marketing Extension Guide No. 3. Rome.
Harvey, A. & Brown, A. 1993. *Micro-hydro design manual: a guide to small-scale water power schemes*. Rugby, UK, IT Publications.
Jonsson, C.O. & Dendy, D. 1984. *Small-scale maize milling*. Technical Memorandum No. 7. Geneva, Switzerland, ILO.
Roie, W. 1989. *Introduction to animal-powered mills*. Eschborn, Germany, GTZ.
Uhlig, S.J. & Bhat, B.A. 1979. *Choice of technique in maize milling*. Edinburgh, UK, Scottish Academic Press.
UNIFEM/WAFT. 1986. *Cereal processing*. Food cycle technology source book No. 3. New York, USA, UNIFEM/UNDP.
Vanek, K.V. 1986. S*mall-scale grain processing schemes in Africa: methods, equipment, energy and power requirements and use of renewable energy resources*. Frederiksberg, Denmark, Royal Danish Veterinary and Agricultural University, Institute of Agricultural Engineering.

Annex 1
Manufacturers of small mills

ABI-Mechanique, BP 343, rue Pierre et Marie Curie, Zone 4c, Abidjan, Côte d’Ivoire.
AFM, Scotmec Works, Ayr, United Kingdom.
Agrico, Box 12127, Ring Road, West Industrial Area, Accra, Ghana.
Alvan Blanch Development Co. Ltd, Chelworth, Malmesbury, Wilts, SN16 9SG, United Kingdom.
A/S Maskinfabrikken Skiold, Saeby, Kjeldgaardswej, PO Box 143, Saeby, DK 9300, Denmark.
Azad Engineering Co, C-83, Bulandshahar Rd, Industrial Area, Chaziabad, India.
Ceccato Olindo, Macchine Agricole, S.N.C. di Ceccato Ilario & Figli, Via Gustiniani 1, 35010 Arsego, Padova, Italy.
Dandekar Brothers & Co. Shivajinagar, Sangli, Maharashtra, India.
Gauthier Agro-industries, Parc Scientifique, Agropolis, 34397 Montpellier Cedex 5, France.
G. North & Son (PVT), Box 111, Southerton, Harare, Zimbabwe.
H.C. Bell & Son (PVT) Ltd, PO Box 701, 24, Glasgow Rd, Mutare, Zimbabwe.
Hippo, R. Brennan, Gilgil, Kenya.
Manik Engineers, PO Box 1274, Arusha, United Republic of Tanzania.
President Mollermaskiner A/S, Springstrup, Box 20, DK-4300, Holbaek, Denmark.
Rajan Universal Exports (Mfrs) PVT. Ltd., 73, Pedariar Koil St, Madras, India.
Renson Landrecies S.A.R.L. 37 route Happegarbes, B.P.12, Landrecies, France.
Steel Structures Ltd., Dandora Rd, PO Box 49862, Nairobi, Kenya.
Tamsa Trading, PO Box 27693, Greenacres, Port Elizabeth 6061, South Africa.
UNATA, B.P.50, 3200 Aaschot, Belgium.
Waittu, PO Box 226, Accra, Wa, Ghana.

Annex 2
Useful Web site links

Australian Centre for International Agricultural Research (ACIAR), Fernhill Park, Bruce Act 2617, Australia. Web site: www.aciar.gov.au
Central Food Technical Research Institute (CFTRI), Mysore, India. Web site: www.cftri.com/unu
International Center for Tropical Agriculture (CIAT), AA 6713, Cali, Colombia. Web site: www.cgiar.org/ciat
International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. Web site: www.cgiar.org/iita
Information Network on Post-harvest Operations (INP*h*O), FAO. Web site: www.fao.org/inpho
International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila, Philippines. Web site: www.cgiar.org/irri
Intermediate Technology Development Groups (ITDG), Rugby, United Kingdom. Web site: www.itdg.org
Natural Resources Institute (NRI), Chatham, United Kingdom. Web site: www.nri.org

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