

Paper given at Kuwait Inst.  
for Scientific Research A1.007  
18 April 1980  
01784  
245-LB-55798

## RESEARCH AND POST-PRODUCTION SYSTEMS

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**ABSTRACT.** Considerably more resources, scientific endeavor and general attention have been given to agricultural production systems than to post-production (or post-harvest) systems in developing countries, particularly in the semi-arid regions of Africa, Asia and the Near East.

The post-production system begins at the time and place of harvest and continues until the harvested product has provided nutritional benefit to the consumer. Post-production systems may be relatively simple, where, for example, on subsistence smallholder farms, the producing and consuming family are one and the same; or extremely complex, wherein the harvested product passes through a series of channels and agencies which conserve, transform, market, distribute and use the product in a final form significantly different from the one harvested.

Wherever the post-production system lies within the spectrum of varying complexity it must be studied as a total system, not as a series of isolated or discrete components. The latter style of approach has been responsible for many attempts to transfer non-transferable technologies. It is argued that while scientific principles are universally applicable and transferable, many technologies, particularly those based upon biological materials, are not. Biological technologies are invariably affected both by the prevailing physical and socioeconomic environments. Consequently, biologically based technologies which embrace virtually all post-production technologies must be elaborated from basic principles, at the place where they are to function and in close cooperation with those who are to use and benefit from the technologies.

It is believed that useful lessons can be learned by students of post-production systems from the methodologies of the farming systems research studies at the international agricultural research centres (IARCs). The International Rice Research Institute's (IRRI) Cropping Systems Program is an example of a thoughtful and imaginative approach to agricultural systems research.

The following text draws most of its examples from post-production systems applied to cereals, food legumes and oilseeds in the semi-arid tropics (SAT), with specific illustrations from projects supported by the International Development Research Centre (IDRC). The basic philosophy and recommendations for a systems research approach apply equally to all other food sources and the by-products derived from various stages of processing and use. Particular emphasis is placed upon the nutritional needs of consumers, particularly those who constitute the rural and urban poor, since it is for their physiological, social and economic benefit that all food production and post-production systems have reason to exist.

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no. 68

Finally, it is proposed that greater attention be given to research management and the training of managers and directors of agricultural systems research, particularly those called upon to direct post-production research or agro-industrial development in developing countries.

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The evidence presented in several papers to this symposium and in other recent publications bear ample testimony to the remarkable stimulus that modern agricultural research has given to food crop production in many developing countries. Much of this research and its consequences has its origin in the family of IARCs supported by the Consultative Group on International Agricultural Research (CGIAR).

At the outset, may we of the IDRC add tribute to and encourage continued support for the remarkable increase in agricultural productivity that has resulted from the work of the IARCs. Unfortunately, their contribution to the technologies of production has nowhere been matched by comparable advances in post-production systems research.

#### POST-PRODUCTION SYSTEMS

Relatively little attention has been addressed to the fate of food crops in developing countries from the time they are ready for harvest until the time they reach the consumer's meal table. This sequence of interdependent events from harvest to consumer constitutes the post-production system, a system that varies greatly in its degree of complexity, dependent upon the prevailing social, economic and physical environment. It is to the post-production system that this paper is addressed. The subject has been discussed in other publications: Hulse and Pearson (1979), Hulse (1978), Forrest et al. (1979), Spurgeon (1976) and GASGA (1978).

The organizers of this distinguished Conference proposed originally that the subject of this discussion be "Technology Transfer in Post-Harvest Systems". For reasons it is hoped will later become evident, the subject was changed to "Research and Post-Production Systems".

It is often stated that post-production, or post-harvest losses, may be as high as 30% of the harvest. If this is so, a 50% increase in production is necessary simply to replace what is lost between the harvest and the consumer. It is possible that the concept of post-harvest loss contributes to the cause. People in general, and supporters of international agricultural research in particular, appear more attracted by research to increase production than research to reduce post-production losses. Even the most imaginative minds appear to find it difficult to accept that two negatives make a positive: that by reducing losses, one effectively increases productivity. Perhaps it would be more appealing if the negative concept of reducing post-harvest losses were replaced by the more positive objective of creating more efficient post-production systems.

The subject of post-production systems, particularly in relation to post-harvest losses, has been comprehensively reviewed and priorities for action recommended in a recent publication prepared cooperatively by several research agencies (GASGA 1978).

The scope of different post-production systems varies greatly in complexity. In the simplest subsistence systems, the crop is grown, harvested, threshed, stored, processed and eaten by a single rural family. Among the highly developed agricultural economies, many more people and much greater investments and energy are consumed in the post-production systems than in the production of food crops. The Canadian food and agricultural system absorbs about 16% of our total national energy consumption. At present, about 80% of all food consumed by Canadians requires some post-harvest energy input. Clearly the big users in the Canadian food chain are the food processing industries; the following being the approximate proportions used by the various sectors: agricultural production 18%; processing and packaging 32%; transportation and distribution 20%; and home preparation 30%.

Post-production research is of essence systems research, yet the components call upon many disciplines, from the physical, biological and social sciences, together with a comprehension of all the social, economic and physical environments by which the post-production system is conditioned and constrained. Throughout its comparatively short life, it has been the purpose of the Agriculture, Food and Nutrition Sciences (AFNS) Division of IDRC to stimulate a more acute awareness of the importance of a total systems approach to post-production technological improvement.

Many instances exist in which post-harvest losses have increased and inefficiencies have been aggravated by projects that have sought to modify a single component of a post-production system out of context to the whole and to the environment in which the system exists. A grain dryer or storage facility suitable for wheat in Manitoba or Minnesota may prove disastrous for rice in Malaysia.

### Transfer of Technology

One could present a weary litany of misfortunes resulting from an unwarranted and overly optimistic expectation of the transfer of technology. Technologies based upon biological principles are invariably difficult and often impossible to transfer from one environment to another. On the other hand, fundamental biological principles, in common with all scientific principles, are universally applicable and transferable. Consequently, it is the belief of my colleagues in IDRC that all post-harvest systems and the technologies of which they are composed, must be developed wherever they are to be applied and in close cooperation with the rural people who will use and benefit from them. It is a *sine qua non* that the first essential in the development and elaboration of any technological component of a post-production system is a clear identification of those by whom the system will be used and those whom it seeks to benefit.

### Crops of the Semi-Arid Tropics

Though the people of the semi-arid tropics (SAT) may derive their essential nutrients from a wide range of food sources, it is evident that the overwhelming majority rely upon cereal grains and food legumes for most of their calories and protein. There exists a substantial volume of published literature on the breeding and agronomy of cereals and legumes relative to grain yield and chemical composition. In contrast, relatively little is to be found on what determinable factors influence post-harvest stability, nutrient availability, and such useful properties as milling quality and cooking characteristics.

Vogel and Graham (1979) describe some of the many ways in which sorghum and the millets are processed and consumed among rural communities of the SAT. They emphasize the need for plant breeders to gain a better understanding of the ultimate consumers' concepts of quality and acceptability, a subject which will be addressed in greater detail later in the text.

Given the location of this Conference, it may seem almost frivolous to observe that for most of the SAT energy remains a primary resource constraint in all post-production systems. Energy, whether human, animal, mechanical, solar or from some form of converted biomass, is essential for threshing, drying, processing and distribution. Probably more than 50% of the total energy used by rural populations in developing countries is for cooking, most of which derives from forest biomass or animal dung. Consequently, in any post-production system the availability and cost of energy will inevitably prove to be the primary constraints to a happier quality of life.

#### Post-Production Systems in the SAT

Because of the immense diversity of traditional and adopted practices that exist, it is impossible to present a codified post-production system that applies throughout the rural communities of the SAT. Figure I presents a familiar, though oversimplified, sequence of components that relate particularly to cereal grains and food legumes. Though these have been discussed in greater detail elsewhere (GASGA 1978 and Forrest et al. 1979), each will be briefly discussed in sequence.

Though each of the components referred to in Figure I is discussed as a separate component, it cannot be too greatly emphasized that the examination of any one component must be preceded by a detailed study of the system as a whole whether it be a simple subsistence system or a complex system involving many rural cultivators, a cooperative or state purchasing and marketing organization, one or more primary and secondary processors, and/or a marketing complex that serves rural, urban, local and distant individual consumers and institutional and commercial users. All too often post-production research and development has proved more of a hazard than an asset by an over-simplistic concern with single components rather than a systems research approach.

#### Organization of the Text Presented

Following the brief review of the individual components of the post-production system, there will be a discussion of a somewhat neglected aspect of the subsistence grains: their physical, technological and nutritional properties. It cannot be too heavily stressed that every component in the post-harvest sequence of cereals and legumes is dependent upon and affected by the physiological, biophysical and biochemical properties of the grain in addition to the physical, economic and social environments in which the post-production system has its place.

The text will be illustrated by various projects that IDRC is associated with in a number of countries.

## RURAL MECHANIZATION

In most countries of the SAT, where the poorest people in the world are to be found, the principal cereals, sorghum and the millets, are usually harvested by hand cutting. A study in Uganda (Vogel and Graham 1979) indicated that between 50 and 70 man days per hectare are required to harvest millet; another IDRC supported project revealed that many West African women spend about 10 hours every day in collecting wood for fuel, in drawing water and in grinding grain by hand.

The breakdown of an African woman's typical workday includes:

|   | <u>Hours per Day</u> |
|---|----------------------|
| Obtaining water                               | 1 - 1½               |
| Wood collection                               | 1½ - 2               |
| Processing of grain<br>(dehulling - grinding) | 4                    |
| Meal preparation                              | 3                    |
| Field Work                                    | varies with season   |

The Senegalese women average a minimum of 70 hours per week of hard physical labor (Yaciuk and Yaciuk 1980). The demands of daily chores involving water, fuel, processing, meal preparation and working in the field leave little time for self or child education, artisan work, visits or leisure time, which are important components of the lifestyle of more privileged people.

There can be no doubt that some degree of appropriate mechanization of the post-production system would greatly benefit many of the people of the SAT countries. Certainly this is true of cereal grain milling, a facility for which many African women expressed a need in order to be free of the drudgery of hand pounding and liberated for more rewarding activities such as tending kitchen gardens and raising small animals.

Many subsistence farmers lack the available capital or credit with which to buy even the simplest machines. Nevertheless, progress is being made in providing efficient mechanization through cooperatives and multipurpose machinery.

In Egypt, the Beheira Engineering Corporation, a parastatal organization, is developing a mechanized system for small farmers in which a single lightweight 10 hp diesel engine provides power to a series of specially designed threshers, drills, planters, sprayers and pumps and also to a general utility transport vehicle (Stanley 1979). This kind of mechanized system shows great promise for smallholder farmers in the SAT who work on 1.0 to 1.5 ha of land. Elsewhere simple hand wheel or bicycle operated threshers are also finding acceptance.

Some countries have encouraged the adoption of short stalk sorghums that can be combine harvested. However, in many countries, particularly those where forests have been largely destroyed, long sorghum stalks are essential resources for fencing, thatching and firewood. Consequently, IDRC is supporting close to 20

social forestry projects in the SAT countries of Africa where sorghum and pearl millet are the principal food crops (Sanger et al. 1977).

#### CROP DRYING

Most fresh plant and animal tissue (except for fully ripened seeds) contains from 75% to 95% moisture. To minimize deterioration, the moisture content must be reduced to a safe level as soon as possible after harvest. In addition to its influence upon stability in storage, moisture content affects virtually all post-harvest operations. No matter what method of harvesting is employed, drying of the crop to a moisture content ideally no higher than 12% is desirable before threshing and storage. Though higher yields of grain per hectare may result from a larger and more compact head on a short straw, many of the traditional sorghum varieties in West Africa tend to be open panicle that in general are easier to sun dry and thresh.

During sun drying, while the solar radiation causes the moisture to evaporate, it is the wind that carries the moisture away. Consequently, sufficient air space must be provided in the stacked grain to take maximum advantage of the prevailing winds. Generally, stacks 2 to 3 m high and 0.6 m wide can be used to dry most grains in the SAT. The bundles in the first row are stacked with the heads facing out of the stack (i.e. bundles are placed tail to tail); the second row is laid at right angles to the first row, and the third in the same manner as the first. This permits uniform air circulation while holding the grain in place. Efficient drying improves product quality by protecting the grain against subsequent mould infection and damaged kernels, which are more difficult to process in either mechanical or manual milling.

In many countries, the most common method of drying crops is simply to spread them on the ground and expose them to the sun and the wind. This, unfortunately, is often a hit or miss process and has the disadvantage of exposing the grains to attack by birds, rodents, flies, moulds, and other undesirable contaminants.

There exist considerable unexplored opportunities for improving systems of drying all manner of edible crops throughout the tropical developing regions. Consequently, over the past several years, IDRC has been actively supporting research into on-farm and farmer-cooperative crop-drying facilities. This type of drying facility is seen as a priority, because lack of transportation facilities to bring the produce to more centrally located, large-scale drying facilities is frequently a major constraint in the post-production system. The small on-farm or rural cooperative-oriented grain dryers must be of simple design, employing inexpensive technology, and capable of being manufactured and maintained from materials that are both locally available and within economic reach of the small farmer or rural cooperative.

As an example of applying scientific principles to a simple technology, a scientist in West Africa determined the zenith angle of the sun and the prevailing direction of the wind for all times of the year for an extensive farming region where sorghum, millet and cowpeas are the principal crops grown. From the data collected, it is possible to construct simple grain drying racks that obtain maximum advantage of sun and wind in the drying process. To gain maximum benefit of solar radiation and prevailing wind, grains and other foods to be dried can be stacked, as described earlier, on simple tilt racks.

6

IDRC-financed projects are developing large-scale solar grain dryers in Egypt; farm-level solar grain dryers in Thailand, Sierra Leone and Niger; and mechanical crop dryers in Guatemala, India, Indonesia, Korea, the Philippines and Thailand. Among the diverse systems under study, a variety of renewable fuel sources have been successfully employed. One type of flatbed dryer, suitable for threshed rice and other grains, may be constructed of relatively inexpensive materials. In addition to using solar radiation, the dryer is equipped with a fan and a burner that can be fueled by diesel fuel, kerosene, straw, rice hulls or wood shavings.

### THRESHING

Threshing grain in most SAT countries involves either beating the heads with sticks on the ground or in sacks or by means of a mortar and pestle. The time required to thresh the grain was found, in most cases examined in Africa, to be related to three principal factors: the structure of the plant; the degree of dryness of the heads; and the method of threshing used. Average time spent per day to thresh grains, in a study undertaken in Senegal, was 1 to 2 hours. Normally 25 to 35 laborers were required to thresh about one half hectare of sorghum or millet (Vogel and Graham 1979).

In those regions of Senegal where the loose panicle types of sorghum predominate, threshing by pounding is a relatively easy operation: consequently, few rural people are prepared to pay for their grain to be mechanically threshed. If and when higher yielding sorghum types with tighter heads gain acceptance, consideration may well have to be given to simple inexpensive mechanical grain threshers to be made available on a community basis.

While the common practice in many SAT countries is to store sorghum and millet on the head and thresh as needed, repeated storage tests in Senegal have shown that when properly dried and stored, the quality of threshed grains exceeds that of grains stored on the head. In general, unthreshed grains suffered greater losses due to insects and mould.

By considering some general guidelines when threshing, it is possible to improve the yield and efficiency of the threshing process: (1) the heads should be threshed on mats, not on sand, gravel, or stones; one recommended method is to thresh on adobe or cement blocks; (2) the grain should have a maximum moisture content of 12% when threshed as this reduces the possibility of mould development and damaged grains during subsequent storage; (3) generally speaking, vitreous endosperm types of sorghum are easier to thresh than those with starchy endosperms which tend to give rise to a higher proportion of shattered grains; and (4) grains should be threshed soon after harvest to reduce field exposure to insects, birds and rodents.

The difficulty of transferring technology, particularly in the form of a machine, is well illustrated by the experience in a project supported by IDRC in the Near East. The project's hoped for technology is a multifaceted small farm mechanization system in which a range of machines is operated from a single 10 hp power unit.

A thresher developed for smallholder mechanization was discovered in Asia and it was believed it could be easily adapted to serve the purpose of a multicrop

thresher in the Near East. Because of the Near Eastern farmers' different demands and conditions, the thresher that proved highly successful in Asia in fact required almost total redesign. Under the prevailing conditions, with a heavier work load, metal fatigue and cracking of the frame occurred. Furthermore, the Near Eastern farmer required the cereal straw to be chopped finely to be fed to animals. The short, fine, cut straw accumulated and choked the sieves and the grain blower and carried with it unseparated seed. The net result was a higher operating and maintenance cost with a much lower rate of throughput.

Modifications included reducing the clearance between the fixed and moving knives. The sieve design was changed to improve seed separation from the fine straw. The fan housing was divided into two sections each with a separate air inlet to allow for a higher air speed where the fine straw was accumulating. A straw walker was added to the top of the sieve to lift off the longer straw. The loss of seed was reduced by lengthening the sieve, lowering the eccentric speed by 30% and by adjustment of the sieve slope. Lowering the eccentric speed significantly reduced the rate of metal fatigue and cracking in the frame.

Following these modifications extensive testing among several villages, including detailed economic analyses, revealed that the redesigned and restructured thresher was more efficient and economic than the traditional threshing practices.

#### STORAGE

Those who pursue the brave new world of improved technology do not always stop to examine what the farmer has learned over many centuries of trial and error. Hermetic storage, though not by that name, was known to farmers in what is now Saudi Arabia more than 5,000 years ago. Nevertheless, traditional processes can be made more efficient and effective by systematic study and the application of basic scientific principles.

The length of time the harvested food crop is stored may vary from a few days up to many months. Storage may be required only until the crop is sold to the operator of the next stage in the food system, or the crop may be expected to provide the basic food supply for the farmer and his family for perhaps nine months.

Furthermore, some carry-over between crop years is desirable as an insurance against poor harvest in succeeding years. Consequently, reliable storage systems are necessary to preserve quality characteristics acceptable to the farmer, his family and whoever else will purchase and use the grain.

A study in Senegal (Yaciuk and Yaciuk 1980) found on average that each family had four children and that overall, about eight people ate together in a single household and that, assuming no losses, each family would need a store of at least 600 kg of cereal in order to survive until the following harvest. Of the 625 families interviewed who stored millet, only 16.8% stored in excess of one tonne and the data in general revealed that in several areas severe food shortages frequently appeared before the next harvest.

In this study of 734 farm families in eight main regions of Senegal, carried out during 1976 and 1977, more than 76% considered their facilities were insufficient for the storage of an adequate stock of subsistence grains.



Few components of the post-production system provide more impressive examples of unreasonable and unfortunate reliance upon the transfer of technology than the storage of food grains. One could present a weary litany of underground storage systems that could be filled, but without mechanical power could not be unloaded; of devices that relied upon a hermetic seal that was difficult to maintain intact (as mentioned earlier, ancient farmers of the region were familiar with the practice of hermetic storage in which an airtight bin is filled with dry grain and sealed whereupon the carbon dioxide of respiration asphyxiates all stages of insect metamorphosis); of metal silos that in the open sun turned into pressure cookers; of storage bins, warehouses and godowns located at sites too far distant and without transport facilities to convey the grain from the farms they were intended to serve.

Several proposed methods place heavy reliance upon chemical pesticides farmers can ill-afford. Many of the misfortunes caused by ill-conceived transfers of technology are the products of well meaning but ill-informed bilateral and multilateral donor agencies; agencies that did not seek first to study the systems already existing before trying to import or transfer a new storage technology from elsewhere.

The tropical environment combined with the physical limitations of some of the traditional structures used for crop storage often account for the high losses of crops during storage. Nevertheless a critical assessment of the comparative advantages and limitations of traditional structures and methods will often reveal their potential for improvement at reasonable cost and with a minimum requirement for chemical control methods. IDRC is supporting several projects in which the first concern is to assess thoroughly what are the relative advantages and shortcomings of traditional systems and by what means these may be economically improved by changes in grain handling and stabilization through the addition of locally available materials. Projects in this category include research into the use of vegetable oil coatings on the grains, or mixing with ash, sand, salt, insecticidal leaves, and other materials in the treatment of storage of crops in Ghana, India, Malaysia, Senegal, Thailand and Upper Volta.

The use of sand and other abrasives scours and impairs the waxy chitinous layer that surrounds the insect's abdomen and causes it to die by desiccation. Several naturally occurring plants possess preservative properties as do certain vegetable oils when applied to grain surfaces.

It has also been found in West Africa that provided the grain is first adequately sun dried and tightly packed into the traditional woven crib, the storage life is equivalent to that of grain stored in much more expensive facilities based upon designs imported from developed countries.

To ensure satisfactory grain storage three variables must be controlled: moisture, temperature, and oxygen. These variables can be controlled by efficient grain drying, adequate construction of the storage bin, and the observance of certain storage precautions.

In general, the larger the bin the more efficient the storage because the bulk of the grain is insulated to a greater extent from changes in outside conditions, provided the grain is cool when the bin is filled. Ideally, a bin

should be about equal in height and width to provide optimum conditions of grain temperature and insulation. If the width is much greater than the height, the resultant higher temperature variations cause condensation that gives rise to gradients in moisture content, with subsequent grain losses due to mould growth at the points of highest moisture content.

In a structure with an open weave the outside ambient temperature and the temperature of the grain will be closely similar; especially when the grain is stored on the head. Solid-wall bins of woven structure reinforced by mud provide better insulation from outside air temperature and thus maintain lower temperature gradients within the grain.

Installation of a large roof with an overhang over the bin or crib greatly reduces the fluctuations in grain temperatures with changes in ambient day and night temperatures: the shade provided by the overhang prevents direct heating of the storage bin walls by the sun. Steel or other metal storage bins are generally not recommended because of their rapid absorption and conductance of solar heat. Several instances have been reported in which metal bins filled with grain and exposed to direct sun have assumed the nature of pressure cookers, the moisture being driven from the periphery to the centre where the moisture content reached a level high enough to steam cook the grain.

It is generally recommended that bins be filled early in the morning when the air temperature and humidity are lowest. Because insects are usually found in the air space, on top of the stored grain, limiting the amount of air in the storage container by packing tightly and filling to the top will help to control insect infestation. The grain should therefore be stored dry and threshed, and packed as tightly as possible into the storage container, eliminating any free air by mixing the grain with sand or ash. As mentioned above, sand and abrasive ash also serve to disrupt the insect's protective waxy outer coating. Studies in Senegal have indicated that satisfactorily dried and threshed sorghum and millet stored admixed with 30% sand incurred fewer losses than grain stored unthreshed, on the head.

In Nigeria, much of the sorghum and pearl millet is stored as unthreshed heads in solid-wall dried-earth *rumbus* employing either of two procedures, *jefe* or *kimshe*. *Jefe* is used for short-term storage and the bundles of sorghum and millet are merely thrown into the *rumbu* and arranged in layers. For storage of 3 to 6 years, the *kimshe* method is used. Here the bundles are dismantled as they are put in the *rumbu* and are then packed in layers. When the *rumbu* is full the mouth is sealed with clay. No local insecticides are used on the grain but sometimes the stems of a fleshy, juicy, xerophytic plant (*tuniya*) are used for protection against rodents. These stems may be built into the foundation when the *rumbu* is built, or alternatively placed on the floor.

In a study in West Africa of traditional grain stores in comparison with silos constructed of concrete blocks, it was found that provided the grain was adequately dried, cooled and tightly packed, as described above, the traditional store of woven grain stalks reinforced with mud, covered by a wide overhanging top, was as efficient and much less expensive than a more elaborate concrete structure, up to a maximum capacity of about one tonne. For larger quantities a silo-magasin, consisting of a rectangular shed constructed of 20 x 20 x 40 cm concrete or mud blocks is more efficient and can be built by village artisans to accommodate almost

16

any quantity of threshed grain. The silo-magasin consists of a series of covered compartments and can be shared communally by two or more families. Additional storage life is acquired by treatment with a residual pesticide.

This form of large store, financed and operated on a community basis, shows useful promise for rural communities, particularly when integrated into a community threshing, drying, and milling system in which each component is of appropriate design and matching capacity.

#### PROCESSING OF GRAINS AND LEGUMES

Only animals normally eat raw, unprocessed grains and legumes. Though traditionally, and among many poor rural communities and subsistence farms, most food processing generally takes place in the home, the commercial transformation of the grains to flour (primary processing) and of the flour to bread, noodles and a variety of other cereal and legume foods (secondary processing) is of growing significance among both rural and urban communities of the SAT.

#### PRIMARY PROCESSING

For many years people in the SAT countries of Africa who subsist mainly on sorghum or millet have been grinding their dehulled grain into flour, using either simple tools or mills designed originally for wheat, rice or maize and which had accompanied the flow of people from Europe or Asia. Today, various kinds of mechanical attrition and abrasion mills are a feature of many rural towns and villages. Though these imported mechanical mills have resulted in a significant reduction in the number of hours spent in the home grinding grain into flour, using hand or animal-powered stone mills, many of them are not wholly efficient mainly because they were designed for a purpose different from that to which they are being applied. They provide eloquent examples of inappropriately transferred technologies.

Many of these mills consist simply of whole grain grinders and few of those examined are able to efficiently dehull the locally grown grains and to separate the bran from a finely ground endosperm. Thus today, throughout the sorghum, millet and cowpea consuming world, the process of dehulling, dehusking or debranning remains for countless women a tedious, manual operation. At the same time, there exists ample evidence of an increasing consumer demand for commercially milled products among African communities, a demand partially met by imported wheat or maize flour.

Imports of foreign cereal grains, whether on commercial or concessional terms, adversely affect the economy by discouraging local grain production and contributing to growing foreign trade deficits.

A recent survey in Senegal (Yaciuk and Yaciuk 1980) found that even in rural areas the volume of imported goods purchased was surprisingly high. Purchased wheat flour and pasta products which all have locally grown alternatives were chosen because they enabled the woman to reduce meal preparation time, by being relieved of the necessity to grind the local grains by hand. The local development of efficient, economical, village-level milling systems helps to create a stable,

11

continuing and expanding market for the cereal grain and legume producers, in addition to offering a convenience and a liberation from weary drudgery among rural women.

### Cereal Milling Technology

All cereal grains consist of three essential components: (1) the germ or embryo, from which the new plant puts out its shoot and root; (2) the endosperm, composed mainly of starch, other carbohydrates and protein, which is the source of food for the new plant; and (3) the seed and fruit coats, a series of thin cellulosic films, some high in protein, vitamins and minerals, that surround and protect the embryo and endosperm and retain the caryopsis as a discrete whole.

The simplest and most straightforward process is to grind the whole seed to a coarse meal. The purpose of most cereal milling processes however is to separate the seed coats (the bran) and the embryo from the endosperm and to grind the latter into a fine or coarse flour.

In the large wheat or rice mills often located near seaport cities, the grains are first carefully graded according to seed size thus permitting a more uniform milling and separation of the various seed fractions. In most rural areas of the SAT the grading of cereal grains is virtually non-existent. Furthermore, many communities need to subsist upon different cereal and legume grains at different times of the year dependent upon the nature and size of the harvest. Consequently, rural grain mills in the SAT require much greater in-built flexibility and versatility than their larger relatives at the city ports which mill only imported size-graded wheat. The rural mill must be capable of dehulling seeds widely different in nature, genetic and agronomic background, and of providing milled products that vary significantly in particle size. Because of its much larger seed, sorghum is generally more easily debranned than is pearl millet; among African women, dehulling pearl millet by hand in the traditional pestle and mortar takes about four times as long as dehulling sorghum.

Different end uses call for flours of different granularities and average particle sizes. Some nomadic peoples of West Africa demand coarse flour (semolina) which they mix in a gourd with camel's milk and blood. The gourd is attached to the camel's saddle and this highly nutritious mixture reconstitutes to a relatively smooth blend as the camel and rider cross the savanna. In contrast, a flour of fine particles thus processed would reconstitute to a lumpy unpleasant consistency.

The desirable sequence to be pursued in developing a cereal grain milling system can best be illustrated by a description of a number of relevant projects which IDRC is supporting in several African countries.

### The Maiduguri Mill

A comparatively successful establishment of a rural multipurpose grain and legume milling system is to be found at Maiduguri in the Northeast State of Nigeria. In addition, this project, which began in 1972, provides a good example of how a vertically integrated systems approach can bring about a rational post-harvest system composed of appropriate locally developed or adapted component technologies. This project is a joint venture of Nigeria's Ministry of Agriculture and Natural

Resources, the Northeast State Ministry of Natural Resources, and local farmers' cooperatives.

Maiduguri, a city of some 150,000 people, lies in an area where the main crops are sorghum, pearl millet, maize and cowpeas with smaller quantities of wheat grown on irrigated land. Though the heart of the system consists of a relatively simple yet novel milling unit, the project encompasses a wide spectrum of post-harvest activities, including threshing, drying, storage, primary and secondary processing, product evaluation, packaging, marketing, consumer acceptance and utilization.

The original simple purpose of the project was to reduce post-harvest grain losses that resulted from relatively inefficient methods of handling and storage, and to increase the monetary return to farmers by offering more economical and attractive facilities for grain purchase, storage, transportation, processing and sale. At the same time, it was designed to provide a facility capable, using the same machinery, of processing several different locally produced cereal grains and legumes into nutritious, acceptable, milled flours and secondarily processed traditional and novel food products.

The project began with an extensive socio-economic study of the existing post-production food grain systems throughout the area around Maiduguri. Agricultural economic surveys revealed that most of the grains produced were retained on farms for the farm family's own needs and that only 10 to 15% of the total grain harvested entered market channels. Most of the grain that entered the market was moved from a central market place to secondary and terminal markets through the intervention of a remarkable number of speculators who bought, stored, and resold the grain at widely different prices throughout the calendar year. Price differentials for sorghum for example were found to amount to between 30 and 40% among four regional markets.

Such of the grain as was mechanically processed was ground on a custom basis in small plate mills driven by diesel engines, most of these plate mills being located in the towns and larger villages. Almost all additional processing was carried out either by the women in their homes or by flour vendors. Many of the women of the household were found to send cereal grains dehulled by hand in a pestle and mortar to these local, comparatively inefficient, plate mills to be ground into flour or grits.

While the construction of the Maiduguri mill building and the basic design and layout of the machinery was in progress during early 1973, a consumer demand and attitude survey was carried out in 1100 households in Maiduguri by women students and members of the home economics department of the Northeastern State Government. The purpose of this study was (a) to determine the type and volume of milled cereal and legume products that were in greatest demand; (b) to indicate what type and volume of flours the pilot mill should produce; and (c) to develop a consumer information program to encourage improved household utilization of processed cereals and legumes in the diet.

This consumer preference study revealed a growing potential demand both for commercially packaged flours from which local women could prepare traditional

cereal foods, thus revealing a potential opportunity for developing more nutritious foods from combinations of cereal and legume flours. Whereas during the mid-1960s leavened bread was comparatively unknown except among the expatriate community, at the time of the survey, 64% of the households interviewed stated that they purchased bread at least once a week, with more than half of the respondents stating they ate purchased bread every day.

The greater flexibility offered by the proposed mill would, it was believed, make possible a wider choice of acceptable and economic convenience foods, supplementation of traditional cereal foods with legume proteins, the substitution of sorghum, millet and cowpea flours for imported wheat in traditional foods and baked bread, and the development of a range of new and appetizing foods composed entirely of sorghum, millet, maize and cowpea flour to be sold through the local markets for immediate or household consumption. Consequently, it was decided that the pilot mill and its ancillary facilities should concentrate upon four main activities: (1) the decortication and milling of sorghum, millet, cowpeas and to a lesser extent maize; (2) the production of bread and snack foods based upon the grains milled; and (3) the development of modified traditional and relatively new food products as a basis for a communally owned commercial food processing and distributing industry.

Because of the wide range of sizes and conditions of the cereal and legume grains to be milled, the principles of break and reduction roll milling, upon which the larger wheat flour mills of the world are based, was clearly too inflexible and too uneconomic. Furthermore, the capacity of the local typical plate grinder mills appeared to range from less than 0.5 to 1 tonne of grain per day depending on the condition of the grinding plates, the engine, and the general overall competence of the operators. Consequently, each of these plate grinders served only a relatively small number of people, losses were exceptionally high, and though apparently simple, most of the plate mills appeared both wasteful and uneconomic.

It was therefore decided to rely upon first, a principle of decortication using either an attrition or an abrasion process, followed by separation of the seed coats by simple aspiration and/or sieving, and the grinding of the endosperm and residual germ in a hammermill.

At first, an attrition-type dehuller, composed of counter rotating mosaic discs in which cutting blades were embedded in a stone or other continuous matrix, was examined but was found to provide a comparatively low yield of decorticated endosperm. Eventually, the most successful machine by which to remove the seed coats was developed, a machine now called the FRL dehuller. It consists of a series of carborundum stones mounted on a horizontal shaft and spaced at 1.5 to 3.0 cm intervals. The rotor so formed is mounted in a rubber lined metal case with a clearance of about 2 cm at the sides and around the bottom of the rotor. A screened inlet is provided along one side of the top with an air outlet at the opposite side which, when connected to an aspiration system, automatically removes the fine bran particles as they are abraded from the sorghum, millet or legume grains. After dehulling, the grains are transferred to a hammermill, followed by a flour sifter in which the ground endosperm is separated into three fractions: (a) fine flour; (b) middlings; and (c) coarse flour or semolina.

A more recent development involves the replacement of the carborundum stones with lighter resinoid discs. By their intrinsic nature, carborundum stones must be formed into relatively thick sections in order to be rotated safely at speeds in excess of 1,000 rpm. The thick heavy stones have two disadvantages; first, the relatively high power demand required to rotate them, and secondly, the reduction in the abrading surface area available for any given weight of grain. Resinoid discs, made by bonding aluminum oxide into a plastic matrix, may be formed into very thin, light, strong sections that can safely be rotated at speeds of more than 6,400 rpm. The use of resinoid discs in the dehuller provides more than twice the abrasive surface at only one quarter the weight of the carborundum stones with a consequent significantly lower power consumption per kg of grain dehulled.

The Maiduguri mill now consists of four component units: (i) a pre-cleaner; (ii) the PRL dehuller; (iii) two hammermills; and (iv) a flour sifter, together with various packaging units. An operations and processing research program is continually in progress and several improvements have been made to the design of the dehuller resulting in a continuous steady increase in the rate of throughput and, therefore, in economic efficiency. The average composition of the mill's products consists of 34% fine flour, 20% middlings, and 46% grits, with an average milled extraction rate of slightly better than 75%. The mill has experienced no difficulty in selling all of the bran separated for animal feed, which in itself represents an important economic gain in that, following traditional pestle and mortar dehulling, virtually all of the bran is blown away during hand winnowing.

Because of the orientation of the Maiduguri Mill's purpose to the satisfaction of consumer needs and demands, simultaneously with the creation of the mill came the establishment of a test kitchen which serves both as a quality control laboratory and a development unit for the elaboration of nutritionally improved traditional products and novel foods based upon the cereal and legume flours manufactured in the mill. Because the pilot mill can achieve a recovery rate of 70 to 80% by weight of the original whole grain, compared with less than 65% usable grain from manual decortication, the mill is providing significantly larger quantities of edible milled grain from the existing harvest, in addition to salvaging and using the by-products in animal feeds.

Using a modified mechanical development system from composite flours, described later in this text, the simple bakery built adjacent to the mill now operates at full capacity and produces 700 loaves a day containing up to 20% of sorghum flour in a composite with wheat.

The IDRC has recently cooperated with the Federal and Northeast State Governments in Nigeria in working out plans for the establishment of a series of milling and processing units, similar to the Maiduguri complex, across the northern semi-arid regions of the country.

#### The Botswana Mill

A related, somewhat different but equally interesting milling and cereal processing project has developed in Botswana, which has greatly benefited from the earlier experience in Maiduguri. Over the past two decades, among the rural and urban people of Botswana, one has observed a significant shift away from sorghum towards maize, commercially processed and imported from South Africa in

the form of a ground maize meal. Because the traditional processing of sorghum is time consuming and laborious, and since no similar processed form of ground sorghum meal was available, imported maize flour consumption has grown to the detriment of sorghum with a resulting serious decline in native sorghum production.

During 1975, the Botswana government requested IDRC's assistance in developing a sorghum milling system somewhat similar to that established in Maiduguri. Eventually it was decided to create a pilot sorghum mill as an integral unit of the Botswana Agricultural Marketing Board depot at Pitsane which is located alongside the rail line in southern Botswana. The continuous flow mill began commercial operation during late 1977 (Eastman 1980).

At the Rural Industrial Innovation Centre (RIIC) in Botswana the PRL dehuller used at Maiduguri was studied and eventually significantly modified in order to combine the desirable flexibility of the earlier design together with the advantage of being able to function either in a continuous flow or a batch system. The PRL/RIIC dehuller is much smaller in size and therefore as a batch unit can be used in small rural communities since it requires only 10 kg of grain to operate efficiently. The principal improvement lies in a reduction in the diameter of the dehulling stones, together with a novel system of unloading the batch model which permits individual quantities of grain to be dehulled without stopping the machine.

Again, as in the case of the Maiduguri mill, the project began with a consumer marketing study among 350 householders from six different districts, in addition to interviews with Botswanan women in clinics, and at bus and railroad stations, in order to determine what characters and quality of milled sorghum flour the householders would be prepared to use and buy.

The acceptability and the willingness of Botswana women to purchase the milled sorghum grain has exceeded original expectations and the mill is now able to produce in excess of 1 tonne a day of milled product and shows an overall net profit in excess of 20% after allowing for all cost of materials, supplies, salaries, maintenance and depreciation on buildings, equipment and vehicles.

Perhaps what is more important, the design of the PRL/RIIC is such that virtually all of the necessary equipment for a continuous flow mill can be manufactured or purchased in Botswana and there appears a distinct possibility that Botswana will become a manufacturer and exporter of the essential component equipment.

What is of far greater overall importance is that the processed sorghum flour is manufactured from, and therefore will serve to stimulate the greater production of indigenous sorghum grain, at the expense of imported maize meal from South Africa. Thus, the Botswana milling project will satisfy a growing consumer demand, develop an agro-industrial capacity both for cereal grain processing and the manufacture of processing machinery, and stimulate agricultural production by providing a greater market for home grown sorghum grain.



## SECONDARY PROCESSING

14

Comparatively few food commodities are consumed directly in the raw or semi-processed state. Highly perishable commodities are inevitably harvested in amounts greater than can immediately be consumed; therefore several processing stages are often needed both to conserve and to transform the basic agricultural commodity from its original to a more stable and/or acceptable form.

### Food Quality and Acceptability

As was illustrated in the case of primary processing discussed above, every secondary processing venture must be preceded by an adequate review and evaluation of actual and potential customer demand, whether that customer be a household consumer family, an institution or a commercial enterprise. It is the opinion of the author and his IDRC colleagues that in comparison with the successful food processing and marketing corporations of Europe and North America, many companies, governments and development agencies working in developing countries have paid less than adequate attention to the attitudes and concerns of consumers, and that the need for studies of those properties and characters of cereal grains, legumes, root crops and other commodities of subsistence that influence quality and useful functional properties, have often been seriously ignored.

Consequently, the Post-Production Systems Group of IDRC is supporting projects in several countries in which the physical, chemical, nutritional and functional properties of various subsistence crops are being studied and quantified. In each case the objective is to establish consumer-based standards upon which to guide plant breeders in the selection of cultivars which are not only higher yielding, of wide agroclimatic adaptability and disease resistance, but which the consumer recognizes as being of desirable and acceptable quality. Such studies on sorghum and millet are being carried out in Senegal, Sudan, and Upper Volta.

In a recent survey (Yaciuk and Yaciuk 1980), Senegalese consumers expressed a marked preference for sorghum with a large white kernel. Larger kernels yield a greater percentage of flour and grits while white hulls necessitate removal of lesser amounts of the outer seed coat layers during dehulling. Both attributes provide a greater percentage of the kernel for consumption. For reasons discussed later, in relation to polyphenols it is probable the white kernels are most nutritious.

IDRC is supporting studies in Nigeria, Sierra Leone, Ghana, the Lebanon, Turkey, Sudan and several other countries of the Middle Eastern region on the quality characteristics of legumes for inclusion in traditional foods.

Simultaneously, in cooperation with a number of other agencies, studies are being made of the principal nutrient deficiencies of poor rural people living in the SAT in order to decide what improvement in the nutrient composition of the basic diets can be introduced through primary and secondary processing systems. A guide to the standardization of methods of evaluating the nutritional and useful properties of legumes was published a few years ago (Hulse et al. 1977).

## Secondary Processing Technologies

As applied to cereal grains and legumes, secondary processing usually starts with the fine and coarse flours and other products from milling operations which are then converted to a wide variety of forms through blending, fermentation, forming, cutting, extrusion, agglomeration, boiling, steaming, baking or frying. Integral in all secondary and primary processing is product evaluation and quality control to ensure uniformity of composition, form and stability combined with desirable standards of wholesomeness.

The traditional secondary processing methods by which noodles, other pasta products, and various forms of bread are produced are too numerous to cover and have been adequately described in many examples of the food technology literature. Consequently, this section of the text will concentrate upon several comparatively recent innovations, beginning with products based upon what have come to be called "composite flours".

### Composite Flours

The descriptive term "composite flours" is a relatively recent addition to the vocabulary of cereal scientists and technologists and in general refers to mixtures composed largely of wheat flour together with one or several other starch and protein sources derived from cereals, roots, tubers, food legumes and oilseeds (Hulse 1974).

### Bread Technology

Though composite flours can be used in all manner of processed cereal products, the interest in composite flours arises mainly from the steadily and continually growing demand for wheat flour among the less developed countries, where leavened bread consumption has been rising steadily over the recent past. In many of these countries, particularly in the SAT, the climate and soil conditions are ill-suited to the production of wheat types suitable for breadmaking. Consequently, these poorer countries are disbursing ever-increasing amounts of their scarce foreign currency to import bread wheat from such wheat exporting countries as the USA, Canada, Australia and Argentina.

While milled flours of sorghum and the millets are suitable for the production of many types of flatbreads, their proteins when hydrated do not display the visco-elastic properties of wheat flour gluten, essential to the production of acceptable yeast leavened bread. Using conventional fermented breadmaking systems, any significant replacement of wheat flour with a non-gluten forming flour leads to a depression in loaf volume and crumb quality.

Nevertheless, the continued importation of foreign wheat or wheat flour constitutes not only a drain upon limited resources of convertible foreign currency, but also depresses local agricultural production of cereal grains. Consequently, there is a legitimate and commendable interest in many developing countries of the SAT in the elaboration of breadmaking procedures which permit the partial or total substitution of wheat flour with flours derived from locally grown and harvested cereals, food legumes and oilseeds.

In those developing countries where wheat bread is appearing with greater frequency in the general dietary pattern, but where it is not widely established, there exist unique opportunities to formulate standards of bread quality that are based more upon nutritional quality than upon loaf volume, crumb color and softness. The need is urgent for research to develop technologies that will permit the use of nutritious composite flours that contain a significant proportion of locally produced grains rather than those which rely entirely upon imported wheat.

Furthermore, the developing countries of the semi-arid and humid tropics need breadmaking technologies suited to their particular needs and conditions bearing in mind that the breadmaking technologies that were developed in temperate climates are ill-suited to tropical conditions. Bread yeast (*Saccharomyces cerevisiae*) functions best at about 25°C which is therefore close to the optimum temperature for fermenting bread dough. In a tropical country a dough temperature of 25°C is virtually impossible to maintain in the absence of expensive refrigeration and air conditioning facilities.

Consequently, the need is apparent for breadmaking systems that rely upon fermenting organisms that function best at tropical temperatures, and for processing systems that employ composites containing significant quantities of sorghum, millet or other tropical grains combined with legume or oilseed protein to provide good nutritional quality.

Though comparatively little progress appears to have been made in the replacement of *Saccharomyces cerevisiae* by fermenting organisms better suited to tropical conditions, a number of workers have reported important advances in novel breadmaking technologies based on composite flours. Among those who have studied the total or partial replacement of wheat flour with other cereal flours for breadmaking, generally speaking two alternative approaches have been pursued. The first has sought a satisfactory replacement for gluten; the second has endeavored to extend sufficiently the effective wheat gluten present to make possible the addition of non-gluten-forming flours. The literature on composite flours in breadmaking and for other purposes was reviewed by Hulse (1974) and by Hulse and Laing (1974), and in a Food and Agriculture Organization (FAO) publication (1973).

In addition to the economic advantage of diluting imported wheat flour with flours milled from indigenous cereal grains, composite flour technology makes possible the nutritional supplementation of bread and other cereal foods with other naturally occurring or synthetic ingredients. The biological value of the cereal protein may be improved by the addition of synthetic lysine, or by naturally occurring substances relatively rich in lysine such as whole or extracted legume and oilseed flours, protein concentrates derived from fish and animal sources, or protein of microbial origin. Other essential nutrients can be added in a form that can be conveniently mixed to the base cereal flour without technological detriment.

#### Mechanical Development of Bread Dough

As with many other food processing technologies, little fundamental change in the principles of breadmaking took place for over 6,000 years. Most of the technological improvements during this time consisted simply of replacing human energy with machine power.

19

Early in the 1960s, a significant and fundamental change took place in breadmaking systems, particularly in Britain and some European countries. This consisted in the replacement of long periods of dough fermentation by mechanical development. In simple terms, the principle of mechanical development is that the physico-chemical changes that take place within bread doughs during long fermentation (a process known among bakers as "ripening") may be simulated more quickly and more uniformly by intense mechanical work upon the dough. In oversimplified terms, during ripening the dough becomes more elastic and therefore able to expand uniformly under the internal pressure that results as the  $\text{CO}_2$  is generated by yeast fermentation of the sugars present. The principle of mechanical development was elaborated in the Chorleywood bread process (Axford et al. 1963, Elton 1965, Chamberlain 1965).

The replacement of long fermentation by mechanical development has many obvious advantages, one of importance being that the dough is not required to sit and ferment for long periods of time, an undesirable procedure in tropical climates where high ambient temperatures encourage the growth of unwanted micro-organisms in competition with yeast, accompanied by biochemical reactions that lead to excessive deterioration of the dough condition and subsequent bread quality.

An unanticipated advantage from the point of view of composite flour technology is that mechanical development permits the use of wheat flour blends considerably weaker in gluten strength than those customarily used in traditional processes.

For example, whereas in a conventional breadmaking system an optimum flour composition might consist of 65% of a strong wheat flour blended with 35% of weaker flours, the Chorleywood mechanical development process permits the use of only 35% of a strong flour combined with 65% of weaker flours.

This discovery suggested to this author (J.H. Hulse) that the principle of mechanical development might permit bread to be produced from mixtures of wheat flour with such non-gluten forming cereals as sorghum, millet and maize. This hypothesis was first put to the test and demonstrated to be valid by Pringle et al. (1969) and later by Dendy et al. (1970) at the Tropical Products Institute (TPI) in the United Kingdom. In both these instances, a powerful mixing machine was used to achieve the necessary degree of mechanical development.

As indicated above, the most attractive advantage of producing bread from composite flours by mechanical development is the ability to incorporate appreciable levels of cereal and legume flours from grains indigenous to tropical countries. At the same time the transfer of the technologies used for mechanical development in Europe is precluded by the relatively high capital cost and high energy demand of the mixing machines needed to achieve the rate of dough development necessary. Consequently, for some time technologists have sought, and are still seeking, efficient, technologically sound and economically sustainable systems of dough development that would permit more widespread adoption in developing countries where bread consumption is increasing but where available capital is restricted and energy costs are high.

One alternative potential means of achieving mechanical development was reported by Bushuk and Hulse (1974). It entails the use of metal sheeting rolls

through which the dough, after preliminary mixing, is compressed and stretched after repeated folding. The continuous compression and stretching of the dough mass produces an eventual visco-elastic condition similar to that which results from high speed mixing.

The use of sheeting rolls, operated manually or mechanically, is not unfamiliar in many small bakeries of Africa, the Caribbean and Latin America, but until the study by Bushuk and Hulse (1974), the author is not aware of any attempt to eliminate or reduce the long fermentation period by mechanical development through repeated sheeting, folding, compression and stretching of the dough mass.

By the employment of sheeting rolls, bread equivalent in quality to that produced by high speed mixing resulted from mixtures of wheat and maize, wheat and sorghum, wheat and pearl millet, and wheat and common millet. As a means of conserving energy demand, a bicycle pedaled source of power was used to drive the sheeting rolls. The process is now under further development as an adjunct to the Maiduguri mill project.

#### Chemical Dough Development

As an alternative to the mechanical development of composite flours, several chemically controlled systems of breadmaking by short fermentation times have been demonstrated. Many of these rely upon the balancing of oxidation-reduction reactions which influence the visco-elastic properties of the hydrated proteins in the dough mass. Unfortunately, most of the chemical substances necessary to such processes are not manufactured in most developing countries. On the other hand, such simple machines as sheeting rolls could be manufactured in many developing countries and therefore are deserving of further study.

It must again be stressed, however, that only the principles of producing bread from composite flours whether by mechanical or chemical means, are truly transferable. The technologies suitable for each community and environment need to be developed where they are to be used, with full regard for the energy and material sources available. As with all technologies, it is essential they be elaborated in a sympathetic, mutual understanding between those who develop and those who will use the technologies and the technologically derived products.

#### Traditional Breadmaking

While it is doubtful if the trend toward leavened bread can be reversed, particularly among growing urban populations, there exist many unexploited opportunities for the development of a wide range of attractive nutritious cereal-based products in the form of flatbreads, cut and extruded noodles and other cereal and legume mixtures in a variety of texturized forms. Greater effort is needed to promote the consumption of the traditional flatbreads of Asia, the Near East, Africa and Latin America, many of which can be made entirely from locally produced cereal grains. These include the unleavened roti, made from ground sorghum or millet in India, the leavened kisra, familiar in Sudan, the injera of Ethiopia and the mugabi of Uganda. The essential nature and the methods of making these and other flatbreads have been described by Vogel and Graham (1979). With some degree of scientific ingenuity many of these traditional foods could be improved in nutritional quality and manufactured by rural industries, if more attention were

given to the essential nature and the quality of these products as demanded by consumers, and the properties of the original raw materials and processed ingredients.

Rather than encouraging the demand for European and North American type leavened breads, would it not be of greater benefit to indigenous agriculture to stimulate small-scale industrial production of the traditional forms of flatbreads, noodles and other nutritious convenient cereal foods?

### Pasta Products

The simplest and least costly method of processing cereal mixtures and composite flours is in the form of noodles, formed from a stiff dough which may be extruded or sheeted and cut before being dried, boiled, steamed, or fried in hot oil. The advantages of the noodle and similar pasta products lie in their simplicity of production, requiring little if any expensive equipment, their intrinsic stability after drying, and the almost limitless range of nutritional composition and final shapes and forms in which they can be fabricated.

### Agglomeration

Though bread is one of the more popular and widely publicized end products from composite cereal flours, several other processing technologies make possible the homogeneous blending of cereal flours combined with nutritionally complementary ingredients. One of the simplest methods of combining different finely powdered ingredients into homogeneous water dispersible granules is through agglomeration. Though, industrially, agglomeration has probably been applied more by the pharmaceutical than the food industry, the underlying principle of agglomeration is essentially that by which couscous is made. Agglomeration consists of lightly wetting the surface of each of the constituent particles with an adsorbed film of water sufficient to cause the fine cereal, legume and oilseed particles to coalesce and stick together in small clumps which after drying remain as relatively porous granules with the capacity to absorb and mix readily with water.

The adherent aqueous films may be applied to the particles from an atomizer, which applies the water in the form of a mist as the composite cereal particles are continually mixed in a twin cone or other tumbler blender. Alternatively, agglomeration may be achieved by continuously mixing the composite cereal blends over a source of steam or water vapour. The essence of the technique is to add only sufficient water and to disperse this water so quickly and uniformly that only the surface of the particles is wetted and that no local dough formation or pasting occurs. It is equally important to create and dry the agglomerated granules rapidly, otherwise irreversible dough clumps will form.

There are many variants upon this technological theme including the more rapid and uniform dispersal of the aqueous phase by injecting the water mixed with a miscible but non-wetting liquid such as acetone which during the subsequent drying process distills off. Though technologically efficient, these more elaborate agglomeration systems, involving the use of flammable liquids such as acetone, are clearly not to be recommended for food processing purposes; first, because of the fire hazard they present and second, in order to be economical, all the acetone must subsequently be recovered by distillation and trapping.

## RECENT ADVANCES IN CEREAL PROCESSING TECHNOLOGY

In recent years a new generation of technologies, based upon various processes of extraction and extrusion, have appeared, some of which are capable of processing a wide range of cereals, legumes and oilseeds and their components in an almost endless diversity of combinations. A number of these technologies call for relatively expensive equipment, multistage processing, together with fairly elaborate facilities for ingredient, product and process control. Furthermore, several of the more highly publicized technologies rely upon techniques of cereal and legume protein concentration that would be uneconomic and beyond the resources of most communities of the SAT.

Though they appear of limited applicability among poor countries, for the sake of completeness it seems desirable to make brief reference to protein concentration and extrusion technologies, since in some of the more affluent countries of the arid and semi-arid tropics, they may find useful application.

### Protein Concentration and Isolation

Protein concentration in legumes and oilseeds can be achieved from a variety of procedures. These have been briefly reviewed by Hulse et al. (1975). Though simple removal of the cellulosic hulls leads to a modest increase in percentage protein content, significant increase in protein content calls for more elaborate methods of concentration.

For many years the techniques of protein concentration by fine grinding and air classification have been applied to cereal grains. The technology is also applicable to a number of food legume flours. The principle lies in the fact that in a finely ground cereal or legume flour, the larger carbohydrate granules preponderate in the heavier particles whereas the protein matrix is broken down to small fragments and therefore protein is concentrated in the finest fraction. Consequently, protein fractionation can be brought about by applying to the finely ground flour particles a centrifugal force opposed by a centripetal air drag. The heavier particles of higher effective mass then move in one direction and the finer protein rich particles are carried in the opposite direction. By determining the critical particle size below which protein concentration is highest, it is possible to adjust the opposing forces so as to gain maximum protein shift. For example, in soft wheat flours, the critical particle size, or "cut size", is about 17  $\mu$ . In sorghum from a floury type of endosperm the cut size is closer to 14  $\mu$ . Protein concentration by fine grinding and air classification is generally more efficient in cereal grains with a soft floury endosperm such as one finds in soft wheats and floury sorghum, than in those with a vitreous endosperm characteristic of hard wheats and corneous sorghums.

Air classification is often more efficiently achieved in legume than in cereal flours since, in general, the starch granules of legumes are of significantly larger average size than those of cereals. That this is so has been demonstrated at the Prairie Regional Laboratories (PRL) in Canada where pea flour (*Pisum sativum*) has been converted by fine grinding and air classification to significantly higher protein contents than occur naturally in the pea cotyledons (Vose et al. 1976).

While air classification is more expensive than the types of milling described above, it is generally simpler, less costly and less hazardous in tropical countries than some of the "wet" systems referred to below. The subject of protein fractionation by solvent extraction of the cereal grains of the SAT has been reviewed by Hulse et al. (1980).

Legume protein concentrates containing 60 to 70% protein may be produced by isoelectric washing in which the legume protein is removed by aqueous extraction at a pH close to its isoelectric point. On the other hand, protein isolates containing more than 90% protein can be produced from legume flours by aqueous or alkaline extraction followed by acid precipitation. What have come to be known as textured protein foods and textured vegetable proteins may be produced in a variety of fashions some of them elaborate in design and complex in execution.

In a typical process, the legume protein is extracted in mildly aqueous extracts, the insolubles being removed by centrifuging. The subsequent addition of sulphur dioxide lowers the pH of the solution causing the proteins to precipitate. The precipitate may then be centrifuged, washed, diluted and further processed to produce a slurry containing 95% of protein. This slurry is made alkaline, filtered, then extruded through spinnerets, similar to those used to make filamental rayon or nylon, into a bath at about pH 4. These individual filaments may be stretched and combined into a ribbon or a tow of monofilaments to which flavors, colors and other ingredients may be added to produce final products bearing a close resemblance to meat or fish in appearance, texture and flavor. It should be emphasized that the yield of protein isolate is directly proportional to the protein content of the original legume or oilseed. Faba beans with an original protein content of about 33% yielded 28% of isolate whereas lentil flour with an original protein content of 22% yielded only 19% isolate under similar conditions.

It is important to understand that isolates are used in food products more because of their functional characteristics than their nutritional properties. In general, legume isolates produced by alkaline extraction and acid precipitation are significantly lower in nutritional value than either the original legume or the protein concentrated by isoelectric washing, because the relative proportion of essential amino acids is significantly reduced by the extraction process.

Textured vegetable proteins have been largely used in what are called meat analogues, a subject that has been reviewed by Horan (1974). Briefly, the purpose of textured meat analogues is to replace, in whole or in part, the flesh meat of animals by plant products which, in the final cooked form, are virtually indistinguishable from meat in flavor and in taste. With the exception of the more expensive extruded protein isolates referred to above, greatest commercial success appears to have been achieved by the partial replacement of meat in comminuted products such as sausage, meat patties and hamburgers.

### Extrusion Technologies

Of much wider interest and application than agglomeration is the ever growing number of extrusion technologies that are used in many countries of the world to produce a wide diversity of processed products for human food and animal feeds. The simplest form of extrusion technology has long been known and consists simply



of forcing a relatively stiff flour/water dough through a die from which the dough emerges as a filament, ribbon or tube and either may be cooked immediately in boiling water, steam or hot oil, or dried and stored almost indefinitely if protected from infestation. Low pressure extrusion provides the basic technology of the pasta products industry and the making of noodles such as the Chinese have produced domestically and industrially over many centuries.

The theory and practice of food extrusion has been comprehensively reviewed by Harper (1979) who classified the various types of food extruders under the following categories:

- (a) *high pressure forming extruders* in which pre-gelatinized cereal doughs are formed into pellets which may subsequently be puffed or toasted;
- (b) *low-shear cooking extruders* used to produce so-called "soft moist" foods that are preserved by careful control of their eventual equilibrium relative humidity through their content of soluble solids;
- (c) *collet extruders* which are designed to produce a high rate of shear over a short distance of travel and which generate a high degree of frictional heat causing the starch present to be gelatinized and partially dextrinized and the mixture upon extrusion to become rapidly expanded into a curl or "collet";
- (d) *high shear cooking extruders* that are used to produce pre-cooked products in which the physical properties are significantly changed to produce "texturizing".

Rossen and Miller (1973) have classified food extruders according to their thermodynamic characters.

Most of the extruders within the author's cognizance consist of a single flighted Archimedean screw rotating in a tightly fitted barrel, the pitch and depth of the flights and the length and shape of the screw being varied according to the end purpose desired. Twin-screw extruders are also under development in several countries. Most extruders are driven by electric motors and according to Harper (1979) the power requirements vary from 0.05 to 0.36 kWh/kg dependent upon the conditions of operation.

The ingredients are fed into the barrel through a hopper equipped with agitators or some other means of preventing bridging and ensuring a uniform rate and composition of ingredient flow and feed to the screw. The barrels vary considerably in length and diameter dependent upon the surface required for heating and cooling and the total residence time necessary to generate the product desired.

Internal pressures in excess of 70 atm are not unusual in the extrusion of mixtures of high viscosity under high rates of shear. Heat within the mass being mixed and extruded as the screw rotates in the barrel may be generated entirely through friction, or the mix temperature may be regulated by heating or cooling jackets surrounding the barrel. In the more elaborate models, temperature and pressure sensors are included to improve the facilities for operational control.

Central to all extrusion processes is the design and construction of the single or twin extrusion screw which acts as a conveyor, a mixer and compressor, and provides the means of changing the physical nature and rheological properties of the mixture of ingredients being processed.

Following the mixing, compression, development, and varying degrees of cooking as it is forced along the feed, compression and metering sections of the flighted screw, the mixture is eventually forced out of the die located at the exit end of the barrel. The die usually consists of variously shaped apertures and cutters which determine the eventual conformation of the extrudate. In many extrusion processes the product temperature is highest immediately before it emerges from the die. As the product leaves the die, and the restraining pressure within the barrel is relieved, the sudden drop in internal pressure causes flashing with a rapid evaporation of moisture and a resultant Joule-Kelvin evaporative cooling effect. Loss of internal pressure may also result in immediate expansion of the extruded mass causing various degrees of constituent disruption and increased porosity, under which circumstances rapid evaporative cooling occurs throughout the mass.

When the process of mixing and compression is short-lived, the internal temperature is raised rapidly, retained briefly, and dropped suddenly after extrusion, heat damage to the thermolabile essential nutrients present will be relatively small. On the other hand, in extruders where internal pressure, temperature and other processing variables are difficult to control, nutrient loss may be significant and highly variable. The hazards of partial blockage at the die, leading to excessive rise in back pressure, internal temperature, and time of dwell, are always to be reckoned with and various devices, such as perforated metal discs inserted between the end of the screw and the die, can help to obviate plugging of the dies by large uncooked or inadequately mixed agglomerates. Various safety devices such as slip clutches, shear pins and pressure reliefs on hydraulic drive mechanisms are alternative means of preventing damage to the component parts.

Extrusion technologies have been developed for the processing of full and low fat oilseed meals, and to produce a range of what are generically described as "textured vegetable proteins", many of which are used as meat replacements or extenders, and for a wide range of infant formulations, snack foods, and what are generally described as convenience foods.

The formation of these textured vegetable proteins from soybean or other legume protein concentrates and isolates occurs through what the practitioners of the art term "protein plasticization". The precise biochemical mechanism by which the texturized protein formation is controlled is yet to be described but it has been suggested that the constituent proteins are disrupted, denatured and subsequently reaggregated into fibrillar configurations through intermolecular peptide bonding.

The advantage of extrusion systems is that predetermined mixtures of ingredients may be blended, wholly or partially cooked, and produced in a wide variety of forms and textures, in a single continuous operation, which, if suitably controlled, need not cause excessive damage to essential nutrients.

It is no disrespect to the many thoughtful, imaginative and innovative research and development activities reported in the literature, to state that extrusion technology is still based largely upon empiricism. Extrusion technology has borrowed extensively from experience in the plastics industry. But given the fact that most of the food mixtures processed, particularly those based upon cereal and legume flours, in addition to being biological and therefore by no means inert, are non-Newtonian and many display visco-elastic properties which rapidly change under conditions of increasing compression, high shear and rapid temperature rise, precise predictability of end product and accurate process control are difficult to achieve. Consequently, process and product development must of necessity depend largely upon empirical experimentation. Furthermore, the greater the degree of process control to be exercised over the high pressure, high temperature extrusion technologies, the greater becomes their complexity, cost of construction and operation.

It should be emphasized that the extruders available commercially vary greatly in their complexity and in the most elaborately designed examples, the number of processing variables are so many that it requires considerable mathematical skill and computer facilities to examine, comprehend and control all of the effects of these variables systematically and simultaneously.

Nevertheless, those of simpler design, particularly those embodying relatively low pressure extrusion systems, may be useful in the manufacture of nutritious cereal, legume and oilseed based food products in small rural industries of the SAT.

#### AGRICULTURAL BY-PRODUCTS

Agriculture, in all of its facets, in which I would include the raising and harvesting of all terrestrial and aquatic plants and animals, consists essentially of the conversion of one form of energy to another through chemical interactions. The Law of the Conservation of Energy, which broadly states that no one may expect to get something for nothing, is included in every science student's curriculum. It should therefore come as naturally as breathing to every scientist that the conservation of biologically derived energy is of the highest priority; from which it should logically follow that the elimination of waste, or products classified as waste, is a matter of equally high priority.

As it relates to biological processes, particularly those from settled agriculture, the term "waste" ought to be replaced by "by-product" since virtually all organic matter can be profitably used in some fashion. Of all the agricultural by-products generated throughout the world, straw, from all forms of harvested plants, is probably the least efficiently used and the by-product with greatest potential as a convertible source of energy. Several recent estimates have indicated that, given improved collection methods, straw could become the most abundant of all the world's non-woody plant materials.

In many of the developed countries, including the European Economic Community's "Energy from Biomass" program, straw is regarded mainly as a potential source of machine or heating fuel. Hydrolysis of the cellulose permits the resulting sugars to be converted to ethanol by yeast fermentation and/or to a

variety of industrially useful chemicals dependent upon the nature of the microorganisms used to bring about the fermentation.

The microbial conversion of straw, lignocellulosic materials from woody plants and a vast array of other agricultural by-products, human and animal waste, to methane, ethanol and other combustible fuels does not fall within the scope of this discussion. What is relevant to a comprehensive study of the post-production system is the use of agricultural by-products as a source of feeding stuffs for farm animals.

IDRC is supporting several projects, in various parts of the world, in which agricultural by-products provide a significant contribution to the essential diets of farm animals. In several countries integrated animal production systems are being developed in which feeds, from cultivated pastures of grasses and forage legumes grown on marginal lands, are complemented with by-products processed by mechanical or biological methods to feed supplements that are nutritious, acceptable to the animals and economic to the farmer.

In the Caribbean and Latin America, the by-products of sugarcane and coffee processing are both being studied in projects financed by IDRC. It appears that, as is the case with other lignocellulosic materials, provided the fibres are cut to sufficiently small lengths, either whole sugarcane without derinding, or bagasse may be fed as sources of energy to ruminant livestock. It has also been demonstrated that the disruption of the propionic acid cycle within the rumen by a high sugar intake may be offset by the addition of glycerol to the diet. What now appears feasible is that, as was demonstrated in Germany during World War I, with the addition of soluble bisulphite to a sugar fermentation system, the Embden-Meyerhof biochemical cycle is diverted, with the pyruvic acid being converted to glycerol rather than via acetaldehyde to ethanol and carbon dioxide. Mexican research scientists have also demonstrated that, by microbiological fermentation of molasses in the presence of urea or other nitrogen sources, a valuable feed supplement to the basic sugarcane diet can be provided.

#### MICROBIAL PROTEIN

One of the difficulties of providing protein supplements for food or feed from microbial sources in the tropics, rests on the fact that most of the past research has been based upon fermentation by yeasts, for which the optimum functional temperature lies close to 25°C. As discussed earlier in reference to breadmaking in the tropics, fermentation by temperate organisms requires mechanical refrigeration to maintain the optimum temperature, since rarely if ever in the tropics is the ground water temperature low enough to permit it to be used as a coolant to maintain the conditions required. Consequently, there is considerable opportunity for research to identify microorganisms that will grow well between 35 and 45°C and convert carbohydrate, combined with inorganic or waste sources of nitrogen, to protein that is nutritious and uncontaminated by toxic substances or antinutrients.

At the University of Guelph in Canada, several such organisms have been identified. One micro-fungus, *Aspergillus fumigatus* grows well at between 40 and 45°C and will both hydrolyze and ferment starch, in the presence of inorganic

nitrogen, to produce a finished biomass which, on a dry weight basis, contains 35% of crude protein (N x 6.25). Since *A. fumigatus* grows best at a pH of 3 to 3.5, it tends not to be affected by such competitive organisms as would interfere with the fermentation of carbohydrate by yeast under non-aseptic conditions. So far cassava starch and the by-products of cassava processing have formed the principal substrates for *A. fumigatus* but there is no reason why this and other tropical organisms may not produce protein enriched feeds from a variety of surplus carbohydrate sources.

At Mahidol University in Thailand, a systematic study is being made of several hundred local species of tropical fungi present in soils and decaying wood. These are being assayed for cellulolytic and lignolytic activity and those which display a high lignolytic activity combined with an adequate capacity to degrade cellulose will be grown on substrates of sugarcane bagasse and rice straw. It is hoped that this research will provide a satisfactory means of converting some of the 55 million metric tonnes of sugarcane bagasse and 180 million metric tonnes of rice straw that are believed to be available throughout tropical countries, to an acceptable and nutritious form of animal feed.

In Syria, research is in progress to convert the straw of various widely grown cereals to a digestible form through alkaline hydrolysis. The processed straw will be supplemented with protein sources derived from the by-products of oilseed, legume and cereal processing.

#### PROTEIN FROM COFFEE PULP

Coffee is an important cash crop in a number of countries of the SAT. Approximately 80% by weight of the coffee berry consists of the moist pulp that surrounds the kernel which, after fermentation and roasting, becomes the primary product. In Latin America it is estimated that about 1.5 million metric tonnes of coffee pulp are thrown away every year. This is unfortunate since the coffee pulp contains significant quantities of nutritionally good quality protein, the 1.5 million metric tonnes destroyed being estimated to contain roughly 100,000 tonnes of protein, roughly equivalent in weight to the protein produced by about 1/4 million ha of soybeans.

Coffee pulp, after being dried in the sun or in flatbed dryers fueled by methane generated from a mixture of sewage and by-products of coffee processing, may be fed to either ruminant or monogastric animals. The principal constraint to a greater use of dried coffee pulp in animal feed lies in the caffeine and other phenolic substances present that tend to reduce the biological efficiency of the pulp in animal diets. The means by which these inhibiting phenolics may be reduced or neutralized is being studied at the Institute for Nutrition of Central America and Panama (INCAP), where it has been found that the ensilaging of coffee pulp, in combination with maize stalks or waste sugarcane, reduced the adverse effect of the phenolics, at least in the diets of ruminants. This work has been reported by Braham and Bressani (1979).

The above represent only a few of the many examples of agricultural by-products that can help sustain a viable animal production industry and encourage the integration of domesticated animals into smallholder farming systems.

## THE CONSUMER AND HOUSEHOLD

Though in the vertical presentation of the Post-Production System sequence in Figure I, the consumer appears at the bottom of the diagram, this presentation certainly does not imply that the consumer is of least importance and last consideration. Nevertheless, as one reviews the scientific literature reporting the ingenious discoveries and innovations of agricultural and food scientists, it is not always apparent that food crops and processed foods are intended first and foremost to provide adequate and nutritious diets for clearly identified communities of consumers.

It is a basic philosophy among my colleagues in the AFNS Division of IDRC that all food and agricultural research and development programs revolve around two mutually dependent and equally important human foci: the farmer-producer and the consumer. Consequently, every production and its concurrent post-production system must begin with a comprehensive understanding of the socio-economic conditions, needs, attitudes and constraints of both the farmer and the consumer in relation to one another and to the environments in which they exist.

## Nutrition in the Semi-Arid Tropics

In the SAT, where so many of the rural poor cling desperately to the razor edge of survival, the nutritional composition of food available must always be a matter of major concern. Waste of any kind is intolerable. Among economically privileged societies the waste of any food resource is deplorable; among the rural poor of the SAT it is disastrous.

It required the severe droughts and resulting crop failures of the early 1970s to draw the world's attention to the precarious state of nutritional adequacy in which the people of the SAT exist. For those persons familiar over many years with the Sahelian region and the semi-arid areas of India, the plight of these, the poorest people in the world, has long been a matter of concern. It was for this reason that when IDRC came into existence in 1970, the highest priority in the AFNS program was assigned to research for the benefit of the rural people of the SAT, those regions where rainfall is invariably sparse and uncertain and where, for a significant period of every year, evapotranspiration exceeds rainfall.

Though semi-arid climate conditions are to be found in many parts of the world, the SAT by IDRC's definition include mainly the Sahelian countries of Africa, the Gambia, Haute Volta, Mali, Mauritania, Niger, Senegal and Chad, together with large areas of Ethiopia, Sudan, Kenya, Tanzania, Uganda, Zambia, Mozambique, Somalia, Botswana, Lesotho, and Swaziland. In India the semi-arid tropical conditions occur in the States of Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu and in parts of Rajasthan and Madhya Pradesh.

Though by strict classical geographical definition, they may not be regarded as truly tropical, conditions of severe regional and/or seasonal aridity are to be found among many of the countries of North Africa, West Asia and the Near East. The communities of these regions therefore fall within our consideration since, in consequence of environmental conditions adverse to highly productive food crop production, they exist in a state of permanent and excessive risk similar to that which prevails in the SAT.

Many of the people of the SAT exemplify the classical vicious circle of malnutrition: an insufficient diet providing an inadequate energy intake, giving rise to a poor resistance to infection, an impaired learning ability and, in consequence, a relatively low work output that generates an inadequate family income, which results in an insufficient diet. Concomitant consequences include a high incidence of infant mortality, a higher than average birth rate to compensate for the high infant mortality, and an increased calorie, protein and other nutrient intake demand among pregnant and nursing mothers and among sick children, in order to offset the ravages of internal parasites and infectious diseases.

The dietary pattern of the people of the SAT is invariably poor and cereals provide more than 70% of the calories consumed. Table 1, taken from data presented at the UN World Food Conference in 1974, presents estimates of the average caloric intake of people living in a number of SAT countries of Africa, expressed as a percentage of the estimated requirement. These and other aggregate figures of caloric intake indicate that in 13 of the 17 SAT countries of Africa the inhabitants consume less than their estimated average caloric requirement.

Of greater concern is that during the decade of the 1970s, for these African countries as a whole, increase in food production failed to keep pace with average population growth and in at least one-third of the countries, production per capita has declined significantly over the past 10 years.

It is to be recognized that overall nutritional adequacy cannot accurately be gauged by national average estimates of production and consumption. Such averages are often misleading in that they bear the implicit assumption that surpluses in some regions or among certain socio-economic groups compensate for deficits elsewhere. National averages also fail to take account of the very significant seasonal variations in calorie intake that are known to occur throughout the SAT. Any detailed review of nutrient intake over a broad spectrum of the rural people of the SAT will reveal wide variations among geographical areas, among countries, among communities, and among and within families living in the same community.

#### Seasonal Variations

Figure II displays the general pattern of seed time and harvest throughout the Sahelian region and clearly indicates the seasons of comparative abundance and scarcity, illustrating the inevitable consequence of seasonal malnutrition. The chart also illustrates the immense importance of creating post-harvest systems that ensure an adequate and safe carry over from the regions and seasons of abundance to those of scarcity.

Food consumption levels throughout the Sahel follow a yearly pattern during which wide seasonal fluctuations are evident. In good years, from December to mid-March immediately following the harvest, is a period of relative abundance. This period of relative abundance extends partly into the dry season during the non-farming months of February and March but between April and July, food supplies dwindle and during August and September serious dietary inadequacies are to be found among those who have not maintained an adequate store or who lack the disposable income to buy from the ubiquitous grain traders.

31

A study carried out by l'Organisme de recherches sur l'alimentation et la nutrition africaines (ORANA) in the Thiès region of Senegal indicated that dietary caloric levels fell to 27% below recommended values during the period August through September. Similar data showing marked seasonal variations have been found in other Sahelian countries with the most serious deficiencies occurring during August-September (Dillon and Lajoie 1980).

#### Urban Poor

In some countries of the semi-arid regions the urban poor appear more susceptible to seasonal caloric insufficiencies than many of the rural poor, a fact which further emphasises the need for greater attention to post-production systems and adequate food storage and distribution patterns to ensure an adequate surplus and transfer of food from the rural to the urban communities throughout each year and between years of abundant and deficient harvests. The contemporary and predictably future process of rural to urban migration that is evident in many developing nations, including those of the SAT, will only serve to aggravate and intensify malnutrition among the urban poor in the absence of efficient post-production systems of conservation, transformation and distribution.

Post-production research and development also embraces agro-industrial development which, if propagated systematically, can provide employment both for landless agricultural laborers and for smallholder farmers during seasons of low agricultural labor intensity. This aspect will be returned to later.

#### Rural Poor

Studies in Africa demonstrate that among the rural population, the most vulnerable to caloric deficiency and malnutrition are first the landless agricultural laborers, whose meagre income is derived almost entirely during the sowing and harvesting seasons, followed by second, the smallholder subsistence farmer. The latter are severely constrained by a small area of production and a choice of crops limited to those that can survive and yield under the prevailing conditions of uncertain rainfall and poor soils. Consequently, for these smallholders in the SAT, it is exceedingly difficult to produce sufficient food grains to feed their families even during years of relatively good harvests. During years of poor harvest and in the seasons immediately prior to the harvest when food stocks are depleted, the nutritional well-being of both landless laborers and smallholder farmers becomes precarious in the extreme. The resulting food price escalations react most severely upon these and the urban poor.

These melancholy conditions will continue to deteriorate in the absence of post-production systems that provide for adequate carry-over of stocks between years and seasons of good harvest and those of deficiency.

#### Infant Malnutrition

Data from systematic surveys and the perceptive observations of people working among the rural poor of the Sahelian countries indicate that nutrients available to small children are not necessarily proportional to the supply of nutrients available to the household.



The majority of families in all Senegalese regions surveyed by Yaciuk and Yaciuk (1980) fed their unweaned children the same foods as are consumed by adults. The general feeling of most mothers was that breast milk was adequate to meet the dietary requirements of the child. After weaning the child normally joined in the family meals, a situation which places the weaned child at a serious disadvantage. The child lacks the physical agility to compete with the older members of his family for his food. Furthermore, the child is often unable to consume enough of the bulky food to obtain the recommended nutrient supply and where the meal consists of a mixture mainly of cereal with pieces of meat, the child often ends up with only small handfuls of the cereal.

In cases where food is insufficient for the whole family, the tendency is for the working adults to be fed at the expense of the children since an inactive child does not jeopardize the family's survival as does an inactive working adult. The death of a young child is just cause for mourning; the death of the principal provider of food and income is tantamount to total and ultimate disaster. Malnutrition among young children not only raises the incidence of infant mortality through susceptibility to infection but also, in many cases, irreversibly retards the child's learning ability which consequently, among those who survive, decreases their future capacity for maximum work efficiency.

Education programs which alert rural mothers to the special nutritional needs of their children, though urgently needed, are obviously extremely difficult to implement. Until post-production research can free the African woman from her demanding and tedious household chores, she cannot be expected to be very receptive to the suggestion that she spend precious time preparing special foods for her younger children.

#### Malnutrition in Pregnant and Lactating Women

Paul et al. (1979) studied, among Gambian women, the quantitative relationships between dietary energy intake and weight gain in pregnancy, birth-weight and lactation performance during the first three months, so as to take into account major differences in the patterns of heavy manual labor at different times of the year in a subsistence farming community. Researchers found that maternal weight gain and the accumulation of subcutaneous fat were significantly lower when the last trimester of pregnancy fell during the time of heaviest farm work and lowest energy intakes. The birth-weight of babies was also significantly correlated with differences in energy intake throughout the year.

During early lactation breast milk yields were significantly related to concomitant alterations in the subcutaneous fat stores. Evidence has been produced which suggests that in undernourished nursing women there could be a competition for dietary energy between the repleting maternal subcutaneous fat organs and the mammary glands at the expense of milk production.

Food intake of pregnant and lactating women in a Gambian rural community was measured for a year, using the precise weighing method (Müller 1979). Grains and groundnuts accounted for most of the energy (73 and 20% respectively) and protein (60 and 28% respectively) in the women's food intake. Consumption of all grains but rice, and consumption of groundnuts were highest following the harvest and then decreasing continuously till the new crops were in. Rice consumption remained the same throughout the year.

Over the whole year, mean daily energy and protein intakes were 1453 kcal and 45.6 g for the pregnant women and 1664 kcal and 53.0 g for the lactating women. Lowest values arose in July, August and September when figures of 1275 kcal and 38.6 g of protein for pregnant women and 1387 kcal and 42.7 g of protein for lactating women were obtained. These figures are lower than those recommended for British pregnant and lactating women (FAO/WHO report no. 522) but they compare well with values obtained by researchers in other Third World Countries (Norgan et al. 1974 and Vijayalakshmi et al. 1975).

In one other study (Paul and Müller in press), in the village of Keneba in the Gambia, a relatively isolated subsistence farming community, researchers found that breastfeeding was common until 18 to 24 months of age, but breast milk output seemed inadequate to support the growth of the child after 3 months of age. Most of the women engaged in heavy agricultural duties during the rainy season of the year and there was clear evidence of seasonal food shortages. Dietary energy intakes averaged 1500 kcal over the year in pregnant women, and 1700 kcal in lactating women, but fell to extremely low levels (1200 kcal) at the height of the rainy season.

The staple cereals of the communities studied were millet and rice, with seasonal variations in groundnuts supply accounting for much of the seasonal variations in energy intake. Cereals were eaten in preparations containing 60% or more of water, which resulted in a low energy density (about 1 kcal/g food) and high bulk in the diet. The intake of other nutrients also showed large deficits compared to internationally accepted recommended intakes, the two outstanding ones being those of riboflavin and calcium, which were less than one-third of recommendations at all times of the year. Thiamin and nicotinic acid intakes were not so low, chiefly because of the amounts contributed by groundnuts. Calcium, vitamin A and vitamin C intakes were higher during the rainy season due to the consumption of leaves. At other times of the year, apart from two months when mangoes are plentiful, the intakes may be extremely low.

#### The Rural Household

It cannot be too heavily underlined that a post-production system is not simply confined to the harvesting, threshing, drying, storage, primary processing and distribution of cereal grains, food legumes and other food crops. It embraces all aspects of the consumer's household and family that impinge upon and react with the food supply system. Consequently, the post-production system must be concerned not only with the nutritional quality and adequacy of the delivered food supply, but also with such important factors as clean safe water supplies for drinking and food preparation, with the sanitary conditions prevailing in villages and homes, with the facilities within the household for preservation and storage of perishable foods, with the control of insect and rodent predators, and, of ever growing importance, with ensuring an adequate supply of fuel with which to cook the food.

It is for this latter reason that IDRC has given so much emphasis to social forestry and is supporting some 20 projects in countries around the Sahara and in the semi-arid regions of East Africa, each of which is concerned with a different aspect of rural afforestation, village woodlots and the more efficient utilization of timber in the form of combustible wood or charcoal (IDRC 1977 and Sanger et al. 1977).

While it may appear intellectually and scientifically more exciting to devote limited research resources to the microbiological conversion of biomass to ethanol to quench the insatiable thirst of the automobile, wood remains the most important fuel for many, probably most, rural people. Therefore, IDRC is supporting research to establish village woodlots, and to combine trees with other crops in countries of the Near East, North, East and West Africa. The more effective use of wood and wood charcoal through the development of household stoves of more efficient thermodynamic design is also under study in East Africa.

Except among the larger pulp and paper manufacturers, production and post-production research on forest products has been sadly neglected, particularly among developing countries. Trees provide not only fuel, but may be a valuable source of building and structural materials, feed and shade for animals, fertilizer and green mulch for crops, and raw materials for many rural industries.

Many trees indigenous to the SAT fall into the above categories. Research supported by IDRC includes the development of species of *Acacia senegal* that are fast growing and give high yields of gum arabic, and of a wide range of leguminous multipurpose species. The improved processing of shea butter derived from *Butryospermum parkii* is also being studied in Mali.

#### Nutrient Deficiencies in the SAT

Because of the heavy dependence upon cereals and legumes, it is important that the total nutritional adequacy of diets in the SAT be considered. The prevalence of protein/calorie malnutrition, particularly among young children, is indisputable. However, PCM varies in its severity among different socio-economic groups, the available evidence suggesting that during the severe droughts of the 1970s the nomads and their children were more severely affected than were settled farmers.

In addition to PCM, vitamin and mineral deficiencies are evident among many of the poorest in the SAT (Dillon and Lajoie 1980). Where cereals are the major staple food, significant deficiencies of vitamins A, C and riboflavin have been reported. One of the most serious maladies among young children and women of child-bearing years is iron deficiency anemia, attributable to the combined effect of inadequate available iron in the diet, together with heavy infections by blood and intestinal parasites which interfere with the absorption and utilization of assimilable iron. Not surprisingly among the land-locked countries of the Sahel goitre caused by iodine deficiency is widely prevalent.

#### NUTRITIONAL QUALITY OF THE SAT CROPS

It may now be useful to review briefly what is known of the nutrient composition of some of the principal crops of the SAT.

Hulse et al. (1980) have reviewed a substantial volume of literature covering more than 1700 references that relate to the biochemical composition and nutritive value of sorghum and the principal millets. The review covers all the authors could find that was published on the influence of genetic, environmental and agronomic factors of production and the effects of the principal technologies of

processing, upon the concentration and composition of the essential organic and mineral nutrients present in sorghum and the millets.

### Protein Quality

Though wide variations in nutrient composition are reported among samples of sorghum and the various millets from different locations and with different genetic backgrounds, it is clear that in comparison with many other cereal grains, sorghum and several of the millets must be regarded as nutritionally inferior.

The range of mean protein contents ( $N \times 5.7$ ) from many analyses of sorghum (*Sorghum bicolor*) range, on a dry weight basis, from 7.1 to 14.2%; in pearl millet (*Pennisetum typhoides*) from 7.8 to 19.3%; in common millet (*Panicum milaceum*) from 9.9 to 17%; in foxtail millet (*Setaria italica*) from 9.1 to 14.4%; and, in finger millet (*Eleusine coracana*) from 5.5 to 9.9%. Mean lysine values in sorghum protein range from 71 to 212 mg/g N and therefore the Amino Acid (lysine) Scores range from 21 to 62 with a median value of about 40. Lysine is the first limiting amino acid in sorghum and all of the millets and mean values of the Amino Acid Score calculated from published analyses range from 32 to 87 in pearl millet; 26 to 78 in common millet; 33 to 36 in foxtail millet; and 47 to 77 in finger millet.

Combined with the relatively low nutritional value of the sorghum protein goes a comparatively low protein digestibility which on average appears to be of the order of 50%. Consequently, people who subsist and rely mainly upon sorghum or one of the millets for their principal source of protein require a higher intake of protein nitrogen than those who enjoy a mixed diet containing significant levels of animal protein. For example, if any person were to subsist entirely upon sorghum as a source of protein, the intake of sorghum protein would need to be approximately five times the protein intake of a person of the same age and energy output whose protein was derived from egg or milk.

In much of the literature reviewed, the level of protein present in sorghum, the other cereal grains and legumes of the SAT is overestimated through an incorrect use of  $N \times 6.25$  as the nitrogen to protein conversion factor. Reliable analyses of the amino acid content clearly indicate that a conversion factor of between 5.5 and 5.7 is more accurate for all the cereals and legume seed proteins of the SAT.

Compared to most other cereal grains, the cellulose and pentosan content is exceptionally high in foxtail, common and several of the other millets. The limited evidence available suggests that the pentosans of wheat bran are more digestible by humans than the pentosans of sorghum or pearl millet (Hulse et al. 1980).

### Polyphenols in Sorghum

A particular nutritional disadvantage of a large number of sorghum types lies in the relatively high proportions of polyphenolic tannins present in the pericarp and/or testa. Though over a number of years a great deal of interest has been displayed by research scientists in the polyphenols of sorghum, it was not until 1976 that the most important condensed tannin was identified and isolated from sorghum and chemically characterized as a polymeric procyanidin, a substance

typical of a family of related polyphenols often found in plants that display a woody habit of growth. These polymeric procyanidins are generally synthesized by the shikimate biochemical pathway. High polyphenolic content is usually associated with a deep brown or reddish brown color of the sorghum pericarp and/or testa and it is believed that the polyphenols present in the outer layers of the caryopsis increase as the growing sorghum grain matures, some reports suggesting that most rapid development occurs between 35 and 42 days after anthesis.

It is demonstrable that the genetically controlled high polyphenolic character in sorghum provides the grain with a defensive mechanism against attack by birds, some insects and microorganisms and to some extent against pre-harvest germination. It is believed to be their astringency, resulting from the coagulation of the glycoproteins of the saliva, that renders high polyphenolic sorghums unpalatable to birds and mammals.

There seems little doubt from the literature available that the polyphenols in sorghum reduce both total and protein digestibility, that they inhibit the activity of various enzyme systems including amylases, possibly lipases and proteases. When fed to laboratory and farm animals, sorghum polyphenols reduce overall biological value, feed efficiency, protein availability, digestibility and nutritional efficiency and increase the excretion of faecal nitrogen. It is clear that not only the protein content in sorghum but other ingested forms of protein can interact in vivo with sorghum polyphenols. Consequently, a higher than average protein intake is desirable in diets high in sorghum polyphenols.

Recently a working group met to review the state of knowledge concerning polyphenols in sorghum, millets, other cereals and legumes and to recommend what future research is required to provide a better understanding of the formation and nutritional importance of polyphenols in the various grains in which they appear to exist. The report of this working group was recently published (Hulse 1980).

There seems little doubt that the influence of the polyphenolics in sorghum can be modified by post-harvest treatment, in some cases for the better, in others for the worse. Research at Purdue University indicates that, as judged by rat weight gain, cooking of high polyphenolic sorghums exacerbates the adverse polyphenolic effect. On the other hand, in those genotypes wherein the pigmented polyphenolics are mainly concentrated in the pericarp, they can be largely removed by abrasive milling such as is described above under Primary Processing, or by wet alkaline decortication processes.

It would appear that the means of reducing polyphenols were discovered empirically by many African people. In certain countries of East Africa sorghum is steeped in wet wood ash before being processed for eating, and in some West African countries highly pigmented pearl millet and sorghum are soaked in tamarind juice (high in tartaric acid) or sour milk (lactic acid) before being cooked. It is conceivable that these treatments may lead to some degree of hydrolysis of the polyphenols present in the grain.

Of particular interest to plant breeders and nutritionists is the recent finding at Purdue University and at the U.S. Fish and Wildlife Service that pigmented sorghums, which by chemical analysis appear high in polyphenolic content and are demonstrably resistant to birds, may be divisible into those which are more

and those which are less nutritionally adverse. It also seems apparent that polyphenol formation and the differences between these two classes of high polyphenol sorghum types are genetically controlled (Bullard and Elias 1980).

Clearly there exists a very great field of research with opportunities for cooperation among sorghum and millet breeders, cereal scientists and nutritionists in order to provide the rural poor of the SAT with cereal grains that are agronomically acceptable to the farmer, nutritionally superior yet acceptable in cooking quality, flavor and appearance to the consumer.

Of equal concern is the nutritional quality of the food legumes of the SAT which, in amino acid composition, are nutritionally complementary to cereal grains; a ratio of roughly two parts of cereal to one part of legume being close to ideal in terms of protein nutritional quality.

Findings from INCAP that certain legumes with darkly pigmented seed coats are nutritionally inferior and of lower digestibility than light seeded genotypes indicate that the problem of the adverse influence of polyphenolics may be more widespread than had been previously realized (Bressani and Elias 1980). The various adverse factors that occur in legumes have been reviewed by Liener (1975) and Bressani and Elias (1977) and will not be repeated here since this is neither the forum nor the medium in which to review comprehensively the nutrient composition of all the crops of the SAT.

#### Grain Quality

Nutritional adequacy falls squarely within the sphere of interest of those responsible for the elaboration, improvement and management of post-production systems. Unfortunately, grain quality in relation to nutritional need and to functional properties and those characters which influence acceptability have been seriously neglected in the past and deserve and demand much greater attention in the future.

Though higher yield potential must remain a high priority for cereal, legume and oilseed breeders, high yield must be combined with other essential properties: grain types that can be satisfactorily processed industrially or domestically; that do not require excessively long cooking or which display other characters unacceptable to consumers; that are selected with due regard to the nutritional needs and deficiencies of the eventual consumers. The future calls for a greater degree of integration of interest and effort among agricultural scientists, and food scientists and technologists than has been evident in the past.

#### AGRO-INDUSTRIAL DEVELOPMENT

Agro-based industries offer a substantial yet relatively untapped potential for off-farm employment and income generation among many rural communities of the developing countries. They deserve a greater degree of systematic study than they have received to date.

Agro-industries, whose purpose is to conserve and transform the raw products of agriculture, represent an integral and important segment of all post-production

systems. Earlier in the text several different methods and technologies by which cereals, legumes and oilseeds can be processed were discussed. Most of the relevant literature and much of the effort of food scientists and technologists working in their institutions throughout the developing world appear largely dedicated to the development of new products and the component technologies by which to produce them.

Relatively little attention appears to be given to increasing the technological and economic efficiency of the food and agricultural processing industries that already exist within developing countries. In order to manufacture and market any new product, someone must establish the necessary facilities for processing and distribution. An existing enterprise can manufacture and distribute a new product only if one of the following conditions exist:

- (a) an unused capacity within the existing processing facilities;
- (b) the elimination of previously manufactured products to make way for the new innovation; or
- (c) the financing and construction of new processing equipment and the buildings to house it.

The second and third alternatives clearly embody varying degrees of economic risk, a risk which relatively few small scale manufacturers can afford to take.

Though the first alternative, the employment of excess and unused facilities, may not be immediately evident on first and superficial examination of most small industries, a hidden capacity for greater productivity often does exist and can be revealed by a systematic operations research study of the whole manufacturing entity, the methods by which its available resources are organized and employed, together with a comprehensive evaluation of the opportunities for, and constraints to a more efficient utilization of the economic, technical and human resources available. As has been demonstrated by the methodologies and techniques employed in modern farming systems and cropping systems research, productivity can be increased and resources can be more efficiently used as a result of operational systems research into all aspects of the post-production system.

Operations systems research can be extremely beneficial to agro-industries, whether they be large highly mechanized complexes, or comparatively simple labor intensive rural food processing factories. The technical and economic efficiency of all industries can be improved by systems research both in the amelioration of existing processes and in the development of new ventures.

#### A SYSTEMATIC APPROACH TO POST-PRODUCTION RESEARCH

Some scientists, not excluding those in developing countries, appear to overlook several important historical facts. First, food and agricultural technologies were in existence many thousands of years before systematic scientific research devoted to food and agriculture came onto the world scene. Half a million years ago Peking man (*Sinanthropus pekinensis*) used fire to cook and therefore to preserve meat from various of the ancestors of our contemporary animals. He probably extracted the juice from wild berries and either he, or one of his many

generations of successors, discovered that the seeds of natural wild grasses could be ground, mixed with water and cooked to provide appetizing foods.

More than 10,000 years ago Egyptians and Sumerians used ridged and hollowed out stones to grind cereal grains, and at some point in time discovered by controlled grinding and winnowing of the ancestors of our modern wheats the means by which to separate all or part of the seed coats from the endosperm. It is interesting that flour milling as practised today is not different in fundamental principle from the system used by the ancient Egyptians, Greeks and Romans, and that only during the last 25 years, with the introduction of mechanical development to replace long fermentation, has any fundamental change taken place during 6,000 years of breadmaking technology.

It seems probable that through the perception of the more curious and imaginative of many generations of farmers, agricultural systems have evolved in a manner that is rational and logical to their agro-climatic, social and economic environments. Consequently, it would seem sensible that food and agricultural scientists who seek to help and improve existing agricultural production and post-production systems, should first comprehend the systems that have been so painfully evolved over many centuries of trial, error and observation.

Food science and technology has contributed greatly to the high standard of living of inhabitants of the industrially developed nations of North America, Europe and Oceania. But in contrast with the success of the international agricultural research system, food science and technology programs for the benefit of the least privileged in developing countries have been generally less spectacular. Though one can find many examples of food research, food technology and food industry development projects in developing countries that have been productive and beneficial, many others have fallen short of original expectations. It is the author's belief that many of those that failed to live up to the hopes of their creators did so because they sought to begin their research in the laboratory rather than with acquiring an understanding of the consumers, food processors and distributors whom their research was seeking to serve; those responsible often overlooked the necessity for a thorough comprehension of the total existing system before attempting to introduce novel innovations or improved components and technologies.

The pattern by which such advanced technologies as nuclear energy, electronics and aero-space machines were developed, presents an intimidating and often misleading example to those who seek to apply science to long-established technologies and artisanal crafts. Nuclear energy may be regarded as an unplanned, unforeseen derivative of remarkable research by scientists whose purpose was to gain a more profound and comprehensive understanding of the structure of matter. The sequence of events that led to nuclear technologies, basic research leading by chance to applied research giving rise to an economically viable technology, is rarely an ideal and, more often than not, provides an inappropriate example for technologies that were devised and evolved by astute artisans and careful craftsmen.

An extensive, expensively equipped central food research institute, particularly if owned, controlled and operated by a national government, may prove less of an asset than hoped for in the improvement and expansion of existing agro-industries, and to the development of relevant, efficient and economic



post-production systems among rural communities. Not only must technologies be appropriate to environments, research, in concept, scope and sequence of endeavor, must be appropriate to the existing and established technological capacity.

Among some multilateral and bilateral donor agencies, one senses an unwarranted optimism in the transferability of technology. As stated at the outset, but it bears repetition, scientific principles are universally applicable; many technologies are not. Biological technologies, whether they relate to the cultivation of edible plants or to the transformation, preservation and distribution of plant and animal products, are greatly influenced by their surrounding environment. Consequently, it is invariably difficult, if not impossible, to transfer post-production technologies and food transformation systems from developed countries with temperate environmental climates to the less developed countries of the semi-arid or humid tropics. Technologies, based on sound scientific principles, need to be developed where they will be used, in close cooperation and mutual sympathy with those who will apply and benefit from them.

Much greater investment is needed in research and development dedicated to a better understanding and improvement of post-production systems. Post-harvest losses continue to run at an intolerably high level, and as described in several of the publications listed in the bibliography, they occur at all stages of the post-production sequence from the time of harvest to the time of consumption. Much greater attention and a systematic approach needs to be devoted particularly to improved post-production systems for the principal cereal grains, oilseeds, food legumes and root crops of the SAT, in addition to many other potential food sources that are or could be added to the diets of poor rural people.

#### OTHER FOOD SOURCES

Though most of this text is devoted to post-production systems as they relate to cereal grains and legumes, other subsistence foods stand equally in need of technically and economically sound post-production systems. For example, a more intensive research effort needs to be dedicated to the preservation and distribution of fish in tropical countries where refrigeration is for the most part unavailable and uneconomic. The promise and potential of aquaculture and mariculture will not be realized until effective and economic methods of fish preservation are adopted. The applied research required must start where the fish are harvested with a thorough study of the climatological, social and economic conditions that prevail; the research at all stages must be pursued in close cooperation with the fishing community that will eventually make use of whatever technologies are elaborated.

Throughout the developing countries, particularly of Africa, fish preservation by smoking and drying is a traditional practice. Yet many of the dryers used and the systems of handling both before and after drying lead to high losses, and in many of the dryers the thermodynamic efficiency falls far short of what is possible.

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Relatively little attention has been devoted to the improved conservation of tropical fruits and vegetables except by means of such high energy technologies as thermal processing or freezing, the products of which are largely for consumption by wealthier communities than are typical of the SAT.

Throughout the world there exist at least 75,000 different edible plants of which probably less than 0.1% are cultivated to any significant extent. According to Cremer (1979) about 90% of the world's harvest of edible crops is supplied by 12 plant species. The introduction and adoption of unfamiliar crops by subsistence or smallholder farmers and their acceptance by consumers is understandably a difficult undertaking. When transformed and offered as constituents of familiar processed foods, the resistance to the acceptance of new foods often disappears. Few North Americans can recognize when their cooked hamburgers and sausages contain sizeable proportions of textured vegetable protein. Consequently, food processing industries provide a source of stimulus to agricultural production and diversification and therefore occupy an important place in all post-production systems.

#### STRENGTHENING THE INDIGENOUS RESEARCH CAPABILITY

There is an urgent need to strengthen food and agricultural research facilities in all developing countries. While external multilateral and bilateral donors may, through financial and technical assistance, contribute to this strengthening process, the greatest responsibility rests within the developing countries themselves, especially with their governments, many of whom need urgently to assign a higher priority to agricultural research, together with a more conspicuous level of dignity to those who engage in food and agricultural science and technology. As long as politicians, military men and white collar professionals are considered superior beings to those who devote their lives to the production, preservation and distribution of essential food, one cannot expect the necessary concentration of intellect and endeavor to be devoted to the food needs of the developing countries.

Furthermore, the food and agricultural scientists of the developing countries must be prepared to spend more time away from their laboratories and experimental farms to gain a more complete understanding of the social, economic and technical opportunities and constraints of small scale producers and processors. It is unfortunate that so many food research institutes in developing countries have been established in major cities, thus ensuring that a wide physical, intellectual and philosophical distance separates the scientist and technologist from the rural communities where the most urgent food and agricultural problems and opportunities are to be found. The serious levels of post-harvest spoilage referred to earlier will never be reduced by scientists manipulating a battery of spectrophotometers in laboratories several hundred kilometers from where the subsistence crops are harvested.

## SYSTEMS RESEARCH MANAGEMENT

Throughout this paper repeated emphasis has been laid upon the total post-production systems and the need for a systematic approach to post-harvest improvement. The subject of the systems approach has been reviewed by Spurgeon (1976) in direct relation to post-production systems and by Hulse (1977) in a more general context.

A "system" may be defined as "a regularly interacting or interdependent group of activities or components that form a unified whole". A systems research approach calls for careful analysis of the manner in which all of the human, social, economic, biological and physical elements interact with one another and with the physical and socio-economic environment in which each system exists and functions. Systems research requires first and foremost a complete and comprehensive understanding of the system that already exists, however primitive or inadequate it may appear. Any proposed technological improvement or change must be considered in relation to the system as a whole, especially with regard to those persons who must implement and live with any changes and improvements that are conceived.

One of the best examples of systems research methodology in the agricultural field is to be found in IRRI's cropping systems research program and the related project network which has gradually evolved over the past nine years throughout Asia. Central to the concept of the IRRI systems approach is the farmer and his family whom the process of change seeks to benefit. Consequently, the process begins by acquiring a thorough understanding of, and familiarity with, those farmers who will be required to implement changes in their established cropping systems. The research seeks first to determine what are their attitudes and constraints to any technological changes that might be proposed. In addition to the preliminary comprehensive baseline study of socio-economic conditions and constraints, the cropping systems methodology calls for a detailed understanding of the prevailing agro-climatic conditions, how they vary seasonally and regionally and, consequently, what cropping systems are agronomically and socio-economically feasible and acceptable. All who purpose to bring improvement and benefit to the post-production technologies of the SAT would be well advised to study IRRI's cropping systems research approach since it is only through a comparable post-production systems approach that true progress will be made and significant benefit delivered to the rural poor of the SAT.

Perhaps the most urgent need in the whole world of food and agricultural science and research is for the training and development of managers of applied research, people who recognize that applied research is by definition research for human benefit and who must therefore acquire a capacity of broader and deeper comprehension and attitude than is generally provided by conventional BSc, MSc and PhD courses. Some scientists appear to believe that managers, like marriages, are created in heaven and that a competent scientist is automatically a competent research manager. It is the author's belief, based on some years of experience, that research scientists who display a potential for management significantly improve their research management capability when given appropriate training and a systematic exposure to management philosophy and experience.

What is of particular need is the formation and training of research managers who understand the principles and practice of systems research; who are able to

examine and appraise not only their own disciplinary specialization but all of the related and contributory disciplines in a broad and comprehensive relation to the whole rather than in narrow and confined perspective.

In the minds of many of our contemporaries, science appears to be equated more with the evils of destruction and despoliation than with the virtues of creating a more just society and the greater satisfaction of human needs. Perhaps this attitude results in part from the disposition of some of our scientific brethren to be more concerned with scientific merit and intellectual elegance than with the value or hazard to humanity of the products of their research.

In no sector of human endeavor should the scientist be more in tune with the needs of humanity than in the realm of agricultural research and development, particularly in the post-production systems sector, the sector that is responsible for providing the consumer with the products of agriculture in a wholesome and acceptable form.

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214

# BIBLIOGRAPHY

- Axford, D.W.E., N. Chamberlain, T.H. Collins and G.A.H. Elton. 1963. The Chorleywood process. *Cereal Science Today*, 8(8):265-270
- Braham, J.E. and R. Bressani. 1979. Coffee pulp: composition, technology and utilization. International Development Research Centre, Ottawa, Canada. IDRC-108e
- Bressani, R. and L.G. Elías. 1977. The problem of legume protein digestibility. In Hulse, J.H., K.O. Rachie and L.W. Billingsley (ed.). Nutritional standards and methods of evaluation for food legume breeders. International Development Research Centre, Ottawa, Canada. IDRC-TS7e:61-72
- Bressani, R. and L.G. Elías. 1980. The nutritional role of polyphenols in beans. In Hulse, J.H. (ed.). Polyphenols in cereals and legumes: proceedings of a symposium held during the 36th annual meeting of the Institute of Food Technologists, St. Louis, Missouri, 10-13 June 1979. International Development Research Centre, Ottawa, Canada. IDRC-145e:61-68
- Bullard, R.W. and D.J. Elias. 1980. Sorghum polyphenols and bird resistance. In Hulse, J.H. (ed.). Polyphenols in cereals and legumes: proceedings of a symposium held during the 36th annual meeting of the Institute of Food Technologists, St. Louis, Missouri, 10-13 June 1979. International Development Research Centre, Ottawa, Canada. IDRC-145e:43-49
- Bushuk, W. and J.H. Hulse. 1974. Dough development by sheeting and its application to bread production from composite flours. *Cereal Science*, 19(9):424-427
- Chamberlain, N. 1965. Mechanical development of bread doughs, Part 2. Milling, 144:444-445
- Cremer, H.D. 1979. Energy input in food production. In Applied sciences and development: a biannual collection of recent German contributions concerning development through applied sciences. Special issue on the occasion of the UN Conference on Science and Technology for Development, Vienna, 1979. A series issued by the Institute for Scientific Cooperation, Vol 14:7-14
- Dendy, D.A.V., P.A. Clarke and A.W. James. 1970. The use of blends of wheat and non-wheat flours in breadmaking. *Tropical Science*, 12(2):131-148
- Dillon, J.C. et N. Lajoie. 1980. Rapport sur l'évaluation de la situation nutritionnelle des populations rurales du Sahel à la lumière des enquêtes effectuées entre 1960 et 1979. International Development Research Centre, Ottawa, Canada. IDRC-MR12
- Eastman, P. 1980. End to pounding: a new mechanical flour milling system in use in Africa. International Development Research Centre, Ottawa, Canada. IDRC-152e
- Elton, G.A.H. 1965. Mechanical dough development. *The Bakers Digest*, 39(8):38-46, 78

Food and Agriculture Organization. 1973. Composite flour programme. Documentation package, Vol.1, 2nd ed. revised. Food and Agricultural Industries Service, Agricultural Services Division, Food and Agriculture Organization, Rome, Italy

Food and Agriculture Organization/World Health Organization. 1973. Report of a joint FAO/WHO *ad hoc* expert committee. World Health Organization technical report series no. 522. Food and Agriculture Organization nutrition report series no. 52. Geneva

Forrest, R.S., W. Edwardson, S. Vogel and G. Yaciuk. 1979. Food systems: an account of the postproduction systems program supported by the International Development Research Centre. International Development Research Centre, Ottawa, Canada. IDRC-146e

Group for assistance on the storage of grains in Africa (GASGA). Cheshire, C.A. (ed.). 1978. Priorities for action in grain post-harvest loss reduction. Kansas State University, Manhattan, Kansas

Harper, J.M. 1979. Food extrusion. CRC Critical Reviews in Food Science and Nutrition, 11(2):155-215

Horan, F.E. 1974. Meat analogs. In Altschul, A. (ed.). New protein foods, Vol. 1A, Technology. Academic Press, New York: 367-413

Hulse, J.H. 1974. The protein enrichment of bread and baked products. In Altschul, A. (ed.). New protein foods, Vol. 1A, Technology. Academic Press, New York: 155-229

Hulse, J.H. 1977. Research management. In Agricultural research management Asia. Southeast Asian Regional Center for Graduate Study and Research in Agriculture, College Laguna, Philippines, Vol. 2: 9-44

Hulse, J.H. 1978. The food scientist in international development. Food Technology in Australia, 9: 354-358

Hulse, J.H. 1978. Food research for whose benefit? Canadian Institute of Food Science and Technology Journal, 11(4): A93-A96

Hulse, J.H. (ed.). 1980. Polyphenols in cereals and legumes: proceedings of a symposium held during the 36th annual meeting of the Institute of Food Technologists, St. Louis, Missouri, 10-13 June 1979. International Development Research Centre, Ottawa, Canada. IDRC-145e

Hulse, J.H., B.D. Fawcett and W.D. Daniels. 1975. Protein supplements - world production and trade. In Harapiak, J.T. (ed.). Oilseed and pulse crops in Western Canada. Western Cooperative Fertilizers Ltd. Calgary, Alberta: 1-60

Hulse, J.H. and E.M. Laing. 1974. The nutritive value of triticale protein. International Development Research Centre, Ottawa, Canada. IDRC-021e

Hulse, J.H., E.M. Laing and O.E. Pearson. 1980. Sorghum and the millets: their composition and nutritive value. Academic Press, London

Hulse, J.H. and O.E. Pearson. 1979. Food and agricultural research - its past and future contribution to agricultural, social and economic development. Paper to the UNCSTD Symposium on Non-Government Agencies - Singapore, January 20-28, 1979. International Development Research Centre, Ottawa, Canada. IDRC-MR<sup>4</sup>

Hulse, J.H., K.O. Rachie and L.W. Billingsley (ed.). 1977. Nutritional standards and methods of evaluation for food legume breeders. International Development Research Centre, Ottawa, Canada. IDRC-TS7e

International Development Research Centre. 1977. Agriculture, Food and Nutrition Sciences Division: the first five years. International Development Research Centre, Ottawa, Canada. IDRC-089e

Liener, I. 1975. Antitryptic and other antinutritional factors in legumes. In Milner, M. (ed.). Nutritional improvement of food legumes by breeding: based on proceedings of a symposium by PAG held at the Food and Agriculture Organization, Rome, Italy, 3-5 July 1972 and PAG Statement 22: "Upgrading human nutrition through the improvement of food legumes". John Wiley and Sons, New York: 239-258

Müller, E.M. 1979. Alimentation de femmes enceintes et allaitantes dans une communauté rurale d'Afrique. International Journal for Vitamin and Nutrition Research, Supplement, No. 20: 73-79

Norgan, N.G., A. Ferro-Luzzi and J.V.G.A. Durnin. 1974. Energy and nutrient intake and the energy expenditure of 204 New Guinean adults. Phil. Trans. B, 268(893): 309-348

Paul, A.A. and E.M. Müller. 1980. Seasonal variations in dietary intake in pregnant and lactating women in a rural Gambian village. In Abei, H. and R.G. Whitehead (ed.). Maternal nutrition during pregnancy and lactation. Hans Huber, Berne, in press

Paul, A.A., E.M. Müller and R.G. Whitehead. 1979. The quantitative effects of maternal dietary energy intake on pregnancy and lactation in rural Gambian women. Trans. R. Soc. Trop. Med. Hyg., 73(6): 686-692

Pringle, W., A. Williams and J.H. Hulse. 1969. Mechanically developed doughs from composite flours. Cereal Science Today, 14(3): 114-120

Rosen, J.L. and R.C. Miller. 1973. Food extrusion. Food Technology, 27(8): 46-50

Sanger, C., G. Lessard and G. Poulsen. 1977. Trees for people: an account of the forestry research program supported by the International Development Research Centre. International Development Research Centre, Ottawa, Canada. IDRC-094e

Spurgeon, D. 1976. Hidden harvest: a systems approach to postharvest technology. International Development Research Centre, Ottawa, Canada. IDRC-062e

Stanley, B. 1979. The little yellow machine. The IDRC Reports, 8(4): 14-15

United Nations World Food Conference. November, 1974. Assessment of the world food situation: present and future. Rome: 51-54

Vijayalakshmi, R., M. Jacob and R.P. Devadas. 1975. Relationship between diet during pregnancy and nutritional status of the newborn. Indian J. Nutr. Diet., 12, 233-237

Vogel, S. and M. Graham (ed.). 1979. Sorghum and millet: food production and use. Report of a workshop held in Nairobi, Kenya, 4-7 June 1978. International Development Research Centre Ottawa, Canada. IDRC-123e

Vose, J.R., M.J. Basterrechea, P.A.J. Gorin, A.J. Finlayson and C.G. Youngs. 1976. Air classification of field pea and horsebean flours: chemical studies of starch and protein fractions. Cereal Chemistry, 53(6):928-936

Yaciuk, G. and A.D. Yaciuk. 1980. Post-harvest technology in Senegal: current practices and future needs. International Development Research Centre Ottawa, Canada. IDRC-MR13



FIGURE 1.

POST-PRODUCTION GRAIN SYSTEM

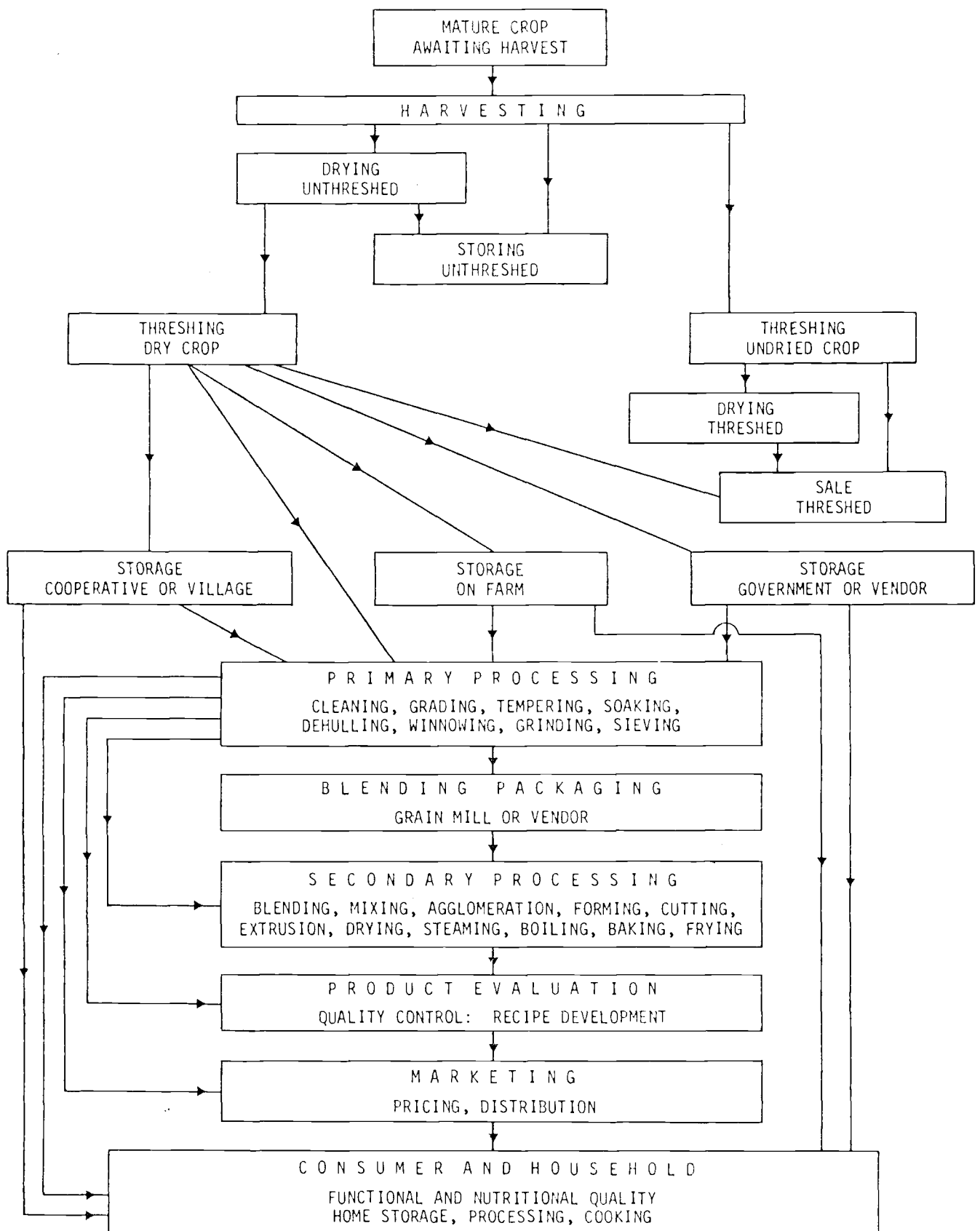


FIGURE II. AGRICULTURAL CYCLE AND RAINFALL PATTERN THROUGHOUT THE SAHELIAN REGION

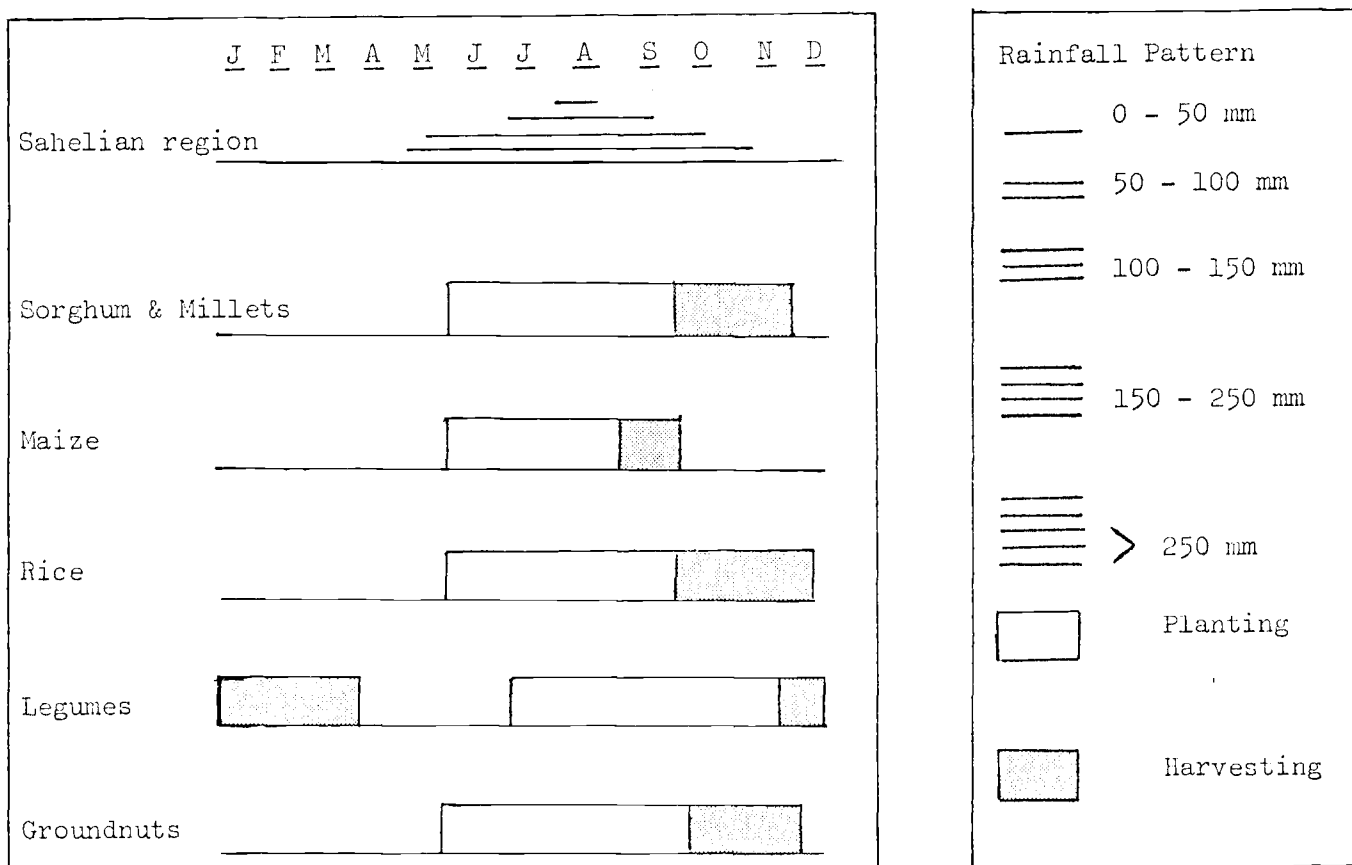


TABLE 1. FOOD PATTERNS FOR THE SEMI-ARID TROPICS (SAT) - 1969-71.

| <u>SAT Country</u> | <u>Dietary Energy Supply 1/</u>        |                                     |
|--------------------|--|-------------------------------------|
|                    | <u>Kilocalories per capita per day</u> | <u>Percentage of requirement 2/</u> |
| <u>Africa</u>      |  |                                     |
| Gambia             | 2490                                   | 104                                 |
| Haute Volta        | 1710                                   | 72                                  |
| Mali               | 2060                                   | 88                                  |
| Mauritania         | 1970                                   | 85                                  |
| Niger              | 2080                                   | 89                                  |
| Senegal            | 2370                                   | 100                                 |
| Chad               | 2110                                   | 89                                  |
| Ethiopia           | 2160                                   | 93                                  |
| Sudan              | 2160                                   | 94                                  |
| Somalia            | 1830                                   | 79                                  |
| Kenya              | 2360                                   | 102                                 |
| Tanzania           | 2260                                   | 98                                  |
| Mozambique         | 2050                                   | 88                                  |
| Uganda             | 2130                                   | 91                                  |
| Botswana           | 2040                                   | 87                                  |
| Zambia             | 2590                                   | 112                                 |
| <u>India 3/</u>    | 2070                                   | 94                                  |

1/ 1969-1971 average

2/ Revised standards of average requirements (physiological requirements plus 10% for waste at household level)

3/ Data was not available for the provinces

Source: United Nations World Food Conference. November 1974. Assessment of the world food situation: present and future, Rome: 51-54