Development and Evaluation of a Single-Pass Vegetable {PRIVATE } Mill

by

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Development and Evaluation of a Single-Pass Vegetable Mill

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A thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria in partial fulfillment of the requirements for the award of the degree of Masters of Science (Agricultural Engineering)

September, 1998

DECLARATION

I hereby declare that this thesis was written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree and all the sources of information were duely acknowledged by means of references.

A. O. LAWAL

September 1998

DEDICATION

This work is dedicated to the local commercial tomato-pepper mill operators who by their innocent activities have unknowingly geared up interest in the work.

CERTIFICATION

This thesis titled: Development and Evaluation of a single-pass Vegetable Mill" by the author, Akeem Oyeyemi LAWAL meets the regulations governing the award of the degree of Master of Science (Agricultural Engineering) of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Size reduction is a basic food processing activity and commercial tomato-pepper mills for reducing vegetables and soaked grains are common in Nigeria. A survey of the types and operational problems of tomato-pepper mills in Sabon-Gari Local Government Area (LGA) revealed a neglect of the commercial tomato-pepper mill in terms of design improvement. The report also highlighted some technical deficiencies and hygiene problems with the mills surveyed. This work, which aimed at alleviating the problems of the commercial tomato-pepper mill, involved the development of a new mill which was produced and evaluated technically. An assessment of the type and level of contamination of materials ground on the commercial mill was also undertaken. Results show that the new mill has a higher benefit-cost ratio and requires less energy for milling than the commercial mill. In terms of milling capacity and the fineness and uniformity of ground material, the new mill compares favourably with the commercial mill. The microbiological tests indicate that bacteria and fungi are the major contaminants of tomato/pepper mixture and that the commercial mills contribute significantly ($P>0.05$) to the bacteria load of ground produce. Although the viable bacteria counts are below the FAO recommended level of 1×10^6, the levels are relatively high and call for caution to minimize the contamination load.

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CHAPTER ONE

1.0 INTRODUCTION

In Africa, cultural recipes have changed very little from ancient times and majority of them demand grinding of the product before cooking. Usually the extent of the grinding is determined by the recipe in question. In Nigeria, various recipes demand either dry or wet milling to a particular consistency (Asota and Kaul 1991). While dry milling produces flour for making a semi-solid food ("tuwo" in Hausa) from such cereals as corn, sorghum and millet and tubers such as yam and cassava, wet milling is related to preparation of local porridge from corn, sorghum, millet recipes from cowpea and soybeans and soups from vegetables. Asota and Kaul (1991) further stated that 70 percent of recipes prepared from cereals in Nigeria demand wet milling. Similarly, almost all recipes of soups in Nigeria require a size reduction (grinding, slicing or chopping) of the vegetables. Size reduction is thus still a basic food processing activity today as it has always been.

The equipment and systems used for size reduction in Nigeria can be classified into two groups as traditional and modern. The traditional systems are hardly used on a large commercial scale. They are usually used at the household/family level. The equipment employed are basically two: pestle and mortar; and grinding stones.

The pestle and mortar system is more suitable for dry products and is used for reducing cereal grains and dried tubers to flours. The mortar is a wooden tool which holds the material to be milled while the pestle (also made of wood) is used to pound the material. A set of grinding stones on the other hand consists of one stone carved out in form of a slab and the other in form of an ellipse or cylinder. The material to be reduced is kept on the slab-like stone and the cylindrical one is used to reduce it in rubbing strokes. It is more ideal for wet milling and is used for milling vegetables and soaked grains. Small-sized pestles and mortars are also available for milling vegetables.

The local size reduction methods described are highly labour intensive, limited in capacities, time consuming and subject the product to contamination with foreign materials.

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There also exists a high likelihood of loss of products during milling. These problems and the fact that these size reduction activities are generally a preserve of women who usually have limited expendable energies have contributed to the mass adoption of modern size reduction equipment with relatively higher capacities and less labor input (Mittal et al., 1982).

With respect to modern size reduction equipment, modern food processing mills employing sophisticated techniques of hammer, burr and roller mills are dotted all over the country and are increasing in number (Asota and Kaul, 1991). Technologies however abound to fill the gap between the traditional and sophisticated methods of size reduction. Of particular note are the plate mill commonly referred to as the tomato-pepper mill and the household blender.

The tomato-pepper mill which is almost entirely locally fabricated is effective for grinding wet products such as a mixture of vegetables (tomatoes, onion and pepper) and soaked grains such as maize, millet, sorghum and cowpea. Earlier work (Mittal et al, 1982) in a comparative analysis of four milling devices - grinding stones, mortar and pestle, hand cranked melon grinder and the tomato-pepper mill, indicated the capacity advantage of the tomato-pepper mill (21 kg/hr) over the 1kg/hr output of the mortar and pestle device. This capacity advantage and the drastic reduction in drudgery have made the tomato-pepper mill very popular among women. It's suitability for commercial use has also endeared it to housewives who now undertake milling as an income generating venture.

Despite these advantages and the popularity of the tomato-pepper mill, the machine is not without problems. Infact it is a device which has suffered neglect in terms of technological improvement, a continuous process aimed at improving the performance of machines. Apparently, because the tomato pepper mill is a common device, it has been taken for granted and thus not undergone any refinement.

A recent survey (Asota and Kaul 1991) identified some of the problems of the tomato-pepper mill as inconsistent machine quality in terms of size, shape and grade; high maintenance requirement and; metal and bacterial contamination of the product. The inconsistency in machine quality arises from the fact that most of the machines are produced by local artisans who neither use any standards nor ensure quality control. The high

maintenance requirement is due to frequent belt slips or cuts and frequent wear of the grinding plate surfaces which render the mill ineffective. While metal contaminants of iron fillings are suspected to come from the wear of the grinding plate surfaces when they come in contact, microbial contamination is due to the unhygienic practices of the mill operators.

The household blender, on the other hand, requires minimal maintenance. The unit is easily cleaned after use and is thus relatively free from contamination. It is however limited in capacity, depends solely on availability of electricity, and requires a relatively high initial capital outlay - about N5000.00 per facility since it is not readily adaptable for commercial purposes. These limitations of the household blender have made the patronage of commercial tomato-pepper mill outfits a preferable option for most housewives despite the potential health hazards stated earlier.

There is thus a clear need for some development efforts to eliminate or alleviate the problems of the tomato-pepper mill. The limitations of the household blender as a suitable alternative to the tomato-pepper mill have made this need even more pertinent.

It is therefore the objective of this work to develop a low-cost vegetable mill that eliminates the problems of the traditional tomato-pepper mill. Specifically, the work will seek to:

i) Determine the level of contamination of ground material from commercial pepper mills

ii) Improve the equipment design

iii) Evaluate the improved machine.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Size Reduction

Size reduction is a basic agricultural processing activity worldwide. Agricultural materials have to be reduced before, during or after processing. Size reduction includes such processes as cutting, crushing, grinding and milling but the terms commonly and generally included under size reduction are varied and not necessarily descriptive of the activities they represent (Henderson and Perry 1976).

The purpose of reducing material sizes are as many as they are varied. For instance, fruits or vegetables are cut for canning, sweet potatoes are shredded for drying, corn stalks are chopped for fodder, limestone is ground for fertilizer, vegetables are sliced for sauces and stews and grains are ground for livestock feed and flour. In these instances, the materials are best suitable for the desired purposes only after undergoing the specified size reduction procedures otherwise they are not suitable for the listed purposes.

2.2 Size Reduction Procedures

Reduction in size of materials by mechanical means does not change the chemical properties of the materials. The uniformity in the size of the end product, though usually desired, is seldom obtained. Henderson and Perry (1976) described three general procedures by which the size of agricultural products could be reduced as: cutting; crushing; and shearing either singly or in combination.

2.2.1 Size Reduction by Cutting

The reduction in the size of a material by cutting can be achieved using a sharp metal edge to slice through the material. Cutting is especially well adapted for reduction of high moisture agricultural materials such as fruits and vegetables.

The most satisfactory cutting device is a knife of extreme sharpness and as thin as structurally can be possible. This provides a smooth cut with minimal energy.

2.2.2 Size Reduction by Crushing

Size reduction by crushing is achieved by applying a compressive force, in excess of the strength of the unit to be reduced, to the unit. Failure results by rupture of the material in all directions. The resultant particles are irregular in shape and size and the characteristics of the new surfaces are dependent on the type of material and the nature of the force.

The crushing force can be applied statically as is done when cracking a walnut in a vice or dynamically as with a hammer mill. It is well suited for reducing limestone and other chemical fertilizers and in producing ground feed for livestock, flour and meal.

2.2.3 Size Reduction by Shearing

Size reduction by shearing is achieved by a combination of cutting and crushing. If the shearing edge is thin and sharp, performance approaches that of cutting while a thick dull shearing edge performs more as a crusher.

Shearing is usually employed for materials of a tough fibrous nature where some crushing may be advantageous and the resultant units are of large uniform size as in ensilage preparation.

2.3 Equipment for size Reduction

Henderson and Perry (1976) described the operations of three reducing devices the hammer mills, attrition mills (also called burr or plate mills) and crushers.

2.3.1. Hammer Mills

A hammer mill consists essentially of a rotating beater and a heavy perforated screen. The material introduced into the housing comes in contact with the beater which consists of a series of hammers turning at 1500 - 4000rpm. These beat the material until the particles are small enough to pass through the screen at the bottom. Fineness of the product is controlled

mainly by the size of the screen and the rate of feeding. Since the hammers are not rigidly fixed to the shaft or swing, there is less danger of the swinging hammer breaking if a large metallic object gets into the mill by accident.

Most of the size reduction is by impact between the material and the hammers. The terrific speed of the hammers produces kinetic energy that is dissipated on the material causing the material to disintegrate. This beating and hammering continues until the resultant particles are small enough to pass through the screen onto a suitable collection or conveying system.

Some of the advantages of the hammer mill are: simplicity, versatility; freedom from significant damage due to foreign objects or when operating empty; and insignificant effect of hammer wear on machine efficiency. The major disadvantages are its inability to produce a uniform grind and its high power requirement.

It can be used for a variety of size reduction and grinding jobs such as pulverizing limestone and other ingredients of commercial fertilizers.

2.3.2. Attrition Mills

Otherwise known as burr or plate mills, attrition mills consist essentially of two roughened plates, one stationary and the other rotating. The material is fed between the plates and is reduced by crushing and shearing. When the material is fed slowly and the flutes are not filled, reduction is probably by shear mainly. With faster feed and filled flutes, both shear and crushing no doubt, are likely to exist. The plates are designed for a variety of jobs and are usually made of chilled cast iron or alloy steel. Operating speeds are usually less than 1200 rpm. The fineness of reduction is controlled by the type of plates and the spacing between them. Provision is usually made for adjusting the spacing between the plates.

The advantages of the attrition mill include: low initial cost; relatively uniform product, and low power requirements as against the disadvantages of foreign objects causing unpleasant noise; excessive burr wear when operating empty; and significant negative effect of worn burrs on machine efficiency.

2.3.3. Crushers

Crushers reduce materials by pressing or squeezing it until the material breaks. Some examples are the jaw crusher, the gyratory crusher and the roller crusher. The roller crushers are more commonly employed for agricultural operations than the other two.

2.3.4. Available size reduction equipment in Nigeria

Asota and Kaul (1991) classified size reduction equipment in use in Nigeria into two viz: traditional and modern.

The traditional size reduction equipment available at the household level in Nigeria are grinding stones and the mortar and pestle. In using grinding stones, one stone is carved out in form of a slab while a smaller one is shaped like a cylinder or ellipse. The material to be ground is placed on the slabs and the smaller stone is used to shear it in rubbing strokes. It is most ideal for wet products. On the other hand, the mortar is a wooden bowl in which dry products can be milled by pounding with a pestle. The material in the mortar is sieved continuously and the residue is re-pounded until all useful material has been removed.

These traditional methods are characterized by high labor demand, limited capacities and proneness to contamination with foreign materials and loss of product. They are however, still adequate in rural locations where there are no modern mills.

With respect to modern mills, those employing sophisticated techniques of hammer, burr and roller mills are dotted all over Nigeria and are increasing in number (Asota and Kaul, 1991). Technologies however abound to fill the gap between the traditional and sophisticated methods of size reduction. Two readily available examples are the popular tomato-pepper mill and the household blender.

i) **The tomato-pepper Mill**

The tomato-pepper mill, a plate mill, is the commonest and most popular household milling equipment in Nigeria today. It's popularity, according to Mittal et al., (1982) in a comparative study of four milling devices, is due to its low operational difficulties and relative capacity advantage (21 kg/hr as against 1kg/hr of the mortar and pestle method). Mittal et al., (1982) further observed that although the pepper mill can achieve 21kg/hr

output, the machines are rarely run on a continuous basis due to intermittent flow of patronage.

Basically, the mill consists of a hopper which holds and introduces the food material to an auger-type conveyor which empties the material between two cast iron grinding plates - one rotating and the other stationary. Grinding is achieved in a similar way to the traditional grinding stone. It occurs by a rubbing action of the plates enclosed in a housing . A side wall of the housing provides a journal bearing to support one end of the grinding shaft while the other end is supported by a bearing fastened to an upright support and carries a pulley for connecting to a prime mover which is usually an electric motor or petrol engine.

Rate of feeding is controlled by the speed of the shaft and a stick is often used to force the material down to the conveyor when there is a delay in the flow of the material. Fineness of grind is set from a handscrew welded onto the stationary plate. This adjusts the distance between the two plates. It is most suitable for grinding a mixture of tomatoes, onions, pepper and sometimes pumpkin. It is also used for milling soaked grains such as maize, cowpea, sorghum and millet.

Although very popular and in common use, a recent survey (Asota and Kaul 1991)identified some problems with the tomato-pepper mill viz: (a) Inconsistency in the quality of the machines available in respect of shape, size and grade. This is attributable to the local artisans who produce the machines using different raw materials resulting, in most cases, in poor quality machines.

(b) Contamination of the ground material with consequent potential health hazards. There are two types of contaminants and they arise from different sources. Bacteria and other micro-organic contaminants are picked up from the food build-up around the leakage zone along the grinding shaft (see A in fig 1). Leakage starts at this point once the auger shaft which runs within iron bushings at this point wears. In order to prevent the leakage, the operators usually tie polythene or cloth material around the leakage zone and as such there is a food build-up. Since the polythene or cloth material are seldom changed, the food build-up remains for a very long time and is suspected to be a good breeding ground for harmful bacteria.

Metal contamination is suspected to come from wears on the rough faced plates as

they rub on each other during grinding. Iron filings from such wear thus add to the contamination load on ground product.

(c) High maintenance requirement. Many parts of the grinder require frequent maintenance. As the surface of the plates wear, the machine is rendered ineffective and thus the plates have to be re-roughened. Frequent belt slips and belt cuts during operation and rusty components are also common phenomena.

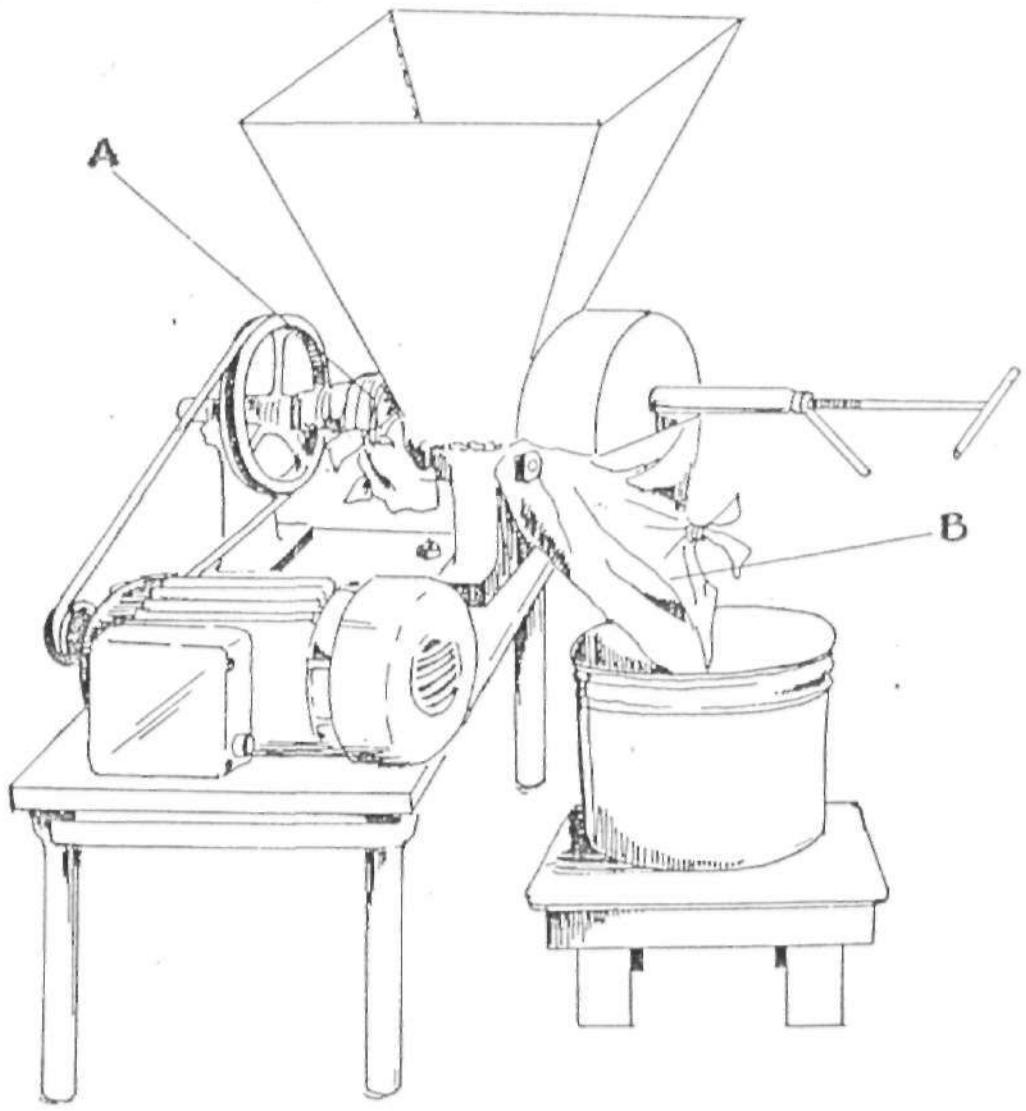


Figure 1.

The conventional pepper mill - users tie leakage points with polythene or cloth material **(A)** or extend the delivery spout with polythene bag **(B).**

(ii) **The Household Blender**

This is another common size reduction machine. It is usually used at the household level and consists basically of two parts - the prime mover and the blending unit.

The prime mover is essentially an electric motor housed in a protective casing. It has a cable and plug by which it is connected to an electricity outlet and an extended rotor shaft. The extended rotor shaft is covered by rubber sprockets and the motor casing allows the blending unit to sit snugly allowing the socket below the bowl to fit on the rotor shaft sprocket. The blending unit, usually about 1 litre capacity, has blending blades fixed inside it at the bottom and connected to a socket located externally on its base. When the bowl is placed on the engine housing, the socket fits directly on the rotor sprocket and when the motor is switched on, the blades inside the bowl turn.

In operation, food material is placed in the bowl which means that the ones at the base will be in contact with the blades. Some water is added, the bowl is covered and then placed on the motor. The motor is then switched on and off intermittently as recommended by the manufacturer until the desired consistency is achieved. With different blade designs, the household blender can be used for a range of products which include various fruit and vegetables and well soaked grains.

The household blender requires minimal maintenance. With the bowl made of plastic and blades made from stainless steel, the unit is easily cleaned after use and thus, it is, to a large extent free from bacteria and metal contamination. It is however limited in capacity; depends solely on the availability of electricity; and requires a relatively high initial capital outlay (about N5000) per family since it is not easily adaptable for commercial use.

2.4. Food Contamination during Processing

Anigo (1987) identified two ways by which foods can be contaminated by heavy metals as natural contamination through the soil whereby the contaminants are picked up by plants during the growing stage as natural trace elements, chemical additives (fertilizers and pesticides) and radioactive products; and accidental contamination during or after processing.

According to Whitman (1978), the problem of metal contamination of food during processing occurs frequently as a result of misuse of equipment or the overlooking of the consequences of using unsuitable metals in apparently insignificant ways. For instance, cadmium is readily soluble in break acids and is often used in plating small pieces of equipment. In recent times, the contamination of food through packaging material has been a great deal of concern (Brian et al., 1970).

While a number of elements (including heavy metals) when present in trace amount are desirable in the body and essential in human nutrition, amounts in excess of what is desired leads to accumulation which is harmful to the body. Cadmium, for example, is a cumulative poison associated with hypertension and esteomalacia, especially among patients with low dietary calcium (Deluca, 1976; Jenning and Rainbow 1979). It also caused itai-itai disease, a painful disabling illness in Japan when see foods contaminated with cadmium are consumed (Tsuchiya, 1976). Similarly, lead in excess of what is desired disturbs the synthesis of heme in the body (Dresel and Falk, 1956) and it causes permanent brain damage in children (WHO,1972). Among the many problems of mercury poisoning are mental retardation, damage to the central nervous system, paralysis and lack of muscular co-ordination (WHO,1974).

In view of the fact that contaminants (bacteria, rust and iron filings) unintentionally picked up from the tomato-pepper mill could reach toxicological proportions, a study (IAR 1990) focused on such aspects of food contamination possibilities. The results indicated that rust and iron filings do not affect the rate of deterioration of the material processed with the market grinder. Deterioration was attributed to the presence of micro-organisms picked up during processing in apparent unhygienic conditions. This is not to say that iron consumed from such foods is not harmful. It could be quite harmful if it accumulates when not in an absorbable state by the body.

2.5. **Development of size reduction equipment in Nigeria**.

It has been observed that there has been very little local efforts in the development of size reduction equipment for vegetables and wet-milling of grains (Asota, 1993). He noted

that while the incorporation of new technologies is a never ending process, it has not been the case with the tomato-pepper mill. He further observed that as common as the tomatoe pepper mill is, it is one of the technologies that have been taken for granted and ha thus not undergone any refinement for a long time. Only one company, Addis Engineering, Lagos was quoted as an organization making efforts at improving the pepper mill. For now, the company has started the production of a somewhat similar mill with all parts made from aluminium with some success (Asota, 1993).

2.6. Performance Characteristics of a Size Reduction Machine.

According to Henderson and Perry (1976), the performance of a machine for reducing the size of material can be characterized by the capacity; the power required per unit of material reduced; the size and shape of the product before and after reduction; and the range in size and shape of the resultant product.

In studying the performance of size reduction machinery, therefore, it is pertinent to develop methods for determining the size characteristics of the ground material.

2.6.1. Methods of particle size Analysis

The size and shape of the individual grains in any mass of material will depend upon the physical characteristics of the material, its previous history and the method of reduction (Henderson and Perry, 1976). Various methods however abound for the determination of particle size and size distribution. Some of these were given by Ituen (1983) as follows:

i) Techniques involving direct measurement e.g. the microscope and the sedimentation methods

ii) Techniques involving fractionation as in sieving and

iii) Techniques involving the evaluation of the surface area as in the evaluation of the surface area of a powder from absorption studies.

The microscope method is by a direct measurement of enlarged images of the particles. Linear measurements of the particles are made using a scale placed on top of the particle image. Allen (1974) listed some problems associated with this method as:

i) the need for a lot of data (measurements) to ensure adequate precision in the derived parameters.

ii) the elimination of variables in the data due to the operators performance

iii) statistical fluctuations in the occurrence of any given size profile (among the particle images). This may be acute if the size ratio of particles is more than 10:1

iv) large time requirement and tiring operation since readings are taken in more than one orientation.

In the sedimentation method which could either be gravity or centrifugal, the stokes diameter distribution of the powder is deduced from the concentration changes occurring within a settling suspension. In the settling of a single sphere under gravity, its diameter (Stokes diameter) can be determined by Stoke's law or the decantation formula.

Stoke's law defines the setting sphere diameter as

$$D = \sqrt{\frac{18\mu u \times 10^8}{(\rho s - \rho f)g}}$$

where μ = viscosity of setting fluid, Pa-s

u = velocity of sphere, ms^{-1}

ρs = density of settling material, kgm^{-3}

ρf = density of settling fluid, kgl^{-1}

g = acceleration due to gravity, ms^{-2}

The Stoke's equation is theoretically valid only for a sphere. But the difference between the volume of an irregular particle and that of a sphere does not represent an error. It actually gives a useful information on the shape of the particle.

The decantation formula is easier and more widely used in practice than the Stoke's equation (Allen, 1974). In the method, a homogenous suspension is allowed to settle for a pre-determined time. The supernant liquid is then decanted and replaced by fresh dispersing liquid. When it is clear, the decanted liquid will only contain particles finer than size D which is defined by the equation.

$$D = k\sqrt{h}/t \text{----------2.2}$$

where h = height at which liquid is siphoned off at time t (usually corrected for meniscus and temperature),cm

k = constant given in tables

t = settling time

D = particle diameter, mm

The decantation method is widely used for laboratory calculations of Stoke's diameters. In general, sedimentation method is desired more in specialized industries like flour, pharmaceutical and paint industries.

The surface area method is largely used in the powder industry. The Gates diagram, a plot of cumulative percent weight undersize versus reciprocal of diameter, is used to estimate the surface area of the particles. The area beneath the curve represents the surface area of the particles (Irani and Calis, 1963)

Sieving is considered the simplest and most frequently used method for particle size analysis (Henderson and Perry 1976). It is however restricted to granular material having the greater proportion coarser than 75um (Allen, 1974).

In sieving, the techniques used have been standardized and should be followed for reliable results. Both the method and time of shaking are also important. Usually the sieves are staked in order of ascending aperture size and the powdered material placed on the top sieve. The stack is then agitated and the material classified into fractions. The results are expressed in terms of the nominal apertures of the sieves used in the analysis. The sieving operation may be carried out wet or dry.

Dry sieving is often possible with the coarser mesh sieves and with the aid of air-jet technique, the lower limit may be extended to 15um (Allen, 1974). Aggregation of particles may be reduced by drying or by adding about 1% of a dispersant (Allen, 1974).

Wet sieving is used for materials which are suspended in a liquid and for powders which form aggregates when dry-sieved. The stack of sieves is filled with the liquid and the material fed into the top sieve. Sieving can be done by rinsing, vibration, reciprocating actions, vacuum, ultrasonics or a combination (Allen, 1974). By moving the sieve up and

down inside the sieving liquid, the direction of flow of the liquid through the sieve openings is continuously reversed. This helps clean the blocked aperatures and disperse agglomerates. With fine sieves, the sieving liquid must have a low surface tension. In some cases, ultrasonic probe may be employed otherwise the material will not flow through the sieve apertures. When a dispersing agent is used, the concentration should not exceed 5 percent solution (ASAE,1979).

The size distribution given by a sieving operation, according to Iruen (1983), depends on the duration of sieving, the variation of sieve aperture, sieve wear, error of observation and experiment and the effect of different equipment and operations.

2.6.2. Characterizing particle size Distribution

Various methods have been used to represent characteristics of particle sizes. A single parameter representation such as the mean particle size or particle surface area is generally inadequate to completely describe a distribution function. Hansen and Stewart (1965) indicated that using the fineness modulus alone to describe particle size is misleading since it represents only a small portion of the size distribution. They also stated that uniformity index which gives an additional information concerning distribution of sizes into coarse, medium and fine grades is also not acceptable. Chung et al., (1977) indicated that particulate materials require at least two parameters to adequately describe their distribution function.

A number of equations to relate the distribution of a powdered material with particle size had been proposed by many authors including Rossin and Rammler,Schuman (Perry and Chilton, 1973) To date, many researchers have used the Schumann equation with great success.

Schumann (Hansen and Stewart, 1965) proposed that many naturally broken homogenous materials yielded a distribution which could be represented by the equation

$$y = 100\,(x/k)^{\infty} \text{----------} 2.3$$

where x = particle size based on the smallest sieve opening
through which the material will pass

y = weight percent finer than x

k = product size modulus (sieve size through which 100% of the product will theoretically pass)

∞ = a distribution modulus

A log-normal plot of this equation yields a straight line of slope, ∞ which intersects the 100% ordinate line at a particle size k. The distribution modulus is constant for products from a number of screen sizes. That is, the product passed through different screens have identical slope. It is also assumed that the distribution modulus has the same value whether it refers to the breakage of a single particle or the entire product of a regular continuous grinding. The distribution modulus gives information on a range of sizes in the product. It represents product uniformity and is directly proportional in magnitude to the degree of uniformity (Hansen and Stewart, 1965). The size modulus, k, indicates the approximate size of the largest particles of a significant quantity in a product.

A log-probability plot is now recognized by the American Society of Agricultural Engineers, ASAE, as the standard of reporting the fineness distribution of ground animal feed (Henderson and Perry, 1976). The log-probability particle size distribution can be described completely by two values, the geometric mean diameter, d_{gw}, and the geometric standard deviation s_{gw} by weight (ASAE,1979). These two values can be calculated analytically by some equations given by Farral, 1976; Henderson and Perry 1976, and Stockham et al., 1977. The parameters d_{gw} and S_{gw} can also be obtained directly from a log-probability plot (Henderson and Perry, 1976; ASAE 1979) using the following expressions.

$$d_{gw} = d_{50} \quad \ldots\ldots\ldots\ldots 2.4$$

where d_{50} = particle diameter at 50% probability

$$s_{gw} = \frac{d_{84}}{d_{50}} = \frac{d_{50}}{d_{16}}$$

where d_{84} = particle size at 84% probability

d_{16} = particle size at 16% probability

The following parameters can therefore, be determined from a log-probability plot to describe the distribution of a sample: the distribution modulus ∞ ; the size modulus k; the geometric mean diameter d_{gw}; and the geometric standard deviation s_{gw}

Headley and Pfost (1966) stated that since no distribution has ever been truly normal or log normally distributed, some biological materials only closely approach log-normal distribution. The end of a straight line plot can be extrapolated to find parameters on the sub-sieve regions (Hansen and Henderson 1972).

None of the above size characterisation systems is useable for all ground grains (Henderson and Perry, 1976). They explained that

grains are composed of many materials including celluose, fiber, starch and oil whose presence in varied amounts in various grains affect the size, shape and distribution of the particles resulting from a grinding operation. Consequently, a sizing procedure, in effect attempts to represent the sum of the distributions of each of a number of completely different components . Results of sizing procedure of grains therefore may not give an accurate representation of each of the material components of the grains but a fair estimate of the distribution of the aggregates.

2.6.3 Energy Size Reduction Relations

Communition or size reduction of materials usually involves a combination of cutting, crushing and shearing forces which are applied to particles in excess of their maximum rupture strength to produce an increased number of smaller particles of irregular sizes and shapes. Hansen and Stewart (1965) stated that energy required for a specific size reduction operation depends on the type of material reduced, the machines or methods used and the particle size range over which communition takes place.

The various laws of communition result in energy relationships which can be derived from this expression (Perry and Chilton,1973).

$$dE = - C\, dx/x^n \quad \text{..... 2.6}$$

where dE = incremental energy

dx = change in particle size

x = original particle size.

c = a constant

n = exponent

The expression states that the energy required to grind is proportional to the change in particle size divided by the original particle dimension raised to the nth power.

Integrating equation 2.6, we have

$$E = -C\int_{X1}^{x2} \frac{dX}{X^n} \quad \text{.....2.7}$$

solving equation 2.7 for n = 1 gives Kick's law

$$E = C \ln (X_1/X_2) \quad \text{.....2.8}$$

Equation 2.8 states that the energy required to produce particle failure through grinding is a function of some initial particle dimension and the reduced particle dimension on the assumption that the particle symmetry exists before and after grinding.

When n = 2, the solution of equation 2.7 gives Rittinger's equation.

$$E = C (1/X_2 - 1/X_1) \quad \text{.....2.9}$$

Rittinger's law assumes that the energy required for reduction of particle size is a function of the new specific surface produced and also that particle symmetry exists before and after grinding.

When n = 1.5, the solution of equation 2.7 gives Bond's equation.

$$E = C (1/\sqrt{X_2} - 1/\sqrt{X_1}) \quad \text{.....2.10}$$

This equation states that the total useful energy in particle size reduction which has been applied to homogenous broken materials is inversely proportional to the square root of the diameter of the reduced particles. Bond also considered the total energy required to grind a material from a theoretically infinite size to one size, D, which was evaluated as the 80% passing size on a screen analysis plot (Headley et al, 1968). The mesh size in microns of the size through which 80 percent of the material passes is selected as the criterion of the feed and product sizes since this is a figure which is already obtained by plotting the results of a screen analysis. It is assumed to be more reproducible than the size of mesh through which 100 percent of the sample passes (Rose and Sullivan 1958).

Equation 2.10 therefore reduces to

$$E = C\,1/\sqrt{D} \text{ ----------2.11}$$

where E = energy input per unit weight of the material ground

D = average product size or diameter evaluated or 80% passing size by sieving

C = constant, depends on type of grinding machine and materials being ground.

McCabe and Smith (1976) stated that Bond's energy is more realistic than Rittinger's and is usually employed to estimate the grinding energy of many commercial and industrial crushers and mills.

Charles (Hansen and Stewart, 1965) combined equations 2.3 and 2.6 and integrated to introduce the energy prediction equation for grinding materials which follow the Schumann size distribution equation as

$$E = AK^{1-n} \text{ .....2.12}$$

where E = energy input per unit weight of material ground

A = constant, depends on machine and material ground

K = product size modulus (same as k in Schumann equation)

n = constant

1-n = slope of log-log plot of E against K.

He further showed that for hard brittle material (which does not show exceptional cleavage), the exponent (1-n)was close to the negative value of ∞ in the Schumann Size distribution equation. Therefore Charles equation is expressed as

$$E = Ak^{-\infty} \text{ .....2.13}$$

Schumann and Charles equations have both been applied with reasonable success to several ground cereal grains (Hansen and Henderson 1966). Headley and Pfost (1968) stated that equations 2.8, 2.9, 2.10 and 2.13 are now used for biological materials though they were originally developed for non-biological materials such as rocks and stones.

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1 The Design

3.1.1. Design concept

Based on the evaluation of the commercial tomato-pepper mill and the problems identified (Asota and Kaul, 1991), it was decided that this new design must eliminate the identified problems and still perform the same functions as the common mill in order to gain user acceptance.

Requirement for this design were therefore considered to be:

i) Permit grinding without subsequent re-charge of product or change in cultural practice

ii) Improve on the efficiency of power utilization and still operate with currently used prime movers

iii) Be simple in design and overall operation to provide an easily reproducible and low-cost machine

iv) Reduction of machine weight for better mobility

v) Re-design of the grinding mechanism to minimise adjustments and wear of the grinding surfaces

3.1.2 Selection of materials and design analysis

The design of the various parts of the equipment, the materials selected and the considerations made in the determination of their sizes and shapes are presented component by component as follows:

i. Hopper

The material selected for the hopper is 16swg (1.5mm) mild steel sheet. This is based on its ready availability, low corrosive attributes and relative low cost.

- The hopper is shaped as shown in the design drawings to assist in weight distribution to balance the assembly and to also ensure a free flow of materials put in it into the milling chamber. This nullifies the need to force the materials into the milling chamber.

In accordance with standards for all-purpose agricultural hopper (ASAE, 1979) the volumetric, C_v, and gravimetric, C_g, capacity ratings of the hopper were determined and are given as:

$$C_v = 6.25 \times 10^{-4} m^3$$

$$C_g = C_v \times 1000\ kg/m^3$$

$$= 6.25 \times 10^{1}\ kg$$

This will conveniently contain 2kg of tomato which is the average quantity of tomato processed at a time by the commercial mill operators.

ii. **Milling chamber**

The milling chamber consists of three components namely:- the power shaft: the milling blades and the chamber casing.

Power shaft

The material selected for the shaft is medium carbon steel (C1040). This is because it is readily available and can be easily machined into desired sizes.

According to ASME (Mark 1951), medium carbon steel has the following strength properties.

Yield stress, S_y = 82.4 kpsi (568.7 MN/m2); and

Tensile stress, S_t = 97 kpsi (668.8 MN/m2);

The maximum allowable shearing stress, Sa, using the ASME code for steel is given as the lower value of either 18% S_t or 30% S_y. This allowable stress is further

reduced by 25% when there is a keyway in the shaft.

Thus

$0.18\ S_t$ = $0.18\ (668.8 MN/m^2)$ = $120.38 MN/m^2$

$0.30\ S_y$ = $0.30\ (568.7\ MN/m^2)$ $170.61\ MN/m^2$

The lower value is $120.38\ MN/m^2$

Considering the key-way, the allowable shearing stress, S_a, is reduced as

S_a = $(1-0.25)\ 120.38.MN/m^2$

= $90.3\ MN/m^2$

= $90.3x10^3 KN/m^2$

Assuming that the maximum shearing stress of a tomato τ_t equals the average compressive stress measured using a tensiometer, then

τ_t = 50N (lab. Measurement)

Similarly the average density of a tomato = $90g/cm^3$ (lab. Determination)

And the average weight of a tomato =50g (lab. Measurement)

Total volume of the milling chamber = $\pi r^2 l$

= $\pi \times (45mm)^2 \times 35mm$

= $2.23x10^2\ cm^3$

Total weight of tomato that can be contained in the chamber

= $2.23 \times 10^2\ cm^3 \times 90g/cm^3$

= 2007g

= 2.007kg

Total no of tomato that can be contained in the chamber

$$= \frac{2007g}{50g} = 40pcs$$

Maximum stress of the tomato load

$$\tau_{max} = 40 \times 50N$$
$$= 200N$$

The torque M_t due to the tomato load $= \tau_{max} \times l$

Where l is the average distance of the cutting edge of the blade from the hub centre

$$= \frac{44mm}{2} = 22mm$$

$$M_t = 200N \times 2.2 \times 10^{-2}\ m$$
$$= 4.4\ Nm$$
$$= 4.4 \times 10^{-3}\ KNm$$

The allowable shear stress for the shaft is represented by

$$S_a = \frac{16M_t}{\pi D^3}$$

Where D is the minimum allowable diameter of the shaft and other variables are as defined and determined earlier

By rearranging,

$$D^3 = \frac{16M_t}{\pi S_a}$$

Substituting M_t and S_a values

$$D^3 = \frac{16 \times 0.0044\ KNm}{\pi \times 90.3 \times 10^3\ KN/m^2}$$
$$= 2.48 \times 10^{-7}\ m^3$$
$$D = 6.284 \times 10^{-3} m$$

This being the minimum allowance diameter of the shaft, a shaft diameter of 20mm was used.

Milling blades

The milling blades were made of 1" mild steel flat bar. Each blade is 38mm long thus leaving a clearance of only 1mm between the blades and the casing. The cutting edge of the blades was sharpened to about 0.5mm thickness. The blades were attached rigidly to a hub which is then fitted on the power shaft within the milling chamber.

The optimum number of blades was determined subjectively by using hubs bearing 2, 4, 8 and 12 blades respectively to mill and then comparing the fineness of grind of material and the time required to complete grinding for each of the various hubs.

Based on these parameters, the 2-blade hub performed less than the other hubs while there was no significant difference between those of the 4,8 and 12-blade hubs. The 4-blade hub was therefore adopted for the design. The blades are arranged symmetrically with adjacent blades having a lag of 90^{o} at equal distances of 9mm thus leaving 3mm clearance at each end of the 33mm hub.

The casing

The milling chamber casing consists of a 100mm diameter end-plate which supports the hopper, the power shaft and bearing and also the cylindrical cover of the blades and power shaft.

Due to the support requirements of the end-plate, it was made of 2mm mild steel sheet while the ring attached to the plate to allow the cylindrical cover to sit was made with 1" flat bar. The cylindrical cover was made with 1.5mm mild steel sheet. The cover has a diameter of 90mm and length of 35mm thus giving the chamber a maximum volume of $2.23x10^{-4}m^{3}$. At the lower portion of the casing, there is a square hole of 20mm sides which opens into the discharge spout.

iii. Motor and Couple

An electric motor was preferred for the design. The size of motor was determined based on the power required for milling determined as follows.

The speed of the blades was based on those of conventional tomato blenders which run at between 1000 and 24000 rpm depending on the make.

A value of 1200 rpm within the range of conventional blenders was therefore used.

Blade speed N = 1200 rpm

Power required for milling, $P = M_t \times \omega$

Where $\omega = \frac{2\pi N}{60}$ rad/s (Hannah and Stephens, 1970)

$\therefore P = M_t \times \frac{2\pi N}{60}$

$= 0.\frac{0044 \text{ KNm} \times 2\pi \times 1200}{60}$ rad/s

= 0.553 KNm/s

= 0.553 Kw

= 0.74hp

This being the minimum required power output of the motor, a 0.746Kw (1hp) electric motor was selected and used.

Couple

For the rigid couple, the diameter of the pins is determined as specified by Hall et. al. (1961):

Assuming the same material for the pin and shaft, the allowable shear stress Sa = $90.3 \times 10^3 KN/m^2$

The torque due to the tomato load Mt is

$$M_t = S_a (1/4\ \pi d^2) \times r \times N$$

Where N = no of pins

D = diameter of pin and

R = distance of pin from the shaft center.

By rearranging

$$D^2 = \frac{4\ M_t}{2\pi r S_a}$$

$$= \frac{4 \times 0.0044\ KNm}{2\pi(0.015m) \times 90.3 \times 10^3\ KN/m^2}$$

$$= 2.068 \times 10^{-6} m^2$$

$$d = 1.438 \times 10^{-3} m$$

$$= 1.43mm$$

Two 5mm diameter pins were therefore used for the rigid couple.

3.1 The equipment

The design of the equipment which was used to produce a number of prototypes is as shown in the attached design drawings.

The design consists basically of a hopper which is connected to milling chamber via a slanted throat. The milling chamber is a cylindrical case which houses a shaft bearing a hub which carriers four straight blades systemically arranged on the hub. The shaft is connected in line with a 1 electric motor shaft through a rigid coupler. The milling chamber opens to an outlet port through a slide gate. The whole assembly is mounted on a trolley for easy transportation.

In operation, materials put in the hopper flow by gravity through the inclined throat onto the 4 symmetrically arranged straight blades in the milling chamber. The power shaft which is connected directly to the electric motor shaft runs at the same speed (≈1440rpm) as the electric motor shaft. The hub bearing the four blades and attached to the power shaft also turns at the same speed thus ensuring that the blades beat and slice the materials flowing into the milling chamber continuously until power is disconnected and the slide gate is opened for the reduced materials to flow out through the discharge spout.

The inclination of the hopper throat helps to prevent back-splash of material while noise and vibration are minimized by ensuring a proper alignment between the motor shaft and milling shaft. A sealed ball bearing was used on the slide wall of the milling chamber (end-plate) to carry the milling shaft. The bearing helps in aligning the shaft properly, restricting its lateral movement and preventing leakage at the point of entry of the shaft into the chamber. The bearing was selected in preference to a bushing as the bushing is likely to wear out faster causing a misalignment of the shafts and a leakage around the bushing thus necessitating more frequent maintenance.

3.2. Technical Evaluation of Equipment

According to Henderson and Perry (1976), the performance of a size-reduction machine is characterised by the capacity, the power required per unit of material reduced, the

size and shape of the product before and after reduction and the range in size and shape of the resultant product.

Considering this, three parameters were evaluated on the new design as follows:

3.2.1. Determination of Machine Capacity

The machine capacity was evaluated by determining the time required to grind a specific quantity of material (2kg) to the finest possible consistency taking into consideration the times for recharging and emptying where applicable. The capacity per hour was then extrapolated from the values determined.

The procedure was repeated thrice and an average calculated for three materials - tomato-pepper mixture, soaked maize and soaked cowpea.

To allow for comparison, the procedure was repeated for the common tomato-pepper mill and the Addis model of the mill.

3.2.2. Energy Measurement

The energy consumption for grinding was measured in a similar way to what Asota (1993) reported. Rather than switching off all other connected electric units in a house apart from a grinding mill and reading the electricity meter however, an electricity meter obtained from the electricity meter company of Nigeria (EMCON), Zaria was connected in series between a wall socket and the grinding machine. The energy consumed was then read directly on the meter.

A known weight of material was ground and the energy consumed measured for three different materials tomato-pepper mixture, soaked maize and soaked beans. The procedure was repeated twice and an average determined. For comparison, the procedure was repeated for the common tomato-pepper mill and the Addis mill.

3.2.3. Particle size Analysis

Two materials, soaked cowpea and a mixture of tomato and pepper, were reduced separately on the equipment prototype and the resultant products analyzed for their particle size characteristics.

Sieving is the simplest and most frequently used method of particle size analysis (Henderson and Perry, 1976) and was used for this analysis. Each ground sample was sieved using a set of 7 Tyler sieves and pan. 250g of each wet ground sample was measured and put in a container and 25ml of calgon (sodium hexametaphosphate and sodium carbonate), a dispersing agent, was added and mixed well. The suspension was then transferred into a stirrer and stirred for about two minutes. It was then poured onto the top sieve. The first sieve was removed and rinsed thoroughly by vertical movement in a basin of water. The water in the basin was then poured into the next sieve placed in another container to avoid spillage or overflow. The process was continued with one sieve washed into another till the last. The sieve fractions were carefully washed out into well-labeled cans of known weight and dried in the oven at a constant temperature of 110 °c to determine the weight of the dry matter retained. Drying progressed until there was no appreciable difference in the weights of the sieve fractions placed in the oven based on regular weight measurements.

The fineness modulus was determined from the results of the sieve analysis. The procedure was repeated using materials from the same sources for the common tomato-pepper mill, the household blender and the Addis model mill.

3.2.4 Other Machine Characteristics

Some measurements such as the weight of the machine, the number of components and time required to dismantle for cleaning were taken for the purpose of scoring the design merits for the commercial and Addis mills and the new design.

3.3. Determination of the level of Contamination.

The level of contamination of material ground on the commercial tomato-pepper mill was determined using a three-stage procedure as described by Collins (1968). The three stages are, microbial isolation, identification and characterization, and enumeration.

To prepare the test samples, three commercial tomato-pepper mills selected at random in Samaru market were used to grind a portion each of a mixture of tomato and pepper which had been surface-sterilized by washing with ringer solution. Another portion of the tomato-pepper mixture was reduced using a household blender which had been washed with sterile water. This served as control.

3.3.1. Microbial Isolation

Microbial isolation involved two isolation methods one for mold, fungi and yeast and the other for bacteria.

a) Isolation of mold, fungi and yeast

Some quantity of the ground product from each of the three tomato-pepper mills and the household blender were plated out on malt-extract agar and potato dextrose agar and incubated at 35°c overnight.

Visible colonies were stored on slant for further identification and characterization based on morphology and culture appearance.

b) Bacteria Isolation

Some quantity of fresh ground product from the three mills and the control were enriched on the peptone enrichment medium and then plated out on each of the various agar media.

For the mixed culture, the growing edges of the colonies were sub-cultured. Serial dilutions were prepared and several plates with small volumes of each dilutions made.

3.3.2. Identification and Characterization

Microbial identification was based on cultural and biochemical tests. Gram staining was also performed on each of the visible colonies as described by Norris (1969).

In order to be able to identify the organisms up to specie level, a number of biochemical tests described by Chessbrough (1980) were carried out. The tests are: casem hydrolysis; catalase test; coagulase test, DNase test; gelatin liquefaction; H_2S production; indole formation; methyl red vogue prokeur (MRVP); oxidase test; and urase activity test.

3.3.3. Enumeration

The estimation of the microbial count was done as follows

a) Total count

Milled tomato-pepper specimens from each of the three commercial mills and the

control were stained with 0.1% methylene after enrichment with peptone water. 0.05ml of each specimen was then mounted in the counting chamber and counted under the x100 of microscope.

The procedure was repeated twice for each of the three mills products and the control product and an average calculated.

b) Viable Count

For each of the specimens from the three mills and the control, 10ml of specimen was added to 99ml of diluent to give 1.10 dilution. 10ml of nutrient agar was cooled down to 45°c in a water bath and then put in petri-dishes which had been set out at three per diluent. 1ml of each dilution was then pipetted onto the center of the respective dishes.

The petri-dishes were then agitated by gently rotating them clockwise, anti-clockwise, forward and backward. The media were allowed to settle and then inverted before incubating at 35°c for 36 hours.

Selected plates showing 30-300 colonies were counted. Colony count was multiplied by average number of colonies per countable plates. The reciprocal of the dilution represents the colony/ml.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Technical Evaluation of Equipment

4.1.1. Milling Capacity

The milling capacities of the new design, the commercial tomato-pepper mill and the Addis model mill determined are shown in table 4.1 below.

Table 4.1. Milling Capacity of the three Mills

{PRIVATE } Product Milled	Milling Capacity (Kg/hr)		
	Common Mill	Addis Mill	New design
Tomato/onion/ Pepper	45	49	51
Soaked maize	18	18	18
Soaked beans	17	19	18

As can be seen from the table, the new design compares favorably with the commercial tomato-pepper mill and the Addis mill in terms of milling capacity. The figures were however extrapolated from capacities achieved from milling for periods much shorter than one hour. Although these capacities are achievable, the use of the new design mill will pose more difficulties for the operator as it is a batch processing equipment. The commercial tomato-pepper mill and the Addis mill are continuous process equipment and as such are likely to make milling easier when large quantities of product are to be milled.

4.1.2. Energy Requirement

The results of the energy requirements for milling soaked maize, soaked beans and tomato/pepper/onion mixture conducted on the three different mills are shown in table 4.2.

Table 4.2. Milling energy requirement of three mills.

{PRIVATE} Product	Energy Requirement Kwhr/kg		
	Commercial mill	Addis mill	New design
Tomato/onion/ pepper	0.063	0.062	0.055
Soaked maize	0.120	0.118	0.095
Soaked beans	0.094	0.091	0.080

The figures show a relatively lower energy requirement of the new design for milling the three different products than the commercial mill and the Addis mill. Smith et al (1994) gave that while measuring the power in the drive line will give the exact requirement of a machine, wattmeter measurements give only the electrical power input to the motor. The efficiency of the motor to transmit such wattmeter - measured power to the machine thus needs to be taken into account

For electric motor - driven machines, power requirement may be established by fitting a torque measuring device in the drive line and measuring the speed of rotation (Smith et al., 1994). Where this is not possible, a good approximation can be obtained by measuring the input voltage, v, and current, A, to the motor and calculating the average power in watts or by connecting a wattmeter between the supply and the motor to give direct power readings.

In the absence of any reliable torquemeter, the power measurements were made by connecting a wattmeter between the supply and the motor thus reading the energy inputs to the motors. The relatively lower energy requirements of the new design can be attributed to its

direct connection to the electric motor which ensures a maximum utility of available power and a minimization of energy losses as against those of the commercial mill and the Addis mill which are connected to electric motors via speed reduction pulleys and belts.

4.1.3. Particle size Characteristics

The values of the average particle size (diameter) determined from the data obtained from the sieve analysis carried out on the two products ground on the four different machines are given in table 4.3. The sieve analysis data and the determinations of fineness modules (FM) and particle size are given in Appendix I.

Table 4.3. Particle diameter (D) of two products ground on four different machines.

{PRIVATE } Product	Average diameter (mm)			
	Commercial mill	Addis mill	Household blender	New design
Soaked beans	1.18	1.13	1.55	1.23
Tomato/pepper	0.76	0.72	1.05	0.94

As can be observed from the table, the tomato/pepper mixture was generally ground to a finer consistency on all the machines than the soaked cowpea. The Addis mill, the commercial mill, the new design and the household blender were found to produce less fine product consistencies in the listed order. The new design compares favorably well with the commercial mill and the Addis mill which produced finer ground products and was found to produce a finer product than the household blender.

4.1.4. Design merits of the various grinders

Results of evaluation related to the assembly of the different machines is given in table 4.4.

Table 4.4. Assembly related merits of the various designs.

{PRIVATE} Factor	Commercial mill	Addis mill	New design
Weight of assembly (kg)	35	45	15
Number of components	19	10	7
Time required to dismantle for inspection/cleaning (mins)	2.5	2	1.5

The table shows that the new design is much lighter than both the commercial mill and the Addis mill. This makes it easier to move around as is the common practice among the commercial tomato-pepper mill operators who move the machines out of the house or store in the mornings and return them after the day's work in the evening. The new design also requires less time to dismantle either for cleaning or inspection. This along with the relatively fewer number of components than in either the common mill or the Addis mill make its cleaning an easier task. The fewer parts also mean that the frequency of parts replacement, where necessary, is likely to be lower in the new design than the other two designs.

4.2. Economic Assessment

The benefit-cost ratio is an important consideration among factors that influence adoption of new technologies. As a measure of the profitability of using a technology (a technology is profitable only when the benefit-cost ratio is greater than 1), its value greatly influences how soon and well a new technology is adopted.

Assuming an annual use of 1500 hours, a life of 15 years and zero salvage value, the benefit - cost ratios of using the commercial mill, the Addis mill and the new design were determined for the purpose of making comparisms. The result is presented in Table 4.5.

The table shows that although the three mills evaluated are profitable to use, the new design has better economic prospects. With a benefit-cost ratio of 3.2, which is over 20 percent higher than those of the other two machines, it is surely a more profitable equipment to invest in. Its pay-back period is also much shorter than those of the other machines.

Table 4.5. Economic indicators of mills at 1500 hrs/annum for assumed life of 15 years and zero salvage value (as at Sept. 1993, the production date of the new design)

{PRIVATE } Indicator	Common mill	Addis mill	New design
Capital investment (N)	5,000.00	6,800.00	4,200.00
Payback period (hrs)	400	544	336
Annual costs:			
a)Depreciation (N)	333.00	453.00	280.00
b) Interest (17.5%)N	875.00	1,190.00	735.00
c) Labor (N2/hr)	3,000.00	3,000.00	3,000.00
d) Maintenance (N)*	1,200.00	1,200.00	50.00
e) Electricity (N)**	1,164.00	1,164.00	1,164.00
f) Housing (N)	600.00	600.00	600.00
Total annual cost N	7,172.00	7,607.00	5,829.00
Total annual revenue (N12.50/hr)***	18,750.00	18,750.00	18,750.00
Benefit-cost-ratio	2.6	2.5	3.2

* Based on annual spare parts requirement
*actual energy demand as per utility (NEPA) bill
***From market survey.

4.3. Level of contamination of ground Material

Tables 4.6, 4.7 and 4.8 give the data of the bacteria, mould and yeast isolations respectively while tables 4.9 and 4.10 show the results of the total and viable bacteria counts.

Table 4.6. Bacteria isolates of tomato/pepper mixture ground on four different machines

{PRIVATE} Household blender (control)	Machine I	Machine II	Machine III
{PRIVATE} Micrococcus	Bacillus	Pseudomonas	Flavobacteria
Staphylococcus	Erwinia	Erwinia	Erwinia
Streptomyces	Flavobacteria	Streptococcus	Streptococcus
Pedicoccus	Streptococcus	Bacillus	Staphylococcus
	Staphylococcus	Staphylococcus	Streptomyces
	Micrococcus	Pedicoccus	

Table 4.7 Mould isolates of tomato-pepper mixture ground on four different machines

{PRIVATE} Household blender (control)	Machine I	Machine II	Machine III
Mucur	Atenena	Penicillin	Rhizopous
Rhizopous	Aspergillus	Aspergillus	Fusarium
	Cladosporium	Cladosporium	Aspergillus
			Cladosporium

Table 4.8. Yeast isolates of tomato/pepper mixture ground on four different machines

{PRIVATE} Household Blender (control)	Machine I	Machine II	Machine III
Rhodotorula	Hansunella	Candida	Schizo- saccharonyce
Torulopsin	Candida	Torula	Torula
	Torula	Saccheronycetes	Torulopsin
	Torulopsin		

Table 4.9. Total bacteria counts of tomato/pepper mixture ground on four different machines.

PRIVATE Counts	Household blender (control)	Machine I	Machine II	Machine III
1st	$2.0x10^5$	$2.10x10^6$	$4.1x10^6$	$5.5x10^6$
2nd	$3.8x10^5$	$6.1x10^6$	$1.0x10^7$	$4.1x10^6$
3rd	3.2×10^5	$5.0x10^6$	$6.2x10^6$	$6.3x10^6$
Average	$3.0x10^5$	$4.36x10^6$	$6.76x10^6$	$5.3x10^6$

Table 4.10. Viable bacteria counts of tomato/pepper mixture ground on four different machines.

PRIVATE Count	Household blender (control)	Machine I	Machine II	Machine III
1st	$7.2x10^3$	$8.0x10^4$	$2,0x10^5$	$.2x10^4$
2nd	$4.6x10^3$	$3.1x10^5$	$4.4x10^4$	$6.6x10^4$
3rd	$1.1x10^4$	$6.8x10^4$	$7.1x10^4$	$7.0x10^4$
Average	$7.6x10^3$	$1.53x10^5$	$1.22x10^5$	$7.6x10^4$

*$1x10^6$- FAO recommended maximum level.

As can be seen from tables 4.6, 4.7 and 4.8, bacteria and fungi (mould and yeast) were found to be the major contaminants of tomato/pepper mixture. The level of contamination was significantly ($P< o.05$) higher in the mixture milled on the three market machines than that of the control as can be seen from tables 4.9 and 4.10. Most of the contaminants are, however non-pathogenic except for a few such as flavobacteria, streptococcus and candida which though are normal flora of tomato/pepper, could become opportunistic pathogens when they find their way into the human body.

Tomato/pepper are normally contaminated with mixed and varied microflora like micrococcus, pedicoccus, aspergillus and penicillin sp. The interrelationship among these microbes and food (tomato and pepper) are examples of microbial ecology (Batzing and van De mark, 1987). Environmental factors play a major role in this interrelationship (Brock, 1976). Such factors, according to Brock (1976) include chemical nature of food, PH, availability of moisture, atmospheric oxygen, number and kinds of contaminating organisms and methods of processing, packaging and preservation.

Of these factors, the chemical composition of the food and its pH are of primary importance (Batzing and VanDe Mark, 1987). Acid foods frequently undergo spoilage by yeast and mould while low acid foods and neutral foods are often subjected to bacterial deterioration.

In acid foods containing carbohydrates such as tomato/pepper, the fungi and mould are favored to be the major contaminating organisms. The myeelia of the mould readily penetrate the skin of the tomaoto/pepper. In this case, the chemical nature of the spoilage involves acid and alcohol production within the more anaerobic interior of the tomato/pepper and an oxidative degradation of the sugar at the tomato/pepper interface. This results in pH rise and this increase in pH allows proteolytic bacteria to enter the juice.

The other major factor that effects the kind of organisms that grow on the tomato/pepper is the availability of oxygen and oxidation-reduction potential (James, 1976). Due to the anaerobic nature of tomato and pepper, contamination and subsequent spoilage is caused by facultative and obligate anaerobes though aerobic organisms occasionally grow at the surface.

Processing is another major source of contamination (James, 1976). Some microorganisms, in form of their spores, are found as formats in dust particles and settle on the machine used for milling . If not properly washed, they find their way into the milled product as is evident from the sharp increase in the total count of micro-organisms (table 4.9) and the diverse genera of fungi isolated from the tomato/pepper milled on the commercial grinders in Samaru market.

Although several factors determine the type of contaminating organisms of pepper/tomato, a particular combination of factors is relative in determining the spoilage organism and those of health hazard (James 1976). Among these major factors is the machine used in handling and processing. Care of the machine is therefore necessary so that pathogenic organisms capable of food poisoning and food infection are not allowed to contaminate the milled tomato/pepper.

Although microbial species in a food may be diverse, only a few are responsible for spoilage and of health significance. For instance orange is mostly contaminated and spoilt by two species of one genus Penicillin Halicus and Penicilin olivaceum illustrating a high degree of specificity.

The high values of total bacteria counts given in table 4.9 though in excess of the FAO recommended maximum of $1x10^6$ are of no serious consequence as the values reflect the total population of both living and dead micro-organisms in the sample. What gives concern is the relatively high values of the viable counts from the three machines used in the market as these figures (table 4.10) reflect the population of only the living organisms.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In appreciation of the shortcomings of the commercial tomato-pepper mill which include inconsistent machine quality, high maintenance requirement and contamination of the ground product, this work was undertaken to determine the type and level of contamination of produce ground on common tomato-pepper mills, develop a low-cost mill which eliminates the problems of the commercial tomato-pepper mill and evaluate the new machine and its output. Based on the results of the work, the following conclusions are drawn.

1. The new equipment design which was developed based on the principles of the household blender provides a better alternative to milling using the commercial tomato-pepper mill which is an attrition mill.

The new mill has a higher benefit-cost ratio, requires less energy for milling and is comparable to the commercial mill in terms of the fineness and uniformity of ground produce and milling capacity.

2. Bacteria and fungi (mould and yeast) are the major contaminants of ground tomato/pepper and commercial mills in Samaru market contribute significantly to the bacteria load of ground produce. Although the viable bacteria counts are below the FAO recommended maximum level of $1x10^6$, the levels are relatively high and call for caution to minimize the contamination load. Most of the contaminants isolated are however non-pathogenic except for a few which may become opportunitic pathogens when they find their way into the human body.

5.2. Recommendation

The following recommendations are made to complement this work in striving for perfection.They are:

1. The design of the new mill should be studied with a view to transforming it from a batch process equipment to a continuous process one. This it is hoped will minimize labor demand in milling bulk quantities of products.

2. As a follow-up to the determination of the level of ground produce, it is recommended that the type,nature and level nof spoilage that occurs when the milled products are kept before usage be investigated.In doing this, efforts should be made to replicate as much as possible, the cultural practices of the local women in keeping the milled products before usage.

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Appendix I

a) Sieve analysis data for tomato/pepper ground on the household blender.

{PRIVATE} Sieve	Wt of Material retained (g)	% of Material retained	Factor	% Multiplied by factor
3/8	0.0	0.0	7	0.0
4	0.0	0.0	6	0.0
8	2.65	3.04	5	15.20
14	28.20	32.41	4	129.6428
28	51.50	59.20	3	177.60
48	4.65	5.35	2	10.70
100	0.0	0.0	1	0.0
Pan	0.0	0.0	0	0.0
	87.00	100		333.14

$$F.M = \frac{333.14}{100} = 3.33$$

$$D(in) = 0.0041(2)^{F.M} = 0.0041\ (2)^{3.33}$$

$$= 0.041in$$

$$= 0.041x25.4mm$$

$$= 1.047mm$$

b) Sieve analysis data for tomato/pepper ground on the common tomato-pepper mill.

{PRIVATE} Sieve	Wt of material retained (g)	% of material retained	factor	% x factor
3/8	0.0	0.0	7	0.0
4	0.0	0.0	6	0.0
8	0.0	0.0	5	0.0
14	11.65	12.8	4	51.2
28	56.22	61.8	3	185.4
48	22.30	24.5	2	49.0
100	0.80	0.9	1	0.9
Pan	0.0	0.0	0	0.0
	90.97	100		286.5

FM. = $\frac{286.5}{100}$

= 2.865

Din = $0.0041(2)^{2.865}$

= 0.03in

= 0.759mm

c) Sieve analysis data for tomato/pepper ground on the Addis model mill.

{PRIVATE } Sieve	Wt of material retained(g)	% of material retained	Factor	% x factor
3/8	0.0	0.0	7	0.0
4	0.0	0.0	6	0.0
8	0.0	0.0	5	0.0
14	10.50	11.9	4	47.6
28	49.60	56.0	3	168
48	27.05	30.5	2	61
100	1.40	1.6	1	1.6
Pan	0.0	0.0	0	0.0
	88.55	100		278.2

$$FM. = \frac{278.2}{100}$$
$$= 2.78$$
$$D(in) = 0.0041\ (2)^{2.78}$$
$$= 0.028in$$
$$= 0.71\ mm$$

d) Sieve analysis data for tomato/pepper ground on the new design

{PRIVATE } Sieve	Wt of material returied (g)	% of material retained	Factor	% x factor
3/8	0.0	0.0	7	0.0
4	0.0	0.0	6	0.0
8	0.75	0.85	5	4.25
14	25.50	28.93	4	115.72
28	49.65	56.32	3	168.96
48	12.25	13.90	2	27.80
100	0.0	0.0	1	0.0
Pan	0.0 88.15	0.0 100	0	0 316.73

$$F.M = \frac{316.73}{100}$$

$$= 3.17$$

D(in)= 0.037in

$$= 0.937mm$$

c) Sieve analysis data for soaked beans ground on the household blender

{PRIVATE } Sieve	Wt of material retained (g)	% of material retained	Factor	% x factor
3/8@	0.0	0.0	7	0.0
4	0.0	0.0	6	0.0
8	14.28	13.98	5	69.9
14	65.00	63.64	4	254.56
28	21.60	2115	3	63.45
48	1.25	1.23	2	2.46
100	0.0	0.0	1	0.0
Pan	0.0	0.0	0	0.0
	102.13	100		390.37

$$F.M = \frac{390.37}{100} = 3.90$$

$$D = 0.0612 \text{ in} = 1.55\text{mm}$$

f) Sieve analysis data for soaked beans ground on the common tomato-pepper mill.

{PRIVATE } Sieve	Wt of material retained(g)	% of material retained	Factor	% x factor
3/8	0.0	0.0	7	0.0
4	0.0	0.0	6	0.0
8	4.60	4.27	5	21.35
14	48.50	45.03	4	180.12
28	51.40	47.73	3	143.19
48	2.60	2.41	2	4.82
100	0.60	0.56	1	0.56
Pan	0.0	0.0	0	0.0
	107.7	100		350.04

$$F.M = \frac{350.04}{100}$$

$$= 3.50$$

$$D = 0.046in$$

$$= 1.18mm$$

g) Sieve analysis data for soaked beans ground on the Addis model mill.

{PRIVATE } Sieve	Wt of material retained(g)	% of material retained	Factor	% x factor
3/8	0.0	0.0	7	0.0
4	0.0	0.0	6	0.0
8	3.85	3.67	5	18.35
14	42.90	40.87	4	163.48
28	54.50	51.95	3	155.75
48	3.20	3.05	2	6.10
100	0.50	0.48	1	0.48
Pan	0.0	0.0	0	0.0
	104.95	100		344.2

$$F.M = \frac{344.2}{100}$$

$$= 3.44$$

$$D = 0.044 \text{ in}$$

$$= 1.13\text{mm}$$

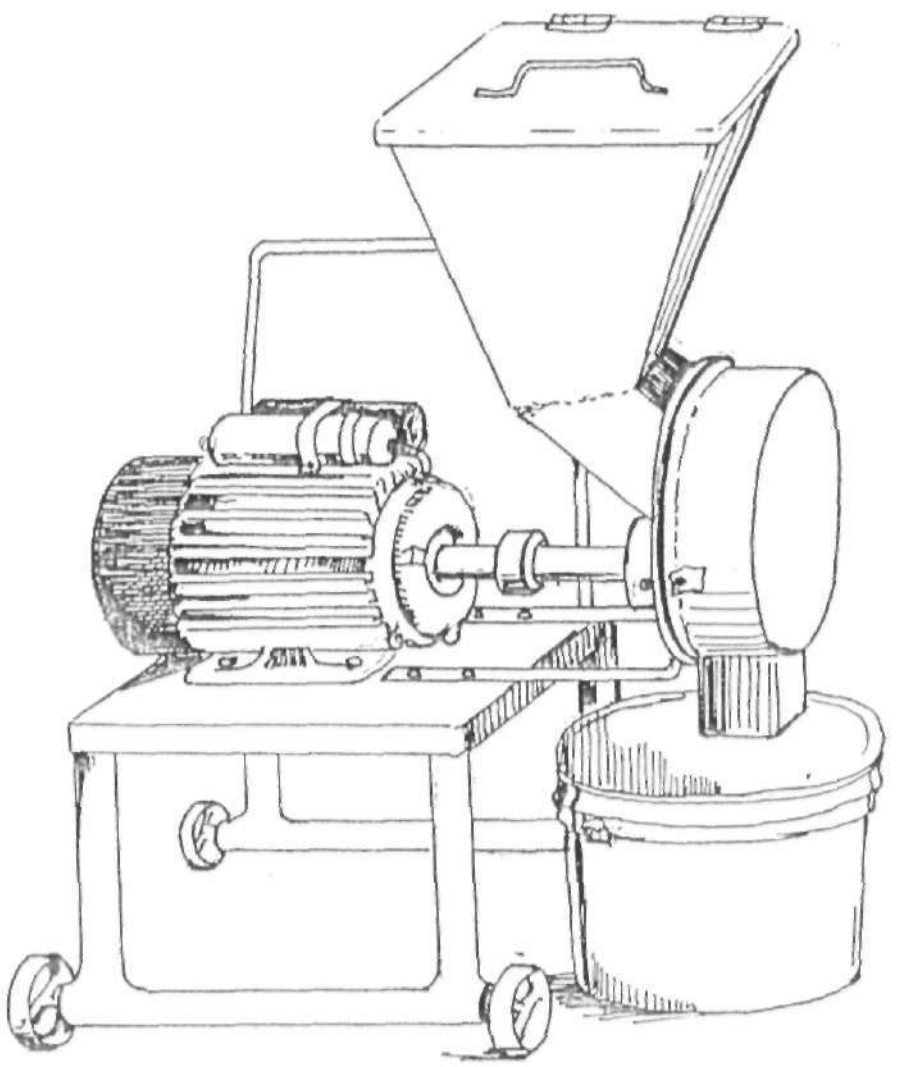
h) Sieve analysis data for soaked beans ground on the new design mill.

{PRIVATE} Sieve	Wt of material retained(g)	% of material retained	Factor	% x facto
3/8	0.0	0.0	7	0
4	0.0	0.0	6	0
8	5.20	4.90	5	24.5
14	51.30	48.35	4	193.4
28	47.80	45.05	3	135.15
48	1.81	1.70	2	3.40
100	0.0	0.0	1	0.0
Pan	0.0	0.0	0	0.0
	106.11	100		356.45

$$FM = \frac{356.45}{100} = 3.56$$

D = 0.098in
= 1.23 mm

DESIGN DRAWINGS



a) A pictorial Sketch of the new mill