Using Food Science and Technology

to Improve Nutrition and Promote National Development

Selected Case Studies

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PREFACE

IUFoST is a federation of 65 countries (represented by their appropriate national bodies, known as Adhering Bodies), and four regional groupings in Europe, Africa, Asia and Latin America. It is thus a global organization for over 200,000 food scientists and technologists and the world voice on food science and technology. It represents food science and technology to other world bodies such as FAO, WHO, Codex Alimentarius, ILSI, UN University, OEDC and the International Council for Science (ICSU).

The primary goal of IUFoST is to promote the advancement of food science and technology throughout the world through education programs, workshops, regional symposia and through activities of the International Academy of Food Science and Technology (IAFoST). Another goal is to foster the worldwide exchange of scientific knowledge and ideas through the biennial World Congress, IAFoST, three scientific journals, an on-line journal and regular Scientific Information Bulletins. As well, IUFoST aims to strengthen the role of food science and technology in helping secure the world's food supply and eliminate world hunger by delivering programs such as distance education, workshops and integrated food systems targeted to these needs.

It was with the last aim in mind that the idea for this handbook arose during discussions at the 13th World Congress of Food Science & Technology held in Nantes, France in 2006. As editors it is our hope that this handbook will show, through the use of case studies, how the application of food science and technology has improved nutrition and promoted national development in developing countries.

This IUFoST handbook is intended to transmit useful information on applications of food science and technology to those affiliated to both developed and developing countries. We hope that making the chapters freely available for download will ensure the widest-possible audience. The handbook is a work in progress and we shall be happy to continue to accept contributions from all those who feel that their experiences in this area are relevant and worth passing on to a wider audience. Please send a 500 word outline of your proposed chapter to the editors. Once your outline has been accepted, the final chapter will be due within 3 months.

We would like to thank all those who have given freely of their time to write chapters for this handbook. Your valuable contributions will provide important IUFoST information to food scientists, technologists and others interested in improving nutrition throughout the world.

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Small and Medium-Size Food Producers and Processors: Potential in National Development, International Trade, And Role in Solving Nutrition Problems

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INTRODUCTION

Developing countries face many difficulties in solving problems of malnutrition, poverty, and improving their national economy [1]. While population trends are changing from predominantly rural to more urban settings, a large percentage of the population in most developing countries remains in the rural areas [2]. At the same time, two major resources of developing countries are current and potential agricultural production, and the rural and urban people that can participate in national development and economic growth through sustainable utilization of agriculture resources. The important role played by small and medium-sized food producers and processors in this process of national development is often not given attention or priority, but is crucial in overall development activities.

This paper examines some of the factors and problems that are important in understanding the pivotal role of agriculture in national development, discusses elements that are crucial to success in sustainable activities, gives some information on countries which have succeeded in effective use of agriculture as an essential element in national development, and make some suggestions for the future.

SMALL AND MEDIUM-SIZE FOOD PRODUCERS AND PROCESSORS

In discussing the role of food producers, processors and marketers, it is useful to consider all the different groups of people involved in the food industry and in agriculture and agriculture-related industries. While much attention is given in the media to large-scale and multinational food companies, there are many more people and entities involved in local food and agriculture activities than in the large-scale companies. Thus, the contribution to national development and economy of the small and medium-size food producers and processors is vital to overall development.

In considering food and agriculture, the first group taken into consideration is always the farmers: small, medium or large. What is not always appreciated, however, is the wide range of activities and products that farms produce (both food and non-food), all of which are important to household and national economy. Farmers produce a wide range of fruits, vegetables and animal products for human consumption. They also produce plant and animal fibers used in weaving and a wide range of other applications; wood for production of furniture, paper, and fuel; hides and skins for production of leather goods; flowers, etc. The fish farming and fishing industries also produce essential foods that are high value products enjoying a very wide range of acceptance in the local and international economy. The industries that manufacture, distribute, service and maintain farm equipment and produce farming inputs such as seeds, fertilizers and pesticides employ large numbers of people and are critical to sustainable agriculture.

After foods and other agricultural products are grown and harvested, it is necessary to either utilize them promptly, or take action to preserve and store them. Marketing of fresh foods requires efficient wholesale and retail facilities in order to avoid food losses which can range up to 50% for certain foods

when proper food handling practices cannot be used. For meat, other animal products and fish, many skilled workers are needed to process these products after they have been produced on farms, or in aquaculture or from fishing activities. Food storage facilities must be able to keep foods correctly, in cold storage or in dry form, and assure that food losses do not occur due to problems caused by attacks of insects, rodents, birds, molds and decomposition. To preserve foods, or produce food products that have an adequate shelf life, canneries, food freezers, and retail food processors such as dairies and bakeries must also have well-trained staff that use good food handling practices to assure quality and safety of foods, and avoid food losses. In almost all countries, the largest employer of rural and urban people are activities related to producing and handling foods and other agricultural products, and in producing and servicing the equipment used in farming and food processing . This is a fact which is often overlooked by national planners when preparing and implementing plans for national development.

NUTRITION, POPULATION AND POVERTY PROBLEMS

Developing countries face a wide range of problems in improving the well being of their people. A major problem facing developing countries is the rapid growth in population that has occurred over the past 50 years, and which will continue. World population in 1950 was about 2.5 billion people, in 1975 about 4.1 billion people, and had grown to 6.0 billion people by 2000. Current U.N. estimates are that in 2025 there will be 7.8 billion people, and by 2050 continued population growth will mean a world population of 8.9 billion people. U.N. estimates also show that 97% of continued population growth will occur in less developed regions, with Asia showing an average increase of 50 million people each year, Africa 17 million, and Latin America and the Caribbean an increase of 8 million people annually. The impact of this continued population growth on land and marine resources and on national economies is significant [3].

Poverty continues to be a significant problem, with over one billion people living on the equivalent of less than one dollar a day, and two billion more people only marginally better off. Malnutrition continues as a major problem with about 800 million people (almost all in developing countries) without adequate access to enough good quality and safe foods to lead productive and healthy lives. This leads to increased infant and child mortality, inability to reach full mental and physical growth potential, low teenage and adult productivity, and reduced life spans. Coupled with poor health care and education facilities, limited access to safe water, and poor sanitation facilities, national authorities have tremendous tasks before them to enable better living conditions for all. Preparing coherent development programs, and effectively implementing them, is a major challenge to all developing countries.

AGRICULTURAL FACTORS FOR NATIONAL DEVELOPMENT

Despite the increase in world population over the past 50 years, improvements in agricultural techniques and practices, and in the food industry as a whole, have enabled per caput food supplies to continue to be adequate for world food needs. Global food per caput production increased by 18% in the 1990's, and average per caput food supplies in terms of food energy rose to 2,761 kilocalories (11,560 kJ) per day. At present the problem is not one of inadequate global food supplies, but rather a lack of physical and economic access to adequate amounts of good quality and safe foods, and adequate and diversified diets for over 15% of the people in developing countries. The need for better access to food, and assuring sustainable agriculture in the face of current problems and population growth, are two major problems countries must solve [4].

Food production and processing techniques have been changing over time to ensure better and more abundant food supplies. The 1970's saw the introduction of the 'Green Revolution' cereal crops that enabled great increases of wheat and rice in Asia in particular, and of other higher yielding basic crops in all regions of the world. High yielding techniques of aquaculture have helped in improving the quantities and quality of fish products available as natural marine and fresh water fish resources have been depleted by over-fishing. Better animal husbandry for cattle, sheep, and poultry have increased the amount of meat and other animal products, and have improved economic access to these

nutritious products. At the local level, mixed farming systems such as those used in Thailand to produce grains, poultry, fish from aquaculture and fruits and vegetables have been very effective in raising nutritional levels of rural populations and increasing the economic status of small farmers and their families and communities. Finally, newer techniques of biotechnology have improved crop production and protection, reduced the level of land preparation and decreased soil erosion, enabled production of food and fiber crops such as cotton with greatly reduced use of pesticides, and can be applied to enable the production of more nutrient-rich foods.

In many countries, small and medium-scale food producers and processors have greatly increased the level of mechanization used in producing and processing food and animal feed. New techniques for preparing land for crops, sowing seeds, applying fertilizer and any needed pesticides, and for harvesting have increased the efficiency of farming, and have at the same time reduced the number of workers needed to produce crops. Similar advances in production efficiency have been made in aquaculture, fisheries, and non-food crop agricultural production. In food drying, storage, processing and marketing, new techniques and equipment have also increased efficiency and reduced food losses. In all of these areas, the service industries for producing and providing maintenance of farm, food storage, processing and wholesale and retail food marketing have created new jobs for thousands of people in rural and urban settings. Thus the food and agricultural sector is by far the largest employer of people in virtually all countries, developed and developing. It should also be noted that other important sectors to developing countries such as tourism must also rely on adequate supplies of good quality and safe foods to assure success and help in foreign exchange earnings.

URBANIZATION AND CHANGING FOOD HABITS

During the past 25 years there has been a rapid increase in the rate of movement of people from rural to urban areas in all countries. The urbanization process has created many large cities in all developing countries, with cities of more than 1 million inhabitants common in many countries, and mega-cities of more than 10 million people in developing countries with larger overall populations. It is estimated that within the next 10-25 years more people will live in cities than in rural areas in virtually all countries.

The production of basic food supplies has kept pace with global population growth and increased urban demand. The success of agriculture in increasing food supplies with more efficient techniques has reduced the need for rural labor. At the same time it has made significant contributions to national economies, making capital available for industrialization and production of other goods, and the construction of urban living quarters, roads, water and sanitation facilities, better schools and health care units. In most developing countries, labor costs are relatively inexpensive, and represent a strong comparative advantage in the setting-up of production facilities for domestic and export needs.

Urbanization has had a profound influence on food and agriculture. Urban populations often retain their rural food habits and demand supplies of traditional foods from rural areas. At the same time, food habits are changing and urban people are more willing to try new foods and food products. The need for simple and low-cost foods for urban workers, school children and others has led to the creation of low-cost restaurants and street food facilities, leading to the employment of many thousands of people in urban food systems. Supplying foods to cities has also created the need for efficient wholesale and retail food marketing structures for fresh, processed, refrigerated and preserved foods.

In urban and rural areas, improved agriculture and higher incomes have led to changing food habits. People who have traditionally had cereal-based diets have created a demand for more meat and animal products, which in turn has created a much larger market for animal feed for cattle, poultry and aquaculture. Nutrition education has also created an awareness and demand for more fruits and vegetables in the diet. Many cities have also changed eating habits so that more meals are consumed outside of the home, including greatly increased consumption of street foods, and the purchase of ready-to-eat foods from street food stalls and retail shops and supermarkets. From the nutritional point of view, many of these changes in dietary and food habits are usually desirable, and have

improved the nutritional and health status of all people. However, strong and continuing nutrition education efforts are needed for all sectors of the population, especially children and pregnant and nursing mothers, to assure that food habits remain nutritionally sound, and do not lead to imbalances in food intake which can cause obesity or food-related diseases.

AGRICULTURE: A MOTOR OF DEVELOPMENT

In preparing and implementing national plans, many developing countries do not give adequate attention to the role of agriculture in overall development. Policies for tourism, mining, manufacturing, banking, buildings, and other infrastructure often receive a disproportionate share of attention, while the importance of agriculture as a source of food, non-food essentials, and of employment of many people is ignored. In many developing countries, facilities for encouraging agriculture and related industries are heavily taxed, reducing effectiveness of the sector and reducing investment, while developed countries heavily subsidize agriculture, rather that tax it. The World Trade Organization Agreement on Agriculture requires all countries to reduce or eliminate agricultural subsidies and other support payments, but this is a slow process, and in the meantime developing countries which do not take appropriate steps to encourage agriculture and related industries are operating their national economies at a serious disadvantage with regard to domestic markets, imports and exports.

A part of the problem of lack of attention to the agriculture and related sectors is a failure to appreciate the value of the goods, services, and employment related to this sector. In many countries the phenomenon of urbanization has led to urban populations that have very little or no idea of where food and other agricultural products come from, or how they are produced. The importance of agriculture to domestic national product and to employment is also not appreciated, and there is often an urban 'snob factor' of selecting imported products which are perceived as being of better quality than similar local products. Lack of investment in the sector also interferes with improving the quality of local products, and a tendency to export the best products and accept low quality foods for local consumption exacerbates the problem. There is an urgent need for better promotion of agriculture, and for facilities that enable better development of the overall sector, with emphasis on small and mid-sized producers and processors that can be the most dynamic part of the overall process.

Agriculture, particularly when properly supported by good government and financial policies, can provide adequate amounts of most foods for human consumption, and for animal feed. The sector also produces wood, vegetable and animal fiber for cloth and clothing, fiber for paper products, hides and skins for leather products, flowers, and a host of other value-added products. New techniques of biotechnology are leading to new agricultural processes where crops can be used to produce vaccines and other pharmaceuticals, or other high-value products. In the area of employment, on-farm jobs are often the leader in overall employment in developing countries, and the number of jobs involved in food and other agricultural processing and infrastructure maintenance is enormous. In addition to having a comparative advantage in agriculture-related employment costs, developing countries have a wide range of products which have tremendous development potential if developed country markets accept and appreciate new fruit and vegetable products which are available from developed countries.

FOOD QUALITY AND SAFETY

In developing the agricultural sector, farmers, small and large food processors and vendors, and the government must pay close attention to the quality and safety of all foods, particularly locally produced products. Consumers in all countries are demanding better quality foods, and expect the government to assure such products. Government services in many developing countries are not adequately funded or staffed to provide extension services to farmers and food processors, or to have properly equipped systems for food inspection, sampling, and analysis. Legal systems to enable enforcement of rules are also often weak. Each country has the need of developing and enforcing national science-based laws and regulations, preferably based on the work of the FAO/WHO Codex Alimentarius Commission, to assure better quality and safety of foods, and to meet the requirements of the World Trade Organization Uruguay Round Decisions.

In the past, farmers and food processors have usually fought against systems that require improvements in food quality and safety, on the basis of costs involved. However, in every country and setting where food quality systems have been introduced, the savings in prevention of food losses, in gaining consumer acceptance of local products, and in overall profits and promoting exports have been dramatic, and far exceed the costs of installing and operating food quality and safety systems. There is a strong role for cooperation between government, food producers, processors, and marketers, and academia to provide the infrastructure and properly trained people needed to assure continued and better food quality and safety. Officials are faced every day with media reports of food scares and misinformation; the only way to counteract this is to have a reliable food quality and safety system involving all sectors, including responsible media representatives.

Systems to promulgate information or misinformation about food and agriculture have become global and instantaneous in all countries. Protecting consumers and the reputation of national products requires a good system of informing all concerned that basic systems for food quality and safety control, education and assurance of consumers are in place and are working properly. In countries such as, for example, Singapore and the United States where consumers have trust in the food control authorities, there are far fewer problems for the food industry because of misinformation about foods than in other countries where trust is lower in the quality and safety of foods, or in food control authorities to protect consumers from fraudulent or unsafe foods. Consumers and consumer organizations have a very important role to play in urging national authorities and the food industry to provide good quality and safe foods, and to provide accurate information to consumers on foods [5; 6].

WORLD TRADE ORGANIZATION

The World Trade Organization (WTO) was founded in January 1995 as the successor of the Secretariat to the General Agreement on Tariffs and Trade (GATT) that was established in 1948. GATT, and subsequently WTO has the international role of promoting free and fair international trade, and in removing or decreasing the impact of non-tariff and other barriers to trade. The work of WTO has tremendous importance to developing countries, and to small and medium-scale food producers and processors. Extensive discussions of WTO member countries between 1986 and 1994 led to what are called the Uruguay Round of Multilateral Trade Negotiations and the texts and agreements adopted cover the trade of many different commodities, products and services. In the area of food and agriculture, the most important agreements adopted are the Agreement on Agriculture, the Agreement on the Application of Sanitary and Phytosanitary Measures, and the Agreement on Technical Barriers to Trade [7].

The WTO Agreement on Agriculture requires WTO member countries to make "substantial progressive reductions in agricultural support and protection over an agreed period of time, resulting in correcting and preventing restrictions and distortions in world agricultural markets." It further states that WTO members are "committed to achieving specific binding commitments in each of the following areas: market access; domestic support; export competition; and to reaching agreement on sanitary and phytosanitary issues."

At present many developing countries such as Thailand have the ability and potential to produce most of the food needed for national consumption, and significant surpluses of some foods and food products that can, or could, be exported. The cost of raw material, labor and energy are all quite favorable in these developing countries, and the products that can be produced for domestic use or export are in demand, including basic products such as rice and other grains, and tropical fruits, fish and fish products.

Most developing countries experience difficulties in developing their overall agricultural potential to its fullest because of a wide range of tariff, subsidy and technical barriers to trade that are in force in other countries with significant demand and potential. In many developed countries such as the USA, Canada, the countries of the European Union, and Japan, agricultural support and subsidy payment systems are in place that provide huge payments to farmers and others involved in food trade, making the costs of foods to national consumers quite high, while exports are subsidized so that surplus

production can be sold at low prices, adversely affecting the world price that is offered to developing country producers.

The role of the WTO Agreement on Agriculture to reduce or eliminate such payments will be of tremendous importance to developing countries, and to their small and medium sized producers and processors of foods, since this will lead to fairer and more equitable trading systems where those countries that can produce and ship at fair and unsubsidized prices will enjoy increased export markets and earnings for all involved, including farmers and food processors. Reaching WTO agreements on reduction of subsidies has proven to be difficult in the USA and the EU, and lack of consensus between developed and developing countries has caused an almost total breakdown in the Doha Round of WTO trade discussions. In the meantime, subsidies related to production, and domestic or export price supports in the USA, the EU and in some other developed countries continue to cause problems in developing countries.

Two other Uruguay Round agreements of great importance to developing countries are the Agreement on Sanitary and Phytosanitary Measures (SPS), and the Agreement on Technical Barriers to Trade (TBT). If subsidy and other agricultural payments are reduced, it will still be necessary for developing countries to assure compliance with legitimate food quality and safety regulations before full advantage can be taken of improved trading conditions. The SPS Agreement requires countries to attempt to harmonize or make equivalent the regulations and other measure used to assure the safety of foods in trade. Laws and regulations governing food safety such as controls for food additives, pesticide and veterinary drug residues, pathogenic microorganisms, mycotoxins, heavy metals and industrial chemicals such as PCBs and dioxins are covered by the SPS Agreement. Other food quality and fraud issues such as basic food standards compliance, regulations for food labeling, and measures to control food adulteration are covered by the TBT Agreement.

Both the SPS and TBT Agreements contain specific or general language that say that national food quality and safety legislation based on the standards, guidelines and recommendations of the FAO/WHO Codex Alimentarius Commission are the benchmark for judging the acceptability of products being sold internationally. If foods and food products meet the requirements of Codex, they should be able to move freely in international trade. Developing countries and countries in transition that wish to promote better domestic and international trade possibilities should therefore take advantage of Codex work and assure that national rules and locally produced food products meet Codex requirements.

INVESTMENTS IN FOOD PRODUCTION AND PROCESSING

It is clear from the above discussion that agriculture and its products are extremely important to improved nutrition and to individual and national economies. Countries that have taken steps to facilitate agricultural development have succeeded in promoting much wider economic success, since a thriving agricultural sector provides employment, food and trade. Other countries that have ignored agricultural development and focused on tourism or simple types of manufacturing for export have had less success in overall development since a strong agricultural sector is critical to other activities such as tourism, and is far more dependable in overall development than manufacturing for export, which tends to move from country to country on the basis of labor costs.

Strengthening the agricultural and food processing sectors does not happen in most countries without significant investment in the sector. Governments can assist in this through providing credit facilities to farmers and small and medium scale food processors, and through the provision of extension services to food producers and processors. However, in most cases significant private investment is also needed to enable farmers and fish producers to mechanize, expand operations, finance inputs, and for the creation, improvement or enlargement of small and medium scale food processing operations. In order to attract private investment funds, developing countries have learned that clear rules for food quality, safety, and food hygiene are necessary before any significant level of investment will be made. Private investors are usually not willing to make loans to the agricultural sector unless laws and regulations exist that can assure adequate markets for raw agricultural products or value-added

products that meet these rules. Thus, governments have a responsibility to assure that such rules exist, and should base them on the work of the Codex Alimentarius Commission to also comply with World Trade Organization requirements.

There are some clear success stories in attracting investment into the food industry in developing countries, and improvements in national economies. In the 1970's FAO provided assistance to the Government of Kenya is setting up a strengthened food control agency, and the project included creating a body of food regulations based on Codex, but prepared in cooperation between the existing food industries in the country at the time and the government. Training was provided to government and industry personnel for food hygiene, quality and safety control, and food inspection and analysis facilities were expanded to the level needed for proper control. Prior to the setting up of this infrastructure, private investment in the food and agriculture sectors was very limited because potential investors were unwilling to invest when rules against sub-standard or fraudulent products did not exist, local products were of variable quality allowing costly imports to compete in local markets, and exports of surpluses were hampered because of quality concerns. After the creation of the strengthened food control system, investment in the food sector rapidly expanded, and the national economy benefited greatly. From 1975 (before the FAO project started in 1976) to 1985, investment in new food and agricultural facilities grew dramatically and overall gross national product related to food and agriculture grew by 15 times the 1975 figure. High quality local products virtually supplanted all imports of products that could be grown in Kenya, and exports to the EU, Japan, and countries of the region soared. The agricultural sector in Kenya continues to be one of the brightest parts of the overall economy.

In Tunisia an FAO project in the late 1970's had similar project inputs to that described for Kenya. Tunisia desired to improve the quality and safety of local food products, and to have more assured access to the markets in the EU. Prior to the FAO assistance market access was hindered by rejections of raw and processed foods due to pesticide residue problems, and low quality. Following the adoption of Codex-based food standards, pesticide residue limits, codes of hygienic practice, and other applicable recommendations and guidelines, and with strengthening of food inspection and analysis facilities, the quality and safety of the national food supply was greatly improved, and export trade was greatly expanded.

In China in the 1980's and 1990's, the government made agricultural development a mainstay of national development plans. The systems devised were comprehensive and included basic extension advice to farmers, creation of small and medium-scale food processors, assuring transportation facilities and roads to enable marketing of products, and infrastructure to manufacture and service equipment important to food production, transport and marketing. These activities provided employment and increased earnings for many millions of people, and enabled the overall economy to grow at a very high annual rate. In the 1990's, increased private sector investment and involvement in the food and agricultural sector increased even further its contribution to national food supplies and earnings, along with assisting in greatly increasing exports.

Chile as a southern hemisphere country has growing seasons that are the reverse of the northern hemisphere. It has production areas ranging from tropical to temperate, and has had for many years the potential to export fresh fruits and vegetables to northern developed countries. During the 1980s Chile encountered severe problems in the export of fresh grapes due to a series of errors in the use of pesticides and unacceptable packaging materials. In one year, the US Food and Drug Administration (FDA) rejected many shipments of Chilean grapes to the USA because the grapes contained low levels of a pesticide that was not allowed on grapes in the USA. In the following year many shipments were rejected due to the use of packets of sulfur dioxide in boxes of grapes, leading to unacceptably high levels of sulfur dioxide in the grapes. Both of these problems were very costly to the national economy and to farmers and exporters, and could have been prevented by better information and extension services. Chile took steps to strengthen food inspection services and to bring national food regulations in line with Codex, and quickly eliminated these problems, bringing its export trade back to a mainstay of the national economy.

In Thailand there have been several examples of activities that have assisted in the growth of the food and agriculture sectors that have had beneficial impact on national food supplies, economy, and export earnings. In the 1980's food canners were having difficulties in shipping certain low-acid canned foods to the USA. US regulations governing the processing of low-acid canned foods and the registration of processes with the US FDA were difficult to understand, or to follow. Through a project with the FAO, the Ministry of Agriculture took steps to strengthen the Division of Agricultural Chemistry and set up the Center of Export Inspection and Certification for Agricultural Products (CEICAP). A strengthened food analysis laboratory was established, and inspectors were trained in inspection of canneries to enable compliance with low-acid canned food rules. Certification of shipments was also initiated and foreign importers quickly learned to rely on CEICAP certification, enabling easier shipment of products and expanded trade.

In the area of fish capture and growing, Thai fish and shellfish products have become very important to local food supplies and to export markets. Some export barriers to trade have been eliminated by Thai government efforts to reach agreements of mutual recognition for fish products from Thailand traveling to Canada, for example, and from Canada to Thailand. Reaching these agreements required assurance to foreign importers that Thai fish products were produced under strict quality and safety rules and procedures that take national rules and Codex requirements into account. These activities have greatly enhanced the reputation of Thai fish products to the benefit of all involved.

NUTRITION PROBLEMS AND FOOD SECURITY

As noted above, many countries are facing problems of nutrition, both those of under-nutrition and micronutrient deficiency problems, or over-nutrition, with accompanying obesity, cardiovascular diseases, diabetes and diet-related cancers. The first priority of every country must be to assure national food security, and household and individual food security. No country is totally self reliant in its food supply and must import certain foods and feeds to have an adequate amount of good quality and safe foods at affordable prices so that all citizens have the opportunity of access to a good, varied and balanced diet throughout the year.

Within the context of the national economy of developing countries, the role of farmers, food processors and marketers in helping to assure food security must be given high priority. In urban settings the contribution of good quality and safe foods at the level of street foods and local markets is extremely important. Efficient marketing systems which allow foods from rural and other production or processing areas to reach wholesale and retail markets in good condition are essential to reducing food losses and to providing good quality and safe foods at affordable prices.

Problems of under- and over-nutrition have some different aspects, as well as some common features. Under-nutrition due to lack of access to enough good quality and safe food for an adequate and varied diet must be solved by systems to make more and varied foods available at affordable prices to those in need, and to provide education on how to eat properly. Over-nutrition and imbalanced diets, and improper lifestyle habits such as lack of exercise, eating too much, and smoking can only be solved by better general and nutrition education. Thus, in both cases there is a need for improved nutrition education, and cooperation between government, academia, industry and consumer groups is essential to better nutrition education. This cooperation must be based on a good understanding between the various groups, and on the development and implementation of a permanent program over many years of good dietary guidance.

WHERE DO WE GO FROM HERE?

It is clear from the above discussion that the food and agriculture sector is crucial to national food security and development, and that small and medium-size food producers, processors and marketers are essential to national food supply. Small and medium-scale farmers and fish producers, people storing foods, transporters and marketers of foods, small restaurants and street food sellers all have essential roles to play. In developing the agriculture and food sectors, the small and medium-sized entrepreneurs are extremely important in maintaining national food traditions and dietary habits that

have served populations well over many generations. At the same time it is necessary to adapt to new realities such as foods from other parts of the world, changing consumer expectations and dietary habits, and trying to have the best of both worlds for all consumers. There is a clear need for better nutrition education in this changing food milieu, and cooperation between government, academia, industry, the media and consumers is essential to assure the best consumer and nutrition education. Science-based nutrition education programs for elementary and secondary schools are particularly important, as is providing convincing and science-based information to the media and consumers to eliminate or reduce the impact of misinformation about food and agriculture that is promulgated by irresponsible groups with hidden agendas.

Assuring the quality and safety of foods is also crucial to overall food and agricultural and national development. Poor quality or unsafe foods can quickly harm individuals, as well as the reputation of national food producers and countries. Rejections of food exports by other countries are costly to the companies and farmers who produced those foods, have an adverse impact on prices offered for future shipments, and can lead to total prohibition of shipments of certain foods from some countries. Using the advice and work of the Codex Alimentarius Commission and the cooperative assistance of FAO or other agencies offering food quality and safety information can help in improving local systems.

Overall food production, processing and marketing systems are essential to national food supplies, particularly when urbanization is taken into account, but are also important to export earnings. Improving the level of production and the quality and safety of foods will enable the development of regional markets in nearby countries. It will also enable increased sales of surplus foods and specialty foods in all countries, particularly developed countries that are big importers of foods.

In order to assure that national policies and needs are taken into account at the international level, countries must develop and implement coherent national programs for food agriculture that take into account the work of organizations such as the Codex Alimentarius Commission and the World Trade Organization. At the same time, developing countries must participate effectively in these international organizations and make their voices heard so that non-tariff barriers will, in fact, be removed, thus allowing developing countries to fully develop the food and agricultural sectors to the benefit of farmers, processors, marketers, and to all consumers.

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The Role of Postharvest Technology in Improving Nutrition and Promoting National Development in Developing Countries: Constraints and Challenges

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ABSTRACT

There have been significant advances in postharvest research over the last few decades that have led to the development of a diversity of appropriate technologies in many countries including several developing countries. This has greatly improved the handling and quality of food crops, and contributed significantly to improving nutrition and national development. Improvements have been made in many aspects of postharvest technologies and handling of perishable foods, including harvesting indices, harvesting methods, pre-cooling methods and applications, storage techniques, packing and packaging, quarantine systems, transport systems especially by road and sea, modified and controlled atmospheres, etc. However, there is a persistent problem in most of the world (especially in many developing countries), where significant quantities of perishable foods are lost every year. Although postharvest R& D in several developing countries has improved significantly, many of the postharvest technological innovations are either not used or used inadequately. The problems in developing countries are very complex in nature, and are not only due to technical reasons. However, from the technical stand-point there are diverse problems related to 'unavailability of adequate technologies', 'unfamiliarity with available adequate technologies', 'inadequate use of or difficulties in the adaptation of available proper technologies', or even the 'refusal to use available proper technologies, due to different reasons'. This paper discusses some of the advances in postharvest R&D in developing countries and some of the 'technical' challenges still faced, and suggests ways for further improvements.

INTRODUCTION

There is no clear definition of the term 'developing countries' (DC), which encompasses a wide range of countries with diverse challenges. Rising incomes and widespread urbanization have been the most important determinants behind the increase in food consumption, especially fresh fruits and vegetables, and have also increased the importance of postharvest handling of fresh commodities [26; 32;33]. The application of refrigeration, packing and packaging, transportation, modified (MA) and controlled atmospheres (CA) have improved significantly over the last 2 to 3 decades [33]. However, the establishment of an adequate 'cold chain' remains the major obstacle facing the handling of foods in general and fresh commodities in particular [2;32;33]. More improvements in other handling techniques are also still needed [34]. Following the trend in developed countries, consumer interest in functional foods has been increasing in some DC, and will continue to increase [17]. The situation in DC is very different from one country to another. As food resources are limited, not only new technologies, but also conventional technologies have to be mobilized to help solve complex problems [19;34].

THE FOOD INDUSTRY IN DC

The food industry in DC, especially that of the fresh horticultural crops industry, is faced with tremendous growth and market demand, both for the local markets and for export, but there is

minimal or no regulatory action for enforcing minimum quality standards and implementing food safety assurance practices [24;29;32;33]. This situation, especially for the local markets, has dictated that the whole responsibility lies with the food manufacturers and handlers to deliver safe and wholesome food to the consumers.

Total world production of fresh fruits and vegetables (FFV), except nuts and potatoes, is about 1.35 billion metric tons (MT), an increase of 43% over the decade 1994 to 2003. Of this 1.05 billion MT are produced in DC (FAO estimates for 2003). World fresh fruit production was about 488 million MT, of which 365 million MT were produced in DC; world vegetables production was about 861 million MT of which 681 million MT were produced in DC. However, the world export of fresh fruits and vegetables was 73.3 million MT, of which only 37.5 million MT were from DC. The value of world FFV exports was $45.1 billion (an increase of 51% in value over the decade), but the share from DC was only $14.9 billion. World fresh fruit exports were 46.2 million tons, of which 25.7 million came from DC. World vegetable exports were 27.1 million MT (a 62% increase since 1994) but only 11.8 million MT were from DC.

DC dominate world FFV production, producing three quarters of the world supply. China is the world's largest fruit and vegetable producer with 36% of world production. India is the second largest producer but only has a 9.4% share of world production. Other important DC FFV producers are Brazil (fruits), Mexico (fruits), Turkey (vegetables) and Egypt (vegetables). Together these countries produce almost 55% of all FFV produced worldwide.

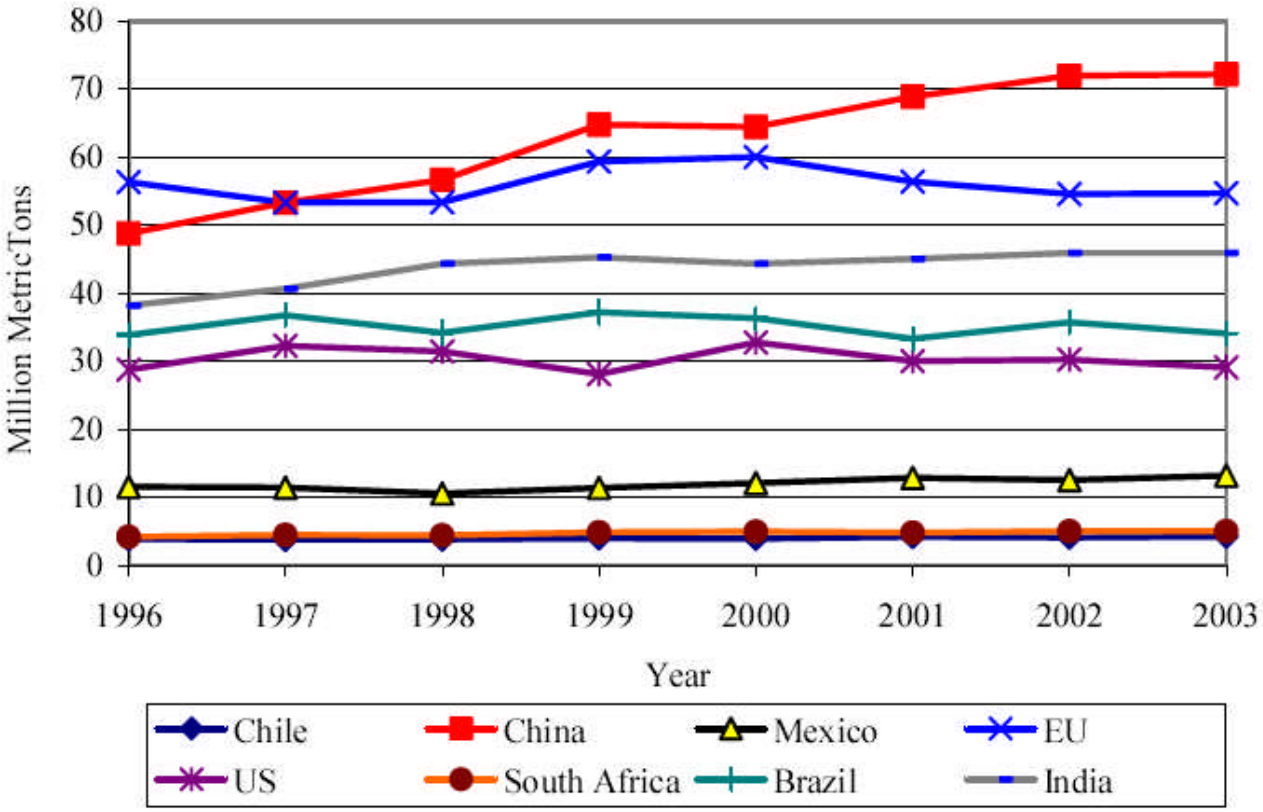

Figure 1. Top eight world fruit producers (source: FAOSTAT, 2004)

Although a considerable share of world FFV production is the result of FFV grown and consumed locally in DC, DC are playing an increasingly important role in the global fruit and vegetable trade. Roughly two-thirds of all DC exports are from just eight countries. Mexico is by far the most important DC exporter of FFV with almost 22% of export share, totaling $3.2 billion in 2003. Even more significant is Mexico's share in fresh vegetable exports which account for 45% of total exports from DC. Mexico and China (the second biggest fresh vegetable exporter) capture 61% of the total value of vegetable export. With $1.5 billion in export trade, Chile is second to Mexico in FFV exports. Chile

exports mainly fruits and is the most important fresh fruit exporter in DC. Other important FFV exporters in DC are (in descending order of importance) Ecuador ($1.2 billion, mostly fruit), Costa Rica (0.9), South Africa (0.8), Turkey (0.6) and Argentina (0.5). Thus DC capture only about a third of world FFV exports value, although this share is growing. Just a handful of DC, mainly from Latin America, account for two thirds of all DC exports.

The opening of international commerce in fruits and vegetables through WTO negotiations offers enormous potential for enhancing the income of small farmers, processors, and exporters as well as for increasing foreign exchange earnings for DC.

Most DC have a warm (equatorial, tropical or Mediterranean) climate, which means that refrigeration is very important for food, especially perishables, preservation. The application of refrigeration, packing and packaging innovations, transportation technology (especially marine transport), modified and controlled atmospheres have improved significantly in some DC over the last 2-3 decades and therefore high value fresh horticultural crops in DC are exported to different markets [32].

However, food systems in DC are not always as well organized and developed as they are in the industrialized world. The long-term solution for DC to sustain demand for their products in world markets lies in building up the trust and confidence of importers in the quality and safety of their food supply systems. This requires improvement in national food control systems and within their industry, especially with regard to food quality and safety programs.

Food systems are complex. In the case of DC, the majority are still highly fragmented and dominated by small-scale producers and handlers. This has its own socio-economic advantages. However, as large quantities of food pass through a multitude of food handlers and middlemen, control is more difficult and there is a greater risk of exposing food to contamination or adulteration. Lack of resources and infrastructure for post-harvest handling, processing and storage can lead to losses of food quality and quantity, and greater potential for microbial contamination. On the whole, DC focus more on increasing agricultural production than on preserving these agricultural products, thus explaining why post-production losses are so high.

POSTHARVEST (PH) LOSSES IN DC

Estimates of postharvest (PH) losses in DC are two to three times those of the developed countries [16;18;33]. Both quantitative and qualitative losses take place in horticultural crops between harvest and consumption.

Location	Range (%)	Mean (%)
From production to retail sites	5-50	22
At retail, foodservice, and consumer sites	2-20	10
Cumulative total	7-70	32

Table 1. Estimated postharvest losses of fresh horticultural food crops in developing countries [16]

The reduction of PH losses involves: (1) understanding the biological and environmental factors involved in deterioration and (2) use of PH technology procedures that can control senescence and maintain the best possible quality [16]. Reducing PH losses could, presumably, add a sizable quantity to the global food supply, thus reducing the need to intensify production. As well, that production in several regions of the world such as in parts of Africa and the Middle East, has become more difficult because of lack and/or low quality of water, deteriorated land, etc. Exactly how much of the world harvest is really lost is unknown. Surprisingly little solid information exists on the precise amount and nature of loss, partly because losses vary greatly by crop, by country, by climatic region, and partly because there is no universally applied method of measuring losses. As a consequence, estimates of total PH food losses are controversial, varying widely from one report to another, generally from about

10% to as high as 80% [6;33]. Most of these losses can be prevented, thus increasing food availability. There are many indications that food currently produced is plentiful, but unfortunately different factors and reasons prevent it from finding its way onto the plates of those who need it most. It is certain that food losses are significant in staple crops, and much higher in perishable foods. PH food loss translates not just into human hunger and financial loss to farmers but into tremendous environmental waste as well.

Reduction of PH losses is the easiest, least costly and most effective means for increasing food availability, improving the nutritional status of the population and conserving the natural resources (land and water). High PH losses are primarily the result of a lack of trained capacity in PH technology; deficient PH-specific facilities; inadequate technologies; inadequate marketing systems; lack of information, government regulations and laws; and limited investment in the sector.

Reducing PH losses of food, especially that of perishable food crops, is extremely critical for DC, and will require cooperation and effective communication among governments, industry (private and public), research, education, and extension personnel. Increasing food availability through loss reduction is easier and less costly than through increasing food production. This is especially true for some DC with limited agricultural land and water resources, and soil problems, among other limitations. Losses can be substantially reduced by the adaptation and application of existing PH technology procedures. A systematic analysis of each commodity production and handling system is needed to identify appropriate strategies for each particular case.

Several biological and environmental factors contribute to PH losses, but the effects of many of these are well understood and many technologies have been developed to reduce these effects. However, many have not been implemented in DC due to socioeconomic factors such as marketing, transportation, government regulations and legislation, unavailability or lack of knowledge of using adequate technologies, lack of information, etc. Growers in most DC lack efficient, dependable, fast, and equitable means of marketing, and therefore significant losses occur. This problem is accentuated by lack of communication between producers and receivers, and lack of market information. Marketing cooperatives are needed in DC to facilitate marketing and to provide central accumulation points. Alternative distribution systems should be encouraged. Production should be maintained as close to the major population centers as possible to minimize transportation costs. Better wholesale marketing facilities are needed in most DC.

Mrema and Rolle [21] indicated an evolution of priorities within the PH sector of DC from a primarily technical focus geared towards the reduction of losses, towards a more holistic approach designed to link on-farm activities to processing, marketing, and distribution. However, the major constraints continue to be high PH losses, poor marketing systems, weak R&D capacity, and inadequacies in policies, infrastructure, and information exchange. Several initiatives have been underway since 2001, either on PH, or related to PH. The Agricultural and Food Engineering Technologies Service of FAO, in collaboration with the Global Forum for Agricultural Research (GFAR) and the Global Post-Harvest Forum (PhAction) recently embarked upon the development of a new global PH initiative geared toward addressing the challenges faced by the sector in DC [12;27]. Goletti [9] listed the most relevant issues for DC as follows: the need for a regulatory framework that promotes growth while safe-guarding welfare; adequate market information to be given to all participants involved; further investment in PH research; and participation in international agreements that promote trade and food safety.

Several authors have presented a strong argument in favor of devoting more resources to PH R&D efforts in DC [3;22;23]. Although minimizing PH losses of already produced food is more sustainable than increasing production to compensate for these losses, less than 5% of the funding for agricultural research is allocated to PH research areas [15]. Goletti and Wolff [10] stated that "while research on the improvement of agricultural production has received considerable attention and funding, until recently PH activities have not attracted much attention from international research organizations." They identified the following five reasons to justify an increased commitment to PH research by the international agricultural system: a) high internal rates of return; b) international public good

character; c) effect on poverty; d) effect on food security and health; and e) effect on sustainable use of resources. Goletti and Wolff [ibid.] concluded that "as the significant contribution of PH research to CGIAR goals such as poverty reduction, food security and sustainability becomes clear, and in the light of high rates of return, the very skewed allocation of funds to production versus PH topics cannot be justified. Since so far relatively little has been invested in PH research, there is potential for large impacts as constraints and bottlenecks are removed. It would thus be desirable to reexamine current funding priorities and to allocate a larger proportion of resources to the PH area."

POSTHARVEST TECHNOLOGY AND HANDLING IN DC

PH technologies refer to the stabilization and storage of unprocessed or minimally processed foods from the time of harvest until final preparation for human consumption [4]. PH technology including selection, preservation, packaging and processing has contributed to the promotion of agricultural production through the improvement of farmers' income by raising the value of agricultural produce. In fresh horticultural crops the main spoilage vectors are bruising, rotting, senescence, and wilting. Bruising is avoided by careful handling and use of adequate packages/packaging. Rotting is controlled by good housekeeping, gentle handling to avoid breaking the skin, cool storage, and use of preservatives. Senescence is retarded by refrigerated handling or MA and CA. Wilting is controlled by high humidity and cold storage.

Temperature control and fluctuation remains the major problem facing the handling of foods in general and fresh horticultural crops in particular in DC. Other technical problems include packing, packaging, transport, markets and marketing, quality control and assurance, hygiene and food safety [33;34].

As in developed countries, changes in the way foods are produced, distributed, stored and retailed, reflect the continuing increase in consumer demands in many DC for improved quality and extended shelf-life for packaged foods These demands are placing ever-greater importance on the performance of food packaging. Many consumers in DC, especially in urban centers, want to be assured that the packaging is fulfilling its function of protecting the integrity, quality, freshness and safety of foods.

Modified atmospheres (MA) and controlled atmospheres (CA) are used in different forms in DC [31; 34]. MA and CA are used in several DC for marine transport of various commodities such as cantaloupe, limes, grapefruit, banana, mango, avocado, pome and stone fruits [31;33;34]. CA is used for the storage of apples, pears and kiwifruit in some DC such as Mexico, Chile, Argentina, Uruguay, Brazil and Jordan [33]. CA storage is used fairly adequately in most DC, but MA and CA for transport is still facing some difficulties mainly originating from a lack of system standardization by service providers, failure to employ adequately trained technicians, and lack of research to establish optimum requirements for several of the crops grown and exported from DC.

MAP for fruits and vegetables, especially for vegetable and fruit salads, is used in very few DC, and what use there is has been promoted by major supermarkets chains. The challenges facing the application of safe MAP and CAP for fresh perishables in DC are enormous. The use of MAP in DC can be limited for several reasons:

1. The unavailability of appropriate films that can provide safe atmospheres, especially under abusive temperature conditions [14]. Packages that provide safe atmospheres at one temperature may result in anaerobic conditions at higher temperature [5].
2. The expense of using MAP technology, both on the basis of film cost and the modification of packing line systems [14].
3. Problems associated with maintaining package integrity during handling (transport, storage, marketing, etc). Package materials must be flexible and easy to use but strong enough to survive handling abuse, especially common in DC.

Figure 2. Use of modified atmosphere for bananas in the Dominican Republic (E. Yahia)

Figure 3. Application of modified atmosphere for marine transport of some fruits in Mexico (E. Yahia)

Figure 4. Controlled atmosphere storage of apples in Mexico (E. Yahia)

Films currently used in MAP in DC are mainly low density polyethylene (LDPE) due to its low cost, and PVC. Technological developments in this field in DC are very few [33].

It has long been recognized that increases in temperature during shipping, handling, or retailing MA packages could cause a decrease in package O_2 levels because respiration tends to increase more than permeation of O_2 through polymeric films. Using trucks that are not pre-cooled, improper handling at transfer points, and retail display under non-refrigerated conditions contribute to this problem. The factors that are needed to assure the successful use of MAP and CAP of perishable foods in DC include: a) efficient distribution system, b) good quality of raw ingredients, c) low initial microbial load, d) proper hygiene conditions during processing and handling, e) proper temperature control throughout the whole food chain. Researchers in DC have attempted to develop MAP for horticultural crops, especially for tropical fruits, but results have been very variable (31). Some of the reported benefits may be due to maintaining a humid atmosphere around the commodity rather than to modification of O_2 and CO_2 concentrations. However, effects of gas modification in addition to humidity control resulted in significant increase in the PH life of several crops such as cactus stems [11;35]. Variable results of the research on MAP in DC (as is the case in some developed countries) are due to little experimental control, especially regarding the different types of polymeric films used without appropriate characterization.

Temperature control is the single most important factor in food preservation, especially for perishables. The deficiency, abuse or fluctuation of the cold chain (temperature and RH) not only increases the deterioration of the product, but can also trigger safety problems. High or fluctuating temperatures can increase product senescence and decay, and therefore increase losses; it can also increase RH and may cause water fluctuation, especially in packages, which greatly increases the proliferation of spoilage microorganisms.

Practically all PH handling activities, including sorting, grading, packing and packaging, are done manually. PH-specific infrastructure (cold storage facilities, refrigerated transport, packinghouses, etc) is either scarce or not functioning adequately in several DC. PH research, education, and extension facilities are very poor in several DC and there is a general lack of PH expertise with poor collaboration and networking among them.

Figure 5. Experimental use of modified atmosphere packaging for vegetables exported from the highlands of Guatemala (E. Yahia)

The level and type of packaging used in several DC is usually determined by the final market for which the produce is destined and the availability of packaging materials. Produce is generally supplied in close-knit jute sacks, used bags, plastic or wooden crates. Corrugated carton packages are generally used for the packaging of produce destined for export markets, and is still not very common for products marketed locally in several DC. Packaging containers are often too small or too large, resulting in significant losses. Produce is often packed in containers which lack vents, or newspaper padding is used around produce, impeding air circulation and thus preventing adequate cooling. The use of refrigerated storage techniques are increasing in many DC, but their capacity is still very low, and most fresh horticultural crops intended for the local markets are still maintained without refrigeration. A considerable volume of the horticultural crop production in several DC is lost due to a lack of cooling. Pre-cooling is still not very common in several DC.

Refrigerated storage facilities exist in larger cities, but do not exist in rural areas. Many of these facilities are poorly maintained owing to a lack of appropriate technical personnel and difficulty in obtaining the spare parts required for repair. Natural cooling (i.e. use of cold air during winter or cold nights) is used in PH applications in some countries such as China, Iran, Turkey and Pakistan. Crops which exhibit comparably low perishability (e.g. potatoes, onions, pears and pomegranates) are sometimes stored on-farm without refrigeration. Natural cooling processes are very simple, and involve piling produce in an open space (covered with polyethylene sheets and/or straw), open sheds, rooms in houses and adobe or brick structures of various types. Heavy losses may be sustained, depending on the type of crop or weather conditions. The commercial use of ionizing irradiation is extremely limited in DC.

Packing house facilities are increasing in several DC, but many are used almost exclusively for export products. Crops intended for local markets are either packed in the field in open spaces, or may be transported in bulk to the market. Another area of concern is the location of packing houses. In Egypt, for example, 56 of the 58 fruit packing stations are concentrated in the Nile Delta Region, while there is a shortage of packing stations in other regions [1]. Existing packing stations are only exploited to 40%

of their capacity, and several of these only function seasonally (e.g. stations used for packing potatoes and oranges).

Figure 6. Packaged vegetables in South Asia

Existing road infrastructure is generally deficient in several DC, particularly in rural areas. Railroad systems are non-existent in most DC, or not used effectively for perishable food transport where they do exist. Transportation costs, in particular that of refrigerated transport, are quite high owing to poor road infrastructure and the high price of fuel. Access to marine transportation systems is also limited in many countries. Air transport is used for export, but at a high cost. Most farmers in the region have very limited transport facilities available to them. The most commonly used transport modes in several DC are bicycles, three wheeled vehicles and small non-refrigerated trucks. Larger trucks which are generally not refrigerated are used by traders, resulting in significant losses during transportation. Relatively few refrigerated trucks are available in many DC, and are primarily used for export crops.

Horticultural crops in many DC are marketed mainly through the private sector, although a few government marketing companies exist in some DC. Fresh produce marketing involves the movement of produce from farmers to commission agents in wholesale markets located in major cities. A majority of locally-produced and imported products are distributed by wholesale markets in most DC. The wholesale market in Amman, Jordan, for example, handles approximately 62% of locally-produced fruits and vegetables, with 7% used in food processing while the remainder is marketed directly to exporters, distributors, catering suppliers, and consumers [13]. A chain of 'Assembly Markets' serves the rural areas, and may be equipped with grading, packaging and cold storage facilities. Wholesale markets are found in major cities, and are commonly controlled either by town governments or county councils. Major wholesale markets are generally considered 'free markets', where prices are largely controlled by supply and demand and bargaining between buyers and sellers. Sellers are commonly either producers or brokers. Wholesale markets in DC are often poorly equipped and lack quality control facilities. They are generally over-crowded, suffer from lack of organization and major infrastructure such as adequate loading/unloading spaces, cold temporary stores, ripening facilities, adequate transportation facilities, communication, and therefore suffer substantial food losses. Food retailing is generally conducted through either of four major channels: wet markets, central markets, grocery stores outlets, and supermarkets.

Figure 7. Transporting vegetables by river in Bangladesh

As infrastructure in many DC improves, it opens up new markets and opportunities for farmers. Better roads and access to water and energy allow for improved food preservation, even in rural areas. New developments in information technology allow for quick access to market information through telecommunications. The internet is increasingly proving itself a useful means for gaining market information and also for market negotiations through trade association web sites. Better access to domestic and international markets made possible by improved infrastructure has considerable effects on the development of PH technologies related to storage, processing, and quality control. Moreover, the new opportunities resulting from better infrastructure may well relate to commodities that are more likely to benefit from PH research. For example, in Madagascar, it was shown that an improvement in transportation infrastructure made it profitable to export roots and tubers [9].

POSTHARVEST RESEARCH AND DEVELOPMENT IN DC

PH research contributes to food security, safety and health in several ways. Improved storage technologies reduce PH food losses, and thus increase the amount of food available for consumption. PH research can also contribute to sustainability by finding alternatives to chemicals which have polluting effects on the environment, and are hazardous to human health. Thus alternative pest control mechanisms reduce the need for pesticides, which reduces pollution, minimizes accidents with pollutants, and also lowers pesticide residues in food consumed by humans.

While there is a large body of literature on the impact of production research, studies on the impact of post-production research are still very few and not done using universally-accepted methods. PH research might well have an impact comparable or even superior to that of production research, yet it might well be lacking the nature of international public good. While research on the improvement of agricultural production has received considerable attention and funding, until recently PH activities have not attracted much attention from international research organizations. However, there is an emerging consensus on the critical role that PH systems can play in meeting the overall goals of food security, poverty alleviation and sustainable agriculture particularly in DC.

Significant advances have taken place in the last few decades in research and development (R&D) in PH [34]. Some of these advances include gas monitoring and control, transport (especially marine transport, and transport in controlled atmospheres), packages and packaging, controlled atmosphere (CA) storage, modified/controlled atmosphere packaging (MAP/CAP), physical quarantine treatments, minimal processing, ethylene control, etc. However, little of these advances have originated in DC, and several of these advances have not found application in many DC, although a great need is obvious.

Generally, there are some improvements in research activity in DC, including in PH research, although it is still very low. Although research productivity has increased significantly in DC compared to previous decades, it is still relatively low, due to many internal and external reasons. Some of the most important internal factors are related to economic conditions, the education system, and several technical obstacles. Research infrastructure and building of research capacity and human resources are very expensive, and only very few DC have been able to advance partially. Federal expenditures on science and technology have been very limited in DC compared to developed countries. Science in DC has been treated as a 'marginal activity' and was perceived even as an 'ornament' [28].

The GDP invested in science in all of Latin America throughout the period 1990-2000 was 21% of the amount invested in the USA alone [25]. Latin American investment in R&D represented only 0.59% of the regional GDP in 1998, a very weak effort compared with 2.84% in the USA and 1.5% in Canada. In addition, there is an almost total lack of participation by private industry in DC in paying for the cost of science and technology. The disparity in scientific output between DC and developed countries is very evident [7;8;20;]. For example, UNESCO [30] estimated that in 1997 developed countries accounted for some 84% of the global investment in scientific R&D, and approximately 88% of all scientific and technical publications registered by the Science Citation Index (SCI). Many DC are characterized by a weak educational and scientific infrastructure and a lack of appreciation of the importance of science and education as an essential ingredient of economic and social development. Fortunately, the education system in some DC is improving.

Traditionally, research and training of researchers in DC has not been done as a multi-disciplinary, systems approach. In addition, team-work and collaboration (South-South collaboration, and even collaboration within the same country) has not been very important in DC, and is still not done adequately. Therefore, the very limited activities and resources have always been very fragmented. Similar problems and mistakes have been repeated in many DC, and poor productivity and participation has been the result.

Application of appropriate PH technologies is much more complicated than simply the establishment of adequate R&D programs, and involves many other complex factors that should be taken into consideration. The reasons for the lack of application of some PH technologies in many DC are due to four reasons: a) unavailability of adequate knowledge and technologies; b) unfamiliarity with the availability of adequate technologies, due to poor education and extension; c) inadequate use or difficulties in the adaptation of available proper technologies; unfortunately, this happens with the most basic PH technologies such as refrigeration/cooling, packages/packaging, transport, MA and CA for storage, transport and packaging; d) refusal to use some available technologies, due to different reasons but mostly economic, social and cultural.

PH research should not be limited to storage conditions but also to market requirements, breeding and cultivation circumstances. Rather than concentrating on isolated topics such as storage technology, an emphasis on the whole PH system can help identify bottlenecks and constraints, and increase the impact of research in each area. This systems approach has led research and assistance organizations to try to characterize existing PH chains in some DC. Additionally, domestic and international marketing services need to be strengthened, especially to improve market access for smaller and marginal producers. The growing importance of environmental concerns also presents opportunities and challenges for PH research in DC.

Although PH research productivity has been very low in Chile for the last 20-30 years (about 0.26%), the country was able to implement adequate PH infrastructure and capacity. Other countries such as

Kenya and Morocco were able to establish a relatively adequate PH capacity for some crops, despite the very low PH research productivity (about 0.4% and 0.03%, respectively over the last 20 years). Therefore, in addition to trying to improve their R&D capacity, DC can take advantage of the availability of adequate PH technologies developed elsewhere.

Activities that proved to be important for the development of adequate PH capacity include training, education, extension and technology transfer. Taking into consideration the very limited resources, and other obstacles facing PH research in DC, this should be directed towards very specific problems where there are clearly no solutions developed elsewhere, and to 'knowledge-generating' research. Research in DC should be adequately justified, and be more efficient. PH research in DC should also be practiced within the context of scientific research in general in these countries and should not be isolated, in order to take advantage of other disciplines such as chemistry, physics, biology, ecology, engineering, etc. which are showing some improvements in some DC. The development of other disciplines of scientific research in DC can be used as support to improve the development of PH research. There are positive indications that PH research in some DC (such as Mexico) is starting to interact and collaborate with other disciplines, and thus show some improvements.

A closer look at the trends over the last decade reveals some important advances in research productivity in general in some DC. For example, Latin America and China, although representing, respectively, only 1.8% and 2.0% of the scientific publications worldwide, have increased the number of their publications between 1990 and 1997 by 36% and 70%, respectively, which is much higher than the 10% increment reached by Europe. The percentage of global scientific publications from North America actually decreased by 8% over the same period [30]. A closer look at the Americas indicated that between the period 1990 to 2000, the USA contributed 84.2% of scientific publications, Canada contributed 10.35% and Latin America 5.45% [25]. However, the proportional change in the number of publications revealed that scientific publishing in Latin America increased the most rapidly in the Americas, far outpacing the USA and Canada. Further analysis, correcting the number of overall publications for the amount of money invested in R&D for each region, also shows that in contrast to both Canada and the USA, the trend in Latin America has been an increase in relative output throughout the 1990's.

Not enough highly qualified PH specialists are available in DC, and most of them are in universities and research institutes. There is a major shortage of researchers, especially of skilled and effective extension experts and technical personnel. Many farmers and food handlers are still totally unaware of proper PH handling and treatments. Agricultural research in DC is relatively active in some DC, but still needs major improvements in other countries. There are several examples of improvements, where some infrastructure has been established, and researchers and technicians were trained. Research on PH in many DC is, however, still limited, weak and without clear objectives. Very few researchers are known to be actively working on the PH handling of fresh horticultural crops. Research objectives are often not defined, and there is little collaboration between research and industry and among researchers in the region. It is also important that researchers in DC learn from the positive (and also the negative) experiences from abroad, and network both regionally and internationally. Research priorities must be clearly identified, and short-, medium-, and long-term plans established.

Successful and active relationships between the research and the industrial sectors are vital to development of the food sector in DC. This relationship varies from one country to another, but in general it is very weak especially in the PH sector. Additional investment is required to conduct market research in DC. Research institutions in DC should improve their coordination and collaboration in conducting such marketing studies. Priority should be given to regional market integration, marketing information, market intelligence, and regional investment in supporting industries for PH handling practices such as packaging, cooling, transportation, etc.

Extension systems in many DC are still very weak, and suffer from a lack of effective communication methods for disseminating information. Research is very poorly linked to extension. In most DC, extension activities are carried out through Ministries of Agriculture. Several DC lack efficient market

information services. Availability and access to PH literature is difficult and very poor in many DC. Strengthening information exchange and communication among DC, and even within each of the DC, and with the outside world is very limited and must be improved. The use of internet-based services should be promoted. Several institutions in DC offer technical and professional education and training in agriculture, but only a few offer post graduate training. Infrastructure for PH education and training in several DC is extremely limited and funds are lacking. In addition, the maintenance of this infrastructure is poor in several DC. Adequate infrastructure for PH education, including laboratories, equipment and adequate libraries, are required in several DC.

SUGGESTED RECOMMENDATIONS FOR IMPROVEMENTS OF PH IN DC

There are many different DC, with very diverse PH systems and problems, thus requiring diverse solutions:

PH 'specific' problems. Although PH is not a new discipline, there is still a total lack of PH activity in a few DC, weak activity in some and reasonably active research and application in others. However, in most DC, specific PH problems are not fully identified and characterized, and therefore solutions will not be easily found or implemented. Specific problems need to be identified in each country and specific solutions need to be tailored accordingly in each country.

Research. Few specialized PH institutions exist in DC, and PH research, education and extension are not very active in several DC. Improvement in the PH sector is pivotal to stabilization of the food supply in DC. There is an urgent need for the enhancement of agricultural and rural development through fostering agricultural research and technology development/transfer, and by strengthening inter- and intra-regional collaboration. Research in DC needs to be justified and made more efficient. Researchers need to be more multidisciplinary and collaborate with researchers of other disciplines (engineering, biology, ecology, chemistry, physics, etc). Collaboration within the same country and within the same region should be increased. Federal and private sector investment in research needs to be increased very significantly.

PH education/extension. The availability of appropriate PH technologies, and the difficulties in several DC to easily establish sound research programs, requires that more attention be given to PH education and extension, which is very weak in most DC. Growers and distributors should be 'made aware' and should be trained adequately to exploit the existing knowledge and technologies.

Technology transfer. Technology transfer programs in most of the DC are either totally lacking, or are not operating adequately, and therefore should be improved significantly.

Increase private sector participation/reduce government involvement. It is clear that the successful stories in agriculture in general and in PH application in particular in DC have been due to private sector leadership. In contrast, many of the failures have been due to government controls.

'Middle (man) sector' versus 'linking farmers to markets'. Historically, increasing production and productivity at all costs, especially at the cost of a deterioration in resources (such as water availability and quality, and soil quality), has been and still is the priority in almost all DC. In many cases this has been more of a political move rather than a sincere effort to increase food availability. In fact, unfortunately it seems that this 'politically sound slogan' has been picked-up by some international organizations. As a result, food is being produced in several countries at a very high cost (economically and environmentally) only to be lost before it reaches the consumer. Great investments are still being made in increasing productivity by the reclamation of new lands (sometimes not adequate for production), deforestation, and spending on several other resources (such as chemicals, energy, imported laborers, etc). Some of the new initiatives on 'linking farmers to markets' are excellent, but only if they are not at the cost of trying to eliminate the 'middle sector'. Working side by side and collaborating with and educating the middle sector is important for the development of the PH sector, and for reducing PH losses.

More involvement of researchers from DC in the activities of the different PH initiatives. Very little involvement of experts from DC is noted in all initiatives and activities on PH, including those in DC.

Adequate collaboration between researchers in DC, especially at the regional level. There is more collaboration between researchers in DC and developed countries than between researchers within the DC. Although collaboration between researchers in all countries is important,

the very poor 'south-south' collaboration gives rise to several problems such as repeating similar problems and fragmenting very limited resources.

CONCLUSIONS

There is excellent potential for improving food availability in DC and also in penetrating world markets by improving food production systems and reducing food losses. Applications of PH technologies and R&D in some DC have increased significantly in the last few years. However, PH handling techniques and R&D in several DC, especially for crops intended for national markets, are still deficient and need significant improvements. Some refrigerated storage facilities are established in big cities, but very little or almost none are in rural areas. In addition, most of the available refrigerated facilities in some DC lack adequate maintenance and management. Many crops, especially potato and onions, are still stored at ambient temperatures, resulting in very high quantitative and qualitative losses.

Quality standards and quality control measures are not commonly used in several DC, especially for products intended for national markets. Adequate transportation facilities are reasonably good in some DC, but are either not available or not functioning adequately in several other DC. In general there is a scarcity of trained service technicians in most DC.

There are major weaknesses and difficulties in communication in several DC, which hampers several aspects of development, including food availability. There is a lack of sufficiently qualified personnel for information collection, and still very weak access to the internet and to international networks on information in some DC, and lack of necessary information and communication facilities.

Technical assistance to producers/handlers is adequate in a few DC, but very scarce and deficient in several others. Marketing systems and infrastructure are improving and in fact are reasonably strong in some DC, but still face major difficulties in many other DC.

Although PH research is reasonably active in some countries, it is scarce or even totally lacking in other DC; it is without defined objectives in most DC. Research infrastructure is slightly improving in some DC, but still poor in many of these countries. Education on PH has improved in a few DC, but is still poor or non-existent in several DC. There is clearly a very weak collaboration between researchers, and between the research and industrial sectors in most DC. PH extension is still very weak in most DC. In several DC there is no clear linkage between research and extension in PH. There is still a lack of available, locally-written publications on PH, and most are still written in foreign languages (especially English) which makes it difficult for many people to understand and utilize the information.

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The Role of Traditional Food Processing Technologies In National Development: the West African Experience

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ABSTRACT

The capacity to preserve food is directly related to the level of technological development. The slow progress in upgrading traditional food processing and preservation techniques in West Africa contributes to food and nutrition insecurity in the sub-region. Simple, low-cost, traditional food processing techniques are the bedrock of small-scale food processing enterprises that are crucial to rural development in West Africa. By generating employment opportunities in the rural areas, small-scale food industries reduce rural-urban migration and the associated social problems. They are vital to reducing post-harvest food losses and increasing food availability. Regrettably, rapid growth and development of small-scale food industries in West Africa are hampered by adoption of inefficient and inappropriate technologies, poor management, inadequate working capital, limited access to banks and other financial institutions, high interest rates and low profit margins. While a lot still needs to be done, some successes have been achieved in upgrading traditional West African food processing technologies including the mechanization of gari (fermented cassava meal) processing, the production of instant yam flour or flakes, the production of soy-ogi (a protein-enriched complementary food), the industrial production of dawadawa (a fermented condiment) and the upgrading of the kilishi (a traditional roasted dry meat product) process and the traditional West African cheese-making process.

INTRODUCTION

High post-harvest food losses, arising largely from limited food preservation capacity, are a major factor constraining food and nutrition security in the developing countries of West Africa, where seasonal food shortages and nutritional deficiency diseases are still a major concern. Protein-energy malnutrition (PEM) and the various micronutrient deficiency disorders including vitamin A deficiency (VAD), nutritional anemias due to deficiencies of iron, folic acid and vitamin B_{12}, and iodine deficiency disorders (IDD) remain important public health problems. PEM and IDD have profound consequences on growth and mental development of children and VAD, apart from its damaging consequences on the eye (xerophthalmia and night blindness), is a major contributory factor to the high rates of child and maternal morbidity and mortality. It is estimated that about 50% of perishable food commodities including fruits, vegetables, roots and tubers and about 30% of food grains including maize, sorghum, millet, rice and cowpeas are lost after harvest in West Africa. Ineffective or inappropriate food processing technologies, careless harvesting and inefficient post-harvest handling practices, bad roads, moribund rail systems, bad market practices and inadequate or complete lack of storage facilities, packing houses and market infrastructures are some of the factors responsible for high post-harvest food losses in West African countries.

The capacity to preserve food is directly related to the level of technological development and the slow progress in upgrading traditional food processing and preservation techniques in West Africa contributes to food and nutrition insecurity in the sub-region. Traditional technologies of food processing and preservation date back thousands of years and, unlike the electronics and other modern high technology industries, they long preceded any scientific understanding of their inherent nature and consequences (32). Traditional foods and traditional food processing techniques form part of the culture of the people. Traditional food processing activities constitute a vital body of indigenous knowledge handed down from parent to child over several generations. Unfortunately, this vital body

of indigenous knowledge is often undervalued. Regrettably, some of the traditional food products and food processing practices of West Africa have undoubtedly been lost over the years and the sub-region is the poorer for it. Those that the sub-region is fortunate to retain today have not only survived the test of time but are more appropriate to the level of technological development and the social and economic conditions of West African countries. Indeed, simple, low-cost, traditional food processing techniques are the bedrock of small-scale food processing enterprises in West Africa and their contributions to the economy are enormous. The objectives and main features of some of these traditional food processing techniques are presented in Table 1.

Table 1. Objectives and main features of traditional West African food processing techniques [11]

Technique/operation	Objectives	Main features/limitations
1. Preliminary/post-harvest operations: Threshing	To detach grain kernels from the panicle.	Carried out by trampling on the grain or beating it with sticks. Labor-intensive, inefficient, low capacity.
Winnowing	To separate the chaff from the grain.	Done by throwing the grain into the air. Labor-intensive, low capacity, inefficient.
Dehulling	To remove the grain from its outer protective casing.	Carried out by pounding the grain in a mortar with pestle. Labor-intensive, low capacity excessive grain breakage.
Peeling	To separate the peel or skin from the edible pulp.	Manual peeling with knives or similar objects. Labor-intensive, low capacity, loss of edible tissue.
2. Milling (e.g. corn): Dry milling	To separate the bran and germ from endosperm.	Carried out by pounding in a mortar with pestle or grinding with stone. Laborious, inefficient, limited capacity.
Wet milling	To recover mainly starch in the production of fermented foods e.g. ogi.	Carried out by pounding or grinding after steeping. Laborious, limited capacity, high protein losses, poor quality product.
3. Heat processing: Roasting	To impart desirable sensory qualities, enhance palatability, reduce anti-nutritional factors.	Peanuts are roasted by stirring in hot sand in a flat-bottom frying pot over a hot flame. Laborious, limited capacity.
Cooking (e.g. wara)	To contract curd and facilitate whey expulsion, reduce microbial load, inactivate vegetable rennet, impart desirable sensory qualities.	Loose curd pieces are cooked in a pot over wood fire. Limited capacity.
Parboiling (e.g. rice)	To facilitate milling and enrich milled rice with B-vitamins and minerals.	Done by steeping paddy rice in cold or warm water followed by steaming in bags in drums. Limited capacity, poor quality product.

Blanching	To inactivate plant enzymes and minimize oxidative changes leading to deterioration in sensory and nutritional qualities, e.g. enzymatic browning.	Slices (e.g. yam for elubo production) are heated in hot water in a pot for various durations. Limited capacity, poor quality product.
4. Drying: Shallow layer sun drying	To reduce moisture content and extend shelf life.	Product is spread in a thin layer in the open (roadside, rooftop, packed earth etc.). Labor-intensive, requires considerable space, moisture too high for long-term stability, poor quality.
Smoke drying (e.g. banda)	To impart desirable sensory qualities, reduce moisture content and extend shelf life.	Meat chunks after boiling are exposed to smoke in earthen kiln or drum. Limited capacity, poor quality product.
5. Fermentation	To extend shelf life, inhibit spoilage and pathogenic microorganisms, impart desirable sensory qualities, improve nutritional value or digestibility.	Natural fermentation with microbial flora selection by means of substrate composition and back-slopping. Limited capacity, variable quality.

TRADITIONAL TECHNOLOGIES AND RURAL DEVELOPMENT

The food industry in West Africa consists of large foreign-backed companies, government-owned or sponsored companies and medium-scale, small-scale and very small-scale (as small as one person) enterprises owned by indigenous operators (39). Some of the large foreign-backed food companies operating in Nigeria producing a wide range of processed foods and beverages marketed in the West African sub-region include Nestle Nigeria Plc, Cadbury Nigeria Plc, Unilever Nigeria Plc, Flour Mills of Nigeria Plc, Nigerian Bottling Company, Nigerian Breweries, Guinness Nigeria Plc and West African Milk Company affiliated to Friesland Coberco Dairy Foods. One of the first truly indigenous food companies in Nigeria that pioneered mechanized processing of local agricultural raw materials into indigenous foods such as yam flour, cowpea flour, dried milled capsicums (pepper) and egusi (*Colocynthis citrullus*) was Lisabi Mills (Nigeria) Limited established in Lagos in 1938. There is no doubt that in West Africa large-scale food industries financed through joint ventures with equity and loans from national and international financial institutions (the food multinationals) play a unique role in promoting industrial development through employment generation, value-added processing and training of skilled manpower. Although food multinationals have considerable export potentials through value-added processing, their impact is felt greatest in the urban areas.

Rural development is closely linked with the promotion of small-scale food industries that involve lower capital investment and rely on traditional food processing technologies. By generating employment opportunities in the rural areas, small-scale food industries reduce rural-urban migration and the associated social problems. They are vital to reducing post-harvest food losses and increasing food availability. It is clear from experiences with large, fully mechanized processing plants in Nigeria and other West African countries, that small-scale food industries, involving limited mechanization of the traditional methods of food processing, with possibilities for replication in the rural areas where the raw materials are produced, offer better prospects for success. Full mechanization often results in higher overhead costs. In addition, small-scale plants have the advantage of being able to match

processing capacity with raw material supply and are, therefore, less adversely affected by raw material shortages than large-scale food industries. Unfortunately, rapid growth and development of small-scale food industries in West Africa are hampered by adoption of inefficient or inappropriate technologies, poor management, inadequate working capital, limited access to banks and other financial institutions, high interest rates and low profit margins (12). Small-scale food enterprises rely on locally fabricated equipment and a study of these enterprises in Nigeria identified lack of spare parts for equipment maintenance and repair as a major problem constraining their growth (61).

One of the greatest challenges facing food scientists/technologists in West Africa today is the upgrading of the traditional technologies of food processing and preservation (12, 57). In most cases, the traditional methods of food processing and preservation in West Africa remain at the empirical level. They are still rather crude, are not standardized, and are not based on sound scientific principles making them, in their present form, unsuitable to large-scale industrial production. The processes are often laborious and time consuming and invariably the quality of the products require substantial improvements. Since women are largely involved in traditional food processing, reducing the drudgery associated with traditional food processing operations, through the introduction of simple machines, would make life a lot easier for women with attendant benefits for the well-being of the family and society at large. In upgrading these technologies, the food scientist or technologist is faced with the challenge of modernizing the processes and equipment while still retaining the traditional attributes of the food products crucial to consumer acceptance. While there have been some instances where the introduction of modern techniques has resulted in products unacceptable to consumers, a number of successes have been recorded. Some of these include the mechanization of gari production, the production of instant yam flour or flakes, the production of soy-ogi, the industrial production of dawadawa and the upgrading of the kilishi process and the traditional West African cheese-making process.

TRADITIONAL FERMENTATIONS

Fermentation is one of the oldest and most important traditional food processing and preservation techniques. Food fermentations involve the use of microorganisms and enzymes for the production of foods with distinct quality attributes that are quite different from the original agricultural raw material. The conversion of cassava (*Manihot esculenta, Crantz* syn. *Manihot utilissima* Pohl) to gari illustrates the importance of traditional fermentations. Cassava is native to South America but was introduced to West Africa in the late 16th century where it is now an important staple in Nigeria, Ghana, Ivory Coast, Sierra Leone, Liberia, Guinea, Senegal and Cameroon. Nigeria is one of the leading producers of cassava in the world with an annual production of 35-40 million metric tons (23). Over 40 varieties of cassava are grown in Nigeria and cassava is the most important dietary staple in the country accounting for over 20% of all food crops consumed in Nigeria. Cassava tubers are rich in starch (20-30%) and, with the possible exception of sugar cane, cassava is considered the highest producer of carbohydrates among crop plants.

Despite its vast potential, the presence of two cyanogenic glucosides, linamarin (accounting for 93% of the total content) and lotaustralin or methyl linamarin, that on hydrolysis by the enzyme linamarase release toxic HCN, is the most important problem limiting cassava utilization. Generally cassava contains 10-500 mg HCN/kg of root depending on the variety, although much higher levels, exceeding 1000 mg HCN/kg, may be present in unusual cases. Cassava varieties are frequently described as sweet or bitter. Sweet cassava varieties are low in cyanogens with most of the cyanogens present in the peels. Bitter cassava varieties are high in cyanogens that tend to be evenly distributed throughout the roots. Environmental (soil, moisture, temperature) and other factors also influence the cyanide content of cassava (20). Low rainfall or drought increases cyanide levels in cassava roots due to water stress on the plant. Apart from acute toxicity that may result in death, consumption of sub-lethal doses of cyanide from cassava products over long periods of time results in chronic cyanide toxicity that increases the prevalence of goiter and cretinism in iodine-deficient areas. Symptoms of cyanide poisoning from consumption of cassava with high levels of cyanogens include vomiting, stomach pains, dizziness, headache, weakness and diarrhea (7). Chronic cyanide toxicity is also associated with several pathological conditions including konzo, an irreversible paralysis of the legs reported in

eastern, central and southern Africa (31), and tropical ataxic neuropathy, reported in West Africa, characterized by lesions of the skin, mucous membranes, optic and auditory nerves, spinal cord and peripheral nerves and other symptoms (55).

Without the benefits of modern science, a process for detoxifying cassava roots by converting potentially toxic roots into gari was developed, presumably empirically, in West Africa. The process involves fermenting cassava pulp from peeled, grated roots in cloth bags and after dewatering, the mash is sifted and fried (see Figure 1).

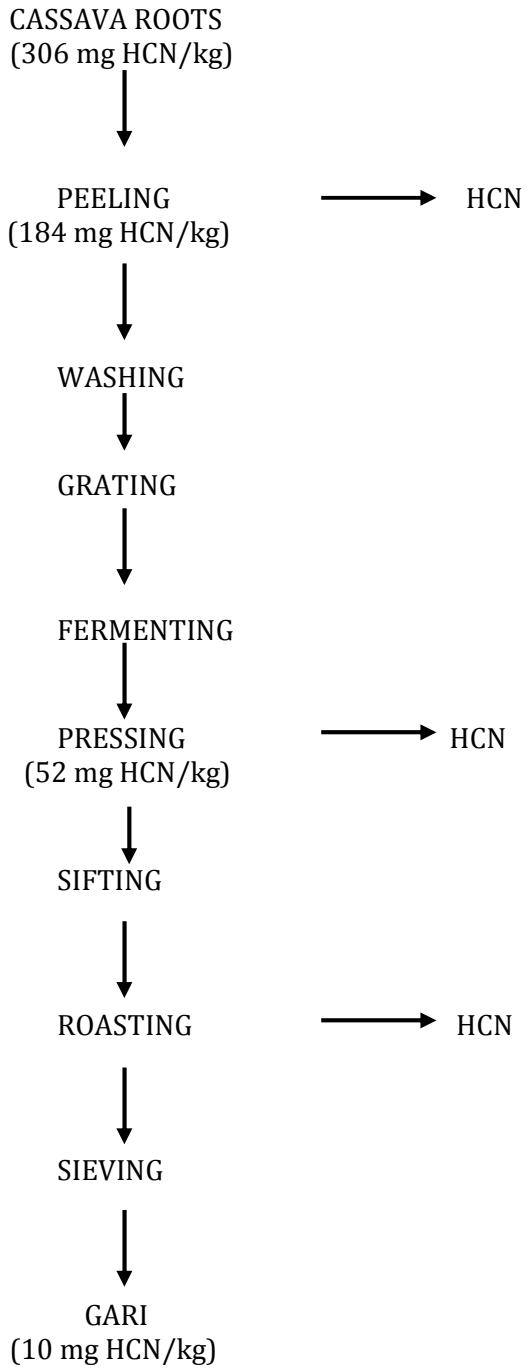

Figure 1. Process flow chart for gari production showing points of cyanide removal
(HCN values are from [51])

During fermentation, endogenous linamarase present in cassava roots hydrolyze linamarin and lotaustralin releasing HCN. Crushing of the tubers exposes the cyanogens which are located in the cell vacuole to the enzyme which is located on the outer cell membrane, facilitating their hydrolysis. Most

of the cyanide in cassava tubers is eliminated during the peeling, pressing and frying operations (Figure 1). Processing cassava roots into gari is the most effective traditional means of reducing cyanide content to a safe level by WHO standards (30) of 10 ppm, and is more effective than heap fermentation and sun drying, commonly used in eastern and southern Africa (22). Apart from 'gari' there is a vast array of traditional fermented foods produced in Nigeria and other West African countries (Table 2). These include staple foods such as fufu, lafun and ogi; condiments such as iru (dawadawa), ogiri (ogili) and ugba (ukpaka); alcoholic beverages such as burukutu (pito or otika), shekete and agadagidi; and the traditional fermented milks and cheese. Lactic acid bacteria and yeasts are responsible for most of these fermentations (25). The fermentation processes for these products constitute a vital body of indigenous knowledge used for food preservation, acquired by observations and experience, and passed on from generation to generation.

Table 2. Some traditional Nigerian fermented foods

Fermented Food	**Raw Material (Substrate)**	**Microorganisms involved**	**Uses**
Gari	Cassava pulp	*Leuconostoc* spp. *Lactobacillus* spp. *Streptococcus* spp. *Geotrichum candidum*	Main meal
Fufu	Whole cassava roots	*Lactobacillus* spp. *Leuconostoc* spp.	Main meal
Lafun	Cassava chips	*Leuconostoc* spp. *Lactobacillus* spp. *Corynebacterium* spp. *Candida tropicalis*	Main meal
Ogi	Maize, sorghum, millet	*Lactobacillus plantarum* *Streptococcus lactis* *Saccharomyces cerevisiae* *Rodotorula* spp. *Candida mycoderma* *Debaryomyces hansenii*	Breakfast cereal, weaning food
Iru (Dawadawa)	African locust bean (*Parkia biglobosa)* Soybean	*Bacillus subtilis* *B. licheniformis*	Condiment
Ogiri (Ogili)	Melon seed (*Citrullus vulgaris*), Fluted pumpkin (*Telfairia occidentalis*), Castor oil seed (*Ricinus communis*)	*Bacillus* spp. *Escherichia* spp. *Pediococcus* spp.	Condiment
Kpaye	*Prosopsis africana* (algarroba or mesquite)	*Bacillus subtilis* *Bacillus licheniformis* *Bacillus pumilus*	Condiment
Ugba (Ukpaka)	African oil bean (*Pentaclethra macrophylla*)	*Bacillus licheniformis* *Micrococcus* spp. *Staphylococcus* spp.	Delicacy usually consumed with stock fish or dried fish
Palm wine	Palm sap	*Saccharomyces* spp. Lactic acid bacteria Acetic acid bacteria	Alcoholic drink
Burukutu/Pito/Otika	Sorghum Millet & maize	*Saccharomyces* spp. Lactic acid bacteria	Alcoholic drink

Shekete	Maize	*Saccharomyces* spp.	Alcoholic drink
Agadagidi	Plantain	*Saccharomyces* spp.	Alcoholic drink
Nono (Fermented milk)	Milk	Lactic acid bacteria	Drink or converted to butter
Fura-da-nono Kunu-da-nono	Milk-cereal mixtures	Lactic acid bacteria	Drink
Warankasi (Soft cheese)	Milk	Milk coagulated by plant rennet. Lactic acid bacteria produce lactic acid from lactose.	Meat substitute

Apart from detoxification by the elimination of naturally-occurring nutritional stress factors, other benefits of traditional fermentations include reduction of mycotoxins such as aflatoxins as in ogi processing and the conversion of otherwise inedible plant items such as African locust bean (*Parkia biglobosa* Jacq) and African oil bean (*Pentaclethra macrophylla* Benth) to foods, i.e. iru and ugba respectively, by extensive hydrolysis of their indigestible components by microbial enzymes. Fermentation improves the flavor and texture of raw agricultural produce, imparting a desirable sour taste to many foods, such as gari and ogi, and leading to the production of distinct flavor components characteristic of many fermented foods. Fermentation may lead to significant improvement in the nutritional quality of foods by increasing the digestibility of proteins through hydrolysis of proteins to amino acids, increasing bio-availability of minerals such as calcium, phosphorus, zinc and iron through hydrolysis of complexing agents such as phytate and oxalate, and increasing nutrient levels, especially B-vitamins, through microbial synthesis (11).

Mechanization of Gari Processing

The mechanization of gari processing underscores the role that improvements in traditional food processing technologies can play in national development. Labor requirements for traditional processing of cassava into gari, fufu, lafun and other products are huge. Excluding labor for harvesting the tubers, about 415 man-hours are required to process a 10 ton per ha yield of cassava to gari (38). Considerable man-hours are spent on peeling, sifting and frying (Fig. 3). Hand peeling is a major bottleneck in traditional cassava processing. It is slow and labor intensive with an output of 25-30 kg/man-hr. Abrasive peelers with much greater capacities are less efficient than hand peeling because of greater loss of edible tissue and the need for extensive manual trimming. There is some prospect for lye peeling of cassava roots but there is as yet no commercial practice (60).

Figure 3. Gari frying over a wood fire by the traditional method

While it is true that traditional technologies are constrained by reliance on manual operations, full-scale mechanization, even when technically feasible, is not always economically justifiable as experiences with large, fully mechanized cassava processing plants in Nigeria have shown (5). Within the two extremes (traditional and full-scale mechanization), there is a wide ranging technology-mix suitable for different scales of processing operations (24, 37). Large, fully mechanized gari processing plants were largely unsuccessful in Nigeria because of low capacity utilization, high overhead costs, poor management and lack of requisite technical expertise for operation and maintenance of sophisticated, capital-intensive equipment.

In contrast, tremendous success has been recorded with small-scale gari processing factories in which some of the tedious manual operations of traditional cassava processing such as grating, pressing and sifting are replaced by machines while still retaining other manual operations. In these factories, the traditional method of grating cassava roots which involves rubbing of peeled cassava roots against the raised surface of nail-pierced metal sheets is replaced with the use of mechanical graters. The traditional method is not only laborious and time consuming; it is unsafe as accidental bruising of hands occurs frequently. Apart from mechanized grating, pressing and sifting, frying of dewatered cassava mash is done in sheltered communal fryers with chimneys that have much greater capacities than the traditional cast-iron pans. In addition, they are comfortable and the inhalation of smoke and potentially toxic fumes is minimized (Fig. 4). These small-scale gari processing factories have sufficient flexibility, allowing processing capacity to be matched with raw material supply. They provide employment in the rural areas, reduce post-harvest cassava losses and provide a good source of income to farmers and processors.

Figure 4. Gari frying in a sheltered communal fryer with chimney

Dawadawa Fermentation

Dawadawa or iru is the most important food condiment in Nigeria and many countries of West and Central Africa (21). It is made by fermenting the seeds of the African locust bean. The seeds are rich in fat (39-47%) and protein (31-40%) and dawadawa contributes significantly to the intake of energy, protein and vitamins, especially riboflavin, in many countries of West and Central Africa. For the production of dawadawa, African locust bean seeds are first boiled for 12-15 hr or until they are tender. This is followed by dehulling by gentle pounding in a mortar or by rubbing the seeds between the palms or trampling under foot. Sand or other abrasive agents may be added to facilitate dehulling. The dehulled seeds are boiled for 30 min to 2 hr, molded into small balls and wrapped in banana leaves. A softening agent called 'kuru' containing sunflower seed and trona or 'kaun' (sodium sesquicarbonate) may be added during this second boiling to aid softening of the cotyledons (43). The seed balls are then covered with additional banana leaves or placed in raffia mats and allowed to

ferment for 2-3 days covered with jute bags (46). Alternatively, the dehulled seeds, after boiling, are spread hot on wide calabash trays in layers of about 10 cm deep, wrapped with jute bags and allowed to ferment for about 36 hrs. The fermented product is salted, molded into various shapes and dried (42). The main microorganisms involved in dawadawa fermentation are *Bacillus subtilis* and *Bacillus licheniformis* and one of the most important biochemical changes that occurs during fermentation is the extensive hydrolysis of the proteins of the African locust bean. Other biochemical changes that occur during dawadawa fermentation include the hydrolysis of indigestible oligosaccharides present in African locust bean, notably stachyose and raffinose, to simple sugars by α- and β-galactosidases, the synthesis of B-vitamins (thiamin and riboflavin) and the reduction of antinutritional factors (oxalate and phytate) and vitamin C (29, 42). An improved process for industrial production of dawadawa involves dehulling African locust bean with a burr (disc) mill, cooking in a pressure retort for 1 hr, inoculating with Bacillus subtilis starter culture, drying the fermented beans and milling into a powder (42). Cadbury Nigeria Plc in 1991 introduced cubed dawadawa but the product failed to make the desired market impact and was withdrawn. It would appear that consumers preferred the granular product to the cubed product.

PRODUCTION OF COMPLEMENTARY FOODS

It is generally agreed that breast milk is adequate both in quantity and quality to meet the nutrient and energy requirements of the infant up to the age of four to six months. Beyond this period, complementary or weaning foods are required to supplement the mother's breast milk. The weaning period is the most critical in the life of infants and preschool children, with serious consequences for growth, resistance to diseases, intellectual development and survival if the child's nutritional needs are not met. Unfortunately, in West Africa and other parts of Africa, traditional complementary foods are made from cereals, starchy roots and tubers that provide mainly carbohydrates and low quality protein. These complementary foods exemplified by ogi are the leading cause of protein-energy malnutrition in infants and preschool children in Africa (9, 28). African infants experience a slower growth rate and weight gain during the weaning period than during breastfeeding due primarily to the poor nutritional qualities of traditional African complementary foods such as ogi. Apart from their poor nutritional qualities, traditional African cereal-based gruels used as complementary foods have high hot paste viscosity and require considerable dilution before feeding; a factor that further reduces energy and nutrient density (40). Although nutritious and safe complementary foods produced by food multinationals are available in West African countries, they are far too expensive for most families. The economic situation in these countries necessitates the adoption of simple, inexpensive processing techniques that result in quality improvement and that can be carried out at household and community levels for the production of nutritious, safe and affordable complementary foods.

COMPLEMENTARY FOODS FROM CEREAL-LEGUME BLENDS

As cereals are generally low in protein and are limiting in some essential amino acids, notably lysine and tryptophan, supplementation of cereals with locally available legumes that are high in protein and lysine, although often limiting in sulfur amino acids, increases protein content of cereal-legume blends and their protein quality through mutual complementation of their individual amino acids. This principle has been utilized in the production of high protein-energy complementary foods from locally available cereals and legumes. Community-based weaning food production using 4:1 ratio of locally available cereals and legumes have proved successful in many African countries. 'Weanimix', a weaning food made from a cereal-legume blend, developed by the Nutrition Division of the Ministry of Health in Ghana was introduced on a large scale in the country in 1986 (59). To promote the production of weaning foods from locally available cereals and legumes at the household level, grinding mills were provided to rural women groups in Ghana with UNICEF assistance (56). Although legume supplementation increases protein content and protein quality of cereal-legume blends, the types of cereal and legume involved as well as the blending ratios are critical. Increasing legume concentration in the blend generally increases the protein score until a new limiting amino acid is imposed. Using a blend quality prediction procedure based on the amino acid scores of mixtures of cereals and legumes, the relative performance of maize, millet and sorghum supplemented with cowpea, groundnut, pigeon pea, soybean and winged bean in various weaning formulations has been

estimated (56). Mixtures of cereals with groundnut produced the poorest quality blends due to the relative inadequacy of groundnut protein in complementing cereal amino acids. Soybean and winged bean produced the best quality blends with cereals, followed by cowpea and pigeon pea in that order (56).

IMPROVED TECHNOLOGY FOR OGI PRODUCTION

Large-scale industrial production of weaning foods involves sophisticated technology including drum drying, spray drying and extrusion cooking. For the production of weaning foods at household and community levels, capital-intensive, sophisticated technology is inappropriate. Ogi, koko and similar products from locally available cereals remain the most important complementary foods in West African countries especially Nigeria, Benin, Ghana and Senegal. Consequently, efforts at improving the nutritional quality of complementary foods in the West African sub-region have been directed predominantly at ogi. The traditional preparation of ogi involves steeping maize, millet or sorghum in water for 1-2 days, followed by wet-milling, wet-sieving and fermentation for 2-3 days. The major microorganisms associated with the fermentation of ogi are lactic acid bacteria (*Lactobacillus plantarum* and *Streptococcus lactis*) and yeasts (*Saccharomyces cerevisiae, Rodotorula* spp*., Candida mycoderma* and *Debaromyces hansenii*). Considerable nutrient losses occur during ogi manufacture and depending on the processing method used protein losses may be as high as 50% (47, 4).

Several approaches have been adopted in improving the quality of ogi. Instant dry ogi powder was produced by drum drying the slurry from the fermentation of dry-milled high lysine maize flour with starter cultures of *Lactobacillus plantarum*, *Streptococcus lactis* and *Saccharomyces rouxii* (18). The product had a higher lysine content relative to ogi produced by the traditional method. Another approach was to drum dry ogi slurry from regular maize followed by fortification with lysine and other amino acids (1). For the production of dry ogi powder at community level, hot air cabinet drying of ogi is preferred to drum drying because it is less sophisticated and simpler in content and operation. An upgraded traditional process involving wet-milling, wet-sieving with gyrating shaker and sieves, fermenting, de-watering with a screw press, followed by drying in a cabinet dryer, milling, sieving and packaging is particularly suited for production of ogi powder at community level (2). Co-fermentation of maize and locally available legumes has also been used to improve the nutritional quality of ogi. 'Soy-ogi' and 'cowpea-ogi' or 'ewa-ogi' are two of such products (6, 8, 45). Soy-ogi developed by the Federal Institute of Industrial Research, Oshodi, Lagos, Nigeria is made by milling steeped maize and soybeans into a paste that is allowed to ferment. The fermented slurry is fortified with minerals and vitamins, pasteurized and then spray dried. Apart from improvement in protein content and quality, co-fermentation also reduces flatulence and anti-nutritional factors associated with legumes. Sprouting has also been used to improve the nutrient content of ogi and cereal-legume blends used as complementary foods (58, 48).

A variety of complementary foods have been developed in which ogi powder is enriched by the incorporation of legume or defatted oil seed flours (19, 52). A novel approach was the supplementation of ogi at levels of up to 25 % with tempe flour, an Indonesian product, made by fermenting soybeans with the mold *Rhizopus oligosporus*. Addition of tempe flour improved the nutrient content of ogi with significant increases in lysine and tryptophan (26). Maize-based complementary foods made from whole maize flour or ogi powder and supplemented with soybean, cowpea and groundbean tempe had high protein quality, with nutrient contents within the range prescribed by the FAO/WHO pattern for processed weaning foods (53, 54). They were comparable with commercial baby foods produced by food multinationals in Nigeria and can support the growth of infants in developing countries especially during the critical weaning period (27, 53).

PRODUCTION OF INSTANT YAM FLOUR

Yam, possibly the oldest cultivated food plant in West Africa, is of major importance to the economy of the sub-region that accounts for the bulk of world production of the crop. By far the most important product derived from white yam (*Dioscorea rotundata* Poir) is fufu or pounded yam, popular throughout West Africa. Traditionally, pounded yam is prepared by boiling peeled yam pieces and

pounding using a wooden mortar and pestle until a somewhat glutinous dough is obtained. Arising from the need to have a convenience food and reduce the drudgery associated with the preparation of pounded yam, various brands of instant yam flour are now available in West Africa since the introduction of "poundo yam", which is no longer in the market, by Cadbury Nigeria Ltd in the 1970s. Instant yam, on addition of hot water and stirring, reconstitutes into a dough with smooth consistency similar to pounded yam. The product is so popular that considerable quantities are exported to other parts of the world, especially Europe and North America, where there are sizable African populations.. Commonly, instant yam flour is produced by sulfiting peeled yam pieces, followed by steaming, drying, milling and packaging in polyethylene bags (37). Instant yam flour can also be produced by drum drying cooked, mashed yam and milling the resultant flakes into a powder using a process similar to that used for production of dehydrated mashed potato (49, 50).

WEST AFRICAN CHEESE-MAKING

The scientific study of traditional West African cheese-making offers another example of the growing understanding of the inherent nature, strength and limitations of traditional African food processing and preservation techniques. Cheese-making is one of the oldest methods of preserving excess milk and is a major business worth billions of dollars in many industrialized countries. Indeed, cheeses are now unique products in their own right and cheese-making has advanced beyond being merely a food preservation technique. Cheeses are produced by the coagulation of milk casein by an enzyme preparation (rennet) or an acid, usually lactic acid. Calf rennet derived from the abomasa of 10 to 30-day-old milk-fed calves, containing rennin or chymosin, is the coagulant of choice for industrial cheese-making. It is preferred to microbial and plant rennets because of its low proteolytic activity. The nomadic Fulani has, since ancient times, processed milk into a soft cheese known as warankasi in Nigeria or woagachi in the Republic of Benin as a means of preserving excess milk. Warankasi is a good source of animal protein and is used to replace meat or fish, or in combination with them, in various food recipes. Its low lactose content makes it an acceptable food to many people who suffer from lactose intolerance associated with milk consumption in African and Asian population due to low levels of intestinal β-galactosidase (lactase).

The traditional West African cheese-making process was developed (presumably empirically) by the nomadic Fulani and is based on the milk-coagulating properties of juice from the leaves of the sodom apple plant [*Calotropis procera* (Ait.)]. The juice, obtained by crushing sodom apple leaves, is mixed with cows' milk gently heated in a pot over a wood fire (Fig. 5). Following coagulation, the loose curd pieces are poured into small raffia baskets and allowed to drain. In the Republic of Benin, the cheese may be further processed by sun drying and coloring with extracts from threshed sorghum ears or other plant materials that impart a reddish color to the cheese (Fig. 6). The unit operations of traditional cheese-making are similar to those of industrial cheese-making and consist of milk setting, cutting or breaking of the curd, cooking of the curd and draining or dipping (13, 44). The process is very unhygienic; there are numerous opportunities for product contamination and there are no quality standards. Consequently, the quality of the product is highly variable and often very poor.

Starting with pasteurized milk and applying scientific knowledge of the biochemical properties of sodom apple proteinases, an improved cheese-making procedure based on the traditional process has been developed (10, 15, 16). Vegetable rennet prepared by precipitating the milk clotting proteinases in sodom apple leaves with ammonium sulfate is used as coagulant (14). This allows better control of the coagulation process and reduces product contamination. Following coagulation, the curd pieces are drained in stainless steel hoops instead of raffia baskets, salted and pressed in a hydraulic press to reduce the moisture content and extend the shelf life (Fig. 7). Cheese yields and recovery of milk components (95.6 % for fat, 85.5 % for protein) were very good when the improved cheese-making process using sodom apple rennet as coagulant was compared with a laboratory cheese-making procedure using calf rennet (15).

Figure 5. Addition of juice from crushed sodom apple leaves to milk in traditional West African cheese-making

Figure 6. Retailing of warankasi in Benin Republic (courtesy of M. Egounlety)

RAW MILK (4.7 kg)

↓

PASTEURIZE (72°C FOR 16 SEC OR 63°C FOR 30 MIN) AND COOL

↓

ADD 1.8 mM $CaCl_2$ AND MIX THOROUGHLY AT 40°C

↓

ADD 7 mL PARTIALLY PURIFIED VEGETABLE RENNET AND STIR FOR 2 MINUTES

↓

HEAT GENTLY AT THE RATE OF 1.5-2°C PER MINUTE UNTIL CURD FORMATION AT ABOUT 75°C

↓

MAINTAIN AT 75°C FOR 30 MINUTES

↓

COOK CURD PIECES WITH GENTLE STIRRING BY INCREASING TEMPERATURE TO 80°C FOR 10 MINUTES

↓

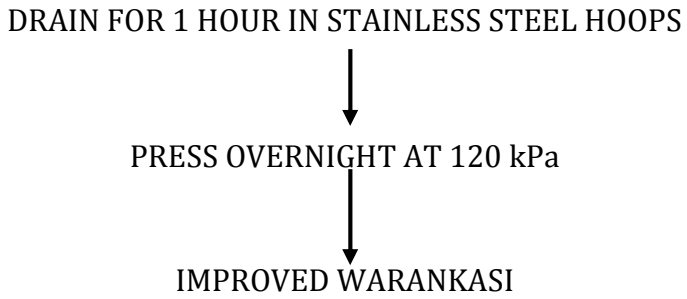

Figure 7. Outline of an improved process for the production of warankasi

PRODUCTION OF KILISHI AND OTHER PROCESSED MEATS

Suya (tsire or balangu), banda (kundi) and kilishi are the most important traditional processed meats in Nigeria and other West African countries including Chad, Niger and Mali where they provide valuable animal protein in the diets of the people. Banda is a salted, smoke-dried meat product made from chunks of cheap, low quality meat from various types of livestock including donkeys, asses, horses, camel, buffalo and wild life (41). The meat chunks are pre-cooked before smoking/kiln drying or sun drying. The traditional smoking kiln for banda is usually an open-top, 50-gallon oil drum fitted with layers of wire mesh that hold the product, and fired from the bottom. Banda is a poor quality product, stone-hard and dark in color. Unlike banda, suya and kilishi are made by roasting spiced, salted slices/strips of meat (usually beef). Kilishi is different from suya in that a two-stage sun-drying process precedes roasting. Consequently, kilishi has a lower moisture content (6-14 %) than suya (25-35 %) and a longer shelf life. A variety of spices and other dried ingredients are used in kilishi processing including ginger (*Zingiber officinale*), chillies (*Capsicum frutescens*), melegueta pepper (*Aframomum melegueta*), onion (*Allium cepa*), *Piper guineense*, *Thonningia sanguinea*, *Fagara santhoxyloides* and defatted peanut (*Arachis hypogea*) cake powder. Kilishi consists of about 46% meat and about 54% non-meat ingredients, with defatted peanut powder accounting for about 35% of the ingredient formulation (36). Other traditional processed meat products in Nigeria include ndariko and jirge (41). Ndariko is made by sun drying long strips of meat with or without the addition of salt and spices. Jirge, like ndariko, is prepared by sun drying meat strips; but the meat for jirge is first cut into chunks and allowed to ferment to develop the desired sour taste before sun drying.

A major source of concern, from a public health standpoint, as revealed by consumer surveys, is the unhygienic conditions under which meat products are often processed and retailed in Nigeria and other West African countries (34). For products such as suya and kilishi, the spices used in their processing are potentially sources of microbial contamination. Microbial populations including coliforms exceeding acceptable limits for ready-to-eat meat products and the presence of a wide spectrum of pathogenic bacteria have been reported in retail suya (35). Consequently, research efforts have been directed at improving the quality, wholesomeness, safety and shelf life of traditional processed meats through the upgrading of the traditional technology and the control of microbial contamination (33, 17). A model pilot plant for improved processing of kilishi has been established in Benin City, Nigeria under an International Development Partnerships (IDP) collaborative research project between Wilberforce University, USA and the University of Benin, Nigeria funded by the United States Agency for International Development (USAID)/the United Negro College Fund Special Programs (UNCFSP) and the Raw Materials Research and Development Council of Nigeria (Fig. 8). The pilot plant uses improved technology involving cabinet (tray) drying and vacuum packaging and has clearly demonstrated the benefits arising from upgrading traditional food processing technologies in terms of improved product quality, shelf life, consumer acceptance, export potential and income generation (3).

Figure 8. Slicing of beef in kilishi pilot plant (courtesy of J. O. Igene & H. A. Agboola)

CONCLUSION

The critical role that food science and technology plays in national development cannot be overemphasized in West African countries where high post-harvest losses, arising largely from limited food preservation capacity, is a major factor constraining food and nutrition security. Seasonal food shortages and nutritional deficiency diseases are still a major concern. While the large food multinationals play a unique role in promoting industrial development in West Africa through employment generation, value-added processing and training of skilled manpower, their impact is felt greatest in the urban areas. Small-scale food industries that involve lower capital investment and that rely on traditional food processing technologies are crucial to rural development in West Africa. By generating employment opportunities in the rural areas, small-scale food industries reduce rural-urban migration and the associated social problems. They are vital to reducing post-harvest food losses and increasing food availability. While a lot still has to be done in upgrading traditional West African food processing technologies, some successes have been achieved including the mechanization of gari processing, the production of instant yam flour, the production of soy ogi, the industrial production of dawadawa, and the upgrading of the kilishi process and the West African cheese-making process.

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Solar Drying in Developing Countries: Possibilities and Pitfalls

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ABSTRACT

People in developing nations are often faced with insufficient food supplies. These shortages may be seasonal in nature, lasting from the end of one growing season until the beginning of the next harvest, or they may be longer due to successive poor growing seasons. Countries faced with food shortages are often forced to import food and must pay world market prices which they can ill-afford to do. Reliance on imported food drains the country of its financial resources, which if spent domestically would stimulate growth throughout the local economy. It is a basic fact that the sustainable development of any nation or society depends on a safe, nutritious, dependable, and affordable food supply. Without this, economic growth and its associated advantages can be seriously impeded. This paper examines, questions, and challenges the feasibility of using solar drying at the individual farm level for food preservation. Solar drying of tomatoes is used as an example. Factors blocking the widespread uptake of food processing technologies and envisioned short-comings of the adaptation of these technologies to local economies are also discussed.

INTRODUCTION

This paper examines a real-life situation involving chronic seasonal food shortages in a developing country, along with the impact on the country's overall development and growth.

This small developing nation lacks much of the infrastructure required to promote the standard of living of its citizens. There are few paved roads and in most parts of the country there is no electricity or other utilities necessary for the development of food processing facilities. What limited and localized electrical generating capacity the country does have is unreliable with regular 'brown-outs' (i.e., fluctuations in voltage) and frequent 'black-outs' (i.e., complete power interruptions). The country is mainly agrarian with family holdings of several hectares. One of the main crops grown in this country is field tomatoes which have two growing seasons per year. Fresh tomatoes, similar to Roma tomatoes (Figure 1), form a dietary staple item for most of the residents.

Figure 1: Roma Tomatoes as Used in Solar Drying Trials

During a typical harvest period, tomatoes are extremely plentiful within the country and local markets are overwhelmed with their abundance. As a result, tomato prices are depressed and farmers who rely on them as a source of income receive low returns for their efforts. In addition, the lack of paved roads increases the time that it takes to get the product to markets in populated centres and often results in produce being damaged during transportation. While unsold tomatoes in the markets spoil and must be discarded, some tomatoes may remain unharvested and left in the fields literally rotting on their vines due to unfavourable market conditions.

At the end of the growing season, supplies of tomatoes diminish rapidly. Within a few weeks there is a shortage of fresh local tomatoes, and throughout the period until the next harvest, tomatoes must be imported to meet the country's demands. To pay for these imports, funds must be transferred to off-shore suppliers thereby reducing the domestic financial resources of the country as it is forced to import tomatoes and other perishable crops.

While overcoming the reliance on food imports is recognized as a priority for the country's development, finding a solution to the problem may not be an easy task.

DEFINING THE PROBLEM

The problem itself is relatively easy to define: there are simply too many tomatoes ripening in a very short time period. In more developed countries these excess tomatoes would be processed into tomato sauce, tomato paste, or ketchup; or they might be processed and canned whole, sliced, or diced. However, canning requires abundant, reliable energy to supply heat for retorts and other thermal processing equipment. These energy supplies are often lacking in developing nations. Even in countries where there is electricity in the major centres, there may be no power grid to distribute it to outlying areas.

EXAMINING POTENTIAL SOLUTIONS

Drying of the tomatoes was considered to be one of the few processing options that could be utilized under the constraints imposed in this country. The use of conventional forced-air dryers or ovens was considered not to be feasible in many areas. Once again, this was due to the lack of energy to power fans and appropriate instrumentation, as well as fuel to provide heat to the dryers.

Since this country, like many of the nations facing these problems, is in a tropical or sub-tropical area, solar energy was viewed as an attractive alternative for drying food products. Numerous projects have been undertaken to investigate the potential for solar drying of crops such as tomatoes. Dried tomatoes could then be stored in a relatively shelf-stable form for use until the next harvest of fresh tomatoes. An international assistance project was focussed on assessing food preservation at the individual farm level to provide shelf-stable products between harvests [4, 5]. It was reasoned that transferring food preservation technology such as solar drying to farming families would provide them with the means to set aside a portion of their crop for personal use during the period between harvests; thereby reducing their reliance on imported fresh tomatoes.

Solar drying of tomatoes is not a novel idea [1, 2, 3, 7]. Indeed, it continues to be practised successfully on a commercial scale in several countries where conditions are suitable. However, the real issue in this example is the applicability of solar drying at the individual farm level. There are numerous drawbacks associated with solar drying that must be considered. In order to understand the situation, it is necessary to examine a combination of factors including: the drying properties and kinetics of the product; prevailing environmental conditions; finished product storage, usage, and attributes; and the potential for technology uptake by the target user group.

TOMATO DRYING

PROPERTIES AND KINETICS OF TOMATO DRYING

Understanding the process of how a particular material actually dries is a commonly over-looked aspect of food drying. Many processors feel that it is sufficient to expose the food product to as much heat as possible to remove the required amount of moisture in as little time as possible. Their failure to understand that the manner in which the water removal takes place can result in such negative impacts as:

- Nutritional degradation (e.g., vitamin loss)
- Flavor changes (e.g., burnt, toasted, or carmelized)
- Color changes (e.g., toasting or browning)
- Reduction of functionality (e.g., starch gelatinization during drying)
- Loss of structural integrity (e.g., stress-induced cracking)
- Case hardening (i.e., formation of an outer hard dry shell)

To avoid heat damage, temperatures below 60°C are quite appropriate for many food drying applications. Higher temperatures may be used during the initial drying stages for some foods, but this is entirely dependent on the food itself and must be thoroughly investigated before use. Solar drying avoids exposing the food material to excessively high temperatures, since temperatures above 60°C are not easily achieved in small-scale drying units.

Another requirement for drying is an adequate supply of air to remove moisture from the surface of the product being dried. In forced-air dryers, this is usually not a problem since the same hot air that is used to bring heat to the product and evaporate the moisture from its surface will carry that moisture out of the dryer. However, air movement is an issue in solar dryers. While heat can be trapped inside the drying chamber, the moisture content of the air near the surface of the material being dried can increase to levels nearing saturation. The high moisture content of this boundary layer air can reduce the rate at which moisture can be removed from the surface of the product. The overall high humidity of the air inside the solar dryer itself can also reduce the dryer's water removal capacity. By increasing the flow of air, the efficiency of a solar dryer can be enhanced. In cases where air flow through the solar dryer relies on natural convection, it is often difficult to address the lack of sufficient air flow. Some solar dryers utilize electric fans for increased air circulation, which is not feasible in areas lacking access to electricity.

Tomatoes are very high in moisture content. On a wet basis, Roma or plum tomatoes contain approximately 93% to 95% moisture. As a comparison, mangoes may contain 80% to 85% moisture, and apples typically contain 84% to 85% moisture. Looking at the actual moisture content of these three products on a dry basis, tomatoes may contain approximately 13 to 19 grams of water per gram of dry solids; mangoes may contain about 4 to 6 grams of water per gram of dry solids; and apples may contain about 5 to 6 grams of water per gram of dry solids. From these values, it is obvious that much more water must be removed from tomatoes to reach a 10% final moisture target (i.e., 0.11 g water/g dry solids) than for the other two examples cited. This high water content makes tomato drying especially challenging.

Figure 2 is a plot of the dry basis moisture content versus time for tomatoes dried in a laboratory-scale tray dryer under a variety of conditions. The three curves shown are for drying at 50°C with an air velocity of 0.1 m/s; 58°C with an air velocity of 0.1 m/s; and 50°C with a 0.5 m/s air velocity. In this work, an air velocity of approximately 0.1 m/s was considered to be representative of the low air flows found in solar dryers equipped only with small fans to enhance air circulation, while 50°C is a temperature easily achieved in most solar dryers in strong sunlight under clear skies. 58°C was used as an elevated temperature for comparative purposes, as was the air velocity of 0.5 m/s.

Figure 3 shows the moisture ratio versus time for each of the three drying conditions used in Figure 2. By dividing the dry basis moisture at any time 't' by the initial dry basis moisture, a dimensionless value can be obtained [9]. In this way, the drying of numerous samples with different initial moisture contents can be compared directly. Inherent in this approach is the assumption that the initial moisture differences are not substantial enough to affect the overall drying kinetics.

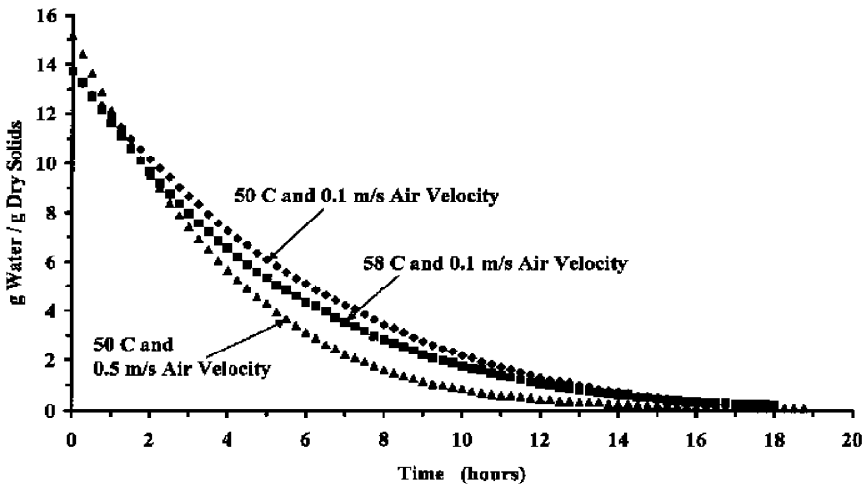

Figure 2: Dry Basis Moisture versus Drying Time for Roma Tomatoes in a Tray Dryer

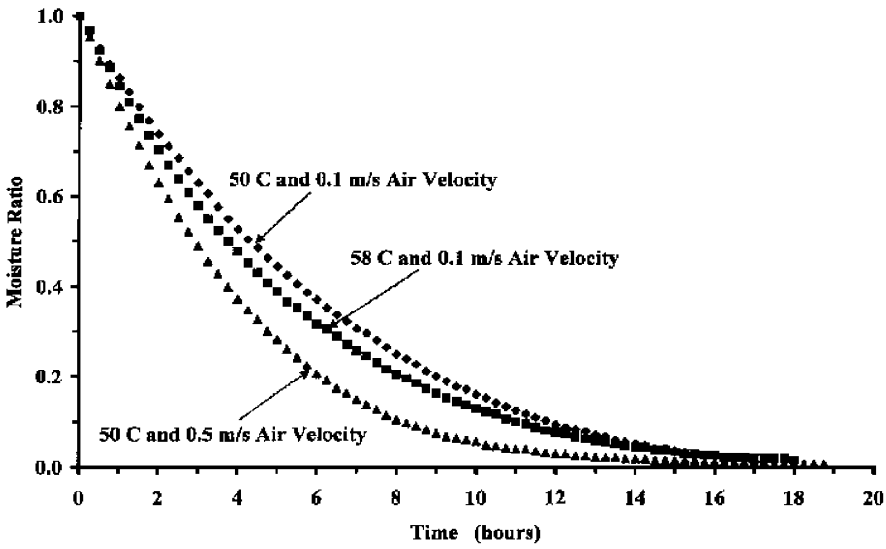

Figure 3: Moisture Ratio During Drying for Roma Tomatoes in a Tray Dryer

Table 1 shows the water removal rate in the constant rate drying period based on the linear portion of each of the three curves during the first 2.5 hours in Figure 2.

Table 1: Initial Water Removal Rates for Various Drying Conditions of Roma Tomatoes

Drying Conditions	**Water Removal Rate (during first 2.5 hours)**
0.1 m/s air velocity at 50°C	1.73 g water/g dry solids/hour
0.1 m/s air velocity at 58°C	2.01 g water/g dry solids/hour
0.5 m/s air velocity at 50°C	2.71 g water/g dry solids/hour

Figures 2 and 3, plus the information presented in Table 1, indicate that achieving a relatively high air velocity through a dryer may be more important for water removal than having a higher temperature inside the dryer. This is particularly relevant to solar drying where the natural convective airflow within a solar dryer is very slow, and may not be sufficient to disrupt the saturated boundary layer of air around the bed of wet product inside the dryer. Designers of some prototype solar dryers intended for use in developing countries have included large fans for improved air circulation. Such design features prevent the use of these dryers by those who do not have electricity available, for whatever reason.

PREVAILING ENVIRONMENTAL CONDITIONS

A major problem associated with solar drying is the prevailing environmental conditions [4, 5, 6]. For efficient and effective solar drying, lengthy periods of uninterrupted sunlight are required. Cool, cloudy, and rainy conditions may persist at the later stages of the harvest season, making solar drying entirely inappropriate.

From Figure 2, it can be seen that an extensive drying period is needed to reduce the moisture of the tomatoes to approximately 10% (wet basis) or 0.11 grams of water per gram of dry solids on a dry basis.

Figure 4 shows a prototype solar dryer used in the studies presented here. It consists of a small metal-lined cabinet from which air is exhausted by two solar-powered fans. These are the two circular devices mounted on the front of the dryer near the top of the drying chamber in Figure 4. Air is thereby drawn into the bottom of the drying chamber through the black metal heat collector. The weight of the material being dried can be monitored by the balance on the top of the dryer from which a rack inside the dryer is suspended. The entire dryer is mounted on a rotating platform to follow the course of the sun throughout the drying period.

Figure 4: Prototype Solar Dryer Used in Drying Studies

Figure 5 shows partially dried tomato wedges (each one-eighth of a Roma tomato) on the rack inside the dryer. The temperature of the air contacting these tomato wedges can be measured by a sensor attached to the bottom of the drying rack.

Figure 5: Partially Dried Tomato Wedges Inside the Solar Dryer

Figure 6 shows an example of the dry basis moisture content versus time during two separate solar drying trials with Roma tomatoes.

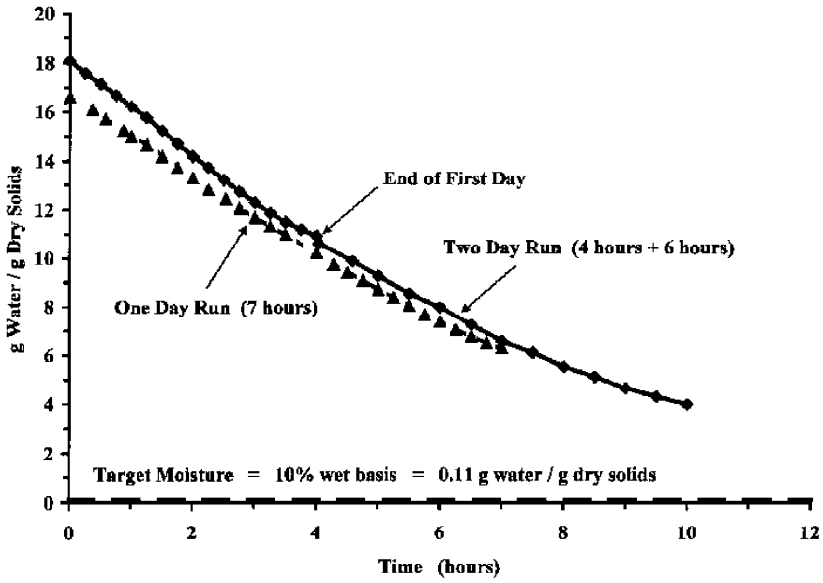

Figure 6: Dry Basis Moisture versus Time for Roma Tomatoes in Prototype Solar Dryer

The solid line in Figure 6 is for a two-day run using tomatoes with a relatively high initial moisture content (18.0 grams of water per gram of dry solids or 94.7% wet basis moisture). The temperature in the dryer was approximately 45°C and the air velocity was approximately 0.1 m/s. During the first three hours of drying, the water removal rate was 1.95 grams of water per gram of dry solids per hour. After four hours of drying, conditions became unfavourable and drying had to be halted for the day. The tomatoes were removed from the dryer and stored in a sealed glass jar under refrigerated conditions until the following day. Drying continued for an additional six hours before the test was terminated. After ten hours of drying the moisture content had fallen to 4 g water/g dry solids or 80% wet basis moisture. An additional 3.9 g water/g dry solids would still have to be removed to achieve the 10% wet basis target moisture shown by the dashed line near the bottom of Figure 6. When the

tomatoes were re-introduced into the dryer on the second day, an interesting response was observed in the moisture removal rate. Due to moisture diffusing to the surface of the tomato wedges during overnight storage, there was more water available for removal from the surface of the tomatoes at the start of the second day than there had been at the end of the previous day. This created a short increase in the water removal rate before diffusion control of the drying process once again took over.

The second curve in Figure 6 (the broken line and triangular data points) shows the results of a single seven-hour run using tomatoes with a somewhat lower moisture content than in the two-day run. These tomatoes contained 16.6 g water/g dry solids (or 94.3% wet basis moisture) and were dried at 45°C with an air velocity of 0.1 m/s. The water removal rate during most of this test run was 1.60 g water/g dry solids/hour. After seven hours, the moisture content of the tomatoes had reached 6.3 g water/g dry solids (or 86.3% wet basis moisture).

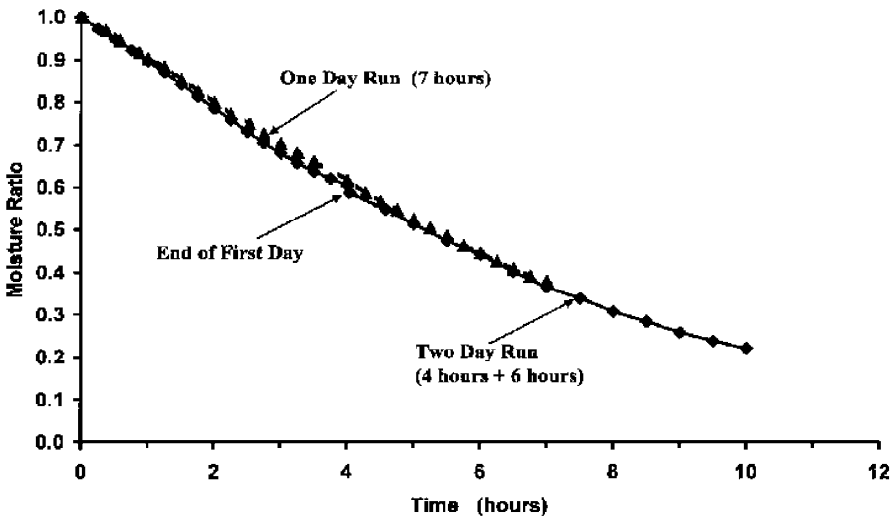

Figure 7: Moisture Ratio During Drying for Roma Tomatoes in Prototype Solar Dryer

Figure 7 is a plot of the moisture ratio versus time for the two solar drying runs from Figure 6. Once again, this allows comparison of the drying on a normalized basis accounting for the differences in the initial moistures of the two runs. Even though these two tests were conducted under similar drying conditions, the initial rates of water removal were slightly different. This could be attributed to the initial moisture contents of the tomatoes. Tomatoes with a higher initial moisture content may lose their moisture more readily at the start of the drying process, before diffusion of moisture becomes the rate-controlling step. Variations such as this complicate the drying process for those unfamiliar with drying kinetics and make it difficult to provide clear, unambiguous instructions to those using a solar drying unit at the farm level.

In all cases, solar drying of Roma tomatoes required more than one day of drying. Tests using a laboratory-scale tray dryer under conditions similar to those found in typical solar drying (see Figure 2: 50°C and 0.1 m/s air velocity) have indicated that 18 hours or more of consistently uniform conditions are required for adequate drying of the tomatoes before they reach a moisture level of 0.11 g water/g dry solids (i.e., 10% wet basis moisture). Typically, areas in the tropics and sub-tropics do not receive adequate sunlight intensities for more than six to eight hours per day. This necessitates holding the partially dried products overnight in the moist confined space inside the dryer. With overnight temperatures of 15°C or higher, there is little or no safeguard against the growth of contaminating microorganisms.

Food safety is a major concern. There is great cause for concern when one considers that these tomatoes could be exposed to warm humid conditions for up to three days before being dry enough to place in storage for future use. In one solar drying run conducted by the author in a tropical country, unsatisfactory weather conditions forced experimentation to be stopped in the early afternoon. The

tomatoes plus other fruits and vegetables being dried were left in the drying cabinet overnight in anticipation of better weather on the following day. Covers were placed over the air inlets and outlets on the dryer to prevent insects and rodents from entering the dryer. When drying was started on the second day, mold growth was noticed on some of the food surfaces and became more apparent after several hours in the sun. The entire batch of material had to be discarded and the interior of the dryer then had to be sanitized before processing the next batch of produce. Such risks would seem to be excessive, especially in light of the level of education and training that potential users of solar drying might have.

Long drying times can create additional problems for those interested in solar drying of tomatoes. There is a limit to how much material can be placed in a solar dryer. It has been suggested that dryer loadings should be limited to 6 kg of wet material per square metre of dryer bed surface [2]. On this basis, it would require rather large dryers to make solar drying a viable option for those with several hundred kilograms of tomatoes to dry.

Insects, rodents, and airborne contaminants such as dust can create unwelcomed challenges for solar drying if the dryers are relatively open to promote the intake of fresh air and exhausting of humid air.

FINISHED PRODUCT STORAGE, USAGE AND ATTRIBUTES

In addition to the problems with the actual drying, there are other complicating factors associated with solar drying of products such as tomatoes. Once its moisture has been reduced to the desired final level, the dried product must then be stored under appropriate conditions until it is used. While sealing the product in clean airtight jars or heat-sealed 'plastic' bags may be suitable for a variety of products, it can be difficult for those in developing countries to obtain suitable packaging and ensure that sanitary packaging conditions are met. Any moisture present in the sealed container that condenses in localized areas can promote the growth of molds or potentially pathogenic microorganisms. This is especially true in the case of low acid products such as tomatoes. Insects may also proliferate inside the sealed containers if the product has become infested during drying.

Unless the raw materials were properly blanched or otherwise treated prior to drying, there is also the potential problem of enzymatic degradation. While temperatures above 80°C are sufficient to reduce enzyme activity, these temperatures are generally not achieved in solar dryers; and even if they were, such high temperatures could have a negative impact on quality if the dried product was exposed to them for excessive lengths of time.

In areas where residents are accustomed to using fresh fruits and vegetables in meal preparations, there can be a need for consumer education in regard to how to use the dried materials. Something as simple as substituting dried tomatoes for fresh tomatoes when making stews and sauces can create problems. One question that arose in a demonstration of sun-dried tomatoes in a developing country was how to use them in salads and still get the appearance and flavour of fresh tomatoes. It had to be explained that there are cases in which dried fruits and vegetables cannot be substituted for their fresh counterparts due to their different product attributes.

POTENTIAL FOR TECHNOLOGY UPTAKE

The ability of the potential user to embrace a particular technology and manage it effectively must always be kept in mind. While solar drying could be the answer to food preservation needs, without proper regard for food safety, it could also be the source of additional serious problems.

The educational level of potential users in developing countries is generally quite low. Understanding of the risks associated with unsafe food handling and processing practices is correspondingly low as well. On top of this is the need for maintaining sanitary conditions and keeping the equipment in good repair. Due to a lack of electricity or affordable electricity, it may not be possible to include circulating fans in solar drying units. Even if the dryers are economical to build, the actual number of dryers required to have one dryer per household in a specific area, may make them prohibitive. There is also

the problem of dryers falling into disuse and being cannibalized for parts to meet other more pressing needs such as the use of the glass or plexiglass panels on the dryers being used to replace broken windows in houses, and such.

Overall, experience has shown that the uptake of knowledge to conduct solar drying and maintain the equipment is lacking in many areas.

ASSESSING THE APPLICABILITY OF SOLAR DRYING

Solar drying has been shown to be an effective method of drying food materials under suitable climate conditions with properly trained personnel monitoring the operation [2]. Small-scale dryers on individual land holdings may seem to address the issue of providing families with the ability to preserve a portion of their crops for use after harvesting. However, there are fundamental shortcomings which must be taken into consideration before large-scale commitments are made to provide solar drying units to every family. Untrained persons attempting to apply drying technology to low acid foods, such as some varieties of tomatoes, under changing environmental conditions, with insufficient sanitation, is an accident waiting to happen. While certain individuals may be able to embrace this technology, the vast majority of the population may not. As an example, in many marketplaces in developing countries, merchants simply spread their products on the bare ground to dry in front of their stalls without apparent regard for the consequences. It has only been in recent years that they have begun to place plastic sheeting under the material they are drying. During the drying process, insects are ever-present and dust is blown onto the products whenever the wind blows.

The scale on which solar drying can be pursued and the time required for drying are two other important considerations. Farmers may need to dry hundreds of kilograms of tomatoes and similar products. It will take approximately 12.8 kg of tomatoes at 93% wet basis moisture to give 1 kg of dried tomatoes with 10% wet basis moisture content. If dryer loadings should not exceed 6 kg of wet material per square metre of dryer area [2], obtaining 1 kg of dried tomatoes will require a solar dryer with over two square metres of drying area. In addition, based on the moisture content of the tomatoes and the associated kinetics of tomato drying, it could take up to three days of good drying conditions to achieve the desired final 10% wet basis moisture.

Coupling solar drying with hot air drying does not completely alleviate these problems; in addition it adds to the complexity of the overall process by creating an additional processing step that now requires external fuel.

Solar drying is viewed as a solution to the food preservation problem in tropical and sub-tropical areas. While these areas receive abundant sunshine, they may also experience daily rainstorms that block the sun for several hours and increase the overall humidity of the ambient air that is ultimately used in the solar drying process. In turn, this reduces the water removal capacity of the air and lowers the solar dryer's efficiency.

Great care should be taken before recommending solar drying of fruits and vegetables in developing countries. While it appears to be a solution to many problems, there are serious shortcomings that must be considered and potentially hazardous consequences if the drying is not conducted properly.

Based on the information presented here and personal observations by the author, solar drying at the individual farm level does not appear to be an acceptable solution to food preservation issues in developing countries.

CONCLUDING REMARKS

There are several issues that must be addressed in assisting economic growth in developing countries. Technology transfer is of major importance in this regard.

In attempting to solve food processing-related problems, every effort must be made to understand the situation into which the technology is to be transferred. This includes the lifestyles of the people and their ability for technology uptake. Showing a person that food can be dried in a cabinet using the heat of the sun is much different than teaching them how to do it, and having them do it on their own. Avoiding potentially harmful results caused by a lack of awareness of food safety issues is something that can easily be overlooked. It is not until scientists from more developed countries work under conditions found in the area to which the technology is to be transferred that they can realize the challenges being faced every day by the people living there. While solar drying may appear to be an appropriate solution to preserving various crops, it is not until attempts are made to actually dry these crops during the harvest season that the true magnitude of the problem can be understood and appreciated. Rather than trying to put a solar dryer in the hands of every farming family and expecting them to use the dryer to preserve their crops, it may be more advisable to address infrastructure concerns in the area (e.g., sanitation, safe drinking water, and passable roads to get crops to market). Expecting farming families to embrace technologies which they do not understand is not a realistic approach to solving the problem of food preservation. It would be more advisable to create centralized drying facilities run by trained individuals on a larger scale for these purposes.

Technology transfer is a process with three basic components. First, a source of the technology is required. In most cases, sources of technology already exist in the universities and businesses of developed nations. Second, a suitable medium for the transfer of information must be found. This could be through formal instruction, printed materials, local extension services, or a host of other methods. Unfortunately, there are many deficiencies in the pathway for technology transfer from developed to developing nations. This is further complicated by the sheer numbers of people involved. The final component for technology transfer is an appropriate recipient or receiver of the technology. Here is where one of the greatest challenges lies. Most technologies require a certain level of training or education for them to be successfully implemented. Trying to transfer technology to everyone is virtually impossible. Therefore, appropriate recipients must be identified before any technology transfer can take place.

For the reasons outlined above, the International Union of Food Science and Technology (IUFoST) has identified food industry workers as potential recipients for training in various food science-related subject modules. By training a group of selected individuals, in-roads can be made into creating a base for future technology transfer and uptake.

ACKNOWLEDGEMENT

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Village Level Processing: Empowerment Through Enterprise Skills Development in Lao PDR, Myanmar and Viet Nam

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BACKGROUND

In Laos, Myanmar and Viet Nam the agriculture sector is the primary source of income for most of the working population in these countries. There is an urgent need to diversify and create additional on- and off-farm incomes as the current income to rural households is regularly disrupted, often falling below expectations, as the rural poor in the countries deal with the vagaries of agriculture. In each of the three countries there is a clear need for enterprise development, marketing skills and a means of coordinating households/communities into collective action groups.

The capability in these countries to develop and operate rural businesses needs strengthening but there is little tradition of households working together. In Lao PDR for example, there is a need for rural industrialization and crop diversification programs, which are only now starting. In Myanmar, an entrepreneurial spirit is present, though people need the necessary skill sets to be able to take full advantage of rural income diversification and to form groups to work together.

In contrast, a key feature of Viet Nam's rural industry base is the presence of Occupational Community Villages or (OCVs) in which many households work together to produce one product. This collective approach allows groups to develop some degree of economy of scale and greatly improves their sustainability and efficiency. Despite the success of OCVs in a national setting, they are not yet fully equipped to move into higher value (quality) markets and do not always have the resources and skills to evolve into small- and medium-scale enterprises.

Using Viet Nam as a model, and by combining the lessons learnt from successful OCVs with skill set and entrepreneur development training, it should be possible to create focal villages in Laos and Myanmar that can be used as reference sites for further replication throughout each country. All three countries are in transition to market economies. The selection of high quality markets will require training in marketing skills. Their future entrepreneurs will require training in skills such as market research, presentation and calculating marketing costs. Providing only technology or even finance is insufficient to prepare the rural entrepreneur to undertake business. Interventions are required that also develop the necessary skill sets enabling rural entrepreneurs to create viable micro-enterprises that can compete in high-value crop markets.

Training interventions that are needed should be focused on-the-job, involving skills training programs composed of (a) management-oriented or 'business' training (in such skills as costing, accounting, and bookkeeping,); (a) production-oriented or technical skills training; and (c) entrepreneurial development training (focusing on the motivational, attitudinal, and behavioral aspects of entrepreneurship). All these are needed, in addition to training on the skill sets involved with the use of food science, preservation technology and nutrition, to enable processing of agricultural raw materials into marketable food products.

INTRODUCTION

A UN Food and Agriculture Organization (FAO) Technical Cooperation Program (TCP) project 'Village Level Processing - Empowerment through Enterprise Skills Development' was launched in February

2006 with a budget of US$379 000. This TCP project was prepared in accordance with the national government priorities on agriculture and rural development in each of the three countries. Its aim was to provide packages of skills necessary for farmers/rural entrepreneurs to coordinate group activities and develop food products that are acceptable to consumers. The products made in a cost effective and efficient way would have the potential to compete in higher-value markets. The project was designed to be compatible with existing regional, technical and finance-orientated initiatives, with the ultimate goal of alleviating food insecurity, while preserving good nutrition among rural communities and individuals, and adding value to foods, thus providing stable incomes to rural households.

OBJECTIVES OF THE PROJECT

OVERALL OBJECTIVES

1. To promote household income generation through improvement of micro-enterprise innovation, management and marketing skills.
2. To promote rural employment opportunities by fostering inter-household cooperation to achieve relative economies of scale and clustering group activities to achieve supply chain integration and diversification.
3. To develop at the national level a core support base consisting of a demonstration site, trainers and support persons providing entrepreneurial assistance to rural enterprises.
4. To link production or technology-based projects to market opportunities through creation of a rural-based entrepreneur culture making technology transfer recipient driven as opposed to donor driven.

Figure 1. Local trainers and FAO team in Lao PDR.

IMMEDIATE OBJECTIVES

1. To train national focal persons in a portfolio of skills required to stimulate and sustain rural enterprises.
2. To upgrade popular traditional food products for identified markets within the regional tourist sector.
3. To develop safe, hygienic practices based on traditional processes and upgrade packaging, supply and distribution.
4. To establish in each country a pilot site, functioning as an active, sustainable enterprise and collectively harnessing the output of a number of households.
5. To add value to on-going technology transfer or credit-orientated projects.

OUTLINE OF PROJECT ARRANGEMENTS

This technical assistance was supported by the FAO Technical Cooperation Program Project "Village Level Processing – Empowerment through Enterprise Skills Development" jointly with the Ministries of Agriculture in Viet Nam, Myanmar and Lao PDR. Each country arranged for an office and staff to operate this Regional Project.

Viet Nam located the project in the Viet Nam Institute of Agricultural Engineering and Post Harvest Technology (VIAEP) as their regional and national training site; Myanmar provided their Central Agricultural Research and Training Center (CARTC), and Lao PDR their Crop Multiplication Centre (CMC) as their training sites.

The project was coordinated by the FAO regional office in Bangkok, and an agroindustries expert from Thailand was recruited as an international consultant and project Team Leader. The Team Leader recruited additional international and national consultants under the project in the following areas and disciplines:

International Consultants:

Food Product Development.
Food Marketing
Food Micro- Enterprise

National Consultants:

-Viet Nam:
1. Product Development
2. Micro-Enterprise

- Myanmar
1. Product Development
2. Micro-Enterprise

-Lao PDR
1. Product Development
2. Micro-Enterprise

RESULTS

Regional Training on Village Level Processing - Empowerment through Enterprise Skills Development at Viet Nam Institute of Agricultural Engineering and Post Harvest Technology (VIAEP), Hanoi, Vietnam.

Between 2nd - 20th October 2006 the Regional Training Course on 'Village Level Food Processing – Empowerment through Enterprise Skills Development' was held in Hanoi, Viet Nam, at VIAEP. In attendance were eighteen participants from Vietnam, Myanmar and Lao PDR, consisting of twelve Focal Point Persons and six National Consultants. There were also two volunteers, one each from Cambodia and Myanmar, who attended at their own expense.

Regional Training Course Topics

The regional training course consisted of the following topics:

Marketing : Theory and Exercise	18 hours
Micro-Enterprise : Theory and Exercise	18 hours
Communication and Group Work	14 hours
Food Processing Theory	11 hours
Food Processing Practicals	40 hours

Marketing Survey Exercise 10 hours
Village visits in 2 villages (Occupational Community Villages OCV)
(to inspect confectionary & noodle production)
Training at the village level: 12 villagers in 1 village
(which is making dehydrated onions)

Considerable time was spent in addition to the above hours stated, in group networking, communication, as well as translation and traveling to the various sites for field activities.

National Training of Trainers on Village Level Processing – Empowerment through Enterprise Skills Development in Vietnam, Myanmar and Lao PDR.

CONCLUSIONS AND OUTCOMES

1. Training Resources

Rapid rural enterprise sub-sector assessments were made of selected OCVs in Viet Nam, detailing success criteria of the agribusiness in terms of raw material production, product flow from raw material through producers and ultimately to the consumer. This material was later used in training resources to be applied in Myanmar and Laos by the trainers and trainees.

2. Trained Core Team of National Focal Persons

Selected focal persons were trained in a range of rural enterprise development and skills, activities will be action-focused using examples from the selected OCVs in Viet Nam and employing a Success Case Replication (SCR) procedure.

3. Identified Traditional Products Suitable for Sale to Local Consumers or Tourists

After developing an inventory of national traditional products in Laos, Myanmar and Viet Nam, a short list of items have been presented to local consumers (or tourists) for feedback. For each country, a food product has been selected for production and marketing, viz., pumpkin crackers for Vietnam, solar dried tomatoes for Myanmar and fried ripe bananas for Lao PDR.

Figure 2. Traditional food samples from Lao PDR.

4. Pilot Sites Operating in Each Country

Viet Nam has located the Viet Nam Institute of Agricultural Engineering and Post Harvest Technology (VIAEP) as their pilot training site, whereas Myanmar has used the Central Agricultural Research and Training Center (CARTC) as their pilot training site and Lao PDR the Crop Multiplication Centre (CMC) as their pilot training site. The trained focal persons supported by technical assistance will work with households in their community to develop a full set of enterprise development skills and a collaborative mechanism enabling households to work together.

5. Value Addition

Many products have been demonstrated as having value addition to the agricultural raw material. Each raw material has been processed into at least three products. Trainers have adapted appropriate processing technology to suit the local demands. Throughout the project the villagers were able to develop the ability to measure and record the value addition and increased income.

Figure 3. Dried chillies and mushrooms in Lao PDR market.

6. Capacity Building

The intention of the project has been to promote food processing and micro-enterprise development and entrepreneur skills of personnel in government, supporting institutions and villages, through demonstration and training. The following elements have contributed to the capacity building aspect of the project.

The initial group of focal persons undertook a Regional Training Course in Viet Nam. This group of National Trainers has translated skills developed in Viet Nam into their local context. The members of the group were then responsible for establishing a local pilot site in their back-home situation, where a modified entrepreneur skill set could be transferred to local extension workers from government and supporting institutions, who in-turn would through their village level training courses, develop 'Village Trainers'.

Training materials have been prepared and/or adapted during the Regional Training in Viet Nam and the establishment of the pilot sites. These contain details on food processing, micro-enterprise development, marketing, group formation and dynamics, use of savings and credit. They can be used and modified jointly in consultation with trainees and trainers throughout the project.

7. Establishment of a Network of Family-based Micro-enterprises

The village level food processing training has been carried out to contribute to enhancement of income generation, food security and nutrition for the members of the pilot site as well as the villagers to be trained. The approach has been centered on family-based micro-enterprise development, creating economies of scale and greater independence through the development of production groups.

Figure 4. FAO village level training in Myanmar.

A group-based Success Case Replication (SCR) approach has been one of several options that was used where appropriate and applicable, to introduce a sustainable mechanism for micro-enterprise skills training in the food-processing sector. In the selection process successful entrepreneurs were identified from vulnerable groups. Success case stories were documented and incorporated into training materials for groups.

The trained pilot site participants were expected to disseminate the acquired skills to other community members and households, through existing farmer group and/or community based learning institutions. Capacity building would continue to be facilitated by close collaboration with the concerned government Ministries of Agriculture, and their Extension Departments.

Figure 5. Village level processing in rural Lao PDR.

SUCCESS CASES FROM THE TRAINING

In Vietnam:

Two trainers have performed their work very successfully, both on Training Villagers and Processing Pumpkin Crackers. They have trained 10 women from their communes in making potato chips and sweet potato chips, added-sugar crackers. Each day 200 kg of pumpkin crackers were processed and packed in 1 kg plastic bags. One kg of fried pumpkin crackers can be sold for the equivalent of US$1.50, so in one day a producer could gross US$300. The product is supplied to restaurants and small shops in bulk and this approach has helped in marketing. It is expected that there will be an expansion of these activities to other nearby communes.

Figure 6. Viet Nam food display.

In Myanmar:

A trainer started food processing to establish a viable enterprise. The products are tomatoes preserves, tamarind toffee, and banana chips. A modified, small solar dryer which cost about 20,000 kyats (US$32) will be used to make products that have good quality packaging to attract the buyer. The products are sent to a broker in a larger town, and to snack shops in the village and nearby. The trainer has also trained ten village participants and one of them is going to start her own enterprise after the village training.

In Lao PDR:

Processed banana chips from ripe bananas have been developed, and this product is different from the training given (using raw banana). This new idea gave very interesting sweet products. Up to 80 hands of banana could be processed per day and sold for 400,000 kips (US$42.32) per day, with a profit of about 200,000 kips (US$21.16) per day.

Figure 7. Production of banana chips.

TCP PROJECT RECOMMENDATIONS

SUCCESS CASE REPLICATION

After training, trainers have successfully carried out training for other women and many of them have started their entrepreneurship, which indicates that the training is a successful. In order to have success case replication, Trainers have to continue follow up on their Trainees to assist them to be successful entrepreneurs.

VILLAGE FOOD PROCESSING TRAINING CENTRE

The Village Food Processing Training Centre in every country should continue to conduct national training by the National Project Directors, National Consultants and Focal Point Persons.

Figure 8. FAO team with local trainers and trainees in Myanmar.

FOLLOW-UP SUPPORT

The training has equipped the Trainers with the essential skills in food processing, economics, marketing, and business management. Practical exercises were lively and taken very positively by the trainees. The success of the training is actually measured by how far the trainees have been able to establish and operate their own enterprises and also conduct training for other villagers. In reality the trainees normally encounter unanticipated complexities and challenges for which no class room or laboratory-based training could have prepared them adequately.

KEEPING THE TRAINING CENTER ACTIVE IN WOMEN ENTREPRENEUR DEVELOPMENT

With strong policy-level backing, together with technical and moral support from the Ministry, the Center may be able to earn its income by conducting training sessions, charging fees on the use of the equipment, and processing food for the markets. The details of cost and income sharing arrangements need to be worked out.

The Center should actively approach the market players such as wholesalers or the potential buyers from different companies or offices. A mix of products needs to be produced and marketed in response to the demand mix for a number of products. This strategy opens up opportunities for low cost production and distribution, and the utilization of seasonally-available raw materials. It also helps to minimize risks of market failures of particular products, and compensate the low profit margins of some products by high profit margins of others. Recently-trained village women can be invited to work for wages on a part-time or full-time basis as per market demands and their time availability, further aiding to women's employment.

ROLE OF NATIONAL PROJECT DIRECTORS

National Project Directors should make contact with local fruit and vegetable associations or allied associations for marketing support.

Figure 9. Pickled tea products from Myanmar.

Figure 10. Lao PDR solar dryer.

ROLE OF THE GOVERNMENTS

The TCP Project strongly recommended that the governments should continue giving support to all participants to carry on their processing activities in the villages. Most participants have learned enough to successfully perform food processing but they may need additional support on product improvement, supply of packaging materials, micro-credit and marketing support.

It was further strongly recommended that the governments should try to find some funds for hiring additional National Consultants and Focal Point Persons to enable them to develop further the positive results of this TCP Project.

ASSISTANCE FROM OTHER ORGANIZATIONS

This TCP Regional Project was a pilot project. With the successes of this pilot project, it is hoped that the results will lead to additional assistance from other international organizations (e.g. UNDP, ADB, World Bank, GTZ, EU and JICA) to continue the expansion and grow the activities. During and after the training, many organizations have visited the success cases and have shown their interest and gained very good impressions from these and other success cases. Of course, the ultimate success of such activities will be the development of viable and sustainable food processing activities that do not require outside assistance, and assure better food quality, safety and nutrition for producers and consumers.

ACKNOWLEDGEMENT

The author would like to acknowledge the major contribution to the projects described in this paper made by Dr. Narin Tongsiri, Former Dean of Agroindustry at Chiang Mai University, Thailand. As FAO Project Team Leader, he identified the other international and national consultants for the project. Sadly he passed away in April 2008.

Figure 11. Team Leader Dr Narin trains village level banana chip makers.

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Improving the Operation of a Commercial Mango Dryer

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ABSTRACT

Mangoes are an important commercial crop in many tropical countries. The drying of mangoes is an ideal value-added opportunity for processors in many developing countries because the processing requirements are relatively non-capital intensive. In addition, there is a ready market for the product both domestically and in the export trade. The regular export trade, dominated by a few countries in South East Asia, consists of mangoes dried with sulphites to stabilize color and with sugar added to improve product texture. Processors in Burkina Faso, West Africa have decided to focus their attentions on the organic market, since mangoes produced in this fashion can be sold at premium prices. The mangoes are usually dried near where they are grown in forced-air cabinet-type dryers fuelled by bottled gas or heated by solar radiation. Sensory quality is particularly difficult to control in this product since, without chemical stabilization or added sugar, colour changes (due to both enzymic and non-enzymic browning) and/or texture defects can occur. Careful control of temperature and humidity parameters as well as drying chamber design is critical to achieving optimal product quality. Dried mango can be used as an illustrative example of the impact of technology transfer on the improvement of small-scale food processors in developing countries. Operational problems that are typically encountered can prevent expansion and reduce profitability. Through technology transfer such problems can be overcome and economic viability achieved.

INTRODUCTION

In this case study, a representative food drying operation similar to many found in developing countries is considered. The fruit of the mango tree (*Mangifera* sp.) is a major commercial tropical tree fruit, grown in many countries of the world. Although the total production of mangoes in Africa is small in comparison to production in other areas of the world, the sale of fresh and dried mango represents an important domestic and export value-added opportunity.

Due to the perishable nature of fresh mangoes, their export to Europe and America from Africa represents a formidable challenge. Capital-intensive cold storage and refrigerated transportation requirements can easily be beyond the technical capabilities of processors in poorer African nations. Dried mangoes, however, are a less capital intensive value-added product that can be easily processed, stored and shipped.

World-wide, dried mango represents a multi-million dollar market. Aimed primarily at the American and Western European countries these dried mangoes, stabilized though the use of sulphites and added sugar, can be used as an ingredient in many products such as breakfast cereals and granola-type bars. Much of the production of dried mango for the above mentioned markets originates in Asian countries such as the Philippines and Thailand. African processors find it difficult to compete in this market with those countries.

Many African countries, however, have identified organically-grown and processed dried mangoes as a market in which they can compete, especially Europe. In Burkina Faso, the mango season begins in June, when especially certified growers (internationally certified by entities such as Eco-cert©) begin shipping their product, primarily from the South-West, to processors throughout the country. Although most mango dryers are centered around Bobo-Dioulasso, many processors also operate outside that area (e.g., Ouagadougou).

In Burkina Faso, processors can operate their businesses in cooperation with other similar processors as a kind of commodity-based cooperative or club (Fr. approche filière), or as an independent entity. The advantage of the filière approach is enhanced access to technical support from governments and Non-Governmental Organizations (NGOs). Mangoes are transported to the processing establishment where they are stored (some for final ripening), sorted and washed.

Washed mangoes enter the processing areas, where they peeled and sliced by hand into about 1cm thick slices. The slices are then arranged upon a drying frame that consists of a fine nylon mesh, placed over a large metal screen, which in turn is supported by a wooden frame (Figure 1). Frame size is about 0.75m by 1.0 m. The processing facility is certified organic by an internationally recognized certifier (Eco-cert©), and meets all of the sanitation and food safety requirements of that organization.

Figure 1: Mango slices being placed onto drying frames

Figure 2: Small production-scale cabinet dryers

Figure 2 shows the small production-scale cabinet dryers that use heated air as the drying medium. Each dryer chamber is about 0.75m wide and about 2.5 m tall. In a typical installation there are eight such chambers. The drying frames, containing the mango slices, are slid into an open chamber, each chamber holding about 20 frames. Once fully loaded, the doors of the dryer are closed and drying commences. After an appropriate time, the dried mango slices are removed from the dryer, cooled, inspected and placed into low density polyethylene plastic bags which are then heat-sealed and labelled.

DEFINING THE PROBLEM

The mangoes produced by these processors must meet organic standards. This means that sulphites or other types of preservatives cannot be used to control enzymic browning. Rather control of enzymic browning must be attained through careful control of product temperature and moisture content. In addition, since no sugar can be added, the texture of the product must be controlled through careful control of water activity (a_w). In an attempt to control enzymic browning, the processors start the drying process at very high temperatures (often as hot as 80°C). Theoretically, thermal denaturation of the intrinsic polyphenol oxidase should occur at this temperature. Drying temperatures are slowly reduced over an 8-12 hour period to about 65°C. There is no monitoring or control of product moisture content, or humidity of the drying air.

Even though the dryer is being supplied with high temperature air, drying of the mango slices is not uniform. When the drying chambers are opened after drying, some slices appear too dry and have inconsistent colour (too dark). The texture of the dry slices also appear to be inconsistent, with some too firm. Paradoxically, a portion of the mango slices appears to be too moist at the end of the run, with voids, or pockets of un-dried mango contained within a pocket of dried, firm mango. If dried mango slices are not quickly placed into heat-sealed plastic bags, they begin to noticeably darken within 2 days.

It would seem obvious that process control has not been achieved using the present regimen. Although denaturation of browning enzymes should occur at temperatures approximating 80°C, the actual temperature of the mango slices will be substantially lower. In this non-adiabatic process, water evaporation from the surfaces of the mango slices reduces internal temperatures. Consequently little control of enzymic browning can occur, resulting in the browning phenomenon seen when dried mangoes are exposed to the air. The texture of the mango slices appears be too dry and firm. Texture control of the product must be achieved through careful control of a_w, allowing the natural sugars present in the fruit to act as humectants. Additional textural defects appear from the effect of case-hardening, where too rapid evaporation of moisture from slice surfaces, hinders or blocks the migration of moisture from the slice interior to the surface. Indeed, some slices must then be placed back into the dryer and dried for several additional hours. Running the dryer with only a partial load of product creates an additional cost and reduces the number of batches that can be dried over the course of the mango processing season.

At these high drying temperatures and high air flow-rates, the problem of browning and non-uniform drying persists. Until the design of the existing dryers and the drying regimens change, very little can be done to significantly improve the quality and value-added opportunity of the product.

In addition to these problems with the mango drying, owner are faced with the seasonal nature of their business. Once the crop of mangoes is harvested and dried, the equipment sits idle until the next processing season begins. In order to maximize the use of their capital assets and spread fixed costs over a longer time period, owners would like to diversify the drying operation by drying other materials during the 'off-season'. However, due to the difficulties being experienced with the mangoes, this is not considered to be a viable option until the dryer problems are resolved.

DESCRIPTION OF THE CABINET DRYER

A schematic diagram of the cabinet dryer is shown in Figure 3. Dimensions of the dryer are not stated since this is meant to represent a generic unit rather than that of a specific operation. Air is drawn into the bottom of the cabinet dryer by fan, is heated by bottled gas, and forced into the drying chamber. Heated air is directed across a number of drying frames containing sliced mangoes in the first dryer section (section "A" in Figure 3). For clarity, only three frames are shown in each section of the dryer, although in actual dryers there are often more than this number. After reaching the downstream end of section "A", the air is directed upwards into section "B" which is separated from section "A" by strategically placed partial ply-wood partitions.

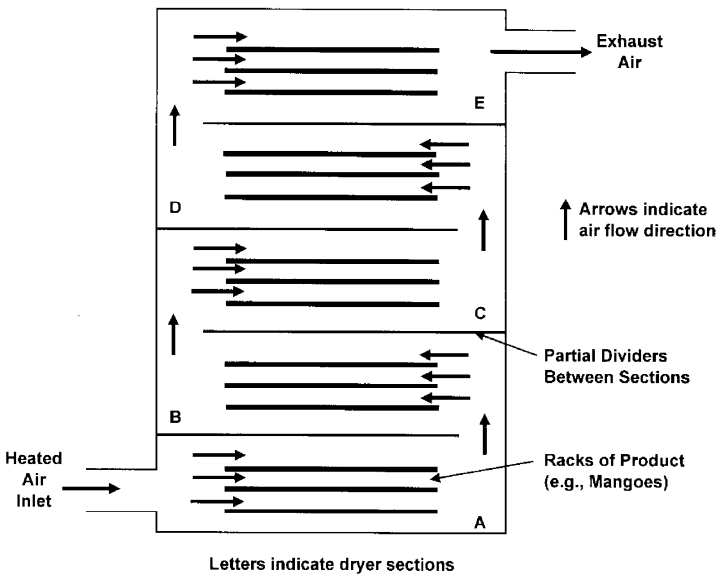

Figure 3: Schematic Diagram of a Production-Scale Cabinet Dryer

The air that has left section 'A' then reverses direction and passes across the frames of sliced mangoes located in section 'B'. At the end of section 'B', the air is once again directed upwards into the third section of the dryer, section 'C', where air flow is once again reversed. Air continues up in this serpentine way through sections 'D' and 'E', after which the air is exhausted into a plenum arrangement, combining the exhaust of two chambers at the top of the dryers and expelled through a common flue.

Temperature of the drying air can be monitored by three or four dial thermometers inserted through the walls of each section. There are no automated process controls on the drying units. Airflow is controlled by adjusting the speed of a motor on a fan that introduces the air into the first zone of the dryer. As with most dryers of this type, the fan is usually run at full speed to maintain maximum air flow to the dryer.

MANGO – COMPOSITION AND DRYING CONDITIONS

The fruit of the Mango tree (*Mangifera* sp.) grown in Burkina Faso are about 125 mm long and about 75 mm in width. The fruit consists of an inedible central flat seed surrounded by yellow flesh and an outer inedible skin. The edible flesh contains about 82% moisture. The main chemical constituents on a % dry weight basis (% d.b.) are shown in Table 1 (3).

The flesh contains about 70% sugar, mostly composed of sucrose, and a relatively large amount of fibre, reflecting the fibrous nature of the fruit. Mango is unlike fruits such as raisin or dates which contain large amounts of sugar, but relatively small amounts of fibre. The fibrous nature of the fruit

explains why dry mango tends to be somewhat firm in texture. Careful control of a_w is essential if the processor is to avoid an overly tough consistency. Figure 4 shows generic water sorption isotherms of mango fruit (3).

Table 1: Compositional Data for Selected Fruit Including Mango (% d.b.)

Fruit	Fru	Glu	Suc	NSP Ara	NSP Xyl	NSP Man	NSP Gal	NSP Glu	NSP Uronic acid	Protein	Ash
Raisin	51.16	43.14	0.00	0.20	0.10	0.00	0.00	0.90	1.10	3.05	2.32
Date	42.25	43.55	0.53	0.17	0.54	0.16	0.34	1.68	1.55	2.39	1.94
Pineapple	21.36	18.33	44.40	1.20	2.10	0.30	0.70	4.00	0.70	2.72	2.72
Mango	17.68	6.36	46.11	3.70	1.10	0.20	1.70	5.40	5.90	3.83	2.19

Fru = Fructose Glu = Glucose Suc = Sucrose Ara = Arabinose Xyl = Xylose
NSP = Non-starch Polysaccharides Man = Mannose Gal = Galactose

In general, dried fruit are considered shelf stable if the a_w is at 0.6 or below. For dried mangoes, the equilibrium moisture content (% d.b.) equivalent to an a_w of 0.6 is about 15% moisture. Careful monitoring of the mango slices as they are drying is essential to avoid over drying. Such over drying could lead to texture defects such as tough consistency.

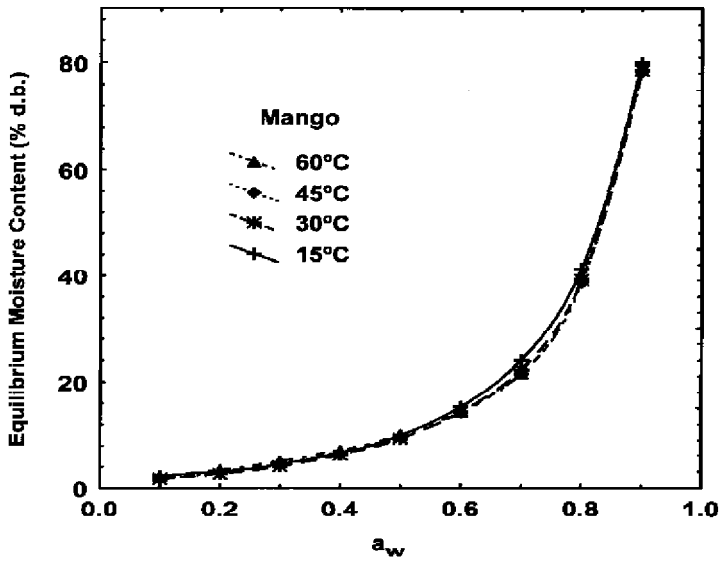

Figure 4: Water Sorption Isotherms of Mango (3)

PROBLEMS ENCOUNTERED DURING DRYING

Through experience, the dryer operators know approximately how long it takes to process an average load of mangoes. After drying for this amount of time, the dryer is shut down and opened to remove the racks of dried product. In general, the mango slices in section 'A' at the bottom of the dryer (Figure 3) are over-dried (i.e., their moisture content is below that considered acceptable) and they are darker in colour (probably due to Maillard reaction products) than those in section 'E' which is the last section of this particular dryer. The mango slices in section 'A' also have a less pliable texture (due to the extremely low a_w) than the softer slices in the final sections of the dryer. Not only is there variation in moisture content from the bottom to the top of the dryer, but moisture content variation also occurs within each section of the dryer. There are often regions along the centre of each rack where the mango slices are drier than those along the edges of the rack. Often, the mango slices on the bottom rack in sections 'B', 'C', 'D' and 'E' are not as dry as those on the upper racks in these sections.

Faced with the problems outlined above, processors may experience excessive rejection of product that fails to meet specifications for moisture, colour, and texture attributes. Mango slices with excessive moisture levels (especially those in section 'E') must receive additional drying which reduces the number of full loads of product that can be scheduled. Overly dry dark product cannot be sold at a premium price, and when possible is sold at a loss to recover some of the production costs. Hand sorting of mango slices from each dried batch to remove high moisture product for reprocessing and overly dried product adds to the labour costs.

In order to improve the operational efficiencies of the mango drying operation, the processor should conduct a thorough 'audit' of the drying process. This audit should consist of two tasks. The first task is to evaluate the drying protocols regarding drying times and temperatures. A flow-chart diagram of the process should be constructed which can outline where potential problems can be identified. Once the locations of the problems have been identified, protocols can be changed to address those problems. These protocols have a profound and direct effect upon the quality attributes of the product. The second task should be to assess the drying equipment itself, to better measure drying parameters and enhance drying efficiencies. Since airflow is one of the primary contributors to drying, along with time and temperature, it seems reasonable to begin by examining airflow patterns within the dryer. While pitot tubes or anemometers could be used to determine actual air velocities and pressure taps could be installed in the dryer to determine uneven pressure distribution, these devices are not really necessary for a basic examination of how the dryer is functioning.

In a developing world situation, it is important that this audit be carried out in as simple a fashion as possible, due to limitations in access to capital and technical expertise. The audit should not be an overly arduous task involving sophisticated analytical equipment.

TASK ONE - DRYING PROTOCOLS

Before making any modifications to the dryer or changing operating conditions, it is necessary to understand what happens to the mangoes during the drying process. In this way, conditions can be better matched to the needs of the product which is something often neglected in many drying processes.

By following a volume element of air through the dryer (as shown in Figure 3), a true appreciation of the process can be obtained. As a volume of air enters section 'A' of the dryer, it is at a high temperature (e.g., 80°C) and at low absolute moisture content. Its ability to remove moisture is high, and it readily takes up moisture from the surface of the mango slices located in section 'A'. The air will also be distributed in a relatively uniform manner due to the inherent design of the air inlet into this section. The relatively dry air absorbs moisture from the product, and its (the air) temperature decreases. As the moisture content of the mangoes decreases, their temperature comes into equilibrium with that of the air. This process continues in section 'A' as the air gains more moisture and loses more heat. It is important to realize that although the main purpose of the very high air temperature (besides removing moisture) is to denature the polyphenol oxidase, no such denaturation can occur, since its (the air) temperature is reduced well below that necessary for enzyme inactivation. As a result, enzymic browning can occur (2). Of perhaps more serious consequence, the high rate of moisture loss from the surface of the mango slices creates a surface layer of very dry mango. This surface layer, once formed, has a very limited ability for rehydration, and can prevent moisture from migrating from the interior of the mango slice to its surface. This phenomenon, known as case-hardening, can block further moisture loss and can lead to the development of interior pockets of moisture which are very hard to eliminate.

As the air continues on its journey, the combination of heat loss and increased level of saturation reduces the water removal capacity of the air as it enters section 'B'. In section 'B', the air will still have sufficient ability to remove water from the mangoes, but it will gain additional moisture and lose more heat as it does so. As the air enters section 'C', its water removal capacity will be further diminished and it will once more gain moisture and lose heat as it passes across the mango slices in this dryer section. By the time the air reaches sections 'D' and 'E' in the dryer, it will no longer be able

to remove moisture from the product at the same rate that it did when it entered section 'A' of the dryer.

If the dryer is operated to produce a satisfactory product moisture in the final section, product in the four previous sections will most likely be overly dried and be suffering other quality attribute problems such as off-colour development and textural defects. From this, it is evident that measures must be taken to ensure that product in each section of the dryer receives a uniformly distributed supply of air at a suitable temperature and initial moisture content to promote optimal quality attributes and efficient drying.

Psychrometric charts coupled with wet and dry bulb temperatures, or dry bulb temperatures and relative humidity readings, taken throughout the dryer can provide a more exact indication of what is occurring to the air as it passes through the various dryer sections. However, simply envisioning that the air is becoming more heavily loaded with moisture and is losing heat as it does so, points out the need for an alternate approach to the drying protocol and how air flow is managed in the dryer.

Figure 5 shows the effects of air velocity (at 50°C) on the water removal from mango slices in a laboratory-scale tray dryer (1). By plotting the moisture ratio (i.e., the dry basis moisture of the mango slices at time "t" divided by their initial dry basis moisture), drying test runs can be compared directly without the distraction of having different starting moistures. In these tests, observations were taken every fifteen minutes over the course of the dryer runs. By comparing the moisture ratios for the mango drying at 50°C with air velocities of 0.2 m/s and 0.5 m/s as shown in Figure 5, it can be seen that increasing the linear air velocity across the surface of the mango slices has a pronounced effect on the rate at which moisture is removed. This can be attributed, in part, to disruption of the stagnant boundary layer of air that impedes the removal of water from the saturated surface of the mango slices. With continuous removal of moisture from the product surface, drying efficiencies are enhanced.

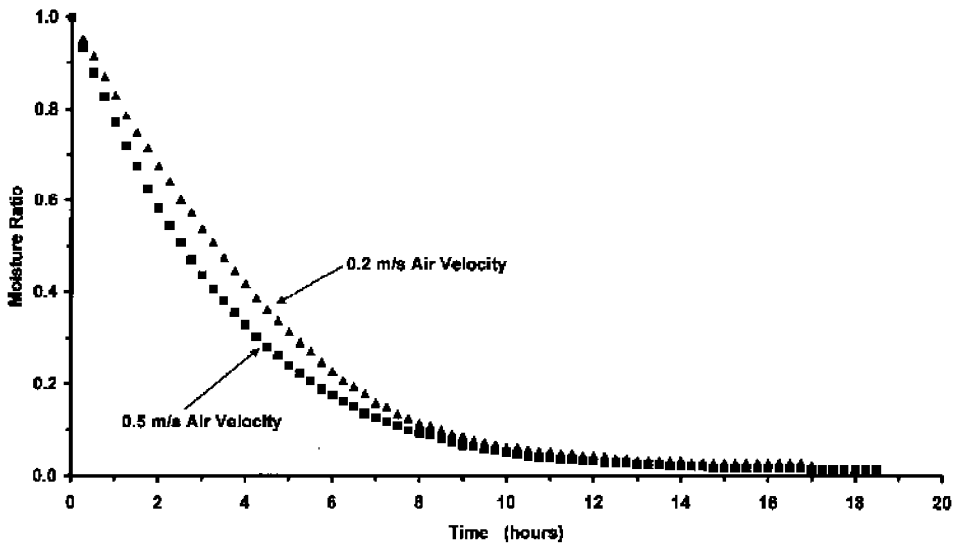

Figure 5: Moisture Ratios versus Drying Time for Mangoes in a Tray Dryer at 50ºC with 0.2 m/s and 0.5 m/s Air Velocities

Figure 6 shows how increasing the temperature with an air velocity of 0.5 m/s can add to the efficiency of water removal for the mangoes (1). Water removal rates during the first 2.5 hours for the drying runs reported in Figures 5 and 6 are presented in Table 2. These values were obtained from plots representing the initial constant rate drying period for mangoes (d.b. moisture versus time), which are not shown in this paper.

Table 2: Water Removal Rates of Mango Slices under Various Drying Conditions

Drying Conditions	Initial Water Removal Rates (g water/g dry solids/hour)
0.2 m/s Air Velocity at 50°C	0.73
0.5 m/s Air Velocity at 50°C	1.38
0.5 m/s Air Velocity at 55°C	1.46
0.5 m/s Air Velocity at 60°C	1.69

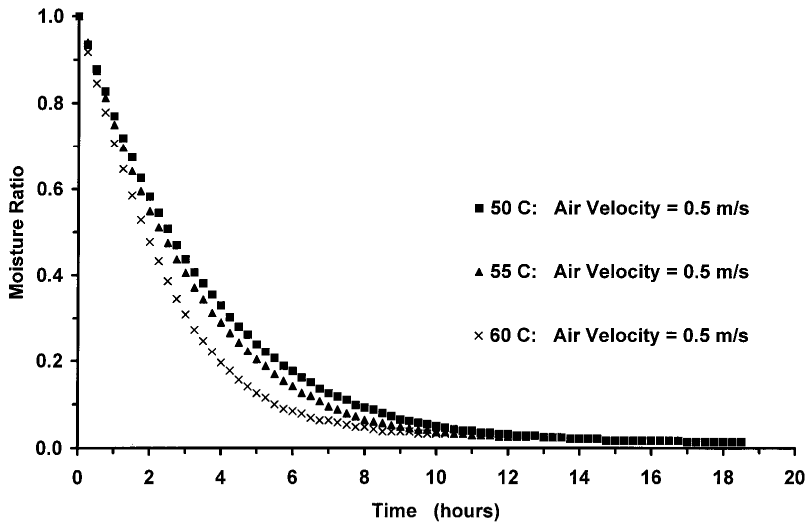

Figure 6: Moisture Ratios versus Drying Time for Mangoes in a Tray Dryer at Various Temperatures

Photographs of the mango slices at the start and end of a drying run appear as Figures 7 and 8, respectively. Figure 8a shows the dried mango slices on the metal rack inside the laboratory-scale tray dryer, while Figure 8b shows them after they have been removed from the dryer.

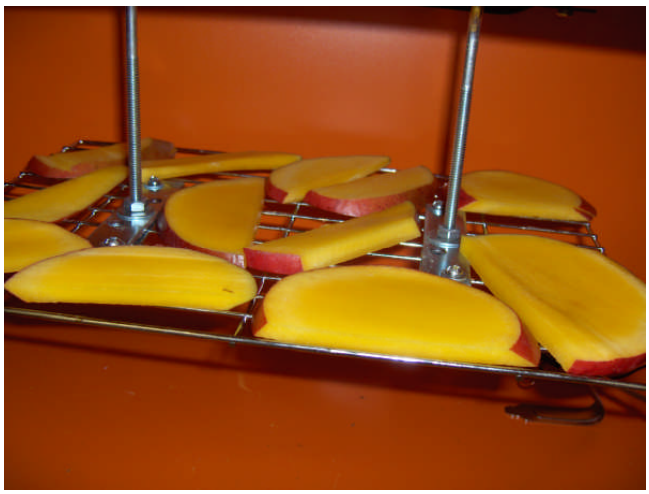

Figure 7: Mango Slices at Start of Drying on Rack in Tray Dryer

Figure 8a: Slices of Mango after Drying on Rack in Tray Dryer

Figure 8b: Slices of Mango after Drying in Tray Dryer (removed from dryer)

Using this information, it becomes quite obvious that drying efficiency increases with an increase in air velocity and temperature (for a given moisture content). In order to produce optimal drying conditions to achieve improved product quality, the drying protocol needs to be carefully monitored. The moisture content and temperature of the drying air need to be as constant as possible as it passes across the complete drying frame. The uniformity of the air distribution patterns must also be increased in order to maintain optimal air velocity.

With enhanced air distribution, the drying protocol should be altered to take advantage of these improvements. Initial drying air temperature should be reduced from the current 80°C to a more moderate 50°C. At the lower water removal rates, moisture from the mango slice interior will have time to migrate to the surface, where it can in turn evaporate. This lower initial water removal rate will avoid problems associated with case-hardening. As drying proceeds, the temperature of the drying air should be slowing increased, still allowing for the movement of water within the mango slices, but also compensating for the lower water moisture removal rates, the result of lowering a_w and increased water binding. Drying air (and mango slice) temperatures as high as 80°C could be tolerated in order to denature browning enzymes; as the product nears the monolayer moisture point. As the product approaches the monolayer moisture point, however, drying air temperature should again be reduced to more moderate temperatures (50°C) to reduce the production of Maillard reaction products (2).

TASK TWO - ASSESSMENT OF DRYING EQUIPMENT

Looking at Figure 3, it can be seen that air entering section 'A' of the dryer strikes a vertical wall at the end of the section and is then forced upwards into section 'B' where it strikes the bottom surface of the horizontal divider between the top of section 'B' and the bottom of section 'C. This flow pattern is repeated each time the air leaves one section of the dryer and enters the next section. The combination of two 90° turns for the air leaving one section and entering the next creates non-uniform air distribution patterns.

One potential way to create a more even air distribution pattern would be to install louvers at the downstream end of each section mounted at a 45° angle to deflect the air upwards into the next section. Similarly, louvers could be mounted at a 45° angle at the upstream end of the following sections to deflect horizontally across the racks of mango slices. In this way, the lower racks of product would receive more airflow than they did previously. Figure 9 shows how modifications could be made by installing louvers and deflectors to direct the air as it travels from one section of the dryer to the next.

By improving the air distribution pattern in the cabinet dryer used for the mangoes, higher linear velocities could be achieved to enhance water removal and drying uniformity. Increased turbulence across the surface of the racks can reduce the 'wall effects' noted in many dryers with poor airflow distribution. It may also be advisable to install several deflectors at the upstream end of each dryer section to deflect air towards the walls of the dryer and minimize side-to-side moisture variations.

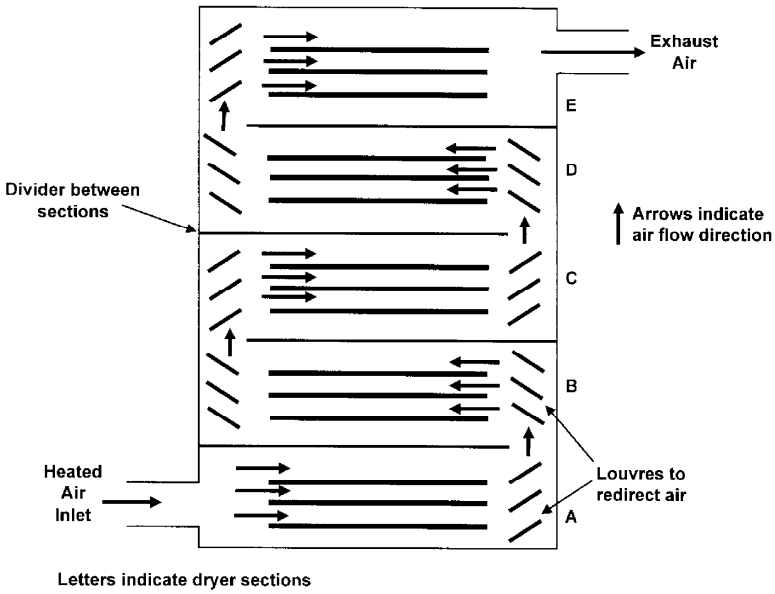

Figure 9: Schematic Diagram of Modified Production-Scale Cabinet Dryer (based on design presented in Figure 3)

There is one significant feature of the dryer design in Figure 3 and the improved design with louvers shown in Figure 9 that still needs to be addressed. Air passing over the mango slices in each dryer section travels to the next section where it is expected to remove water from the mango slices located there. 'Water removal capacity' is an effective manner in which to envision the ability of air to remove moisture from a product. To determine the water removal capacity of air, it is necessary to know how much water the air contains compared to how much water the air could hold if it was fully saturated at that temperature. Absolute moisture contents can be obtained from psychrometric charts, when the dry bulb temperature and wet bulb temperature or relative humidity of the air, are known.

The difference between the amount of water the air is holding and the amount of water it can hold when saturated (i.e., 100% relative humidity) can be described as its maximum water removal capacity.

Figure 10 shows a proposed re-designed cabinet dryer which addresses the problems experienced with the original dryer shown in Figures 3 and 9. Heated air is blown into a plenum that runs the full height of the cabinet dryer. Several entry points, instead of one single supply point, could enhance the uniformity of air distribution into the heated air plenum. Perforated panels form a wall between the heated air plenum and the five sections containing product to be dried. These panels consist of sheet metal or other appropriate matter with small holes (e.g., 2 cm diameter) drilled at regular intervals to provide an open area of approximately 30% to 40% of the total panel area. They act to create a back-pressure in the hot air supply plenum which then promotes uniform distribution of the air into the drying sections. In this way, all five sections of the dryer will receive a relatively uniform supply of heated air with enough water removal capacity to remove moisture from the mango slices. The velocity of the air will also be sufficient to sweep away the stagnant boundary layers that inhibit moisture removal. Once the air leaves each dryer section, it passes through a second set of perforated plates designed to maintain uniform air distribution inside the drying sections. The air then enters an exhaust plenum where it is directed out of the dryer. The exhaust air could then pass through a counter-current heat exchanger where its residual heat could be used to warm fresh incoming air. Optionally, a portion of the exhaust air could be mixed with fresh incoming air to recover some of the heat, providing the exhaust air's water content is not too high for this purpose.

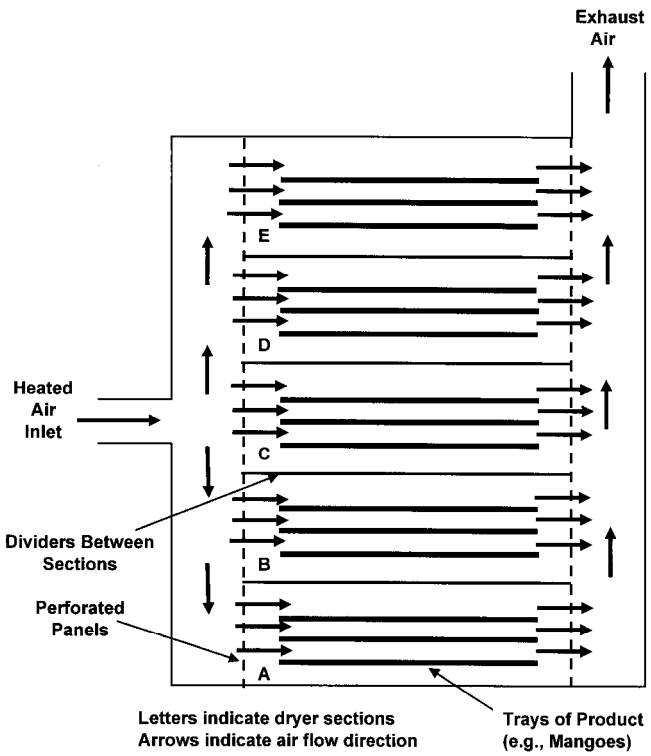

Figure 10: Schematic Diagram of Re-Designed Cabinet Dryer

For smaller dryer loads, sections of the dryer could be blocked off and only as many sections as required would need to be used. This further enhances the flexibility and efficiency of the dryer's operation.

ECONOMIC OPPORTUNITIES

By reassessing drying protocols and re-designing dryers, processors can reduce product variability, thereby lowering losses due to excessive rejection of product that fails to meet specifications for moisture, colour, and texture attributes. This would lead to improved efficiency and enhanced profitability. More runs could be conducted during the harvest season since there would be less need to re-dry mango slices from runs which previously contained overly moist product.

Increased flexibility and uniformity in dryer operation would allow processors to seek out alternate products to dry when mangoes are out of season. Other fruits and vegetables requiring different

drying conditions could be dried by altering drying protocols and dryer configurations to meet the different drying needs. Having the dryer in operation throughout the year would maximize the utilization of the business's capital assets and take advantage of a variety of opportunities.

When dryers are operated year-round, rural employment can become less seasonal and more sustainable. These benefits could then spread throughout the local community. With a larger industrial processing base, capacity expansion or additional diversification could be possible. This would further increase rural employment, providing economic benefits for all. By understanding the drying kinetics of each product being dried, process operating protocols could be modified to match air temperature to the drying needs of the product. During the initial and later stages of drying, lower temperatures may be required by the product. This would allow the dryer to be operated at lower temperatures for as much as half of the drying cycle, resulting in fuel savings and lowering production cost. Not only would this result in fuel cost savings, but over-drying and under-drying could be reduced thereby improving product quality, resulting in more saleable product per dryer run with subsequent improved profitability.

SUMMARY

Small and medium-scale businesses that produce value-added products provide opportunities for economic development in many developing countries. These businesses create jobs and provide much needed incomes for the urban and rural poor. These value-added products, produced from locally sourced raw materials, are not capital intensive, and take advantage of local labour markets, providing decent incomes for those that otherwise would continue to exist in impoverished conditions.

It is important for donor nations, in their official developmental assistance (ODA) programs, to support private sector entrepreneurs in the developing world. With such support, the entrepreneurs will be in a better position to identify markets and develop suitable processing technologies. Continued improvements in production processes can result in new and expanded markets, which in turn can enhance efficiencies and profitability.

Although technology transfer from developed nations is an essential part of any donor nation's ODA, it is important for them to understand the economic and infrastructural constraints found in the developing world. In environments which lack capital with poor infrastructure, optimization of relatively simple, straight-forward processes should be favoured. By examining the mango drying business from a fundamental perspective, basic changes can be recommended that have the potential to overcome most of the difficulties outlined in this case study. It is important, however, for developed countries to promote appropriate technologies: to do otherwise would be to chance disappointing results.

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Implementation of a Two-stage Drying System for Grain in Asia

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ABSTRACT

Methods for drying products such as grain continue to increase in sophistication. One method suited to drying cereal grains has been developed and applied to Asian conditions. This is the concept of two-stage drying which breaks the moisture reduction operation into two separate stages. Since grain after harvest is subject to observable deterioration within the first twelve hours, the first stage covers initial high-speed removal of water, reducing the product water activity to a level sufficient for medium-term storage. The second stage involves slow continued dehydration to a moisture content suited to longer term storage, using near-ambient in-bin mechanical aeration at conditions suited to a safe rate of moisture reduction at best economy. Since Asia covers a range of climates (ranging from tropical to temperate), computer modeling was used to optimize the application of in-store drying. Two-stage drying interfaces best with bulk handling and requires a sufficient volume of product to justify careful management and trained operators. The first stage should be designed to reduce the water activity to below 0.80. Equipment suitable for the first stage includes any form of fast dryer, including the fluidized-bed dryers developed through a series of Australian government research projects with Thailand and now commercialized. The second stage allows further reduction in water activity to about 0.70 and has been primarily implemented through in-store dryers. These dryers consist of large bins in which bulk product at several meters depth (typically 4 m for tropical conditions) is aerated with ambient air heated by a small amount. A set of aeration bins of this form serves multiple purposes, which are receival cooling, aeration holding, drying, storage and fumigation. The main incentive for two-stage drying is recognition of the drying mechanics of rice grains which are soft above about 18% moisture content and can be dried rapidly without damage. In fact if dried in a suitable temperature range, their surface hardness may be increased, reducing damage when subsequently milled. Below 18%, rapid drying may induce fissuring, causing a predisposition to fracture during milling. Gentle, slow drying allows moisture and thermal re-equilibration within the grain to relax drying stresses and improve milling yield. In addition, near-ambient drying benefits from the natural drying capacity of the air, reducing the energy and hence environmental impact.

INTRODUCTION

The main purpose in drying farm produce is to reduce its water activity from the harvest level to the safe storage level in order to extend its shelf life. Once the produce has been dried, its rate of deterioration due to respiration, insects, microbial activity and biochemical reactions should diminish leading to maintenance of quality of the stored product.

Grains are among the world's most important commercial crops. They can be dried in a number of ways. The traditional way, used since the beginning of agriculture, consisted of sun drying the harvested produce on the ground. The ground may be bare, be covered with a fabric, be a compacted yard of a farm, often be the side of a sealed road, a concrete surface or a basketball court. However, increasing grain production due to agronomic progress, mechanization and irrigation has resulted in more grain being harvested at the same time. In order to be able to dry increasing volumes of grains, various new drying techniques had to be developed.

Increasing mechanization of field, harvest and postharvest operations resulted in the development of bulk handling techniques, initially in the USA and then other industrialized temperate countries. Bulk handling involves integrating operations of crop harvest, safe handling, drying and storage, and provides the opportunity for integrated pest control and the maintenance of seed quality by controlled drying, cooling and aeration. The high cost associated with the acquisition of bulk handling equipment is offset by economies of scale resulting from handling large amounts of grain leading to a lower cost per unit of grain or seed processed versus traditional bag handling. Since drying is an essential part of the bulk handling system, specific drying systems have been developed to suit the handling of grain in bulk.

Grain drying systems can be classified into various categories depending on the operating temperature range. The first category includes high temperature dryers that are used to reduce the moisture content of the grain crop within a short time. High temperatures tend to create moisture gradients within the interior of the kernel and may result in stress cracks. In order to dissipate the moisture gradients, the grain has to be tempered for a length of time. High temperature dryers include recirculating batch dryers, continuous flow dryers, rotary dryers and also fluidized-bed and spouted-bed dryers. The second category includes low temperature dryers that use a fan to blow ambient or near-ambient air through a fixed bed of grain. Provided that the relative humidity of the drying air is below that of the equilibrium moisture content of the grain, moisture will be released from the grain into the atmosphere. Dryers in this category are generally used in silos or warehouses and are called in-store dryers. A two-stage drying system combines the benefits from fast drying, high temperature dryers, i.e. removal of the surface moisture in very wet grain, and those of low temperature drying in terms of grain quality and low energy consumption. Two-stage drying systems have been extensively tested in Australia and in various regions of Asia by the UNSW research team and collaborating partner organizations. As a result of this research, the two-stage drying system has been successfully adopted in a number of tropical countries in Southeast and South Asia (Thailand, Vietnam, NE India) and also in continental or temperate regions of China (provinces of Heilongjiang, Jiangsu, Sichuan and Yunnan).

A factor favoring the adoption of mechanical drying was the increasing use of large-scale bulk handling equipment for grain. The mechanical dryers currently in use by the industry range from high-temperature, high capacity, single stage continuous-flow or fluidized-bed fast dryers with high energy inputs to various types of in-bulk dryers operating at high or near ambient air temperature with low energy inputs but longer drying time. There are various types of in-bulk dryers (10) such as:

- warehouses with in-floor or above floor aeration ducts
- ventilated silos with perforated floors and vertical airflow (round or square)
- ventilated silos with separate inlet and exhaust ducts
- ventilated silos with vertical ducts and radial airflow

Besides the single-stage system, there are combination or two-stage systems that have been developed to take into account different drying rates of grain at various moisture contents. Normally, the first drying stage involves high temperature, fast drying in order to reduce the moisture content from its harvest level so that the product's water activity falls below 0.80. The moisture targeted by fast drying is concentrated at and near the product surface and can be removed easily. Once the first stage drying has been completed, the grain is transferred to a storage bin where it is cooled down to ambient temperature and dried further to a safe storage level using air at near-ambient temperature. The second stage of drying is targeting moisture at the centre of the kernel and thus this process is mostly diffusion driven. The drying rates are significantly lower than during the first stage drying, the second stage drying taking place in the 'falling rate' period.

In-store drying (17) is synonymous with in-bin drying using air at near-ambient temperature. This technique is used when grain remains in store until being milled or exported, or if drying is considered as the primary purpose of the equipment, with the dried grain being transferred to another bin for aerated storage. The advantage of in-store drying is the increase in throughput and reduction of capital cost per unit dried. There may be a situation when the trader needs a fast turnover of grain to purchase a fresh stock.

Two-stage drying has the following advantages (11):

- reduced energy requirements
- increased drying system capacity
- improved grain quality

The reduced energy requirement over conventional drying methods is due to the increased air efficiency compared with continuous-flow dryers, so that less heat is vented to the atmosphere. The second point is related to the capacity of the first stage dryer, since discharge of the grain at higher moisture content before cooling will free the dryer for the next batch of high moisture grain, which is where the high temperature dryers are more efficient. The third point relates to the relaxation time given the grain during the second stage of drying that allows moisture gradients within the grain to dissipate, preventing the outer layer of the grain from being overdried and hence made brittle and susceptible to damage.

HISTORY OF THE DEVELOPMENT OF TWO-STAGE DRYING

The two stages of drying were originally developed independently of each other, in an empirical way, and started being used as a system once the theoretical basis was laid in the 1980s.

IN-STORE DRYING

In-store drying has been practiced in the USA since the 1950s among maize farmers in the North Central Region and rice farmers in Texas (6). The technique was used mostly on an empirical basis and sometimes resulted in grain deterioration due to airflow rates being too low or drying air temperatures too high.

In order to determine the appropriate conditions for the use of in-store drying, systematic studies were conducted resulting in the development of a mathematical predictive model (18) called the 'near equilibrium' model. The model could predict changes in grain moisture content, grain temperature and dry matter deterioration. It took into account factors such as heat transfer through the walls of the bin, respiration of the grain mass and changes occurring in the grain through continuous aeration. The approach consisted of calculating heat and mass balances across a single layer of drying material. A deep-bed was considered as a superposition of a number of single layers of material subjected to a stream of drying air perpendicular to each layer. This work was initially done on maize, a major commercial crop in the USA. Farmers were required to reduce the moisture content of maize to 15.5%. Any deviation from that moisture content attracted a penalty. Maize with a higher moisture content was subjected to a risk of deterioration due to mould and insect activity. Computer simulations based on this model using weather data collected over a long period of time and including temperature and relative humidity from various locations in the maize growing areas were used to predict the drying time for maize in these locations.

Since in-store drying operates at near-ambient conditions, minor changes in these conditions can have large effects on drying rates and therefore careful research was required to ensure that drying air of adequate quality was available each year to be able to move the drying front through the grain bed before a significant deterioration took place in the top layer. As a result of this research, areas in the USA were zoned according to the aeration conditions suitable for in-store drying (18). Schedules for different locations were specified so that grain could be quickly cooled after harvesting and was receiving sufficient aeration for drying. Various systems for improvement in the drying process have been developed over time, particularly for prevention of overdrying of the bottom layer, for reduction of a moisture gradient between the top and bottom layer, for efficient loading and unloading, and also for rewetting of the inlet layer.

In-store drying was later extended to other countries and crops grown in temperate climates. These included wheat in the USA (1), barley in the UK (13) and canola in Canada (12). Considerable research was undertaken in those countries involving the analysis of weather data and appropriate airflow rates in order to design adequate in-store drying facilities. In Australia, in-store drying was adopted by

the rice industry soon after its introduction in the USA (4). It was a logical addition to the conversion from bag to bulk handling in order to deal with the problem of high moisture content at harvest and sun cracking. The usual practice in Australia is to harvest paddy at about 21% moisture content w.b. (wet basis) and dry it in storage to below 14% for storage and milling. The ambient conditions in the rice growing region in Australia are favorable for aeration drying and require no supplementary heating. Initially, round bins with central ducting providing radial air distribution and mesh walls were used. They were later replaced by horizontal warehouses (see Fig. 1) with in-floor or on-floor aeration that provided easier access for loading and unloading of grain. Various systems (outlined below) were introduced subsequently, for example layer filling, computer-controlled bins, supplementary heating and use of computer models in the management of drying and storage operations.

Figure 1: Large in-store dryer used in the rice industry in Australia

In-Bin Drying Systems

The main attraction of in-store drying is that it allows savings on equipment cost by allowing use of the same bin for drying and storage (7). In every design, air passes through the mass of grain, picking up moisture on its way. An important design consideration is to ensure that all the grain in the bin is exposed to the drying air.

The main types of in-bin dryers (5) are as follows:

- full bin: bin is filled with grain, and dried, cooled, aerated and stored in the same bin
- full bin with stirring, allowing more uniform grain treatment
- layer-filled bin, in which grain is dried in successive layers, new grain being added as the previous layer is dried
- on-floor batch in–bin, used for drying a batch of grain and occasionally for cooling as well, in a method similar to the flat-bed dryer in Asia
- recirculating, in which grain at the bottom of the bin is picked up by the auger, swept to the centre and then augured to the top of the bin, where it is respread, allowing the grain to be recirculated for more uniform treatment and reduced airflow resistance
- dryeration, a specific technique in which grain is dried at high temperature in a bin, to within 2-3% moisture content (w.b.) of the actual final moisture required, then transferred hot into a tempering bin. After the drying stresses have been allowed to equalize, the grain is then cooled using ambient air, the stored heat removing the final 2-3% moisture. This produces a high quality grain with low susceptibility to breakage.

An important characteristic of in-store dryers is their low specific energy consumption. The latter is defined as the sum of electric and fuel energy required to evaporate a unit quantity of water. For in-store dryers it is generally less than 3 MJ/kg versus 2.5 MJ/kg for pure water at similar temperature.

Accessories for Improving Performance

Various accessories and operating modes have been developed in order to improve the performance of in-store dryers, generally focusing on grain quality. These include:

- Stir augers

Augers are devices for vertical mixing of the grain. They rotate slowly around the bin, taking 1-2 days to complete a circuit. Major advantages are the reduction of moisture gradient between bottom and top layers, and a decrease in compaction of the bottom layers by the top ones, resulting in an improved airflow pattern. The disadvantages are high cost, wear on augers if used with paddy, mechanical damage to grain and reduced thermal efficiency.

- Air recirculation

The idea of recirculating a certain proportion of the drying air is often used for high temperature dryers. However, since the drying air in the in-store drying process comes to equilibrium with the wettest air, the system has naturally a high thermal efficiency and thus there is no advantage in recirculating the drying air. As a result, the cost of additional equipment is not justified by the limited advantages deriving from air recirculation.

- Dehumidification

Dehumidification is used with recirculation. There are various methods ranging from cooling the exit air in order to remove moisture by condensation to using chemical desiccants. However, except for high value crops such as seed, dehumidification has generally not been adopted for grain due to high equipment cost.

- Grain recirculation

This technique consists of moving partially-dried grain from one bin to another or from bottom to top of the bin. There are obvious advantages from this process in terms of tempering, mixing, repackaging and reduction of compaction leading to a better airflow through the grain bed.

HIGH TEMPERATURE DRYING

High temperature dryers are used to reduce the moisture content of a grain crop within a short time. The crop loses moisture but the drying is halted before the product comes to equilibrium with the low relative humidity of the drying air. Drying at high temperature rapidly removes moisture from the outer layers and causes considerable moisture gradients within the interior of the kernel. If the gradient becomes too great, there is a risk of stress cracks forming with resultant grain damage. In order to dissipate the moisture gradient, the grain has to be tempered for a length of time (in the order of hours), especially in the case of large seeds.

Dryers in this category are generally high capacity dryers operating within a temperature range of 50-300°C, according to the dryer type and crop requirements. The specific energy consumption decreases with increasing drying air temperature. For a dryer operating within 50-200°C temperature range, it is between 3-10 MJ/kg. With increasing air temperature more moisture can be absorbed. This results in a lower airflow rate at higher operating temperatures. As a result, high temperature, high capacity dryers operating at a lower airflow rate are the more cost-efficient dryers in this category.

As with in-store dryers, the development of high temperature dryers accompanied the conversion from bag to bulk handling which started in the USA, and was later adopted by most of the major grain producers. This category includes recirculating batch dryers, continuous flow dryers (concurrent-flow, counter-flow, cross-flow and mixed flow), rotary, fluidized-bed and spouted-bed dryer. The latter two offer particular advantages for grain drying, giving very good grain-air contact and a short exposure time to the drying air.

RESEARCH ON TWO-STAGE DRYING OF GRAIN IN ASIA

This chapter focuses on the research conducted in a number of countries in Southeast Asia, selected regions of China and Northeast India where the authors have been collaborating with local scientific organizations in research on grain drying.

IN-STORE DRYING

Generally, weather conditions in humid tropical climates are less favorable for in-store drying than in temperate climatic zones. Initially, the principles of in-store drying adopted were used for cooling paddy dried in high temperature dryers by aerating bulk grain in a holding bin with ambient air. However, since the late 1970s, researchers in subtropical and tropical countries began studying conditions for successful adoption of in-store drying for paddy and subsequently maize, peanuts and soybeans. Techniques initially developed for temperate countries, particularly optimization achieved by the use of computer models, have been extended to tropical conditions. In order to compensate for high daily relative humidities, higher drying air temperatures and airflow rates have been introduced.

Extensive research on in-store drying of paddy, based on fundamental studies on deep-bed drying of granular solids conducted in the rice growing areas since the 1970s, resulted in improved strategies for paddy drying in Australia (4). The following conditions were found to be essential for successful drying:

- segregation of procured paddy according to moisture contents
- use of low speed fans
- use of aeration strategies taking into account daily fluctuations in weather conditions

These studies were validated on an industrial scale using bins with a capacity of 3000-5000 t and bed heights of 4-7 m.

In order to test in-store drying techniques developed in Australia, collaborative research has been conducted since the early 1980s with scientific partner organizations in Thailand, the Philippines and Malaysia. Later this research was extended to Vietnam, various regions of P. R. China and Northeast India. This research was funded by The Australian Centre for International Agricultural Research. The main objectives of this research were:

- to determine thermophysical data for the main grain crops with the aim of designing adequate drying systems for these crops
- to investigate the first stage drying options for areas where it was required
- to collect weather data in order to be able to simulate a range of drying scenarios occurring in the main grain producing regions
- to study the effects of various drying strategies on the grain quality

The results of the studies were published in a number of journal articles and presented at technical conferences. The major outcomes of these studies are as follows:

- Comprehensive weather data including air temperatures and relative humidities, generally on a three-hourly basis, covering several years for grain producing areas in Thailand, the Philippines, Malaysia, Vietnam, P. R. China and Northeast India (see examples in Fig. 2 and Fig. 3).

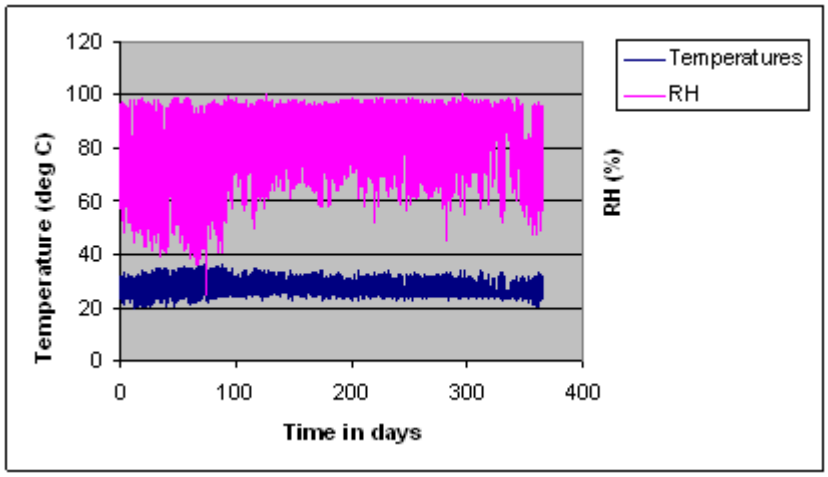

Figure 2. Temperature profile (hourly data) for 1982 from Alor Setar (Malaysia)

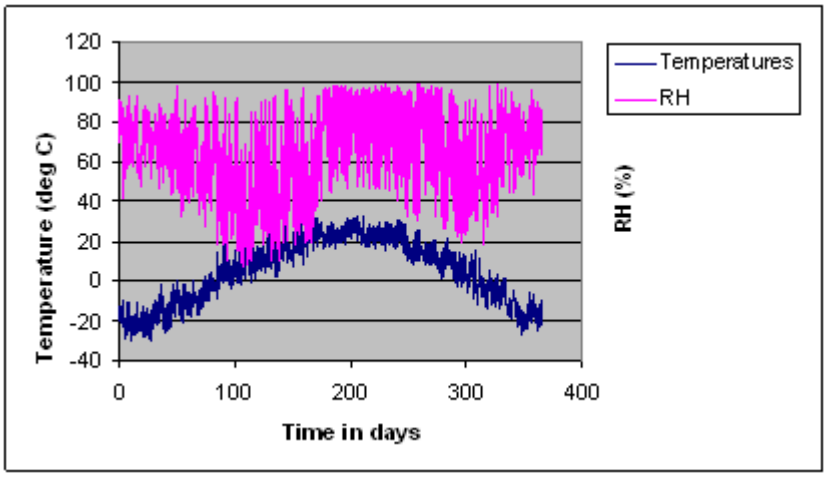

Figure 3. Temperature profile (hourly data) for 1994 from Harbin (P.R. China)

- Thermophysical data comprising bulk and true density, porosity, specific heat, equilibrium moisture contents at various temperature and relative humidity levels, and thin-layer drying equations for a range of varieties of rice, maize, peanuts, sorghum and other grain crops (see Fig. 4).

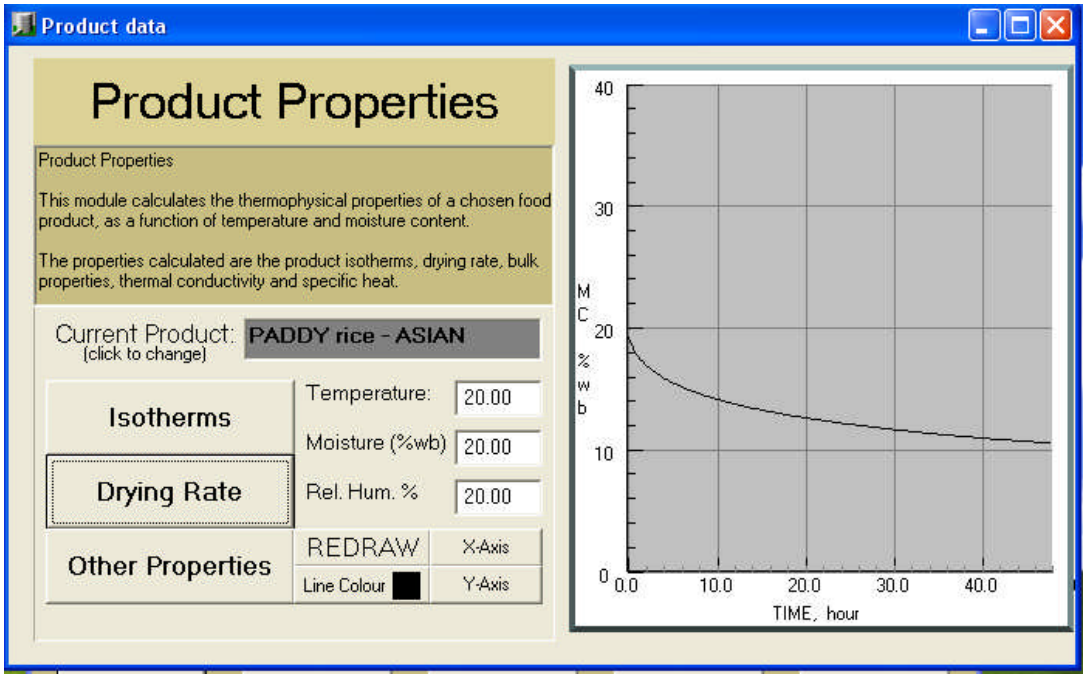

Figure 4. Thin layer drying curve for long grain paddy generated by computer simulation

- Models related to major quality attributes of the grain crops

A computer simulation model based on the thermophysical data obtained above was developed by the research team at the University of NSW in Sydney. The model is based on thermodynamic balances between air and grain. Different strategies can be simulated for in-store drying, among them constant aeration, relative humidity control, time control and modulated burner control. The model makes provision for options such as recirculation of air, stirring of grain, dehumidification and heat losses through the walls.

At a later stage, significant research was conducted in Northeastern China where wet frozen maize is stored in winter until it can be dried after thawing in spring. Weather data for Northeast China and also the major grain growing areas of the country were obtained. Thermophysical properties for frozen maize and later for frozen paddy varieties grown in that part of China were determined (1995-2000).

Simulations (see example in Fig. 5) were used to test the feasibility of in-store drying under climatic conditions of the collaborating countries in Asia. As a result of the simulations, it has been established that in-store drying was feasible and recommendations for making modifications according to climatic conditions were established.

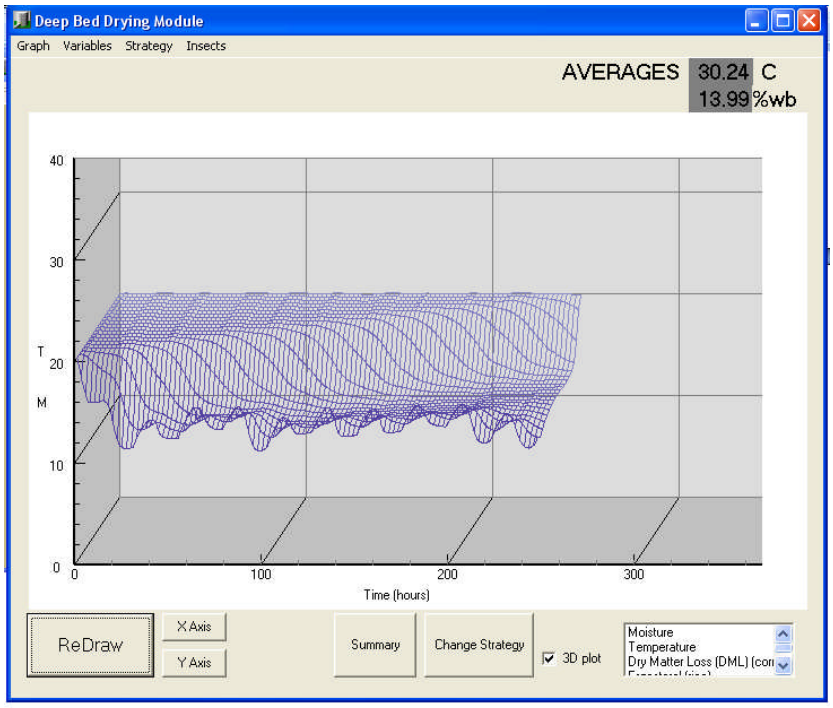

Figure 5. Results of a drying simulation showing moisture content changes in a deep-bed of paddy

FIRST-STAGE DRYERS

High temperature dryers were introduced to major grain producing countries in Southeast Asia in the 1960s, mostly in the large grain export terminals (3). Later on, cross-flow dryers initially designed at the Louisiana State University (generally called LSU dryers) were introduced by large grain mills. A number of local manufacturers soon started building LSU dryers in Southeast Asia. The pace of the introduction, however, was slow since these dryers required multiple passes in order to preserve a high head yield. As a result, tempering steps had to be observed requiring specially-built holding bins and handling equipment. Later on, recirculating batch dryers were introduced but their expansion was often limited by their relatively small capacity.

In China, mixed-flow type brick tower dryers, called double-tower dryers were introduced from the 1950s (16). During the 1960s, the Chinese researchers improved the mixed-flow dryer by adding a

tempering and a cooling section. At the same time, they improved the design of the rotary dryer used for rice in Shanghai. It was also during that time that the designers started studying the possibility of developing a spouted and a fluidized-bed dryer for grain. This work resulted in the development of a fluidized-bed dryer in the early 1980s. Also in the late 1970, many designs of fixed-bed, batch and continuous flow dryers were developed and commercialized. A steam dryer for high moisture maize was also developed and popularized during the 1970s. In the 1980s China imported a few high capacity continuous flow dryers of Western design made entirely from steel. The Chinese engineers started designing their new models based on some of the principles adopted from the Western designs:

- Steel structure without bricks
- Larger capacity (up to 25 t/h)
- Indirect heating

From the early 1990s, researchers at King Mongkut's University of Technology at Thonburi in Thailand in collaboration with the University of NSW team investigated the feasibility of using a fluidized-bed dryer as a fast dryer for paddy and maize (14). They developed laboratory-scale prototypes and conducted experimental and simulation studies on batch fluidized-bed dryer. The experiments led to the optimization of air velocity, bed thickness, fraction of recirculated air and energy consumption. An economic analysis showed that the total drying cost was USD 0.08/kg water evaporated. Subsequently, a cross-flow, fluidized paddy dryer was developed and subjected to thorough testing in order to study the effects of various experimental conditions on the quality of paddy. Once this work was completed, an agreement was signed with a local manufacturer of rice processing equipment and an industrial-scale prototype with a capacity of 1 t/h was built and tested. As early as 1995, commercial units with a capacity of 5 and 10 t/h were designed, tested and built. Within a short time, the fluidized-bed dryer became the second most common mechanical dryer in Thailand. Later on, a cyclonic furnace using rice husks (15) was developed and became widely used with the fluidized-bed dryer. The Thai manufacturer started exporting to other countries in SE Asia and later on to various countries in North and South America and to rice growing countries in Europe.

Research on the fundamentals of grain drying in the fluidized-bed was conducted in Thailand, Australia, Vietnam and the Philippines. Computer simulations based on the mathematical models predicting moisture content and temperature changes in the fluidized-bed dryer have been developed by the project team (see Fig. 6). Biomass furnaces have also been developed in Vietnam and the Philippines.

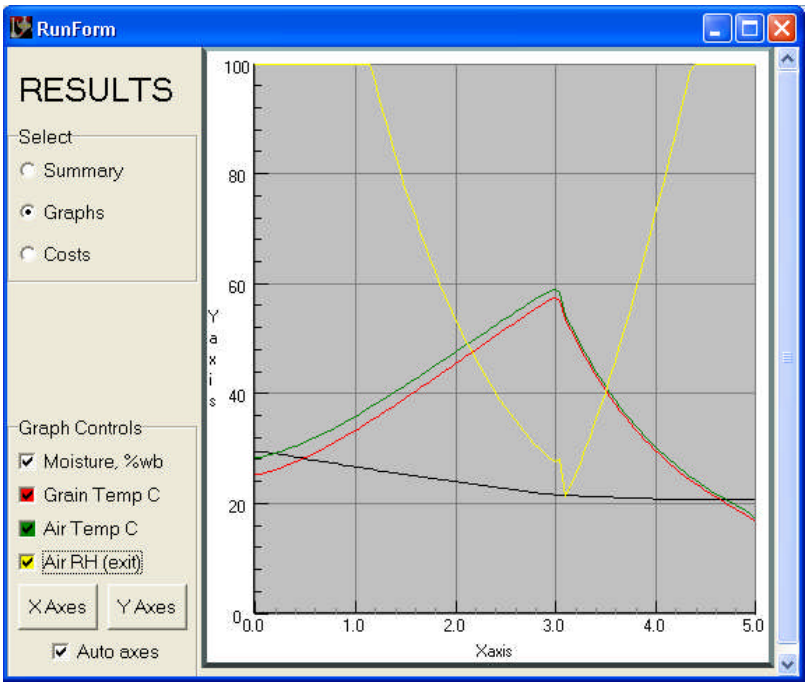

Figure 6. Results of a drying simulation showing a fluidized bed with 3 m drying section and 2 m cooling section

Based on this research, prototypes of fluidized-bed dryers were also developed in Vietnam, the Philippines and India.

Extensive research on the effects of various drying regimes practiced in a fluidized-bed dryer on paddy quality was conducted in Thailand and Australia (19). Among the two quality attributes that affect the price of paddy, the head yield appears to increase with temperature. Yellowing shows the opposite trend without, however, significantly affecting the appearance of rice. The starch properties were also affected by the drying temperature and to some extent by the subsequent storage. Those properties included the gelatinization peak and the endothermic enthalpy of gelatinization, and among the pasting properties, the peak viscosity and breakdown.

Another option for high temperature rapid drying was the development of the spouted-bed dryer. The research was conducted in Australia, Vietnam and Thailand. The work in Thailand focused on a two-dimensional spouted-bed whereas that in Australia and Vietnam was oriented towards a triangular spouted-bed dryer that eventually led to the development of a continuous hexagonal spouted-bed dryer. Mathematical models for drying various grain crops were developed for all these types of spouted-bed dryers (2), (8), (9). Industrial-scale prototypes of spouted-bed dryers have been built in Thailand and Vietnam. The height of the unit built in Vietnam appeared to be the main factor limiting adoption and a purpose-built shed was required to shelter the unit.

TWO-STAGE DRYING SYSTEMS

Based on previous experience in various Asian countries with in-store or fluidized-bed dryers, industrial-scale experiments were conducted in Thailand, the Philippines, Malaysia, Vietnam, various parts of China and northeastern India. The experiments were located in regions where high moisture grain required rapid drying and often the first stage dryer available on-site was used. LSU dryers were used in Malaysia; LSU dryers and later fluidized- and spouted-bed dryers in Thailand; flat- bed dryers and later fluidized-bed dryers in Vietnam; cross-flow dryers and in-bin dryers in the Philippines; fluidized-bed dryers in India and brick-tower dryers in China. Various capacities of in-store dryers were tested, according to the needs of the collaborating grain handler. They ranged from 50 t for some of the seed processors to more than 10,000 t for the large grain depots in northeastern China. In order to reduce the cost of the drying operations, existing storage structures were used and the ductwork and air supply adapted to these structures. Economic assessment showed that the payback periods for in-store drying in Thailand could be less than 3 years if two drying operations were conducted per year (17).

APPLICATIONS IN ASIA

After years of research, two-stage drying systems for grain have been implemented in a number of countries. Often different solutions were chosen according to local socio-economic or environmental conditions. A common characteristic of the acceptance of this system is the scale of drying operation since the larger the scale, the larger the economies of scale and thus the lower the cost per unit of grain dried. Thus larger mills that store grain (rice or maize) for a period of time are the major users of the two-stage drying system. In Thailand, more than 100 fluidized-bed dryers have been adopted by rice or feed mills (for maize). The capacity of the dryers was increasing in response to the demand from the users. It was initially 5 t/h, then 10 t/h and finally 20 t/h. Increasingly they are fitted with rice husk furnaces providing heat for drying (see Fig. 7).

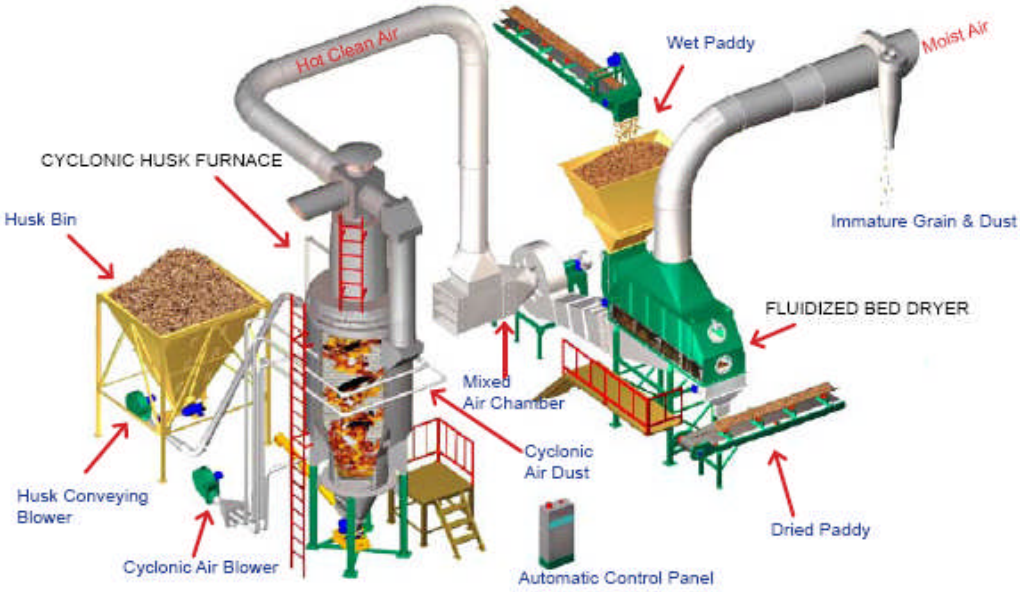

Figure 7. A high capacity fluidized-bed dryer and a rice husk furnace manufactured in Thailand. *Source: Rice Engineering Supply Co. Ltd*

More than 40 mills in Thailand adopted in-store as a second stage of drying. The capacity of in-store dryers varies between 500-2500 t.

In Thailand and Vietnam prototypes of industrial-scale hexagonal spouted-bed dryers have been built and tested with paddy (see Fig. 8).

Figure 8. Examples of industrial-scale prototypes of spouted-bed dryers for paddy:
A) Two-dimensional type in Thailand; B) Hexagonal type in Vietnam

In China, particular emphasis has been put on refining the design of in-store dryers. In order to be able to efficiently use the floor space, the designers chose vertical silos with a radial flow instead of the horizontal flow from bottom to top (see Fig. 9). Such systems were installed in a number of grain depots in northeastern China where japonica rice and maize are dried under subzero conditions.

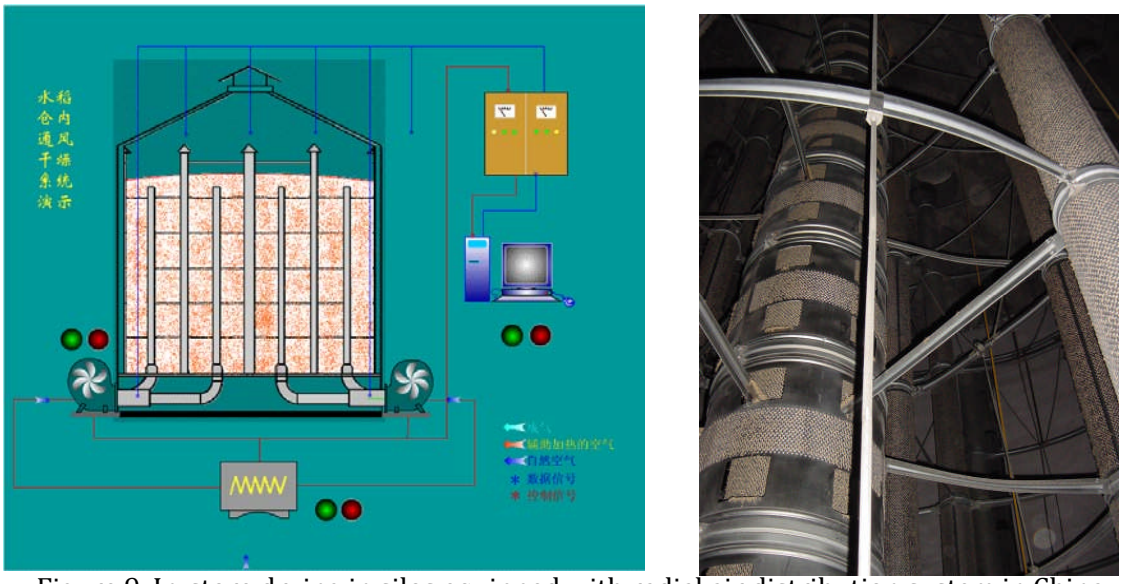

Figure 9. In-store drying in silos equipped with radial air distribution system in China.
A) Schematic showing ductings for inlet and exit; B) Details of ductings

C) Series of silos of 10 m diameter and 13 m height at the Dong Feng Hong grain depot in Heilongjiang, China.

Another option for in-store drying is to use radial air distribution ducting for horizontal warehouses. This is a movable system that can be transferred between warehouses and used for drying or aeration (see Fig. 10). The ductings are designed to be light and can be folded and transported easily. They are inflated by the air supplied to dry the grain. The system comprises a fan, a heater or chiller, flexible ductings and perforated pipes that are sunk into the grain mass. It has been introduced mostly in southern China (provinces of Sichuan and Hunan).

Figure 10. Movable radial air distribution system for horizontal warehouses.
A) Heater and fan outside the warehouse; B) Flexible ductings

CONCLUSIONS

Two-stage drying is a system that takes into account the different drying behavior of grains at different moisture contents. The first stage of drying involving high temperature dryers evolved towards use of grain fluidization, with fluidized- and spouted-bed dryers. There has also been increased use of recirculation of the drying air. More recently biomass furnaces have reduced the impact of fuel cost on the overall cost of drying. For the second stage of drying, in-store dryers are recommended which combine drying and storage. Recent work in China has shown that new configurations of in-store dryer design are possible, allowing flexible adaptation to the needs of industry, with radial air distribution and flexible ducting making the system applicable for both silos and horizontal warehouses.

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EFFORTS TO PROMOTE AMARANTH PRODUCTION AND CONSUMPTION IN UGANDA TO FIGHT MALNUTRITION

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ABSTRACT

Malnutrition is widespread in sub-Saharan Africa. Easy-to-grow nutrient rich foods can help to improve nutrition and food security among communities that heavily depend on subsistence agriculture. In this chapter, efforts to promote grain amaranth in Uganda are described. Grain amaranth was introduced in Kamuli District, Eastern Uganda by VEDCO, a non-governmental organization, in 2005. Makerere University provided technical support to this initiative with Makerere University scientists undertaking studies to determine the nutrition profile of the grain; developing protocols for production of amaranth-based value-added food products; and evaluating the effect of dietary incorporation of grain amaranth on the nutrition status of children. Results show that amaranth grains are high in protein and the proteins are of high quality. The grains are also rich in unsaturated fatty acids, especially linoleic acid, and contain substantial levels of essential micronutrients. Grain amaranth was also found to make acceptable soups, fried and baked products. Feeding trials so far show that grain amaranth leads to improved growth among children. Results from these studies show that grain amaranth has the potential to contribute to improvement of the nutritional status of communities with high levels of malnutrition. The results have been used by extension staff to design evidence-based promotional messages for grain amaranth production and consumption.

INTRODUCTION

Malnutrition is widespread in Uganda and other developing countries. It is a major direct and indirect cause of infant and childhood mortality and morbidity. Besides children, other vulnerable individuals such as people living with HIV and AIDS (PLWHA) have high nutrient requirements. The poor are unable to access adequate amounts of nutrient-rich foods to meet dietary requirements and this is the major reason for the high prevalence of malnutrition. Data from 1995 to date show a prevalence of stunting among children aged <5 years in Uganda ranging between 37 – 39%. Statistics from other countries in sub-Saharan Africa and South East Asia are not much better. There is therefore a need to identify nutrient-rich foods that can be produced inexpensively to meet the nutrient requirements for these vulnerable groups.

Grain amaranth has the potential to contribute to addressing the nutritional needs of vulnerable people because of its high protein content, superior protein quality, high content of essential fatty acids and micronutrients.

Figure 1: Amaranth plant (head loaded with seeds)

Amaranths, which comprise the genus Amaranth, are widely distributed, short-lived herbs, occurring in temperate and tropical regions. There are about 60 Amaranth species, several of which are cultivated as leaf vegetables, grains or ornamental plants, while others are weeds (Kauffman and Weber, 1990). The main species grown as vegetables are *A. tricolor, A. dubius, A. lividus, A. creuntus, A. palmeri* and *A. hybridus* while *A. hypochondriacus, A. cruentus* and *A. caudatus* are the main grain species (Teutonico and Knorr, 1985). Amaranth produces a large amount of biomass in a short period of time (Kauffman and Weber, 1990) and therefore has the potential to contribute to a substantial increase in world food production. Grain yield of up to 5,000 kg/ha has been reported (Stallknecht and Schulz-Schaeffer, 1993).

Figure 2: Dry raw amaranth seeds

Amaranth is one of the few plants whose leaves are eaten as a vegetable while the seeds (Figure 2) are used in the same way as cereals; there is no distinct separation between the vegetable and grain types since the leaves of young plants grown for grain can be eaten as both human and animal food. When the leaves are harvested in moderation, the grain yield is unaltered. Vegetable amaranth species are utilized for food in different parts of the world. Grain amaranth can be used as seeds or flour to make products such as cookies, cakes, pancakes, bread muffins, crackers, pasta and other bakery products (Teutonico and Knorr, 1985). Kauffman and Weber (1990) provided a description of the variety of products made from amaranth in different parts of the world. These include soups and stews from whole grain; *alegria*, a confection made from popped amaranth in Mexico; *atolea*, a fermented Mexican drink made from roasted amaranth flour; *chichi*, which is a form of beer made from amaranth in Peru; *sattoo*, a gruel consumed in Nepal, and *chapatti* made in different parts of Asia.

NUTRITION AND HEALTH BENEFITS OF GRAIN AMARANTH CONSUMPTION

Consumption of grain amaranth is reported to have nutritional and health benefits, ranging from a general improvement in well-being to prevention and improvement of specific ailments and symptoms including recovery of severely malnourished children and an increase in the body mass index of people formerly wasted by HIV/AIDS (SRLP, 2005; Tagwira *et al*., 2006). Tagwira *et al*., (2006) documented perceived benefits of consuming grain amaranth among communities in Zimbabwe. The communities claimed that eating grain amaranth made them feel healthier and they noticed improvements in the health of their children. Specific health improvements noted included improvement in appetite, fast healing of mouth sores and herpes zoster, and weight gain for PLWHAs. Amaranth consumption was also associated with higher milk production among breast feeding mothers.

The improvements in general well-being and health reported by people who included grain amaranth in their diets are generally explainable by its high nutritional value. Some specific nutritional and health benefits of amaranth consumption have been elucidated. Amaranth oil has been shown, in animal studies, to lower total serum triglycerides and levels of low density lipoproteins (LDL) (Esculedo *et al*., 2006). Similar effects have been reported in humans (Martirosyan *et al*., 2007). High levels of serum LDL are associated with coronary heart disease. The serum LDL lowering effect of amaranth has been attributed to the tocotrienols (unsaturated forms of vitamin E) and squalene in amaranth oil. These compounds affect cholesterol biosynthesis in humans (Martirosyan *et al*., 2007). They are also believed to have anti-tumor and antioxidative activity (Kim *et al*., 2006a), pointing to potential anti-cancer effects.

Supplementation of patients with coronary heart disease with amaranth oil has been shown to contribute to a decrease or disappearance of headaches, weakness, increased fatigability, shortness of breath during a physical activity, edema of the legs towards the evening hours and feeling of intermission of heart function in most patients (Martirosyan *et al*., 2007). In addition, decrease in body weight has also been reported. Consumption of grain amaranth has also been shown to have potential benefits to diabetics. Studies suggest that supplementation of diets with amaranth grain and amaranth oil improves glucose and lipid metabolism in diabetic rats (Kim *et al*., 2006b). The fasting serum glucose levels and the glucose tolerance of the diabetic rats were both improved.

INTRODUCTION OF GRAIN AMARANTH IN UGANDA

Grain amaranth was introduced to Kamuli district, Uganda in 2005 by local NGO Volunteer Efforts for Development Concerns (VEDCO) under a program called Sustainable Rural Livelihoods (SRL). VEDCO has partnered with Makerere University to undertake studies on the nutritional value of the common varieties of grain amaranth grown to inform the promotional activities. Studies have also been conducted on the processing and preparation of grain amaranth.

Under the SRL program, extension workers were trained on aspects of grain amaranth production, nutritional value, preparation and processing methods. The trained extension workers were then charged with introducing grain amaranth to communities in Kamuli district. The aim was to promote grain amaranth for household food and nutrition security among the small and medium holder farmers and groups of disadvantaged people.

Grain amaranth demonstration and multiplication gardens were established to provide a source of seeds for farmers interested in producing and consuming the crop. Farmers were trained in seed production, selection and management and given seeds to establish seed multiplication plots on their farms. Two varieties of grain are now widely grown and these are identified as golden and white. The yield on farm gardens is around 3 tonnes per hectare but farmers maintain rather small gardens (average is less than a quarter of a hectare).

Currently, there seems to be no clear market for grain amaranth. Efforts towards market development are therefore required. Product development and value addition could be used to create markets for the crop.

Because the current demand for amaranth is not large, production is low. Community members are producing what they can consume themselves and small quantities for selling locally. In addition a few buyers come from elsewhere e.g., Makerere University Food Science staff, VEDCO staff, relatives and friends. There is need for massive demand creation.

NUTRITION COMPOSITION OF GRAIN AMARANTH

Analysis of grain amaranth obtained from farmers' fields showed that the grains were rich in proteins, lipids, energy and fiber (Table 1).

Table 1: Proximate composition of grain amaranth varieties commonly grown in Kamuli, Uganda

	%	
Nutrient	**White amaranth**	**Golden amaranth**
Protein	12.37	13.04
Carbohydrate	63	63.4
Lipid	6.89	7.29
Fiber	6.33	7.01
Ash	2.85	3.60

Amaranth grains are also known to contain substantial amounts of vitamins and minerals (Table 2). Amaranth grains contain twice the level of calcium found in milk, five times the level of iron in wheat, and higher sodium, potassium and vitamins A, E, C and folic acid than cereal grains (Becker *et al.*, 1981).

Table 2: Amaranth content of selected vitamins and minerals

Nutrient	**Content (mg/g)**
Iron	17.4
Zinc	3.7
Sodium	31
Potassium	290
Calcium	175
Vitamin C	4.5
Niacin	1.45
Riboflavin	0.23
Thiamine	0.1

Source: www.eap.mcgill.ca/CPAT_1.htm: Accessed November 2008.

Grain amaranth has higher levels of protein than most grains and its protein is of higher quality than that of most cereals and pulses. The varieties grown in Uganda have been found to have protein content of 12-13%, which is higher than that of most cereal grains and other common staples. Grain amaranth proteins contain substantial amounts of the essential amino acids that tend to be marginal in common cereals and pulses (Table 3). The level of lysine in both varieties grown in Uganda was found to be above the FAO/WHO reference and more than double the level reported for maize. Methionine levels in the amaranth grains, though slightly lower than FAO/WHO recommended level, is about 3

times the levels in beans. However, amaranth has lower levels of threonine and phenylalanine than the FAO/WHO reference protein and marginal levels of leucine and valine. It should be noted however, that the essential amino acids that are low in amaranth are quite abundant in most diets.

Table 3: Amino acid composition of grain amaranth varieties commonly grown in Uganda in comparison to that of maize and beans

Amino Acid	Content (g/100 g protein)				
	White amaranth	Golden amaranth	Maize	Beans	FAO/WHO Reference
ASPARTIC ACID	7.929	7.492	7.48	10.61	
GLUTAMIC ACID	19.248	19.720	18.37	13.29	
SERINE	6.462	6.090	4.51	4.85	
GLYCINE	8.983	8.700	3.85	3.3	
HISTIDINE	3.346	2.997	5.5	2.28	
ARGININE	9.853	10.295	5.5	4.99	
THREONINE*	2.291	2.030	3.63	4.01	4.0
ALANINE	4.216	4.447	5.72	3.75	
PROLINE	4.812	4.833	6.49	3.25	
TYROSINE	3.941	4.108	4.07	2.94	
VALINE*	4.812	4.785	4.51	5.41	5.0
METHIONINE*	2.200	2.513	1.76	1.04	3.5
CYSTEINE	0.275	0.193	2.31	0.09	
ISOLEUCINE*	4.491	4.350	4.29	4.06	4.0
LEUCINE*	6.279	6.187	13.75	7.1	7.0
PHENYLALANINE*	4.629	4.592	3.63	4.96	6.0
LYSINE*	6.233	6.670	3.41	5.87	5.4

*Essential amino acids

The protein digestibility of the 2 varieties grown in Uganda was found to be around 72% but roasting and popping, the two commonly-used preparation methods, were found to reduce digestibility to 60.6% and 52.5%, respectively. The level of tannins, an anti-nutrient known to reduce protein digestibility, in the grain amaranth varieties grown in Uganda was found to range from 0.11% catechin equivalent to 0.42%, which is higher than the levels in other grains like millet and sorghum. The level varied with the geographical area where the amaranth was grown. The levels of other nutrient inhibitors such as hemagglutinin, trypsin inhibitor and saponins in amaranth have been reported to be within the non-critical range (Escudero *et al*., 1999).

The carbohydrates in amaranth grain consist primarily of starch made up of both glutinous and non-glutinous fractions. Amaranth starch granules are much smaller (1-3 μm) than those found in other cereal grains (Teutonico and Knorr, 1985). Due to the unique size and composition of amaranth starch, the starch may exhibit distinctive characteristics which could be of benefit to the food industry (Lehman, 1988). Amaranth starch seems to have potential for use in the preparation of custards, pastes and salad dressing (Singhal and Kulkarni, 1990a, b).

Amaranth grain obtained from farmers in Kamuli was found to contain 6.9-7.4% oil (Table 1) and the oil was made up predominantly of unsaturated fatty acids, with high levels of the essential fatty acid linoleic acid (Table 4). Based on its fatty acid profile, it can be concluded that grain amaranth is reasonably safe for consumption by individuals that are at high risk of chronic non-communicable diseases such as coronary heart disease and diabetes. Its high content of linoleic acid, an essential fatty acid, makes it suitable for consumption by children since they need essential fatty acids for proper growth and development.

Table 4: Fatty acids profile for grain amaranth from Kamuli, Uganda

Fatty acid	Content (mg/g)	
	White	Golden
Palmitic acid	1.92	2.31
Stearic acid	0.17	0.21
Oleic acid	2.19	1.92
Linoleic acid	2.8	2.41

PROCESSING OF GRAIN AMARANTH

The procedures used in the processing and preservation of amaranth seeds in Uganda are quite similar to those documented elsewhere. In this section, a general description of the methods used in processing grain amaranth is provided and the processes or conditions peculiar to Uganda are highlighted. The influence of some processing treatments on nutritional quality and acceptability are also described.

Grain preparation

When the mature amaranth seeds are harvested, they are dried in the sun, winnowed and stored until ready for use. Grain amaranth should be dried to a moisture content not exceeding 12% to limit mold growth. It is also important to clean the grains since the presence of vegetative material in the grain also encourages mold growth. Mold growth is particularly undesirable because it leads to the accumulation of mycotoxins which are carcinogenic. It is also important to store the grain on raised pallets in containers that allow for heat and moisture exchange. Sisal bags, which are widely used for grain storage in Uganda, are quite suitable for storage of grain amaranth. To maintain grain quality and to prevent loss, it is also important to prevent attack by pests and rodents. Storage pests such as weevils and grain borers do not commonly attack the amaranth grains, and therefore post-harvest losses are minimal if storage is under the conditions described above.

Heat treatment

Processing of amaranth seeds involves heat treatment (popping, toasting/roasting), sprouting and milling. Heat treatment helps to overcome milling problems due to the small size of the amaranth seeds; it also takes away the grittiness of the seeds (Oke, 1993). It may be done by popping and toasting/roasting.

Popping of amaranth seeds is normally done in a large, hot pan at a high temperature (an air temperature of about 220°C for 10 – 15 seconds). The seeds are stirred constantly while popping to prevent them from burning and to allow most of them to pop (Teutonico and Knorr, 1985). Popping of amaranth seeds results in an increase in volume (Figure 3) of up to 1,050 % and gives the grains a gritty flavour (Saunders and Becker, 1984). The increased volume makes milling easier. In Uganda, popping is done using an open fire. The seeds are put on a pre-heated pan and the seeds stirred until the majority are visibly popped.

Figure 3: Popped amaranth seeds

Roasting/Toasting

Roasting/toasting can be done in an oven at around 200°C for 5 - 10 minutes. In rural Uganda, ovens are rare and toasted seeds are those that remain in the pan, un-popped, after open fire popping of amaranth seeds. The toasted seeds (Figure 4) are brownish and give a nutty flavour as well when milled.

Figure 4: Toasted/Roasted amaranth seeds

To sprout grain amaranth, clean amaranth seeds are soaked in water overnight at room temperature. The seeds are removed from the water and heaped on a tray, then covered with a clean towel to keep the seeds warm. After 2 days the spouted seeds (Figure 5) are sun dried for 2 days. The dry seeds are rubbed together to get rid of the shoots (these give a bitter taste to the product made out of sprouted seeds), winnowed and the seeds stored (as described above under the preparation and storage section) until ready for milling into flour. Sprouting the seeds increases digestibility and bioavailability of nutrients.

Figure 5: Sprouted amaranth seeds

Milling

The seeds are milled into flour using a milling machine. In Uganda, some families pound the seeds in a mortar and pestle or grind them using a grinding stone. Pounding and grinding are done on a small scale and usually for a few meals to be consumed at home. This is because the flour quickly develops rancidity if it is kept for more than a month at room temperature. Amaranth keeps best when stored in airtight containers to prevent fat oxidation which contributes to rancidity. Families in Uganda store amaranth flour in airtight plastic containers or polyethylene bags (Figure 6) at room temperature and the flour can remain acceptable for 1-2 months.

Figure 6: Amaranth flour of (left to right): raw, roasted/toasted and popped seeds

The seeds are so small that sometimes some of them come out of the mill whole. Amaranth seeds are sometimes mixed together with cassava or other grains such as millet, maize and sorghum and these are milled together to make composite flour. The ratio of amaranth to millet, maize, sorghum or cassava varies according to individual taste and preference.

Utilization of Grain Amaranth

In Uganda, the products made out of amaranth seeds are soup, porridge, posho (stiff bread/porridge), paste (usually mixed with groundnuts) and pops; it is also used as a sauce thickener.

The SRL program has promoted the use of grain amaranth for feeding malnourished children. The amaranth is usually blended with other grains (mainly maize and millet) and given to children in the form of porridge. Amaranth-based porridge has also been adopted for the feeding of normal children as a complementary food, and for feeding the sick, including PLWHA. Feedback from the community shows a strong association of amaranth consumption and fast recovery from childhood malnutrition and reduced morbidity of PLWHA.

Experiments have been done on incorporating grain amaranth in snack foods commonly consumed by children in Uganda. Acceptable cakes and cookies have been developed with amaranth making up to 70% of the flour used. In other products such as *baggia* (a snack made by cold extrusion of dough followed by deep frying - see Figure 7) and *kabalagala* (a snack made by rolling dough into a flat shape, cutting into a round shape and then deep frying - see Figure 8), acceptable products were made with 100% amaranth flour.

Figure 7: Cold extrusion of dough for making *baggia*

Figure 8: Cutting of dough for making *kabalagala*

These snacks are commonly consumed by children in Uganda. Cookies, cakes and *baggia* are normally made from wheat flour while *kabalagala* is usually made from maize flour. By substituting the wheat or maize flour with amaranth, the protein content and quality as well as the iron, zinc, calcium and B-vitamins content of the snacks were improved. A study is underway to determine the effect on nutrient intake, nutritional status, morbidity and school attendance among school children of substituting the conventional snacks with similar snacks in which amaranth has been incorporated. Results so far show higher weight gain and improved school attendance among children aged 3-5 years snacking on amaranth-based cakes compared to those feeding on wheat-based snacks.

SUMMARY

From the work done so far, it is clear that grain amaranth has the potential to contribute to the improvement of the nutritional status of vulnerable populations such as children and the sick. By developing and promoting a variety of amaranth-based products, consumption of grain amaranth can be increased beyond non-producing communities. Promotion of value-added products can also contribute to expanding the market for amaranth. The next steps will therefore include promotion of value-added products, especially those suitable for feeding nutritionally-vulnerable people.

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Postharvest Storage of Apples in China: A Case Study

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ABSTRACT

China, one of the biggest agricultural countries in the world, has a large production of fruits and vegetables each year. The fruit and vegetable industry has undergone rapid development in China over the last ten years. However, after harvest fruits and vegetables easily lose water and nutritional value due to continued respiration; they are also prone to decay because of contamination from spoilage and pathogenic microorganisms. It is therefore very important to keep postharvest fruits and vegetables fresh during storage to maintain their quality, safety and nutrition. The Chinese government has attached great importance to the safety and nutrition of fruits and vegetables. Three main storage methods are widely used in China: traditional storage, cold storage and controlled atmosphere (CA) storage. In this chapter a case study on apples is used to show how the application of storage technologies has maintained the quality, safety and nutrition of fresh apples in China.

FRUIT AND VEGETABLE PRODUCTION IN CHINA

China is the biggest country for fruit production and vegetable export. According to the Chinese Ministry of Agriculture, the area for vegetable cultivation has expanded rapidly in recent years from 11 thousand hectares in 1996 to 180 thousand hectares in 2006. The yield of vegetables was more than 300 million tons in 2007 and the export volume ranks first in the world. At the same time, the area planted in fruit has also increased quickly, from 8.7 thousand hectares in 1996 to 10.7 thousand hectares in 2006, and the total output from 46.53 million tons to 95.99 million tons, accounting for 17% of world fruit production.

At present, the development of the fruit and vegetable industry faces several serious problems in China [1]. One problem is that most fruits and vegetables are grown in relatively concentrated areas and their production is seasonal. Another problem is that the growth of fruit and vegetable production has exceeded the growth in demand in recent years. In addition, the transport of fruits and vegetables between northern and southern China has increased year after year, resulting in a large nationwide distribution of fruit and vegetable products. All of these problems show that a considerable portion of fruit and vegetable products cannot be consumed in a timely manner after harvest. Therefore it is particularly important to preserve these products until they can be consumed rather than go to waste. Effective storage can prolong the shelf life of fruits and vegetables and maintain their quality, safety and nutrition.

ROLE OF STORAGE IN ENSURING QUALITY, SAFETY AND NUTRITION

Postharvest fruits and vegetables remain physiologically active after harvesting. Respiration, which is the primary metabolism, can affect and constrain the life span of fruit and vegetable products, as well as quality and nutrition changes during storage. Continuing respiration after harvest of fruits and vegetables results in quality deterioration and nutrient reduction. Most fruits and vegetables are high in water content (between 65% and 96%), so they very easily lose weight due to transpiration of water during storage. This leads to a deterioration in the quality of fruits and vegetables and may even result in loss of their commercial value. Postharvest fruits and vegetables also produce ethylene during maturation. Ethylene, a ripening agent, can accelerate fruit and vegetable aging, and weaken antiviral and antimicrobial abilities. Post-harvest fruits and vegetables are also prone to decay because

of spoilage and pathogenic microorganism infestation during storage. All of these result in a decline in the quality, nutrition and safety of postharvest fruits and vegetables [2].

Generally speaking, effective storage can create environments with low temperature and high humidity, or low oxygen and high carbon dioxide, or low ethylene and asepsis, which are beneficial for fruit and vegetable preservation [1-4]. Low temperature and high humidity inhibit the enzyme activities which are necessary for respiration and the growth of spoilage and pathogenic microorganisms which make fruits and vegetables decay; it can also prevent water loss. Low oxygen and high carbon dioxide prevent fruits and vegetables from maturing by inhibiting respiration, while low ethylene and asepsis decrease the rate of maturation and the spoilage by microorganisms.

Thus effective storage can postpone fruit and vegetable ripening and senescence, inhibit respiration and transpiration, reduce the formation of ethylene, and increase their antiviral and antimicrobial abilities to maintain their quality, nutrition and safety as long as possible.

MAIN FRUIT AND VEGETABLE STORAGE METHODS USED IN CHINA

Three main methods are currently used for storage of fruits and vegetables in China: traditional storage, cold storage, and controlled atmosphere (CA) storage [1].

Traditional storage

Traditional storage is the most widely used method, particularly in North China where the average temperatures are quite low (annual range 4-13°C). It is applied to the majority of low-value fruits and vegetables and includes simple preservation and ventilation preservation. Simple preservation is one of the traditional fresh-keeping technologies in China and uses storage facilities with a simple structure, requiring fewer building materials, having low construction costs and making use of local climatic conditions such as kiln, cave, trench and shed. Ventilation preservation takes advantage of natural low temperatures to reduce the temperature in the storage room resulting in a low storage cost and easy management. Generally, simple preservations such as kiln storage, cave storage, trench storage, well storage, and burying storage are widely used in the vast rural-producing areas, while ventilation preservation is mainly used in sales areas. Figures 1 and 2 show well storage of sweet potatoes and kiln storage of bananas, respectively.

Figure 1: Well storage of sweet potatoes

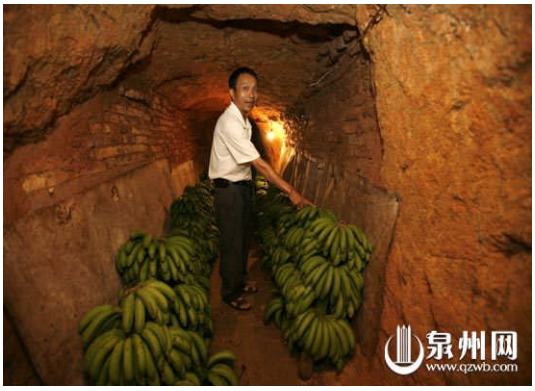

Figure 2: Kiln storage of bananas

Cold Storage

Cold storage involves controlling the temperature in a storage room using mechanical refrigeration. It is used for more than 30 percent of the total fruit and vegetable storage in China. Figure 3 shows cold storage of vegetables in a large cold storage room.

Figure 3: Cold storage of vegetables in a large cold storage room

Controlled Atmosphere (CA) Storage

CA storage is an effective storage method which can achieve the purpose of fruit and vegetable fresh-keeping through naturally or artificially regulating and controlling the temperature, oxygen concentration and carbon dioxide concentration in a permanent storage room. CA storage, though starting very late, has developed rapidly in China. Many large-scale commercial CA storage rooms have been built in China and are used for preserving a variety of fruits and vegetables, especially high-value products such as apples, kiwi fruit, litchis, longan, green cauliflower, mushrooms and peas. Figures 4 and 5 show commercial CA storage facilities in Fujian and Hunan provinces, respectively.

Figure 4: Large-scale commercial CA storage facility in Fujiang province

Figure 5: Medium-scale commercial CA storage facility in Hunan province

CASE STUDY - STORAGE OF APPLES IN CHINA

The annual production of apples in China is about 25 million tons, accounting for 34 percent of the total world production. Of this quantity, approximately 4% are exported, the main export markets being Russia, Philippine, Indonesia and the European Union. The storage and transport processes for apples in China [1;2;5] are presented in Figure 6.

Harvest

Different varieties of apples have different harvest times in China. Usually, the harvest time of early-maturing varieties is about 100 days after florescence, mid-maturing varieties about 100 to 140 days, and late-maturing varieties about 140 to 175 days. Apple which are going to be stored for any length of time should be harvested in advance, usually about 7 to 10 days ahead of the standard harvesting period.

Postharvest Treatment

Precooling and prestorage
In China, apples are harvested from September to October. During this period, the temperature is relatively high so the crop should be precooled by mechanical refrigeration as soon as possible. However, because there is a lack of large refrigeration equipment in China, it is usually precooled by the natural cold weather at night in most areas.

Chemical treatment
Chemical treatment is necessary for precooled apples because it can reduce the incidence of physiological disease and improve the storage performance of apples. In China, precooled apples are often immersion-cleaned by chemical solutions before the preservation process. Many kinds of chemical solutions are used for immersion-cleaning, including calcium chloride solution (3%-6%), ethoxyquin solution (0.25%-0.35%) and thiabendazole solution (1000-2500 mg/kg).

Classification
Classification or grading of apples can be carried out either before or after storage but prior to sale and can be done mechanically or manually, the latter being more common in China. Many classification indices have been confirmed, but color, size, mechanical damage, diseases and pests are the four basic

ones in China. Most varieties of apples are classified according to these four indices. Figures 7 and 8 show mechanical and manual classification of apples, respectively.

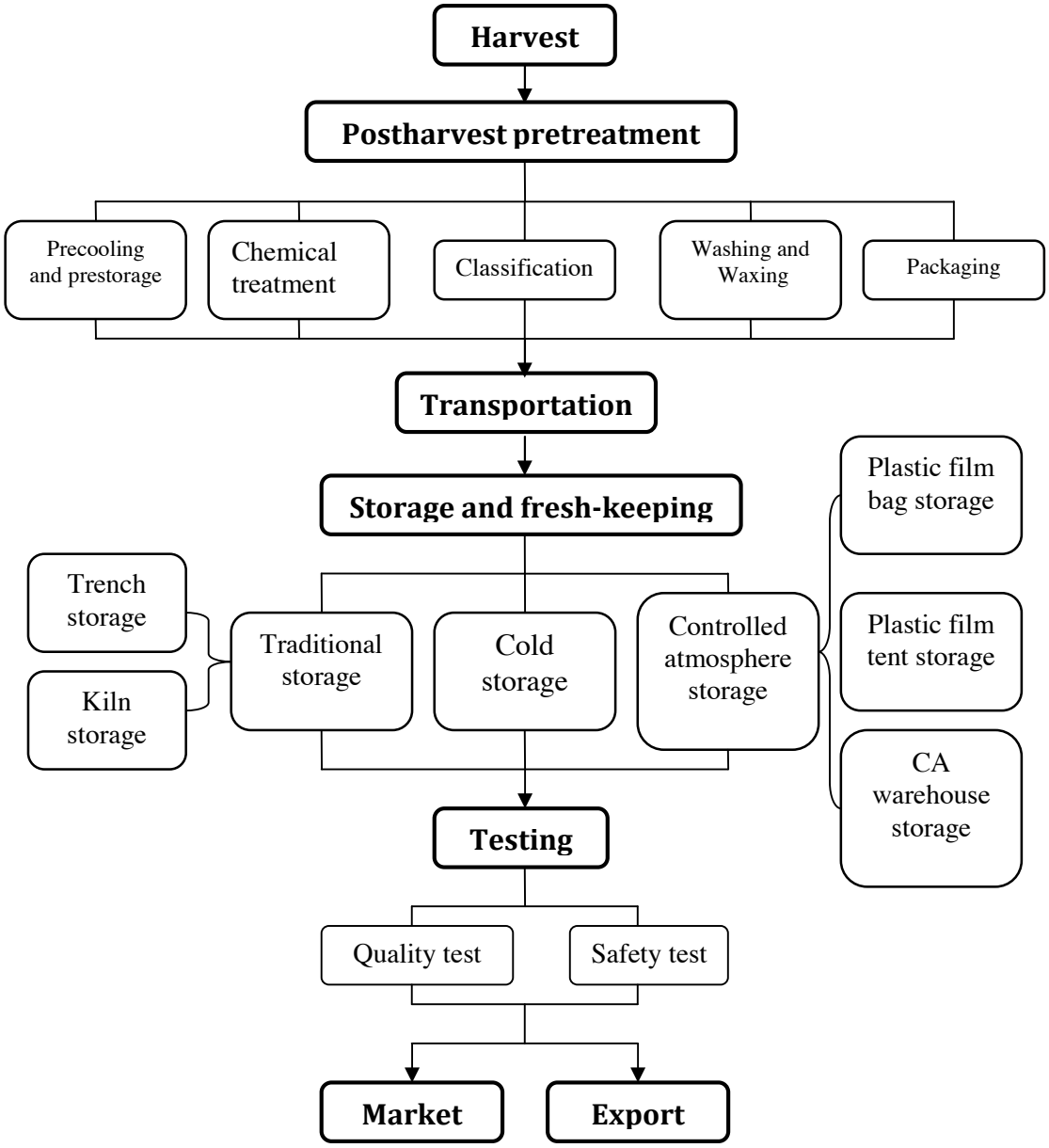

Figure 6: Storage and transport processes for apples in China

Figure 7: Machinery classification of apples

Figure 8: Manual classification of apples

Washing and waxing

The purpose of apple washing is cleaning and sterilization before the processes of transportation and storage. The chemical solutions used for washing apples are hydrochloric acid (1%) or 200-500 mg/kg of potassium permanganate solution or 200 mg/kg bleaching powder. Wax treatment can inhibit water and weight loss of apples during transportation and storage; it can also increase the brightness of the fruit surface. Many kinds of machines are used for apple washing and waxing in China (see Figure 9). Figure 10 and 11 show the washing and waxing process for apples.

Figure 9: Equipment used for apple washing and waxing

Figure 10: Apple washing

Figure 11: Apple waxing

Packaging

Wrapping papers containing diphenylamine or ethoxyquin are widely used for the inner packaging of apples in China. As for the outer packaging, cartons are the main choice. Generally, cartons made of yellow paperboard are used for domestic packaging of apples, while cartons made of high-strength corrugated paperboard are used for export packaging in China (see Figure 12).

Transportation

During transportation of apples, mechanical damage should be avoided and respiration should be reduced as much as possible. The predominant vehicles used for short-haul transportation in China are trucks and sometimes tractors; animal-drawn and manpower vehicles are also used. Truck and railway transport are the main methods of long-distance transportation; refrigerated rail cars are also used but they are not very common.

Figure 12: Manual packing of high-grade export apples in China

Storage

The main storage methods used for apples are traditional storage in northern China, and cold storage in southern China. CA storage is commonly used to preserve some of the top quality varieties.

Traditional storage

Traditional storage is a major method used for preserving apples in northern China. It has the advantage of low cost over other methods. Two main ways of traditional storage are used, one is called trench storage (Figure 13), and the other kiln storage (Figure 14). Trench storage is suitable for preserving late-maturing varieties. Trenches used for preserving apples are about 1-1.5 meters in width, 1 meter in depth and 20-25 meters in length. Before use trenches are filled with wet sand at a thickness of 3-7 cm. Then apples are placed in the trenches at a thickness of 33-67 cm and the trenches covered with a reed mat or maize straw in order to maintain and control the temperature. Although trench storage is simple, it is very effective. The storage period of apples preserved in trenches can be 5 months.

Kiln storage is widely used in apple-producing areas in Loess Plateau in China. There are many discarded kilns in Shaanxi and Shanxi province. Local fruit growers make full use of these kilns to preserve apples. Usually, kilns used for preserving apples are about 3-3.3 meters in width, 3-3.5 meters in height and 30-50 meters in length. During the night, both the doors and air vent are opened in order to take full advantage of natural low temperatures at night to lower the kiln temperature. During the day, both the doors and air vent are closed so as to prevent hot air entering the kiln. In this way, the air temperature of kilns can maintain 0-6°C during the whole year. Generally, kiln storage of postharvest apples begins in the autumn and ends in the spring, or even summer.

Cold storage

Cold storage is the primary way to preserve apples in southern China because of the natural high air temperatures. Usually, apples are stored in refrigerated (-1 to -3°C) warehouses（Figure 15）within 1-2 days after harvest and the temperature of the apples is lowered to -1 to 5°C after 3-5 days. The relative humidity in refrigerated warehouses should be controlled at 90-95% during storage. This method of storage can keep apples fresh for more than 6 months.

Figure 13: Trench storage of apples

Figure 14: Kiln storage of apples

Figure 15: Large-scale refrigerated warehouse

Controlled atmosphere storage

The most widely used CA storage of apples at present in China is simple CA storage (also called spontaneous regulating CA storage or film packaging storage). It is a very common but effective method and includes plastic film bag storage (Figure 16) and plastic tent storage (Figure 17). CA warehouse storage (Figure 18), due to its high cost, accounts for a relatively small proportion and is mainly used for high-grade export apples.

Figure16: Plastic film bag storage

Figure17: Plastic tent storage

Figure 18: High-grade export apples stored in CA warehouse

Quality of Fresh Apples after Storage

The harvest quality of apples, including appearance, taste, texture, safety and nutritional value, declines due to continuing respiration, ethylene production and the occurrence of post-harvest diseases. Quality cannot be improved, but it can be largely maintained during storage. Generally, the main features of quality maintenance during storage are successful control of skin background color and weight loss, high retention of flesh firmness, and retention of soluble solids and acid to give the desired sugar to acid ratio. Therefore, an effective storage method should prevent all of the above quality changes.

Traditional storage, the major method used in apple-producing areas in northern China, can prevent most of the quality changes of apples for 2-5 months (during autumn and winter), while cold storage, the primary method used in southern China, can keep the quality of apples for 3-5 months, and for some varieties more than 6 months. Both traditional storage and cold storage can create a low temperature environment for apples. Temperature is the single most important factor in maintaining quality of apples during storage. Low temperature (0-5°C) can reduce post-harvest respiration, and consequently quality deterioration and nutrient reduction. Cold storage can also create a high humidity (85-95%) environment, which prevents weight loss due to transpiration of water during storage. CA storage, the most effective storage method used in China, can create environments not only with low temperature and high humidity, but also low oxygen and high carbon dioxide. Thus it can maintain almost all the quality features of apples during storage. Today, many combined preservation methods such as traditional storage

combined with plastic bag preservation and chemical treatment, cold storage plus plastic bag preservation and chemical treatment, and CA storage plus chemical and physical treatment, are widely applied in apple storage in China. These combined methods are more effective than a single one.

Much research has been done on post-harvest storage of apples in China. Table 1 summarizes the results of some of this research on quality changes of fresh apples during storage under different conditions.

Safety of Apples after Storage

The safety problems of apples during storage are mainly the result of contamination by spoilage and pathogenic microorganisms. Usually, they exist in post-harvest fresh apples and continue to grow and breed during storage. Spoilage organisms make apples decay, while pathogenic microorganisms produce a variety of apple diseases. Rotten or diseased apples are unsafe, as they could have poisonous and harmful substances produced by spoilage and pathogenic microorganisms during storage.

Effective storage should inhibit the growth and propagation of spoilage and pathogenic microorganisms, or even destroy them. Many storage methods used in China, including traditional storage, cold storage, CA storage and combined storage, can get good results in controlling spoilage and pathogenic microorganism infestation during storage, as they can create environments with low temperatures which are unsuitable for the growth and reproduction of spoilage and pathogenic microorganisms.

Nutritional Quality of Apples after Storage

The nutritional value of fresh apples is very high, being rich in carbohydrates, vitamins and trace elements. However, the nutritional quality of post-harvest apples is prone to decrease during storage due to respiration and transpiration. Among all the nutrients, organic acids, sugars and water are most vulnerable. Post-harvest respiration consumes organic acids and sugars, while transpiration results in water loss. Organic acids and sugars have a direct impact on the taste (sweetness) of fresh apples. Water content affects the appearance, firmness and taste of fresh apples. Researchers have demonstrated that organic acids, sugars and water content of fresh apples decrease very quickly during room temperature storage (20-25°C) [15]. Vitamins, especially vitamin C, are also very easily lost due to oxidation. Significant decreases in vitamin C content (from 9.5 mg to 2.9 mg per100g), were found in fresh apples after two months of storage at room temperature (20°C) [16].

Effective storage should prevent loss of nutrients during the whole storage period. In China, many storage methods can achieve good results in maintaining nutritional quality. Table 2 shows the effects of different storage techniques used in China on the nutritional quality of fresh apples during storage.

CONCLUSIONS FROM CASE STUDY

China, the largest apple producer in the world, has always attached great importance to the storage of apples. Effective storage can maintain the quality, safety and nutritional value of apples for a long time. Many storage methods have been used to preserve apples in China, of which traditional storage, cold storage and CA storage are the most widely used. Traditional storage, the major method used in apple-producing areas in northern China, can prevent most of the quality changes of apples for 2-5 months. It takes full advantage of natural low temperatures in northern China to keep apples fresh during autumn and winter. Cold storage, the most widely used method for preserving apples all over China, especially southern China, can maintain apple

quality, safety and nutritional value for nearly 6 months. Although it costs more than traditional storage, it can be used at any time and in any place. CA storage, one of the most expensive storage methods used in China, can achieve even better results in apple preservation but because of its high cost, it is only used for the preservation of high-grade export apples.

Overall, China is doing very well in apple storage although there are still certain gaps between China and some developed countries. Improved storage methods need to be developed so that the positive effects of storage can be further improved.

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Table 1: Effect of different storage methods on quality of fresh apples during storage

Cultivar	**Storage method**	Storage period (months)	Rotten rate (%)	Weight loss (%)	Flesh firmness (kg/cm^2)		Soluble solids (%)		Reference
					Before	After	Before	After	
Golden delicious	Trench storage	5	2.86	12.1	9.99	3.22	16.34	14.76	6
	Kiln storage + Plastic bag preservation	5	0.75	5.2	9.99	5.37	16.34	13.10	
Qinguan	Trench storage	5	7.12	9.0	12.88	3.80	12.80	12.18	6
	Kiln storage + Plastic bag preservation	5	0	4.5	12.88	4.90	12.80	12.92	
Marshal	Trench storage	5	5.56	14.3	9.80	2.84	12.34	12.96	6
	Kiln storage + Plastic bag preservation	5	0	5.7	9.80	4.18	12.34	13.94	
Red fuji	Kiln storage	6	13.3	10.1	13.2	8.6	13.4	13.0	6
	Kiln storage + Plastic bag preservation	6	1.3	4.9	13.2	11.0	13.4	12.8	
	Cold storage	5			8.0	6.9	14.1	15.2	7
	Cold storage + 1-MCP treatment	5			8.0	7.8	14.1	15.0	
	CA storage	6			8.0	6.6	14.1	15.1	
	CA storage + 1-MCP treatment	6			8.0	7.7	14.1	15.3	
	Plastic bag preservation	5	19.7	12.14	12.41	8.49	12.58	11.54	8
	Plastic bag preservation + Polysaccharide treatment	5	10.8	3.75	12.41	8.78	12.58	12.05	
Starkrimson	Kiln storage		27.1	15.8	10.5	4.6	10.8	8.6	6
	Kiln storage + Plastic bag preservation		4.3	8.6	10.5	6.8	10.8	10.7	
	Cold storage	4			8.88	7.98	11.20	10.73	9
	Cold storage + 1-MCP treatment	4			8.88	8.80	11.20	11.92	
Pink Lady	Cold storage	6			8.4	5.9	13.8	16.1	10
	Cold storage + 1-MCP treatment	6			8.4	8.1	13.8	15.2	
Anglin	Cold storage	7			10.5	6.2	14.3	13.3	11
	Cold storage + 1-MCP treatment	7			10.5	9.4	14.3	12.3	
Gala	Cold storage + Plastic bag preservation	3		2.07	10.10	6.81	14.0	13.68	12
Jinhong	Kiln storage	4	45.79		10.48	5.17	12.45	11.23	13
Golden Marshal	Cold storage	8	16.2	8.7	16.2	10.5	12.1	13.3	14
	CA storage	8	1.8	1.0	16.2	14.8	12.1	12.8	

Table 2: Effect of different storage methods on nutritional quality of fresh apples during storage

Cultivar	**Storage method**	Storage period (months)	**Nutritional quality**						Reference
			Total sugars (%)		Total acids (%)		Vit C content (mg/100 g)		
			Before	After	Before	After	Before	After	
Red Fuji	Cold storage	5			0.34	0.14	12.41	5.83	17
	Cold storage + PVC bag preservation	5~6			0.385	0.231	14.84	9.34	
	Cold storage + $Ca(ClO)_2$ treatment	6			0.41	0.29	13.12	11.98	18
	1-MCP treatment	5			0.30	0.98	19.52	12.01	19
Starkrimson	Cold storage	6			0.242	0.121			20
	Cold storage + 1-MCP treatment	6			0.242	0.201			
	Cold storage + PVC bag preservation	5~6			0.376	0.253	9.89	5.47	17
Jinhong	Kiln storage	4	9.21	9.70	0.77	0.43	8.150	2.078	14
	Kiln storage + Plastic bag preservation	4	9.21	10.85	0.77	0.57	8.150	2.987	
	Kiln storage + Plastic tent preservation	4	9.21	10.23	0.77	0.54	8.150	5.048	
Gala	Cold storage + Plastic bag preservation	3	12.20	8.89	0.33	0.10			12
Jonagold	Cold storage + PVC bag preservation				0.321	0.249	15.12	11.04	17
Anglin	Cold storage	7	10.98	8.23	0.28	0.07			11
	Cold storage + 1-MCP treatment	7	10.98	9.23	0.28	0.19			
Golden Marshal	Cold storage + PVC bag preservation	6			0.658	0.433	10.52	7.24	17
Yue Shuai	PE bag preservation	3	11.45	9.25	0.319	0.168			21
	PE bag preservation + 1-MCP treatment	3	11.45	10.05	0.319	0.225			
	Cold storage + PE bag storage	7	11.45	8.72	0.319	0.110			
	Cold storage + PE bag storage + 1-MCP treatment	7	11.45	9.61	0.319	0.208			

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Improved Nutrition and National Development Through the Utilization of Cassava in Baked Foods

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ABSTRACT

Cassava (*Manihot spp.*) has become an important crop in many parts of the world for processing into several human foods and industrial commodities. Increased utilization of cassava and its products has been a catalyst for industrial development, creating sources of income for farmers, processors and traders. In poorer developing countries of the tropical and semi-tropical climates where wheat cannot be, or is not, cultivated, cassava has become a major source of revenue, contributing significantly to the improvement of food and livelihood security by directly or indirectly helping to reduce the huge foreign exchange expended on wheat, a major raw material in the production of bread, biscuits and pastry products. This chapter highlights the importance and use of cassava in the bakery industry. The benefits of including cassava, partly or wholly, are highlighted. Also discussed are the problems involved in the conversion of cassava into products on an industrial basis, e.g. the large amounts of material required for industrial processing, pre-process storage of cassava roots and flour and the influence of pre-process root storage, root maturity and flour storage on the physicochemical and sensory attributes of cassava biscuit; possible solutions are highlighted. Nutritional improvement of cassava flour products is also discussed.

INTRODUCTION

Cassava is a short-lived perennial shrub which is grown anywhere between the latitudes 30°N and 30°S, an area which is encompasses some of the poorest countries of the world (Bokanga, 1995). It is a dicotyledonous perennial plant belonging to the family Euphorbiaceae grown only in the hotter lowland tropics mainly for its starchy roots, though its leaves are also used as vegetable. It has been reported that cassava is an important staple for over 500 million people in the developing world (Cock, 1985). As a crop, cassava is hardy, contributing to feeding the populace in areas that are marginal to other crops such as marginal, unproductive or depleted lands where other crops yield essentially nothing (Cock, 1985; Bokanga, 1995) or in areas that experience long dry seasons and uncertain rainfall (Cock, 1985).

The two common botanical forms of cassava are *Manihot esculenta* Cranz and *Manihot utillisima* Phol. This classification is based on the cyanoglucoside content of the tubers, which also classify the tubers as "sweet" or "bitter" cassava, the sweet form have low (<140ppm) cyanoglucoside content while the bitter cassava contains greater than 140 ppm cyanoglucosides (linamarine and luteostraline) on dry weight basis. A further distinction is that while the cyanoglucosides are evenly distributed throughout the sweet, low cyanide cassava tuber, they are majorly located in the peel in the "bitter" high cyanide cassava and are removed with peeling during processing of the tubers.

Most of the total world production of cassava is processed for direct human consumption, also for livestock and as starch. Cassava is often castigated as an "inferior food crop", "poor people crop" (Hahn and Keyser, 1985) and as a "dangerous crop". These labels on cassava were due to some limitations of the crop including low quality and quantity of protein, the presence of cyanogenic glucosides (Cooke and Coursey, 1981) and poor storage of the tubers (Akingbala et al., 2005). Table 1 shows the strengths, weaknesses, opportunities and threats (SWOT) analysis of the traditional cassava processing techniques. Consequently, the challenges associated with cassava processing are multifaceted and efforts required to address them would require similar dimensions (Falade and Akingbala, 2009).

Table 1. Appraisal of the traditional processing of cassava into different products

Strength	**Weakness**
• Highly perishable and toxic cassava is being converted to a more stable and edible form by fermentation process • No requirement specialized processing equipment • Amenable to small scale operation • Provision of rural employments • Supplementation of the small income in the rural households • Provision of personal security and small capital investment from the scarce cash resource for rural women • Enhancement of food and livelihood security	• Poor hygienic condition • No specific processing condition temperature • No specification of variety • "Chance" inoculation with reduced action • Poor dewatering/fermentation facilities • Variable flavour, e.g. gari • Use of grater with variable apertures • Poor packaging and distribution practices • Low shelf life of cassava • High labour requirement for processing • Long processing times • Low energy density of cassava and cassava products
Opportunity	**Threat**
• Specification of variety (to enable appropriate machine design in terms of shape and sizes • Consume cassava on a daily basis without any obvious sign of intoxication • Provision of variety in diets	• Presence in cassava of the cyanogenic glucosides linamarin and lotaustralin • Cassava toxicity • Competing uses of cassava • Malnutrition due to low quantity and quality of protein of cassava

Source: Falade and Akingbala, (2009)

CASSAVA STORAGE

Cassava roots when left attached to the main stem can remain in the ground for several months without becoming inedible and farmers often leave cassava plants in the field as a security against drought, famine or other unforeseen food shortages (Bokanga, 2007). However, incipient quality deterioration starts after the roots have reached maturity, e.g. starch content decreases while fibre increases. The roots after harvesting start actively deteriorating within 2-3 days and rapidly become of little value for consumption or industrial application (Bokanga, 2007; Hahn, 2007). This initial physiological deterioration is followed by microbial deterioration 3–5 days after (Rickard & Coursey, 1981). Because of the large amounts of material required for industrial processing, two to three days of pre-process storage of cassava root is inevitable, during which time physiological changes that reduce starch yield and the quality of processed cassava products occur in the raw material (Akingbala et al., 1989; Ihedioha et al., 1996), thus making pre-process storage the main problem of cassava utilization on an industrial scale.

Several methods of storage have been proposed for cassava roots. However, most of the methods are not economically viable for storing the roots prior to processing on an industrial scale, considering the low prices of cassava products. Storage methods, which result in a reduction of moisture loss from the roots, have good potential for pre-process storage on an industrial scale. Rickard & Coursey (1981)

reported that cassava roots were stored in moist sawdust for up to 8 weeks with minimum deterioration. Storage of cassava roots in trenches also reduced spoilage (Agboola, 1985; CIAT, 1983). Roots pre-treated with a microbial protectant (CIAT, 1993) and sealed in polyethylene bags have exhibited reduced moisture loss (Rickard, 1985), reduced oxygen tension (Oudit, 1976) and maintained excellent storage quality. However, storage quality may be very different from utilization quality. Ihedioha et al., (1996) and Akingbala et al., (1989) reported that cassava food utilization properties change long before physical deterioration is observed in stored roots. Therefore it is expedient to process cassava roots promptly, or store for a minimal period prior to processing.

PROCESSING OF CASSAVA

Raw cassava roots and uncooked leaves are not palatable; they also contain varying amounts of cyanide which is toxic to man and animals. Due to their bulkiness and high moisture content (~70%), transportation of the roots to urban markets is difficult and expensive. Consequently, cassava must be processed to increase the shelf life of the products, facilitate transportation and marketing, reduce cyanide content and improve palatability. Processing of cassava helps to reduce postharvest losses and stabilizes seasonal fluctuations in the supply of the crop (Hahn, 2007). Processing methods developed in Africa to convert raw cassava into food have been described by Hahn (1989). The unit operations involved in cassava processing include washing, peeling, soaking in water or holding in air for different times to permit fermentation of the root, drying, grinding/milling, roasting (garification), steaming, pounding, sieving and mixing in cold or hot water. Specific combinations of these unit operations lead to a myriad of different cassava products appealing to a wide range of consumers (Bokanga, 1995).

Figure 1: Peeling of harvested cassava roots.

Processing and Nutrition

Processing of cassava often results in nutritional improvement even in the most toxic (highest concentration of cyanogenic glucoside) cultivars. Detoxification of cassava, to a large extent, occurs during the processing of the roots when the cell structural integrity is usually lost. The cyanogenic glucosides come into contact with the hydrolytic enzyme linamarase, thus initiating the formation of HCN. Akingbala et al., (2005) reported about a 95% decrease in cyanoglycoside content after grating and nearly 98% after fermentation of cassava during gari manufacture. Since food processing usually includes heating, the HCN produced is likely to evaporate completely (Bokanga, 1995). However, boiling whole bitter cassava root can result in toxicity as the hydrolytic enzymes are denatured by heat without hydrolysing the cyanoglucosides.

Fermentation and product nutritional quality

Lactic acid fermentation which is generally employed in processing cassava products also assists in hydrolysis of the cyanogenic glucosides to sugar and volatile HCN which is removed during further

processing by heating. Apart from the detoxifying effect on cassava, it is safe to presume that lactic acid fermentation also confers on cassava products such as fufu and fermented flours the same advantages it confers on milk, nuts and other proteinous products, e.g. increased digestibility, increased protein content, improved protein quality and increased vitamin content. Increased protein contents have also been reported in the conversion of cassava into gari (Akingbala et al., 2005).

Processing of Cassava into unfermented flour

One of the emerging non-traditional uses of cassava in Nigeria is the use of high quality cassava flour (HQCF) for baking applications. Cassava flour is produced by different methods depending on the locality. In West Africa, particularly in Nigeria, cassava flour is made from freshly harvested roots. The roots are peeled, washed and cut into chips. The cassava chips are sun-dried, milled into a fine powder and packaged in moisture proof materials. The process of production of HQCF suitable for baking was developed by the International Institute of Tropical Agriculture (IITA) and has been described by Onabolu and Bokanga (1995) and Abass et al., (1998). Actually, IITA developed two methods for cassava flour production: grating and chipping. The grating method uses machines and processes similar to those widely used for gari production in Nigeria. It is more flexible and adaptable to cassava of low and high cyanogenic potential. The chipping method is faster and requires the use of only the chipping machine before drying; however, its use is limited to cassava of low cyanogenic potential. This technology for unfermented flour production has been disseminated in Nigeria through training of farmers, women's groups, staff of national agricultural extension agencies and NGOs (Abass et al., 1998). The use of HQCF for baking, pastry production and other catering purposes has also been developed (Onabolu et al., 1998) and demonstrated to home caterers, bakers and industrial food processors who have adopted the technologies (Abass et al., 1998).

Figure 2: Sieving of dried and milled cassava flour.

Despite the benefits of the HQCF technology to all producers and users, Abass et al., (1998) enumerated some problems that hinder high quality cassava flour production and continuous availability and utilization. Some of the problems include high cost and inadequate supply of fresh cassava, lack of working capital, dependence on weather for drying, labour (intensive, shortage, expansiveness and seasonality), and transportation (high cost, bad roads) (Abass et al., 1998). Others include insufficient drying space, low and unstable selling price of HQCF (users dictate prices), low demand for HQCF and lack of access to market (Abass et al., 1998). These problems could be location specific (Mlingi et al., 1998) and time dependent, and could be due to the effect of the vicious cycle associated with cassava production (Abass et al., 1998). The location effect was shown in an economic analysis of cassava flour production in Masaki and Dar es Salaam for use in biscuit factories, which indicate that cassava flour can only be processed economically in the farms located outside Dar es

Salaam city due to the great difference between the comparative costs of fresh cassava at the two locations (Mlingi et al., 1998).

CASSAVA FLOUR UTILIZATION

Cassava flour is used in a number of ways in South India, South East Asia and Africa. It can be made into a type of porridge by mixing with water or rice before cooking (Balagopalan et al., 1988). Traditional Indian foods such as chappathis, uppuma, puttu, iddlies, and dosa can be made from cassava flour. In the Philippines, cassava flour is used in delicacies such as bibingka, seeman and kalanay (Balagopalan et al., 1988). Cutlets are made by mincing the grated roots and mixing with fried onions, cashew nuts, black gram and coriander leaves. The mixture is then made into balls dusted with maida flour and lightly fried. The flour can also be used for making breads, biscuits and salad dressings, custard powder, ice cream powder, flakes, vermicelli, etc. Cassava flour can also be used for making other delicacies such as cassava dumplings, cassava fruit cake, cassava cakes, cassava banana fritters, cassava puttu, cassava uppuma, cassava masala poori, cassava porotta, cassava vattayappam, cassava idiappam, cassava iddli and cassa dosai (Balagopalan et al., 1988).

Among the popular cassava products in Nigeria such as gari, fufu and lafun, cassava flour is the easiest and cheapest to make and the highest income generator (Abass et al., 1998). The use of cassava flour in food rations has clear advantages. The inclusion of cassava in composite flour for the production of fast foods would reduce cost and enhance the production of noodles, breakfast cereals, and pastries among others (Falade and Akingbala, 2009). Apart from the industries, bakers and caterers, individuals also produce and purchase cassava flour for home use for the preparation of chin-chin, pie (meat and fish), buns and cake among others. Inclusion of cassava flour at between 10-50% and 10% in wheat flour has been used for producing acceptable biscuits and noodles respectively (Table 2).

Table 2. Products made by processors from cassava roots, and from cassava flour at home, ease of production and income generation rating

Product	Number of commercial processors making the products	Frequency of responses by processors		
		Easiest to make	Cheapest to make	Highest income generator
From cassava root:				
Cassava flour	24	13	10	11
Gari	17	0	1	1
Fufu	12	2	0	1
Lafun	11	3	3	1
Starch	7	1	0	4
Tapioca	2	0	0	0
From cassava flour:				
Chinchin	7			
Other pastries, akara, burns, etc.	4	0	0	0
Fish or meat pie	3	0	0	0
Doughnut	3	0	0	0
Amala	2	0	0	0
Cake		0	0	0
Semo (HQCF mixed with maize or rice)	2	0	0	0

Source: Abass et al., (1998)

For the production of different pastry and baked goods, caterers and bakers have substituted cassava flour for wheat at different levels of 10-100% and 5-20%, respectively. Figure 3 shows the pastries that can be made from composite flour. Research at IITA has also shown that cassava flour (100%) can be used to prepare bakery products such as cakes, cookies and doughnuts (Onabolu and Bokanga, 1995). The resulting products are readily available and sold in Nigeria, thus helping to improve food

and livelihood security. The benefits of the use of HQCF include increased profit as a result of the lower cost of HQCF compared to wheat, and increased yield of products, particularly biscuits. Users noted that the quality of pastry products, biscuits and noodles improved when good quality flour and the right processing method for their manufacture was used. The highlighted benefits of flour indicate good prospects for commercial production and utilization of cassava (Abass et al., 1998).

Figure 3: Pastries made from composite flour.

In order to facilitate the production of consistent quality products, a number of criteria for screening HQCF prior to purchase have been specified and are shown in Table 3 (Abass et al., 1998). Utilization of cassava flour would help promote cassava production, increase farmer's income, create more jobs, reduce dependence and consequently the foreign exchange expended on wheat importation. These would add up to an improvement of food and livelihood security for the vast majority of the citizenry.

Table 3. Major quality criteria of cassava flour set by industrial users

Quality criteria	Specification
pH	5.0-8.0
Moisture content (%)	10-12
Ash (%)	<0.9
Colour	White
Odour	Not detectable
Taste	None or sweet
Sand or any other contaminants	Not present
Particle size	Same as for wheat
Cyanogenic potential (CNP)	National (Nigeria) limit (10ppm)

Source: Abass et al., (1998)

In Tanzania production of bakery and confectionery products such as bread, biscuits, cakes and noodles is limited to wheat flour and the total annual needs of wheat flour in the country was 127000 t (Food Security Bulletin, 1998). Domestic output of wheat was 61000 t in 1996/97 with the rest (42000 t) being imported at a cost of USD 6 million (Mlingi et al., 1998). By substituting cassava flour for only 20% of the wheat in the country for biscuit manufacture, Tanzania could save about USD 1.2 million of foreign exchange annually (Mlingi et al., 1998). Based on experiences from other countries such as Nigeria, Cameroon, Cote d'Ivoire and Ghana, Tanzania has initiated a research program geared towards diversifying cassava use (Mlingi et al., 1998). According to Kapinga et al., (1998) trials by the Ministry of Agriculture and the Tanzania Food and Nutrition Centre showed that cassava could economically substitute wheat flour to produce biscuits, cakes, bread, doughnuts and noodles.

Cassava bread

There is a great increase in the consumption of bread and other wheat-based products worldwide because of changing food habits, increasing population, urbanization, and the convenience of these

ready-made foods (Akingbala et al., 2009). This has created unnecessary financial problems for many poor tropical countries which are naturally unsuitable for growing wheat and therefore have to import wheat to sustain their new wheat-based diets. Also, for the many that suffer from celiac disease, a chronic enteropathy characterized by an inadequate immune response to ingested gluten from wheat, rye, barley, and triticale (Sciarini et al., 2008), reduction in the consumption or outright elimination of gluten-free foods would be desirable (Turabi et al., 2008). Wheat importation and celiac disease could be tremendously reduced by partial or complete substitution of wheat flour with flour or starch from tropical crops such as cassava, yam, and sweet potato, and cereals such as maize, rice, sorghum, and millet. For some products, attempts have been made to completely eliminate wheat flour by substituting other flours and changing the recipe for the products. Generally such moves require government support. In Nigeria, there is a regulation that all wheat flour should contain 10% non-wheat flour inclusion, which in the 1980s required about 200,000 tonnes per year of cassava flour of which only about 10,000 tonnes could be supplied (Mkpong et al., 1990). Figure 4 shows bread made from wheat and composite flours on display for sale in Nigeria.

Figure 4: Bread on display for sale in Nigeria.

In South America, cassava bread "Cazabe" is an important traditional fermented food made by the Tukanoan Indians from bitter cassava (Balagopalan et al., 1988). To prepare the flour/starch extract used for the bread, freshly harvested roots are washed, peeled and then pulped. The wet pulp is strained in a large basket, rinsed with water, squeezed, kneaded and pressed against the strainer to dewater. The extracted starch suspension is collected in a large clay pot, the starch is allowed to settle and the liquids decanted off the top to make juice. Once separated, the starch and fiber are relatively stable and can be left in pots or leaf-lined baskets for several days or buried in leaf-lined pits and stored for longer periods (Balagopalan et al., 1988). This mash is used for breadmaking.

Research and development activity for the preparation of bread based on cassava have been taken up by many international and national organizations throughout the world. In the composite flour program development of bakery products and paste goods from cereal and non-cereal flours, starches, and protein concentrates, the Food and Agriculture Organization (FAO) of the United Nations has given a description of two innovations being tested to employ larger quantities of cassava, corn or sorghum flours in bread making: (a) In bread without gluten programme, substances that agglutinate starch (glyceryl monostearate (GMS), 10% emulsion) are used to substitute for wheat gluten. In order to compensate for the nutritional inferiority of an all-starch bread, considerable amounts of plant proteins are added in the form of peanut or soy flours producing a bread that is more nutritious than traditional ones; (b) Attempts have been made to increase the proportion of non-wheat flour inclusion in wheat flour to more than 10% (Balagopalan et al., 1988).

Attempts have been made by several workers and organizations to improve the traditional bread preparations or develop composite flour technology for cassava based preparations by mixing other starches with cassava flour (Balagopalan et al., 1988). Different wheat flours have been diluted with various proportions of cassava starch and flour (Shittu et al., 2007, Shittu et al., 2008) and cassava mash (Crabtree et al., 1978a,b). Defloor et al., (1995) and Khalil et al., (2000) specifically reported that

inclusion of cassava flour into wheat flour up to about 30% could still give an acceptable fresh loaf depending on the source of wheat flour. Bread containing 20% fresh minced cassava showed higher sensory evaluation ratings (Crabtree et al., 1978a). To cut expenses on wheat importation and find wider utilization for the increasingly produced cassava roots, the Nigerian government mandated the use of composite cassava-wheat flour for baking by adding minimum of 10% cassava flour to wheat for a start. In spite of the small amount of cassava flour (10%) included into wheat flour (90%), the breadmaking characteristics of the composite flours from different cassava genotype grown with or without fertilizer application differed significantly (Shittu et al., 2008). The greatest effect of cassava genotype was realized on crumb moisture while fertilizer application had the greatest effect on the bread crumb texture (Shittu et al., 2008). Flour from unfertilized roots also showed significant differences in performance in making composite cassava-wheat bread loaf, which resulted in Shittu et al. (2008) concluding that careful selection of cassava root variety and application of fertilizer are important factors that should be considered in optimizing composite cassava–wheat bread quality.

The production of dried products of cassava is wasteful in terms of the energy required for drying, particularly since the dried products will be rehydrated during the bread making process. The incorporation of fresh minced cassava into bread has been described by Crabtree et al., (1978b). This technique has the advantage of eliminating the need for an energy-consuming drying stage and should be of special interest to bakeries in rural areas of the developing world where fresh cassava is readily available. Bread containing 20% fresh minced cassava rated higher than products from higher levels of cassava substitution in all assessments except sensory evaluation. If cassava is to be processed into dried flour before incorporation into bread, low temperature drying at around 50°C is recommended to ensure that the flour is light in colour. The longer storage life of dried cassava products may alternatively be advantageous in urban situations remote from cassava-producing districts and for the export market. The use of composite flours will enable developing countries to save some scarce foreign exchange expended on importing wheat flours (Ogunsua, 1989). Studies on improving nutritional quality of cassava bread by incorporation of flours rich in proteins have been investigated as early as in the 1960s. Kim and De Ruiter (1961) reported the suitability of flours derived from cassava, yam, sago and arrowroot in breadmaking when combined with protein concentrates obtained from soybean, peanut, cottonseed and fish meal. De Ruiter (1970) studied the mixture of cassava starch with soybean or groundnut flours using a GMS emulsion as improving agent for breadmaking.

To ensure the commercial success of this composite cassava wheat flour technology, systematic studies need to be conducted to fully understand the best way to formulate product and to determine the optimal processing conditions required to realize high quality baked products. Shittu et al., (2007) reported complex polymeric changes caused by the changing temperature–time combinations in baking, which may be peculiar to the use of composite cassava wheat flour in breadmaking. The influence of baking temperature was specifically more significant on loaf volume and crumb moisture while baking time had a more significant influence on loaf weight, crumb dryness, hardness and density. Literature reports of studies relating cassava flour properties to food uses are presently few. An example of such a study conducted by Eggleston et al., (1993), observed that cassava flour's diastatic activity and maximum paste viscosity influenced the specific volume of gluten free bread loaf from soy-cassava flour.

Cassava biscuits

Wheat is the major ingredient in the Nigerian biscuit baking industry, and it was the only source of flour for biscuit production prior to the reduction in wheat importation in 1996. In a swift move to remedy the problem, the industry sought cheaper and readily available raw materials. Cassava and corn flours have now found important places in the Nigerian biscuit industry. Cassava is particularly used due to its good baking qualities. As at 1998, there were 18 brands of biscuits and a brand of noodles in which cassava flour was used in Nigeria (Abass et al., 1998). Other flours have been used in biscuit manufacture. Figure 5 shows the biscuits made from composite flour. Tyagi et al., (2007) studied the nutritional, sensory, and textural characteristics of defatted mustard flour fortified biscuits, and Eneche (1999) reported the manufacture of biscuits from blends of millet flour and pigeon pea flour in different proportions. However, among the possible roots and tuber flour

substitutes, cassava is the best choice to replace wheat partially or completely because of its high yield and low cost of production (Morton, 1988).

Figure 5: Biscuits made from composite (cassava/wheat) flour.

It has been reported that 20% cassava substitution for wheat could be used for biscuit production without affecting the flavour, texture and colour of the products (Mlingi et al., 1998). Partial substitution of wheat flour with cassava flour up to 40% has been reported to be satisfactory for the production of biscuits (Eggleston et al., 1992; Omoaka and Bokanga, 1994). Oyewole et al., (1996) were able to produce acceptable biscuits by completely substituting wheat flour with cassava flour. Quality of cassava flour or starch for biscuit manufacture would be affected by the cultivar, the pre-process storage of the tubers, storage of the flour/starch (Akingbala et al., 2005), and crop maturity (Akingbala et al., 2009). Most research investigations are centred on the production of flour from freshly harvested cassava roots at the village farm level and in many urban centres. Production of cassava flour for biscuit manufacture would be affected by delays in processing of roots due to collection and transportation problems between the farm sites and the processing centres, and delays in processing caused by the slow manual peeling process that is often employed. Moreover, the large amount of tubers required for industrial application takes time to harvest and gather and the highly perishable tubers may lose some of their utilization quality, including reduced flour/starch yield, increased enzymatic activity, and increased difficulty of peeling among others (Akingbala et al., 1989), which affect the final flour and product quality.

Biscuits are a more robust product without the overriding effects of gluten on texture. A recent report by Akingbala et al., (2009) indicated that neither age of tuber nor length of preprocess storage of flour affected biscuit spread, colour, taste or aroma significantly, though root maturity tended to favour biscuits made from flour from 12 month old as against that from 23 month old roots. Akingbala et al., (ibid.) reported that the average diameter (5.6 cm), height (0.50–0.51 cm), and spread ratio (11.0–11.2) of biscuits manufactured from both cassava and wheat flour, which was used as the reference sample, were not significantly ($p<0.05$) different. However, average weight of the cassava biscuits (13.4 g) was significantly ($p<0.05$) greater than that observed for wheat flour biscuits (11.9 g). This may be due to differences in the moisture contents of the biscuits which was 8.7–8.8% for cassava flour biscuit and 8.3% for biscuit made from wheat flour.

Fat and protein contents of the cassava biscuits were lower than those of wheat biscuits due to the higher fat and protein contents of wheat flour compared to cassava flour (Akingbala et al., ibid.). Apart from a probable reduction in the nutritional value of the cassava flour biscuits, the low protein content would be of little significance since biscuits are structurally and texturally different from a loaf of bread. Gluten is important for bread and the quantity and quality of the proteins present in flour have a major influence on the rheological behaviour of the dough, particularly when flour is the major constituent of the formula (Maache-Rezzoug et al., 1998). Ash and fiber contents of biscuits made of

flour from 12-month-old cassava roots were similar to that of wheat biscuits but lower than observed for biscuits made of flour from the 23-month-old roots (Akingbala et al., 2009). This was probably due to increased lignification of the roots during further growth which was reflected in flour composition (Akingbala et al., 2009). Generally, proximate composition of the biscuits in this study was in conformity with the standard specification (Wills et al., 1984) for biscuits.

CONCLUSION

The uniqueness of cassava in improving nutrition and bringing about national development in the food industry cannot be overemphasized. While other commodities such as corn, millet and soybean have been suggested and used as substitutes in the production of composite flours, the use of cassava has been shown to outweigh their benefits. The inclusion of cassava flour and starch in wheat flour for the preparation of biscuits, cakes, bread, doughnuts, noodles and other baked goods has several socio-economic advantages. Utilization of cassava would resolve the vicious cyclic effect associated with its production, increase stakeholders' income, create more jobs, solve some health problems and reduce dependence on wheat importation. These benefits can be summed up as improvements in food and livelihood security for the vast majority of citizens.

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Agriculture, Nutrition and National Development

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Introduction

It is probable that extensive ocean farming, hydroponics or soil-less cultivation, test tube cultivation, protein from petroleum and single cells and other similar techniques may contribute to our future food supply. In the immediate future, however, we will have to rely primarily on mother earth to feed us and our animals. As far as we can judge now, soil will continue to be the most important medium for crop growth, since several of the other techniques rely heavily on the use of non-renewable resources of energy. We also do not know what the long term consequences of certain trends in ocean farming, such as induced upwelling, will be. Upwelling is a physical, ocean-atmosphere process leading to the transfer of high concentrations of chemical nutrients from sea bottom into the zone where there is active carbon assimilation thereby producing food for fish. It has been estimated that about half of the world's fish production occurs in the restricted coastal upwelling areas. If artificially upwelling is resorted to, it is possible that there may be richer harvests of marine life for some time. But already the lesson of the Peruvian fisheries reminds us that if man in his greed tries to over-exploit a resource he will come to grief. A sad consequence of the drop in the availability of anchovies along the Peruvian coast is the dwindling in the population of the Guano birds, from about 30 million some years ago to about a million now. If the Guano birds disappear, the finest natural fertilizer in the world formed by the deposits of these birds will also gradually get exhausted.

Attention to economic ecology

First among the emerging concepts of management of biological assets is attention to economic ecology. I used the prefix "economic" before "ecology" to underline the fact that what we need is as high an economic growth rate as possible through the use of the principles of ecology rather than the kind of ecology discussed frequently in the affluent nations which is of the conservationist or zero growth rate kind, intended to preserve the high standards of living already achieved. For the sake of convenience, I would like to classify arable land in India into five groups – arid, semi-arid, humid, irrigated and hilly regions. It is obvious that there are numerous climatic variations in these groups. *Kharif* (Monsoon) and *rabi* (Winter) seasons have not the same significance in south India, as they have in the north. This is why agricultural technology becomes highly location and situation specific, necessitating a considerable amount of local research and testing work, before a new technology can be recommended to the farmers. While ideas and concepts can be transplanted from one region to another, the actual material and techniques will have to be tailored to suit the local agro-ecological and socio-economic milieu.

The arid zone occupies in India an area of 320,000 sq. km. of hot desert and 70,000 sq. km. of cold desert where extreme aridity combined with low temperature limits the possibility of growing crops to about 5 months in a year. Hence, the strategy for agricultural growth in the cold desert regions has to depend largely on the cultivation of quick-growing cereals, oilseeds and fodder crops and the rearing of goats, giving Pashmina wool. The hot desert regions, in contrast, have an abundance of sunshine, land and soils capable of responding to management, well adapted grasses and trees, excellent breeds of sheep, goat and cattle and considerable reserves of ground water. Water and not land, is the principal limiting factor and hence all attempts have to be focused on maximizing income per litre of water.

Reclaiming the desert

Afforestation has to be the focal point for reclaiming the desert. Large scale planting of shelter-belts could help to minimize wind erosion and decrease the dust over the desert. Scope for the establishment of pastures and grazing lands is great and strip cropping involving the setting up of permanent grass strips to prevent wind damage will help to increase the yield of crops like millets and grain legumes substantially. A millet-grain legume mixed cropping will strengthen household nutrition security.

An important need in the desert areas is the preservation of organic matter for the soil. Unfortunately, due to deficiency of fuel, the available organic wastes are generally used for burning and trees are cut in an unplanned manner. Often in the desert areas, the water is saline and women have to walk several miles every day to fetch sweet water. Solar stills to produce water for drinking in such area will be a great boon to the villagers.

Sophisticated techniques for raising crops in desert areas with very limited quantities of water are now becoming available. These involve cultivation of vegetables and high value crops under air-inflated polyethylene houses using economic methods of water supply like drip or sprinkler irrigation.

Unfortunately, we have no arrangements now either to mitigate the rigour of a bad season or to derive maximum advantage from a good season. For example, some years provide opportunities for planting in the desert a large number of trees and for seeding large areas with grasses. In spite of the shallow nature of the soils and the calcium carbonate pans which occur in the subsoil, thereby increasing run-off and reducing infiltration, abundant moisture was available to facilitate the establishment of trees, shrubs and grasses. The district administration tried its best to get the available seeds sown, but the magnitude of the programme was small in relation to the opportunities that were available. This lesson from the Indian desert is also valid for sub-Saharan Africa.

"Good weather code"

What is needed in such areas is a *Good Weather Code*, which will spell out the types of activities that should be undertaken in the event of rainfall being good.

About 60 per cent of India's cultivated area is rainfed and since about 42 per cent of food production comes from such areas, there is variation in food production depending upon the amount and distribution of rainfall. Semi-arid areas, where often the annual potential evapo-transpiration exceeds the mean annual rainfall, need special attention in the Indian sub-continent and sub-Saharan Africa. These sub regions have been plagued for centuries by periodic droughts, floods, soil erosion, instability in production, drinking water scarcity, unemployment, under-employment and other forms of human suffering. The earliest research effort on dryland agriculture was started in India by Tamhane in 1923. Subsequently, a rather comprehensive programme was evolved by Kanitkar for improving the productivity of rainfed farming. This formed the basis for the Dry Farming Scheme started in 1933 by the Indian Council of Agricultural Research. The basic features of the dry farming practices developed in the past were bunding to conserve soil moisture, application of farmyard manure to supply plant nutrients, deep ploughing once in three years, shallow preparatory cultivation and interculture, low seed rate and wide spacing of crops. Official estimates placed the increase in crop yields, due to the adoption of this package of practices, at about 15-20 percent over a base level of 200 to 400 kg per hectare. Although these programmes failed to catch the imagination and interests of the farming community, they did make a useful contribution in the areas of moisture conservation and erosion control.

Intensification of dryland research

It is experiences of this kind that led to the intensification of dryland farming research in 1970 through the initiation of an All-India Coordinated Research Project on Dryland Agriculture with the collaboration of the Government of Canada. Meanwhile, international interest in upgrading the productivity as well as the stability of production of the dry farming regions of Asia, Africa and Latin America grew and resulted in the establishment by the Consultative Group for International Agricultural Research (CGIAR) of an International Crops Research Institute for the Semi-arid Tropics (ICRISAT) at Hyderabad in 1972. ICRISAT has developed useful techniques for enhancing the productivity and sustainability of rainfed farming systems.

The new phase of dry farming research has resulted in considerable data on better moisture conservation and use, new cropping patterns, crop life-saving techniques and mid-season corrections in crop planning in the drought-prone areas. The pilot project areas attached to the dry farming research centres are helping to identify the socio-economic and operational constraints in the transfer of the technology from the research farm to the farmer's fields. At present, the gap between potential and actual yields in millets, oilseeds and grain legumes may be as high as 200 to 300 percent in many rainfed areas and bridging the yield-gap movement is hence an untapped opportunity.

Since water is the major limiting factor, a priority area of research is the standardization of techniques by which as much of the precipitation as possible can be conserved for crop use, either directly in the soil profile through infiltration or through run-off collection and storage. Deep ploughing, for example, promotes a vertical rather than a tangential flow of water in red soils with a dense sub-soil. The cultivation of deep rooted crops like castor, pigeon pea and cotton further helps in improving the soil texture and in adding organic matter through root deposition. Run-off storage structures are being developed both for individual small farms and for larger water sheds. Obviously, the most effective method will be the cooperative management of an entire watershed. If sufficient water can be collected in community-owned ponds, a life-saving irrigation can be given at the time of grain formation when the crop will benefit most from the supply of a little water. Anil Agarwal and Sunita Narain (1997) in their book titled "Dying Wisdom" have chronicled the steps taken in the past by local communities to conserve every drop of water.

In black soil areas with moderate rainfall, there is scope for double cropping or rationing, provided suitable surface drainage can be introduced during the rainy season and appropriate tillage practices can be developed. Drainage and sound soil and water management will again need some degree of cooperative endeavour on the part of a watershed community. There is also great scope for introducing better inter-cropping practices in areas with annual rainfall ranging from 625 to 1000 mm.

Climate Management

Progress has been made in identifying crop varieties which are relatively photo-insensitive and which have a shorter duration and the resulting ability to escape drought. Suitable varieties in rice, *jowar* (sorghum), *bajra* (pearl millet), minor millets, sunflower, safflower, castor, mustard, groundnut, pulses like *moong, urad* and *arhar* (grain legumes) and cowpea and cotton are becoming available. As a result, different cropping patterns can be developed to suit different weather models. For example, some of the common weather aberrations are (a) early or delayed onset of monsoon, (b) long breaks in the monsoon and (c) inadequate rainfall. If the monsoon is very early, short duration legumes could be taken followed by regular season crops. For normal sowing, *jowar*, for late sowing, *bajra* and for very late sowing *setaria* are some of the possibilities. When there are long breaks in the monsoon, the *jowar* or *bajra* crops affected by drought could be rationed. Since early varieties of *arhar* are now available, a crop of this pulse can be taken in north India between July and December. Then, with the help of dew or winter rains, a crop of sunflower can be raised in the same field from February to April. Much better use of dew can be made in the north India during winter. Dr. R.D. Asana, our eminent plant physiologist, developed a model of a wheat plant capable of retaining dew. We need research of this

kind in all rainfed winter crops. We should evolve for each soil and rainfall belt, a series of alternative cropping patterns to match different weather probabilities. It would also be necessary to build the appropriate seed and fertilizer buffers and organize community nurseries in order to put into practice alternative crop schedules, when the weather proves truant. Just as grain reserves are important for food security, seed reserves are essential for crop security.

Multiple and relay cropping

The potential of irrigated areas to produce much higher quantities of food, feed, fibre and fodder plants through multiple and relay cropping is now well known. If these defects are overcome a minimum of two good crops can be raised, and the production of about 8-10 tonnes of food and other grains per hectare per year obtained. Organic matter content, while taking up intensive farming practices, a continuous monitoring of the soil for major and micro-nutrients and for pathogens will be essential. Legumes should find a place in the rotation and as a rule, crops sharing common pests and diseases should not succeed each other. It would be better to alternate deep and shallow rooted crops so as to tap nutrients from different soil depths.

High-altitude research

High altitude areas have received relatively little scientific attention. Ecological conditions vary greatly even within short distances in these areas depending upon aspect, latitude, altitude, slope, soil depth and distance from the plains. Large variations in temperature and rainfall occur and the length of growing season is controlled by the time of occurrence of snow in winter and its disappearance in the spring. Erosion will be a serious problem and in several of these areas, data are needed on minimum tillage, suitable implements to ensure timeliness of operations, fertilizer use and weed control. Both horticulture and nomadic sheep husbandry require considerable attention.

Besides rainfall, altitude and latitude, the ecological conditions of soil and season need understanding for the improvement of biological productivity. Large areas in developing countries are affected by salinity and alkalinity where crops either do not grow or give very poor yield. Soil salinity is also becoming a problem in black soils, where irrigation facilities have been developed recently. An understanding of the nature of the problem and of the physical and chemical characteristics of the soil profile would be necessary to introduce the most appropriate corrective measures like gypsum application, drainage, crop and varietal choice and fertilizer use. Acid soils also require special care and in particular, the most effective methods of phosphorus application will have to be worked out.

Synergy in agriculture

Having discussed some of the broad features of crop planning on an ecological basis in order to meet the challenges arising from a warming planet, we now turn to the application of three other important concepts in agriculture. The first of these is the concept of synergy. Synergy is not a new concept, since this mechanism, which results in the product being something much more than the sum of the parts, has been the most potent tool involved in natural evolution. For developing high synergy cropping systems, an understanding of population behaviour and performance, rather than merely of the characteristics of individual performance, is essential.

Chinese peasants devised over a thousand years ago methods of producing high yields of fish with low inputs of money and technology. They did this on the basis of two principles. First, a body of water is a three dimensional growing space. To treat it like a field by planting only one kind of crop is likely to result in wasting the majority of that space. Secondly, any fertile pond will produce a number of different fish food organisms. However, most fish are not omnivorous, but are rather selective in their diet. Thus, stocking single species in a pond wastes not only space but food. Chinese fish culturists took advantage of these two characteristics of the pond environment through polyculture or stocking several types of fish. Recently, under an All India Coordinated Project on composite fish culture, suitable species of fish have been identified which can give cooperatively about 3,000 kg of fish per

hectare in about 6 months. The species involved are both Indian carps like *catla, rohu* and *mrigal* and exotic carps like grass carp, silver carp and common carp. Such high synergy aquaculture systems can revolutionize fresh water fish production in developing countries.

The Chinese have again taken advantage of the possibility for raising pigs and ducks in conjunction with the culturing of fish. In a 4.4 hectare Chinese farm, pigs, fish and aquatic plants were raised together. Abut 30 tonnes of pig meat were produced per year, with the primary feed being the aquatic water spinach, *Ipomoea repens* which grew luxuriantly in the fish ponds fertilized by the pig manure. Besides the pigs, some 3000 kg of fish were cultured in the small ponds. The main food for the fish was algae, which grew well in the enriched ponds. Ducks could complement a system like this, their wastes being added to the ponds.

Changing plant architecture

The search for synergy has led both to the re-patterning of plant architecture in many economic plants and to the development of cross-bred farm animals which are efficient in the conversion of feed into the product for which they are raised by man. What the breeders now look for are the plant types which can maximize production per unit of area, time and water. Thus, plant types which will not shade each other or fall over each other and which will promote better light interception and carbon dioxide fixation are now sought after. In the earlier strains, many of the characteristics had been selected for performance under adverse circumstances and not for high yield under good management. Because of their plant and leaf characters, a larger number of productive tillers per square metre can be packed into the new varieties of wheat and rice compared to the old ones. New plant types of pearl millet can respond to a population density of about 250,000 plants per hectare, in contrast to less than 100,000 plants in the case of the earlier strains. The concept of population explosion in fields has also permeated horticulture. Growingly, emphasis is being placed in orchards on the selection of dwarfing root stocks.

Unfortunately, breeding for resistance to pests and diseases is often a never-ending task. The resistance tends to break down, following the build-up in nature of new races of the pathogen capable of attacking a variety earlier released for its resistance. Seeds of new strains have hence to be multiplied and distributed speedily. Dynamic varietal diversification and seed multiplication programmes are essential to sustain a good crop production programme.

Outwitting the pathogen

Will the struggle between the breeder and the pathogen be an endless one or will one outwit the other? The breeder is adopting a multipronged strategy, working on a type of resistance, technically referred to as horizontal or field resistance, which is likely to be of a more enduring type. He is also trying to develop escape mechanisms by altering the growth phase of the plant in such a way that it does not synchronise with the peak multiplication and infectious phase of the pathogen. He is also trying to understand the biochemistry and physiology of resistance, hoping in this way to find effective and cheap chemical methods of control. More recently, recombinant DNA techniques are being used to create novel genetic combinations for biotic and abiotic stresses. While all these approaches need to be followed with vigour, our immediate hopes lie in the genes for resistance found in the primitive cultivars and other wild and cultivated genetic material occurring particularly in the 'centres of diversity' of crop plants. Thus, the rich collections of rice conserved in the Gene Bank of the International Rice Research Institute in the Philippines constitute a veritable mine of valuable genes.

Therefore there is need for a holistic definition of food security along the following lines:

- Every individual has the physical, economic, social and environmental access to a balanced diet that includes the necessary macro- and micro- nutrients, safe drinking water, sanitation, environmental hygiene, primary health care and education so as to lead a healthy and productive life.

- Food originates from efficient and environmentally benign production technologies that conserve and enhance the natural resource base of crops, farm animals, forestry, and inland and marine fisheries.

Equally exciting are the opportunities now available for adding a nutritional dimension to crop improvement programmes. According to several authorities, including Drs. C Gopalan and P V Sukhatme of India, malnutrition in countries which have cereals as the staple food, is mostly the result of under-nutrition, arising in turn from inadequate purchasing power.

More area of pulses and oilseeds

There is considerable scope for releasing areas from sorghum and pearl millet for pulses or oilseeds in rainfed areas by improving the productivity of these crops, replacing the old varieties by high-yielding ones.

Genetic improvement of nutritive quality of basic staples is another avenue of providing better nutrition, at no extra cost. Chemical fortification with limiting amino acids, which used to be the major approach advocated ten years ago, has given way now to attempts to improve genetically the amino acid balance and nutritive quality of crops like rice, wheat and maize, sorghum, barley, potato and sweet potato. This field of research was stimulated by the discovery at Purdue University in the USA of genes conferring a higher content of lysine, an essential amino acid, in the protein of certain strains of maize and more recently in *jowar*. This is of particular significance since the nutritional disorder pellagra has been found by the National Institute of Nutrition at Hyderabad in areas where sorghum is the staple. Another important finding is the identification in Sweden of a barley strain with high protein and lysine. This line of research may help to produce high yielding-cum-high nutritive quality strains. An international consortium known as "Harvest Plus" is working on genetic enrichment of nutritive quality using the techniques of molecular genetics. A food-based approach to nutrition security will then be possible.

Harmony

This involves the development of management concepts in areas like disease and pest control and the balanced growth of different components of a production system. Scientists have been developing effective vaccines against the important diseases of cattle. A vaccine against lung work in sheep has been developed using the principle of radiation attenuation. In general, however, the awareness of the need for quarantine and sanitation is not widespread.

Depending upon the cropping pattern, water availability and market demand, profitable mixed farming systems can be developed. Poultry rations usually contain as high as 60-70 percent of cereal grains. However, several agricultural and industrial by-products like rice bran, wheat bran, slaughter-house waste, fishery wastes, etc. could be used as poultry feed. Similarly, there are opportunities for introducing new rations like a mixture of bagasse, molasses and urea.

Growingly, concepts like pest control are giving way to procedures which help to raise good crops through better management with minimal assistance from chemical methods of control. Such integrated procedures of pest management involve an appropriate combination among methods like selection of resistant varieties, use of parasites and predators, both native and introduced, ecological control through modifications in cropping systems and agronomic practices, development of microbial pesticides, use of attractants and repellants including sex hormones, development of various methods of inducing sterility in pests and use of selective chemical insecticides. Safer chemical pesticides are also being developed.

Biological control of pests

Biological control involving the control of pests through their natural enemies is receiving increasing attention. In the past, more emphasis had been placed on an inundation approach involving the mass breeding and release of indigenous natural enemies. Emphasis is now shifting to obtaining more effective parasites and predators from other areas where the same or related pests occur. Attempts are in progress in some countries in Africa to control serious water weeds like water hyacinth and *Salvinia* through introduced parasites. If such parasites prove to be highly host-specific, it may also be possible to initiate similar studies in India, since these aquatic weeds are causing serious problems in tanks and waterways particularly in eastern India and Kerala.

Economy through recycling

An integrated nutrient supply system involves the development of an appropriate schedule of manuring with organic and inorganic manures in each agro-climatic zone. There is great scope for raising leguminous shrubs or fertilizer trees on bunds of irrigated fields or all along irrigation canals and rivers for providing green leaf manure. Success in conserving cow dung and other wastes for use as manure will depend upon the availability of alternative source of fuel.

Devices like bio-gas plants are yet to become popular. The conversion of grains through fermentation into usable ethyl alcohol, the growing of trees specifically for generating thermal power, the development of new high-yielding crops for industrial energy and recycling animal waste by anaerobic fermentation are some of the possibilities under economic assessment in several countries.

Fertiliser use efficiency is very low at present and the common assumption of return from the applied nutrients is 10 kg of grain per kg of NPK nutrients. Scope for improving fertilizer use efficiency exists through procedures like adjusting fertilizer dose to soil test values, better water management, weed control, split application, placing the fertilizer a little below the soil surface, and use of nitrification inhibitors where leaching losses are likely to be high. Seed-cum-fertilizer drills help to achieve good seed germination and fertilizer distribution. When yields increase, deficiency of phosphorous and of micronutrients like zinc become important, as was seen in Punjab after the introduction of high-yielding varieties of wheat. A continuous monitoring of the status of soil health is hence important.

There is apprehension that phosphorus reserves may get greatly depleted within the next century. Hence, every attempt should be made to use wastes like basic slag from steel mills, sources like rock phosphate and Laccadive sands and also promote the solubilization of insoluble phosphates through microbial secretion of organic acids which dissolve phosphates.

Cutting post-harvest losses

A major problem in the safe storage of grains is the high moisture content, particularly in paddy. Studies carried out at the Paddy Processing Centre in Tiruvarur, India on the effects of salt sprays both before and after harvest have shown that this technique could help to bring down the moisture content to about 12 per cent rapidly. Bad storage not only results in a quantitative loss of all food material, but more importantly, there could be considerable deterioration in nutritive quality. The problem is acute in crops like groundnut which develop aflatoxins following fungal infection.

In some of the rich nations, where there is a move towards reducing the total per capita meat intake, food technologists are now developing textured vegetable proteins resembling meat products. Plant proteins which were not formerly of value in human nutrition are also now becoming usable due to the removal by processing of the toxic or anti-nutritional factor. For example, a milling technique called the Liquid Cyclone Process can help remove gossypol from cotton seeds. Methods for removing the toxic glucosinolates present in rape and mustard seeds have been standardized in Sweden. The Central Food Technological Research Laboratory at Mysore, India has standardized several useful

milling and processing techniques and the improved methods of pulse milling particularly deserve popularization since they can save over 10 percent of milling losses.

Changes in processing and utilization can completely change the market value of a commodity. For example, until some years ago research for the improvement of robusta coffee had been given less importance on the assumption that the world demand would be only for arabica coffee, which has a superior flavour. The advent of instant or soluble coffee has however changed the position, since robusta has good solubility. Similarly, lac (the scarlet resinous secretion of a number of species of insects) was regarded until recently as a dying industry. However, the price of lac has gone up since some important new uses for lac have been found. Demand for cassava has also greatly grown. These few examples are sufficient to indicate how in order both to maintain and develop further markets for agricultural produce, there is need for monitoring trends in processing and utilization. All this will call for a Food Technology and Market Intelligence Unit which can keep research workers constantly informed about the relative priorities they should assign to problems having a bearing on export trade.

An exciting era

We are thus in an exciting era in agricultural and food science. Thanks to the growing involvement of more and more physicists, chemists, climatologists, mathematicians and engineers in studying and solving biological problems, we can hope for continued progress in unraveling new approaches to improving productivity. Remote sensing, satellite photography and satellite television have all great applications in soil and ground water survey, crop census preparation, disease forecasting, prediction of floods and cyclones and mass communication.

Bridging the Know-how – do-how Gap

For an efficient adoption of the technology at the field level, in an era of climate change, there is need for the development by scientists of appropriate drought, good weather and flood avoidance codes for such agro-ecological areas. Such codes would be of immense benefit to the developmental administrators as well as to local extension agencies. The only approach to rapid economic development which can succeed is to optimize the advantages of farmer-participatory research and knowledge management.

Changes in cultural practices

Several basic changes in cultural practices are often needed to get the best out of new crop varieties. For example, in dwarf wheats sowing has to be shallow, first irrigation has to be given at the time of initiation of crown roots and population density should be higher. In rice, traditional practices such as low seed rate under direct seeding, wide spacing, deep planting and bunch planting under transplanted conditions and drying the field to promote the establishment of seedlings are all intended to retard luxuriant vegetative growth in the earlier tall varieties, which have a proneness for both excessive vegetative growth and lodging or falling down. In contrast, the new dwarf rice varieties need almost the opposite kind of treatment if they are to reveal their full genetic potential yield.

It is not only in agriculture and dairying that new techniques need to be popularized but also in inland and marine fisheries. There is need for “Fish for All” Training Centres, where training can be imparted in an end-to-end manner, i.e. from capture or culture to consumption.

Like game and wild life sanctuaries, there is a need to develop “Agro-biodiversity Sanctuaries” in areas where valuable genes are found in the native cultivars and flora. Such a step can help to prevent the erosion of valuable genes. In contrast to soil erosion, gene erosion is not visible to the naked eye and hence does not attract the same attention.

Gene Banks for a Warming Planet

The Bicentenary of Charles Darwin's life and work reminds us that without diversity there will be no scope either for natural or human selection. Also, biodiversity is the feedstock for the biotechnology industry. Recombinant DNA technology has opened up uncommon opportunities for developing novel genetic combinations to meet the challenges arising from adverse alterations in temperature, precipitation, frequency of drought and floods and sea level associated with climate change.

Thanks to the spread of participatory breeding and knowledge management systems involving scientists and local communities, *in-situ* on-farm conservation resulting in field gene banks is now becoming an integral part of national biodiversity conservation strategies. The significance of such conservation will be clear from the existence of over 125,000 genetic strains of rice, of which over 100,000 are now in the cryogenic gene bank of the International Rice Research Institute in the Philippines. This invaluable gene pool is one of the greatest assets in relation to adaptation to the consequences of global warming.

Mankind now depends largely on a few crops like wheat, rice, corn, soybean and potato for sustaining global food systems. If due to natural calamities, the production of any of these crops is affected, the prices will go up and food deficient countries will face food riots. Millets like *Panicum, Paspalum, Setaria*, and *Pennisetum*, as well as crops like *Chenopodium*, tubers and grain legumes require leas irrigation water and are at the same time rich in micro-nutrients like iron and calcium. Such orphan crops are also sources of genes conferring tolerance to drought, floods and sea water intrusion. Several publications of the US National Research Council such as "Lost Crops of the Incas: Little-known Plants of the Andes With Promise for Worldwide Cultivation" and "Lost Crops of Africa" provide information on the role agro-biodiversity played in the past in ensuring sustainable food and health security. Unfortunately, the food basket is now shrinking with the spread of commercial farming. Genetic homogeneity increases the vulnerability of crops to abiotic and biotic stresses. Saving dying wisdom and vanishing crops has become an urgent task.

There are many cryogenic gene banks around the world. Unfortunately their maintenance is very expensive and the running costs are high. Thanks to an initiative of the Government of Norway and the Global Biodiversity Trust, the Svalbard Gene Vault located near the North Pole can help to conserve for posterity over 4 million accessions. The conservation continuum is now complete at least in the case of agro-biodiversity.

The M S Swaminathan Research Foundation in Chennai, India has conserved an assemblage of genes for a warming India. These genes also come from plants which are not part of the normal agro-biodiversity collections such as mangroves, which are good donors of salt water tolerance, and *Prosopis juliflora,* an excellent source of genes for drought tolerance. Genes for a warming world should become an international collaborative project so that we can purchase time in equipping ourselves to meet the challenges of climate change. Such partnership among concerned scientists and institutions across the globe should be an important outcome of the Copenhagen Climate Conference.

Changes in educational outlook

What kind of education do we need that would be relevant to developing countries, dependent on agriculture as the major source of livelihood? And what practical steps can we take to change our educational system into such a one?

The changes required are of two kinds: we need to bring about a change in outlook, creating an awareness of biological surroundings, and a consciousness of the possibilities of synergy. This can be done only when there is an inundation, at every level of education, of course materials that will create such a consciousness. We also need to give technical skills to illiterate and semi-literate adults, which will enable them to understand and use efficiently the new technological packages.

During the early years of childhood, before the child begins to receive formal education, and in primary school, the major emphasis should be on living in nature and with nature, learning about nature through direct observation, and using the materials provided in nature to develop scientific skills, aptitudes and habits of thought. How often are children in primary schools forced to remain within the limiting walls of a barren and bare classroom, because of the false impression that education is something that must take place within a building? How many children in primary schools are taken for walks and helped to learn about nature? On the other hand, there are commendable efforts in some places to use nature itself as a medium of education, as in the Meadow School of the late Mrs Tarabai Modak of India, which carried education to shepherd boys right in the meadows where they were grazing cattle. There have been other similar ventures but all have remained small, local and isolated.

Role of Banks and the Private Sector

Both banks and public and private sector companies can play a great role in combining their regular work with the art of communication. Banks can finance entire production programmes, as for example the production of 100,000 tonnes of sunflower oil or the production of a certain quantity of soybean in a suitable area, and thereby assure the credit and other infrastructure for the entire production chain and not merely for components of the chain. Similarly, pesticide firms can sponsor programmes designed to ensure pest-proofing of important crops in the poorest villages in their area of operation.

Involving university students specializing in Nutrition

Students of nutrition can be encouraged to work out horticultural remedies for major nutritional remedies for their respective areas, as shown below:

Overcoming Hidden Hunger
Nutritional Malady and Horticultural Remedy

Malady:	**Remedy:**
Vitamins:	Rape Leaves
Vitamin A	Cauliflower
Vitamin B Complex	Amaranth
Vitamin C	Drumstick leaves
Minerals	Spinach
Iron	Parsley
Iodine	Turnip Greens
Zinc	Carrot
Copper	Tapioca chips
	Sweet Potato
	Yam
	Radish

Technical literacy for farmers

Large numbers of peasants in developing countries are illiterate. Unfortunately, the proportion of illiteracy seems to be higher in areas such as the arid and semi-arid regions, where the scientific transformation of the rural economy requires a much greater understanding of the principles of economic ecology. The Indian Council of Agricultural Research has set-up a number of Krishi Vigyan Kendras (Farm Service Centres) to impart technical literacy to practicing farmers, fishermen and others. These Kendras would select in each area such means of economic growth which are most likely to give major benefits to the poorest sections of the community. In other words, those who are setting up a Krishi Vigyan Kendra will first have to make a survey of the agricultural potential of an area and

then identify those aspects of growth which could help to improve the purchasing power of the poor. Nutrition literacy must be an integral part of the learning exercise.

Social synergy

Ruth Benedict, the anthropologist who first applied the concept of synergy in social sciences, said "Societies where non-aggression is conspicuous have social orders in which the individual by the same act and at the same time serves his own advantage and that of the group. Non-aggression occurs in these societies, not because people are unselfish and put social obligations above personal desires, but because social arrangements make these two identical".

"Cultures with low social synergy are those in which the social structure provides for acts which are mutually opposed and counteractive, and cultures of high synergy where it provides for acts which are mutually reinforcing. In cultures with high social synergy, institutions ensure mutual advantage from their undertakings, while in societies with low social synergy the advantage of one individual becomes a victory over another, and the majority who are not victorious must shift as they can".

According to Abraham Maslow "The high synergy society is the one in which virtue pays. High synergy societies all have techniques for working off humiliation, and the low synergy societies uniformly do not".

There is sufficient evidence in Nature to prove that symbiosis, or the process of mutual assistance and support, is a necessary ingredient for synergy. However, it seems that the very concept of synergy has been very little used, or even understood, by social scientists in its application to man. There is a close correlation between synergy and non-violence, a fact which is becoming evident in the context of the growing violence in the human heart.

"Food for all and for ever" is a goal that can be achieved only by fostering a high synergy society.

Individual and social goals

Individual goals have to be made to coincide with social goals. Communist countries have found their own approaches. Russia, China and Israel have all found their own ways of ensuring the mutually reinforcing nature of individual and social goals. In Russia, for instance, the system of rewards and punishments in schools is such that the individual is rewarded only when the peer group succeeds. At every stage, the success and happiness of the individual is related to the success of the group in such a way that each individual strives to maximize the success of the group.

It is this approach that we should foster for achieving the UN Millennium Development Goal No. 1 relating to reducing hunger and poverty by half by 2015.

To sum up, nutrition security at the level of each individual child, woman and man is essential for a healthy and productive life. Achieving nutrition security will depend upon concurrent attention to food availability, economic access and absorption in the body. This will call for a life cycle approach to the delivery of nutrition safety net programmes, and to integrated attention to a balanced diet, clean drinking water, environmental hygiene, primary health care and primary education. Thus, we need in every country a **Nutrition Security Compact** comprising both nutrition and non-nutritional factors. The recent (2009) L'Aquilla declaration by G8 countries has rightly stressed the need to accelerate our efforts to enable every child, woman and man in our planet to have an opportunity for a productive and healthy life.

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Minimizing Postharvest Losses in Yam (*Dioscorea spp.*): Treatments and Techniques

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INTRODUCTION

Yam belongs to the genus *Dioscorea* (Family *Dioscoreaceae)* and is the second most important tropical root crop in West Africa after cassava. Besides their importance as a food source, yams also play a significant role in the socio-cultural lives of some producing regions such as the celebrated New Yam Festival in West Africa. Yams originated in the Far East and spread westwards. Today, yams are grown widely throughout the tropics. West and Central Africa account for about 94% of world production, Nigeria being the major producer.

The most popular and preferred form of consuming yam is the tuber form, either boiled, pounded, roasted or fried. Better financial returns are obtained by selling the yams as tubers rather than as processed yam flour. Thus, farmers prefer to store most of their yams after harvest. Methods of storage vary from delayed harvesting, storage in simple piles or trenches to storage in buildings specially designed for that purpose, and application of modern techniques.

Causes of storage losses of yam tubers include sprouting, transpiration, respiration, rot due to mould and bacteriosis, and attack by insects, nematodes and mammals. Sprouting, transpiration and respiration are physiological activities which depend on the storage environment (mainly temperature and relative humidity). These physiological changes affect the internal composition of the tuber and result in destruction of edible material and changes in nutritional quality. Storage losses in yam of the order of 10-15% after the first three months and approaching 50% after six months storage have been reported.

A number of treatments and techniques have been developed to reduce these physiological activities and also to protect the tuber from postharvest diseases. These include treatment with chemicals, plant extracts, palm wine and gamma irradiation; storage techniques used include cold storage, improved underground storage and improved yam barns. This chapter discusses research into yam postharvest handling aimed at improving the availability of tubers throughout the year.

YAM PRODUCTION

Yam *Dioscorea spp.* is an important food crop especially in the yam zone of West Africa. Although more than six hundred species of the tuber exist, only a few are important as staple food in the tropics. These include white yam *(D. rotundata*), yellow yam (*D. Cayenensis*), water yam (*D. alata*), trifoliate yam (D. *dumetorum*), aerial yam (*D. bulbifera*) and Chinese yam (*D. esculenta*) [1]. West Africa accounts for 90-95% of world yam production with Nigeria the largest single producer. In 2004, global yam production was about 47 million metric tons (MT) with 96% of this coming from Africa. Nigeria alone accounts for about 70 percent of world production [2]. It is the second most important root/tuber crop in Africa with production reaching just under one third the level of cassava. More than 95 percent (2.8 million ha) of the current global area under yam cultivation is in sub-Saharan Africa, where the mean gross yield is 10 t/ha. In Asia, production for 2004 stood at 226,426 MT [2].

Yam production is relatively expensive compared with other root and tuber crops; this is attributed to costly inputs, especially labour and planting material. Traditionally, yams are propagated by whole

tubers (seed yam) or relatively large tuber pieces. Today yam mini-sets (or small pieces of yam) are increasingly been used as planting material [3]. The tubers are retained from the harvest for the next planting season. The tubers (Figure 1) which are the only edible part have both a tremendous capacity to store food reserves and ability to grow into the deep layer of the soil. The top growth consists of twining vines that may be several meters long depending on species and growing conditions [Figure 2] and require trellises over which to climb.

Figure 1: Yam tuber

Figure 2: The yam plant

Maturity assessment is critical to achieve good quality yam. In the field a mature crop is distinguishable by cessation of vegetation growth and yellowing of leaves. The period from planting or field emergence to maturity is variable depending on the species. Tubers may be harvested 6-10 months after emergence or once at 4-5 months and again at 8-10 months, depending on species [4]. The yield depends on the size of the seed piece, species and environment but normally ranges from 8-50 t/ha in 6-10 months.

IMPORTANCE OF YAM

Yam is important because of its excellent eating quality; they are a preferred food at social gatherings. People consume yams, sweet in flavour, as a cooked vegetable fried or roasted. In West Africa yam is often pounded into a thick paste after boiling (pounded yam) and is eaten with soup [Figures 3 & 4]. Pounded yam is the most popular food form of yam in West Africa and is often reserved for special occasions in the urban areas. Presently, whole roasted yam has become a popular street or fast food in urban areas throughout the West African yam belt [3]. Virtually all production is used for human food. In the major yam producing countries, average consumption is 0.5 - 1.0 kg yam daily [5]. Yam is a preferred food and a food security crop in some sub-Saharan African countries. Unlike cassava, sweet potato and aroids, yam tubers can be stored for periods of up to 4 or even 6 months at ambient temperatures.

Sahore *et al.*, [6] studied changes in nutritional properties of yam (*Dioscorea spp.*), green plantain (*Musa spp.*) and cassava (*Manihot esculenta*) during storage and showed that yam tubers underwent only slight changes over a four week period while cassava and green plantain could be kept only for a week without significant deterioration. This characteristic contributes to the sustaining of food supply, especially in the difficult (food scarce) period at the start of the wet season. Yams are also processed into yam chips and flour that is used in the preparation of a paste. The problems encountered by processors include a lack of suitable raw materials, drying and storage equipment, and poor quality of the processed product.

Figure 3: Preparation of pounded yam

Figure 4: Pounded yam meal with meat and vegetables

Apart from being used for family food, yams are also a cash crop for farmers. Studies show that yam is a highly profitable crop in the yam zone constituting an average 32% of farmers' gross income derived from arable crops [7]. Figures 5 and 6 show a typical yam market in Niger State of Nigeria. Yam also plays a significant role in African socio-cultural traditions. The commercial importance of the crop has not eroded its traditional status. It is an indispensable part of the bride price and in Eastern Nigeria new yam festivals are celebrated annually during the months of August and September. In South-Eastern Nigeria, the cultivation and consumption of yam dates back several centuries. In this area, yam is a totem of masculinity and the centre of annual harvest celebrations; it is also a calendar crop around which the farming season and the annual festival revolves.

Figure 5: Yam collection centre at Garatu, Niger State of Nigeria

Figure 6: Buying and selling of yam in Niger State of Nigeria.

NUTRITIONAL VALUE OF YAMS

Yams are an excellent source of carbohydrate, energy, vitamins (especially vitamin C), minerals and protein. Some cultivars of yam tuber have been found to contain protein levels of 3.2 – 13.9% of dry weight. A yam meal could supply 100% of the energy and protein, 13% of the calcium and 80% of the iron requirement of an adult male [8]. Some food yams have been shown to contain phosphorous and vitamins such as thiamine, riboflavin, niacin and ascorbic acid.

The chemical composition of yam is characterised by a high moisture content and dry matter. The dry matter is composed mainly of carbohydrate, vitamins as well as protein and minerals. Nutrient content varies with species and cooking procedure. Cooking with the peel intact helps retain vitamins [5]. Table 1 shows the ranges of nutritional composition for edible yams species.

Table 1: Nutritional value of yam (Nutrient in 100 g of edible portion)

Nutrient	Range
Calories (kcal)	71 – 135
Moisture (%)	65 – 81
Protein (g)	1.4 – 3.5
Fat (g)	0.2 – 0.4
Carbohydrate (g)	16.4 – 31.8
Fibre (g)	0.40 – 10.0
Ash (g)	0.6 – 1.7
Calcium (mg)	12 – 69
Phosphorous (mg)	17 – 61
Iron (mg)	0.7 – 5.2
Sodium (mg)	8.0 – 12.00
Potassium (mg)	294 – 397.00
β-carotene (mg)	0.0 – 10.0
Thiamine (mg)	0.01 – 0.11
Riboflavin (mg)	0.01 – 0.04
Niacin (mg)	0.30 – 0.80
Ascorbic acid (mg)	4.00 – 18

Source (Osagie, 1992)

Yams may also contain small quantities of polyphenolic compounds (e.g. tannins), alkaloids and steroid derivatives. The carbohydrate content of the yam tuber represents its major dry matter component and may be classified as starch, nonstarch, polysaccharides and sugar. Starch in yam tubers is frequently converted to sugars probably as a result of stresses experienced during growth and storage. The sugar content is influenced by variety, location and cultural treatment. The free sugars consist mainly of sucrose and glucose, with the former predominating. Fructose and maltose have been detected during dormancy/sprouting periods [9]. The published protein content of yam tubers varies very considerably between both species and cultivars and depends on various factors including cultural practices, climate and edaphic factors under which it was grown, its maturity at harvest and length of storage time. High protein content is characteristic of very vigorous varieties with *D. alata* tubers having the highest protein levels among the edible yams. Although the protein content of yam is lower than that in most cereals, yam can provide more protein per hectare per year than maize, rice, sorghum and soybean (Idusogie (1971) as referenced by [5]). However, the value of cooked yam as a source of protein is limited by its bulk, the water content being very high.

YAM STORAGE AND STORAGE STRUCTURES

Yam is an annual crop, so for it to be available throughout the year, harvested tubers must be stored for six to eight months before new yams are harvested. The possibility to store fresh yam tubers is decisively influenced by their dormancy which occurs shortly after their physiological maturity (wilting point). During dormancy, the metabolic function of the tuber is reduced to a minimum. It allows the tuber as an organ of vegetative propagation to overcome an unfavourable climatatic period. Consequently, varieties of yam native to regions with marked arid seasons have a longer period of dormancy than those with a shorter dry season. The duration of natural dormancy fluctuates according to the variety of yam between four and eighteen weeks [8]. During the storage period a substantial amount of yam is lost. Some of these losses are endogenous, i.e. physiological, and include transpiration, respiration and germination. Other losses are caused by exogenous factors like insects, pests, nematodes, rodents, rot bacteria and fungi on the stored product [10]. Good management can easily control the exogenous loss factors while the environment controls other sources of loss.

Yam storage structures and methods were evaluated in the former Bendel State of Nigeria [11] in the middle belt of Nigeria [12; 13] and in Western Nigeria [14]. This work showed that the storage structures used depend on the construction material available, amount of tuber produced, prevailing climatic condition of the area, purpose of yam tuber storage, socio-cultural aspects of storage and the resources of the farmer, in particular the availability of labour and capital. In the humid forest zone yam is stored in a yam barn which is the principal traditional yam storage structure in the major producing areas. Barns in the humid forest zone are usually located under the shade and constructed so as to facilitate adequate ventilation while protecting tubers from flooding, direct sunlight and insect attack. There are several designs, but they all consist of a vertical wooden framework to which the tubers are individually attached [4; 11]. Tubers are tied to a rope and hung on horizontal poles 1-2 m high (Figure 7); barns up to 4 m high are not uncommon. Depending on the quantity of tuber to be stored, frames can be 2 m or more in length. The ropes are usually fibrous; in south-eastern Nigeria they are made from the raffia obtained from the top part of the palm wine tree. Many farmers have permanent barns that need annual maintenance during the year's harvest. In these situations, the vertical posts are often made from growing trees which are trimmed periodically. Palm fronds and other materials are used to provide shade. The vegetative growth on the vertical trees also shades the tubers from excessive solar heat and rain [4].

Figure 7: Typical yam barn in the humid forest zone (individual yams tied to live poles)

The yam barn in the Guinea Savannah zone is constructed from guinea corn stalk, sticks, grass and yam vines. The yams are heaped at different positions in the barn [12; 13]. Such barns are constructed every year and are situated near the house under a tree to protect the tuber from excessive heat (Figures 8 and 9). At the end of the storage period the barn is burnt down and in December/January a new structure is built for the next harvest [13]. Unlike the humid forest where it is important that the yams are separated to avoid rotting, in drier areas such as Niger State the yams can be stacked into piles in the barn [10; 13]. At the onset of the rainy season the yams are transferred to a mud hut or guinea corn storage rhombu to protect them from the rain. Another yam storage structure found in the savanna region is the yam house or yam crib [4; 10]. "Yam houses" have thatched roofs and wooden floors, and the walls are sometimes made simply out of bamboo. They are raised well off the ground with rat guards fitted to the pillars. Yam tubers are stacked carefully inside the crib (Figure 10). Yam is also stored underground in trench or clamp silos. In both methods a pit is excavated and lined with straw or similar material [15]. The tubers are then stored on the layer of straw either horizontally on top of each other or with the tip vertically downwards beside each other. The yams are then covered with straw or similar materials; in some cases a layer of earth is also added.

Figure 8: The yam barn in the Guinea Savanna zone

Figure 9: The interior view of a typical yam storage in the southern Guinea Savanna zone (piled into heaps in a yam barn)

Figure 10: A traditional yam house used in the Savanna region (redrawn from Wilson, 1980)

QUALITY CHANGES OF YAM TUBER DURING STORAGE

Causes of storage losses of yam tubers include sprouting, transpiration, respiration, rot due to mould and bacteriosis, insects, nematodes and mammals [16]. Sprouting, transpiration and respiration are physiological activities which depend on the storage environment, mainly temperature and relative humidity [16]. These physiological changes affect the internal composition of the tuber and result in destruction of edible material, which under normal storage conditions can often reach 10% after 3 months, and up to 25% after 5 months of storage [16].

Investigations on the biochemical changes in stored yam tubers have shown that changes in starch, sugars, and protein take place during long-term storage [17; 18]. A study of yam tuber (*D. dumetorum*)

stored under ambient and cold room conditions showed a rapid drop in moisture and starch content and an increase in the total alcohol-soluble sugars and reducing sugars after 72 hours of storage [17]. The rate of decrease in moisture and starch content and the rate of increase in sugar level were higher in tubers stored at room temperature than those stored under cold room conditions. A similar trend was observed for *D rotundata* cv. Oshei and *D. dumetorum* cv Jakiri after 110 days of storage under ambient conditions [18]; weight losses reached 31% in Oshei tubers and 35% in Jakiri due to sprouting and dehydration. Starch content decreased by approximately 3.5-4.5 g/100 g while sugar and fibre values increased slightly in both cultivars.

A study of the physical, chemical and sensory changes occurring in white yams *(Dioscorea rotundata)* and yellow yams *(Dioscorea cayenensis)* stored for 150 days in traditional barns showed losses in moisture, dry matter, crude protein and ascorbic acid after 120 days of storage [19]. Sensory evaluation rated the stored tubers higher than the fresh tubers. A similar study [20] reported a 17-22% reduction in weight, 30-50% reduction in crude protein and 38-49 % increase in sugar content for two cultivars of white yams (*D rotundata)* stored in a barn. Generally, in stored tubers there is reduction in weight, crude protein, starch and mineral content while the sugar and fibre contents increase [21].

METHODS OF IMPROVING YAM STORAGE

Yam storage problems are essentially of three kinds: (a) direct damage by diseases, pest and nematodes in the field and in storage; (b) sprouting losses; and (c) respiratory and evaporation losses. All these reduce the overall quantity and quality of the tubers with food reserves being increasingly depleted by one or more of these causes. In normal conditions, tubers of many clones remained dormant for 10-12 weeks before sprouting started. Researchers have worked on a number of methods and techniques to improve yam storage. Different intensities of gamma irradiation offered some technical advantages for storing yam tuber for fresh consumption [22; 23; 24]. Irradiation was an effective treatment for the inhibition of sprouting of yam (*D. rotundata*) for a storage period of six months at doses of between 7.5 and 15 krad without inducing adverse changes in acceptability or physiological properties [22]. An average dose of 120 Gy and a dose rate of 114 Gy/hr were applied to the cultivar *D. rotundata cv Asana* and irradiated and non-irradiated tubers stored for 6 months side by side using two different types of storage, viz. barn and storage on the ground; results showed that irradiation reduced sprouting in both storage types [23]. However, rotting increased with storage time and there was less rotting in the yams stored in the barn than those stored on the ground. It was also observed that there was less rotting in the non-irradiated yams stored on the ground than the irradiated ones. After six months of storage food products made from irradiated yams were judged to be better in quality than those made from the non-irradiated ones. Differences in varietal responses to gamma irradiation have been reported [24].

Some chemical compounds have been used to prolong dormancy and retard sprouting [25-29]. Gibberillic acid (GA) when applied to tubers soon after harvest was able to extend dormancy by 9-11 weeks for *D. rotundata* and by 13 weeks for *D. alata* species of yam tuber [25; 26]. *D. alata* tubers treated with GA at the beginning of storage germinated 4 weeks later than controls, the effect being less when treatments were given later; treatments given after three months of storage were too late to inhibit germination [27]. Chloroisopropyl phenylcarbamate (CIPC) solution and powder which is successfully used to inhibit dormancy on potato tubers did not have any effect on *D. rotundata* [28]. The effect of maleic hydrazide in controlling sprouting in yam showed that soaking the tubers of *D. esculenta* and *D. rotundata* in 1000 ppm solutions for ten hours before storage reduced the rate of sprouting by 16% and 8% in *D. esculenta* and *D. rotundata* respectively [29]. However, others [22] reported that maleic hydrazide was not effective in inhibiting sprouting in *D. rotundata* tubers. Other chemicals used in yam storage include commercial wax, lime, benlate and captan. The observed effects of chemicals on the storage life of yam tubers have been summarised, with there being species and cultivar differences in the response of yams to chemical treatments [5; 30].

Plant extracts have been used to improve the quality of stored yam tubers [31-33]. The effect of neem bark water extract, neem bark slurry and neem leaf slurry treatments on the quality of stored yam

showed that sprouting was delayed by one month in all neem-treated tubers [32]. Rotting was also delayed by three months in tubers treated with neem bark extract; a similar result was observed when using neem bark extract and neem leaf slurry for sprouting [33]. However, the neem treatments in this case did not have any effect in reducing or delaying rotting. The effect of lime and neem wood ash treatment in three different cultivars of bruised *D. rotundata* tuber*s* showed that lime was more effective in controlling rot in stored yam tubers than neem wood ash [31]. Another means of controlling rot and inhibiting sprouting in yam tubers is the use of palm wine; farmers claim that tubers treated with palm wine show less rot but this claim is yet to be substantiated.

The use of improved yam storage structures has been reported by some authors [1; 14]. The improved barn is rectangular in shape with varying dimensions. The floor is cemented and raised above the ground level to prevent pests from gaining access to the barn. The walls are constructed of plastered concrete one meter above the ground and the rest is prefabricated chicken wire mesh joined together by welding [14]. The roof is either corrugated aluminium sheet, raffia mats or grass. Inside the building are a number of wooden shelves which have compartments and the yams are arranged on these shelves. The advantage of this structure is that placing the tubers on the shelf require less time and labour, provides adequate ventilation (through the wire mesh) and the space between the wall and the shelves facilitate free movement during inspection of the tubers [1; 14]. Studies were undertaken to obtain quantitative data on the weight loss of stored yam tubers as affected by air temperature, relative humidity, length of storage on sprouting and tuber weight [34-36]. Yam tubers stored for six months in a traditional yam barn, a pit structure with cross and vertical ventilation via a centrally located chimney and another pit structure without a chimney showed that the psychrometric air conditions were characteristically different in the three structures [34]. Average air temperature was 25°C, 27°C and 35°C for pit with chimney, pit without chimney and barn respectively and the humidity was highest in the pit with chimney and lowest in the barn. The low temperature in the pits was due to shielding from solar radiation and the cooling effect of the shaded soil mass surrounding the pit structure. The low temperature in the pit with a chimney resulted in delayed sprouting and reduced weight loss compared to the other structures. Similar results were obtained by others [35; 36]. In addition to the low temperature in the pits, the diurnal temperature variation was also low compared to the barn.

In another study the storage environment was modified by ventilating the barn [21; 37]. The effect of intermittent and continuous air flow (achieved by placing a standing fan in the barn) on weight loss and sprouting of white yam tubers was a significant reduction in sprouting and weight loss of tubers when supplied with air flow [37]. A similar result for sprouting and weight loss was observed when intermittent (six hourly) air flow was incorporated in a conventional yam barn [21]. At the end of the storage period, the percentage of rotting was significantly lower in the barn with intermittent air flow (less than 2%) compared to the barn with no air flow where 12% of the tubers were decayed [21].

Regular removal of sprouts as a means of reducing weight loss in stored tubers has been studied [20; 27; 38]. By removing the growing shoots weekly, weight loss of stored yam tubers can be reduced and useful storage life increased [27]. If tubers are stored on shelves where air circulates freely around them, then the new sprouts can be easily seen and rapidly removed. This technique will extend the storage life by up to 8 months. Monthly removal of sprouts reduced fresh weight loss during 5 months storage by 11% for cultivars of *D. alata* and *D. rotundata* tubers [38]. There were differences in weight loss due to the sprout cutting technique; cutting of the sprout at the base rather than 1 cm from the base was recommended. Table 2 shows the percentage weight loss for tubers with and without sprouts removed after eighteen weeks of storage in the barn and improved pit storage for two cultivars (*giwa* and *asuba*) of *D. rotundata* tubers [36]; the weight loss for tubers with sprouts removed is lower than when the sprout was not removed.

Table 2: Weight loss for tubers with and without sprouts after 18 weeks of storage (Osunde 2003)

	Weight loss %			
Treatment	*Giwa*		*Asuba*	
	Barn	Pit	Barn	Pit
Sprout removed	22	20	20	18
Sprout not removed	26.3	24.3	22.7	22.7

Storage of yam tubers at a relative humidity of 80% and temperature of 16°C reduces moisture loss and delays sprouting. Adesuye [14] stated that 15°C is a safe temperature for storage of yam and it inhibits sprouting for six months. However, changing the temperature to influence dormancy is limited because the tissue is destroyed when the temperature falls below 15°C. In addition, influencing the storage climate by external energy (refrigeration) is restricted economically due to the high energy cost.

CONCLUSION

Yams are the most nourishing plants in the diet of many inhabitants of inter-tropical regions, to such an extent that their very existence is centred on this crop. The average inhabitant of the yam zone consumes between half and one kilogram of yam daily, representing about half of their total calorific intake. Yams are generally abundant and sold cheaply at harvest time, but later (especially during the planting season) they become scarce and expensive. If yam could be stored without heavy loss, supplies could become steadier, prices would fluctuate less and farmers would be encouraged to grow them by being assured of a steadier income.

This chapter has presented a number of techniques and treatments to improve the quality and quantity of stored yam tuber. However, there is a need for further research into the postharvest storage of yam tuber to better understand differences in varietal responses to treatments. Such research should be conducted in the farmer's field with his active cooperation, so that a large part of the research may be directly linked to his needs, and may thus affect him in the most active way. Finally, there is the need for better funding both locally (in yam growing regions) and internationally (funding organizations) for yam postharvest research and technology transfer.

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Food Processing and Preparation Technologies for Sustainable Utilization of African Indigenous Vegetables for Nutrition Security and Wealth Creation in Kenya

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ABSTRACT

The purpose of traditional food processing is preservation to maintain a supply of wholesome, nutritious food during the year and preservation for the time of scarcity. While food processing still has the main objective of providing a safe nutritious diet in order to maintain health, other aspects, particularly the generation of wealth for the producer and seller, have become increasingly important. While most people in the rural areas still rely on traditional foods for their basic diet, those in urban and cosmopolitan centers tend to purchase processed and packaged foods for convenience. The increasing number of women who now work away from home adds additional pressure for such changes. Even people with a heavily traditional diet are demanding external products either as occasional treats such as gassy drinks, or basic commodities such as white sugar and flour. Although over 60% of the Kenyan populace lives below the poverty line resulting in malnutrition, poor health and inadequate basic necessities, Kenya is endowed with agro-biodiversity such as African Indigenous Vegetables (AIVs) that are highly nutritious, have health benefits, income generation potential and agronomic advantages that need exploiting. Research carried out at Maseno University in 2008 had the aim of developing East African indigenous vegetable recipes in order to promote utilization of AIVs for micronutrient malnutrition alleviation. East African indigenous vegetable products were developed which could contribute to poverty reduction and ensure availability of these vegetables during off-seasons even in supermarkets in Kenya. This technology should be further developed and disseminated to the community to address food insecurity.

INTRODUCTION

The most serious threat to the survival of humanity is the ever-increasing gap between population growth and food supply (Yadav & Sehgal, 2004). Changing customs have lead to the increasing use of convenience foods at home and in food outlets. Mild or minimal processing and preservation treatments lead to high convenience and nutritional value which is advantageous to consumers and food services (Wiley, 1994). However, preservation of agricultural produce is one of the central problems facing developing countries. Owing to the lack of and/or inadequacy of preservation methods, large quantities of urgently needed food spoil there. As time goes on, these problems will be aggravated by the growing dietary needs of growing populations in these countries. In Africa and Kenya in particular, this problem exists with many fruit and vegetable varieties (especially the indigenous ones) resulting in wastage during the in-season and limited supply during the off-season accompanied by high prices (Habwe, 2008; Abukutsa-Onyango, *et al.,* 2006) because most locally available vegetables are seasonal and not available year-long (Chavasit *et al.*, 2002). African indigenous vegetables cannot be marketed fast enough when they are in-season owing to their limited keepability (perishability). Appropriate preservation and storage methods should be performed in order to prolong the consumption of such nutrient-rich foods all year round (Chavasit *et al.,* 2002).

This chapter presents empirical results from a study that sought to develop affordable appropriate food processing and preparation technologies for sustainable utilization of African indigenous vegetables for nutrition security and wealth creation in Kenya. The study also sought to process

African indigenous vegetables by blanching and freeze-drying and to extend the shelf life of the processed African indigenous vegetables through product development using simsim *(Sesamum orientale L.)*.

African Indigenous Vegetables (AIVs)

Indigenous vegetables are those vegetables whose natural home is in a specified region (Maundu, 1997). There are more than 45,000 species of plants in sub-Saharan Africa of which about 1000 can be eaten as green leafy vegetables which happen to be the mainstay of traditional African diets (MacCalla, 1994). *Indigenous* and *traditional* are words used here to describe leafy vegetables that have been part of the food systems in sub-Saharan Africa for generations. Indigenous leafy vegetables are those that have their natural habitat in sub-Saharan Africa while the traditional leafy vegetables were introduced over a century ago and due to long use, have become part of the food culture in the sub-continent (Smith & Eyzaguirre, 2007). Examples of AIVs found across Eastern Africa include African nightshade (*Solanum scabrum*), spider plant (*Cleome gynandra*), vegetable amaranth (*Amaranthus hybridus*), slenderleaf (*Crotalaria brevidens*), jute mallow (*Corchorus olitorius*), vegetable cowpea (*Vigna unguiculata*) pumpkin leaves (*Curcurbita muschata*) and African kale (*Brassica carinata*) among many others (Abukutsa-Onyango *et al.*, 2006).

Immense attention has been directed to fruits and vegetables due to the increased awareness of the health protecting properties of non-nutrient bioactive compounds found in them, making them vital components of daily diets. They also contain non-nutrient bioactive phytochemicals that have been linked to protection against cardiovascular and other degenerative diseases (Smith & Eyzaguirre, 2007). AIVs play a key role in income generation and subsistence (Adebooye & Opadode, 2004). They are inexpensive, easily accessible and provide millions of African consumers with health-promoting compounds such as vitamins, minerals, anti-oxidants and even anti-cancer factors needed to maintain health and fight off infections (MacCalla, 1994; Abukutsa-Onyango, 2003; and ICRAF, 2004). Studies have also shown that countries that retain indigenous vegetable diets and have high consumption of these vegetables are much less likely to be affected by cardiovascular diseases, diabetes and other adverse consequences of nutrition in transition (Johns & Sthapit, 2004). They are compatible in use with starchy staples and represent a cheap but quality nutrition to the poor both in urban and rural areas where malnutrition is widespread (Maundu, 1997).

AIVs could make a positive contribution to world food production because they adapt easily to harsh or difficult environments, the input required for growing them is lower compared with other crops, and they are highly resistant to pathogens thus requiring fewer chemicals and pesticides (Abukutsa-Onyango *et al*., 2006). This makes them suitable and advantageous for people living in areas with high population density like Africa. AIVs can act as a substitute for other cultivated crops to alleviate nutrient deficiencies by increasing nutrient supplies (Engle & Altoveras, 2000). They are inexpensive and easy to cook (Yadav & Sehgal, 2004) and their production can compensate for low vegetable supply during the off-season, potentially helping to alleviate nutrition deficiency during this period (Engle & Altoveras, 2000).

African indigenous leafy vegetables have long been known and reported to have health protecting properties and uses. They are increasingly recognized as possible contributors of both micronutrients and bioactive compounds to the diets of populations in Africa (Smith & Eyzaguirre, 2007). They are a valuable source of nutrition in rural areas and they contribute substantially to protein, mineral and vitamin intake together with fibre; they also add diversity to the diet. AIVs should therefore be included in the diet to overcome various nutritional problems like iron and vitamin A deficiency (Midmore *et al*., 1991; Maundu, 1997; Kawatra *et al*., 2001; Yadav & Sehgal, 2004; Oniang'o *et al.,* 2005). The minerals and vitamins found in AIVs exceed the levels found in exotic vegetables like cabbage; they are also compatible to use with starchy staples because they contain ascorbic acid, which enhance iron absorption (ICRAF, 2004). Table 1 gives the nutrient content of raw AIVs.

Consumption of African Indigenous Vegetables

The International Plant Genetic Resource Institute (IPGRI - now Bioversity) has been involved with the promotion of African Leafy Vegetables (ALVs) in sub-Saharan Africa (SSA) since 1995 (IPGRI, 2004). Much attention has been centered on the exploitation and utilization of unusual plant materials for food. However, much of the attention has been paid to seeds while green leafy vegetable sources have, to a large extent, been ignored (Yadav & Sehgal, 2004). This ignorance is to a larger extent due to populations of Africa having negative perceptions of ALVs and this has led to low levels of consumption, causing poor nutrition status (Obel-Lawson, 2006). IPGRI, in partnership with the Dutch government, has led a campaign to try and reverse the decline in the use of ALVs (Shiundu & Oniang'o, 2007). Per capita consumption of fruits and vegetables in sub-Saharan Africa lags behind that of the other regions, showing an overall decline between 1986 and 1995 (Shiundu and Oniang'o, 2007). While *per capita* apparent consumption of vegetables in developing countries went from 68.7 kg *per capita* in 1986 to 75.3 kg in 1995 on average (a 0.92% increase), sub-Saharan Africa showed a 0.19% decline and remained as low as 29 kg of vegetables *per capita* consumption on average (Segre *et al*., 1998, as cited by Shiundu & Oniang'o, 2007).

Table 1: Nutrient Content (mg/100 g) of Raw AIVs from East Africa

AIV	Ca	P	Fe	Mg	Na	K	Vit C
Amaranth	323.7	89	7.5	122	230	341	50
Nightshade	100.47	62.50	8.63	461	74.22	100	54
Slenderleaf	1,234.4	11.25	28.13	155	22.66	162.50	
Cowpea	428.01	17.23	9.62	46.73	31.25	81.25	8
Pumpkin leaves	231.5	155	1.026	46.45	20.31	125	80
Cassava leaves	300	120	7.7	6	605	-	8
Sweet potato leaves	117.80	30	19.35	61.35	40	620	70
Spider plant leaves	1,484.4	48.95	29.67	47.50	18.75	75	
Tomatoes	14.06	19.04	1.997	11.86	45.193	47.83	10
Onions	39.81	39.54	1.29	18.5	5.32	158.67	11
Simsim	1,429.47	817.5	9.7	459.5	4.21	299	0

Source: Sehmi (1993).

It is ironic that as Africa grapples with malnutrition, the continent is endowed with a high diversity of under-utilized fruits and vegetables that are rich in micronutrients (Oniang'o *et al*., 2005). It is in this regard that beginning in 2001, IPGRI – with support from the International Development Research Centre of Canada - spearheaded a major public awareness campaign including training of farmers to grow leafy vegetables in hygienic conditions; it has also worked with a marketing expert in Kenya to attract new customers for ALVs. A local NGO, Family Concern, distributes the farmers' produce to Kenya's largest supermarket chain (Oniang'o *et al*., 2005). Very little is known about the production and consumption pattern of ALVs in sub-Saharan Africa (Smith & Eyzaguirre, 2007). However, evidence is emerging that ALVs are now a much sought-after item on the menus of back-street eating venues, in five-star hotels and are even served in Parliament (Shiundu & Oniang'o, 2007).

Processing of African Indigenous Vegetables

Large quantities of AIVs spoil due to insufficient processing capacity and growing market difficulties caused by intensifying competition from exotic vegetables (Schippers, 2002). There had been no sustainable production of the vegetables due to neglect and lack of appropriate production technologies, leading to low production and poor distribution of indigenous vegetables in Kenya (MOA, 1999). Drying has been an African way of processing leafy vegetables to make them available during periods of short supply. Although drying is one solution to the problem of perishability, it does not satisfy the needs of a large population of consumers, particularly urban dwellers (Smith &

Eyzaguirre, 2007). Developing vegetable products with extended shelf life can help solve these problems, while also making an important contribution to improving the population's income and supply situation (Habwe, 2008). Traditional sun drying methods often yield poor quality, since vegetables are not protected against dust, rain and wind, or even against insects, birds, rodents and domestic animals while being dried. Soil contamination with microorganisms, formation of mycotoxins and infection with disease-causing microorganisms are the result. The drying equipment used in industrialized countries overcomes all of these problems, but unfortunately it is not very well-suited for use in Kenya because it requires substantial capital investment and a well-developed infrastructure. Solar drying or freeze drying and vegetable product development using simple techniques combine the advantages of traditional and industrial methods, namely low investment costs and high product quality.

In spite of the abundance of African indigenous and traditional leafy vegetables, they remain under-exploited and under-utilized due to various constraints, including processing, distribution and marketing, as well as nutrition information (Shiundu & Oniang'o, 2007). The easy perishability of African Leafy Vegetables poses major challenges with their distribution and marketing (Smith and Eyzaguirre, 2007). Because of the varied growing and harvesting seasons of different vegetables at different locations, the availability of fresh vegetables differs greatly in different parts of the world. Processing can transform vegetables from perishable produce into stable foods with long shelf lives and thereby aid in their global transportation and distribution (Anon., 2006). According to Smith & Eyzaguirre (2007) there is a need to develop and promote locally appropriate processing techniques to minimize post harvest losses and ensure regular supplies of African leafy vegetables from the production areas to consumers in peri-urban and urban centres. Based upon this realization, a study was carried out at Maseno University to develop East African indigenous vegetable recipes which resulted in development of vegetable products.

Methodology

A research study on recipe development of East African indigenous vegetables was carried out at Maseno University, which is located on the equator at an altitude of about 1500 meters above sea level. Long-term average rainfall in Maseno town is 2074 mm per annum and its distribution is bimodal with peaks in March/April and September/October (Oseko, 2007). Soils are mainly dominated by vertisols, with a fairly acidic pH in water of 4.5 to 6.5 (Otieno *et al*., 1993; Oseko, 2007). The soils are also deep, very deficient in P and N, and have a moderate P fixation (FAO, 1997 cited by Oseko, 2007). Mean annual day temperature is 20°C with the average maximum daily temperature not exceeding 31°C and the average minimum night temperature not dropping below 15°C (Otieno *et al*.., 1993; Oseko, 2007).

AIVs commonly found in East Africa, which were used in these experiments, were planted at the Maseno University Botanic garden and included: African nightshade (*Solanum scabrum)*, vegetable amaranth (*Amaranthus blitum)*, slender-leaf (*Crotalaria ochroleuca)*, and cowpea (*Vigna unguiculata)*. Land was prepared by ploughing and harrowing to a fine tilth. The plots of 5 by 5 meters were demarcated and poultry manure mixed with the soil in the demarcated soil at a rate of 5 tonnes per hectare. Seeds of each selected AIV were mixed with the soil at a rate of 1:10 and drilled in the respective plots at a spacing of 30 cm. After two weeks, thinning was done to leave an inter-row spacing of 15 cm for all. All other agronomic practices were done to ensure optimum growing conditions. Harvesting by uprooting of the various AIVs was done at four weeks after seedling emergency for recipe development and evaluation as shown in Figure 1. This was done to enable the researchers to have AIVs with the same harvest age in order to avoid other factors that may lead to nutrient loss in the AIVs, and also have uniform AIVs with similar environmental exposure in order to avoid bias during nutrient analysis. The indigenous vegetables were blanched using the procedure described below and then freeze-dried:

1. A large pan half-full of water was brought to boil until it was boiling rapidly.
2. The prepared vegetables were put into a wire basket and gently lowered into the boiling water.

3. When the water began to boil again, vegetables were left in for two minutes.
4. The basket with vegetables was then removed from the boiling water and plunged into ice-cold water to stop the cooking process.
   The blanched vegetables were then drained and packaged into polythene bags, labeled and then placed into the freezer to freeze dry.

After freeze-drying, vegetable products were developed following a standardized procedure as indicated in the flow chart below.

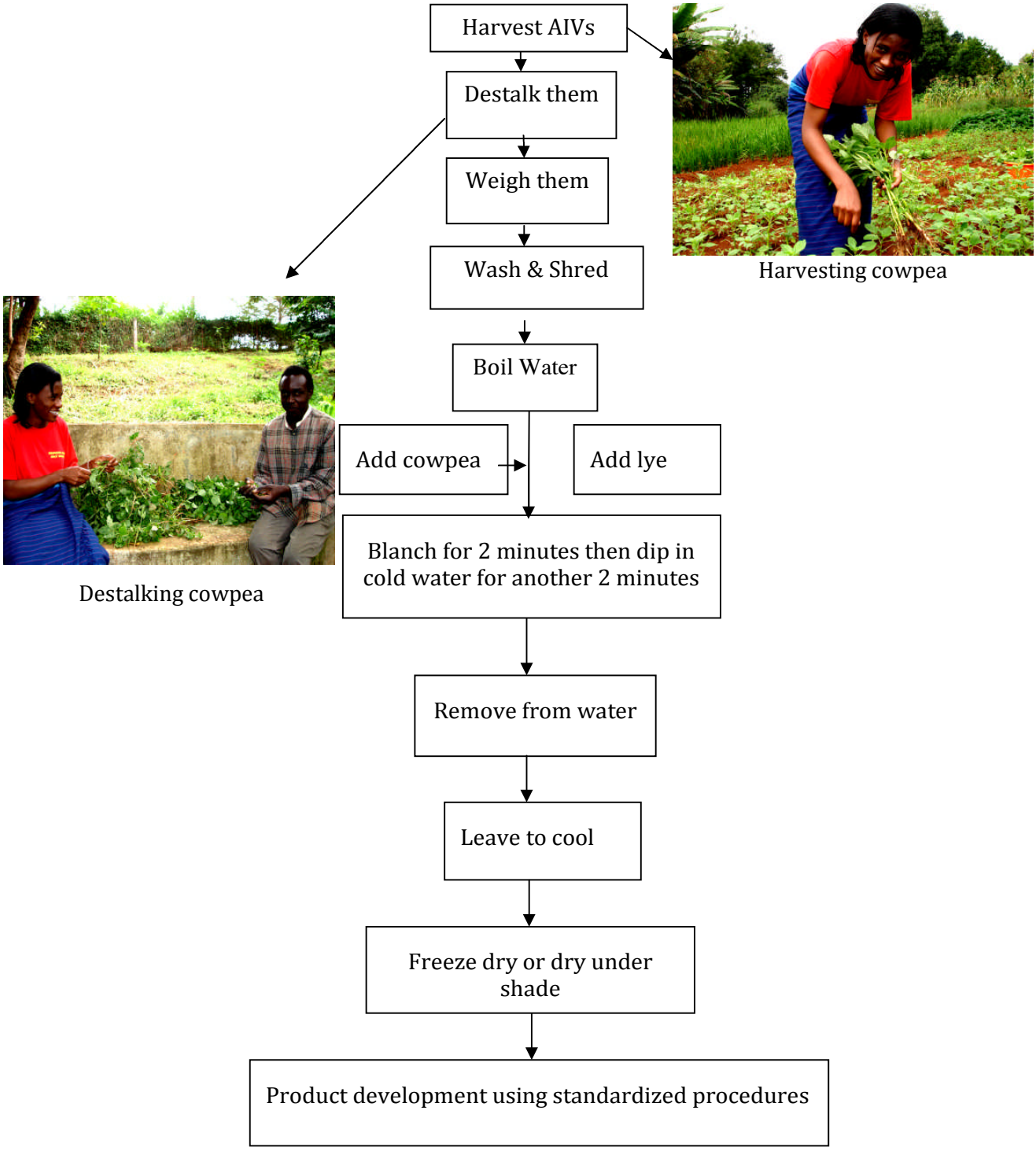

Figure 1. Simplified flow sheet for development of African Indigenous Vegetable products

RESULTS AND DISCUSSION

Products of various shapes and sizes were developed using the selected AIVs detailed above. Figure 2 shows some AIV products developed using appropriate and affordable technologies indicated in the methodology above.

Figure 2. AIV products developed using appropriate and affordable technologies
From left: Simshade (mixture of nightshade/simsim); Simco (simsim/cowpea ladule); and Simama (amaranth/simsim)

AIVs have long held a significant role as important components in African diets; they are indispensable ingredients in soups or sauces that accompany carbohydrates or staples (Smith & Eyzaguirre, 2007). To deviate from the norm, the developed vegetable products can be consumed as snacks or accompany a beverage thus broadening the consumption habits. AIVs are also seasonal. During the in-season a lot of vegetables go to waste because there are too many in the market; however, there is limited supply of these vegetables during the off-season thus leading to increased prices and reduced consumption. Therefore the development of African indigenous vegetable products could go a long way in minimizing wastage during the in-season and ensuring availability of vegetables during the off-season, hence resulting in year-round supply of this nutrient dense commodity.

Like the other agricultural activities in Africa and particularly Kenya, African indigenous vegetable farming relies mostly on rain-fed agriculture. This leads to fluctuating supply of vegetables on the markets because most small-scale farmers lack the means to transport their produce to far-distant and lucrative markets in the urban centers. Farmers are therefore open to exploitation by middlemen; this can be addressed through value-adding processes (Shiundu & Oniang'o, 2007). Value addition through product development will help address the issue of perishability and fluctuating supply of the vegetables on the market. In the long run this will help alleviate barriers to food security and income generation.

The poor state of infrastructure, particularly roads, that is found in most of the rural areas where African indigenous leafy vegetables are cultivated worsens during the rainy season. There is much wastage because of unavailability or limited means of transport to reach the markets at such time. Even those vegetables that manage to get to the markets are poor in quality due to delays and subsequent biological deterioration during transportation and distribution processes (Shiundu & Oniang'o, 2007). As well as helping curb the problem of perishability which demands that vegetables reach the markets quickly or on time, product development will also help minimize biological deterioration of vegetables which occurs during transportation and distribution.

There are possibilities to consider exporting the vegetables because the African or Kenyan diasporas would relish identifying themselves with these vegetables. Asian vegetables are a major component of Kenya's horticultural export industry, because of the people of Asian origin who reside in the United Kingdom and other parts of Europe (Shiundu & Oniang'o, 2007). Development of well-packaged vegetable products will enable the possibility of exporting African indigenous leafy vegetables to Africans, East Africans or Kenyans living abroad.

Implications for Research and Practice

Public education and promotion of African indigenous leafy vegetables needs to support the marketing component.

Farmers need to be trained in marketing and business skills through workshops and seminars to enable them to maximize output as well as income from their farms.

The future of African indigenous leafy vegetables is dependent on increased research on nutrition, processing and marketing.

It is not enough to encourage local farmers to grow their traditional crops without adequate markets. Successful marketing is important in the effort of creating sustainable livelihoods. This could be a major source of employment and add value to vegetable processing.

Traditional crops could be a major source of food in the diet, earn valuable foreign exchange by exporting, provide opportunities for import substitution, and generally benefit a large number of people.

There is need for research in the development of diversified recipes that are nutrient-dense and for alternative uses of these indigenous vegetables.

Some AIVs are believed to have medicinal value. This calls for further research to authenticate this claim and explore the possibility of pharmaceutical properties.

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Indigenous Food Processing Methods that Improve Nutrient Bioavailability in Plant-based Diets of the Kenyan Population: the Example of Zinc

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ABSTRACT

Most Kenyan diets are composed of cereals and legumes that have a high content of zinc inhibitors, whose levels may be reduced through appropriate food processing technologies at the household level. Indigenous food processing methods like soaking, germination, drying, fermentation, boiling, and roasting, and diet combinations usually reduce the levels of zinc antagonists in the plant diets, thus increasing zinc absorption and bioavailability. These methods are used in combination to both enhance organoleptic properties of food, increasing acceptability and also promoting complementation of nutrients. There are food combination patterns that enhance nutrient bioavailability and complementation that were known to most traditional households and are quickly being forgotten due to lack of proper knowledge transfer. There is a need for profiling the indigenous knowledge in food processing, preparation and diet combinations to identify processes that promote nutrient content and bioavailability for improved health and nutrient situation of rural populations whose diets are basically plant based. The identification of suitable sources of absorbable zinc and possible suitable dietary combinations can contribute towards the reduction of zinc deficiency. This chapter discusses the indigenous food processing methods that enhance zinc absorption and bioavailability of zinc in local dietary combinations that could reduce zinc deficiency.

INTRODUCTION

The genetic make-up of a plant or animal, the type of soils in which plants are grown or in which animals subsist, the type of fertilizer used, and the agro-ecological conditions of the area will determine the nutrient content of a plant or animal food material. At the pre-and post-harvest handling level the state of maturity at harvest, food processing and preparation methods, packaging, and storage conditions determine the nutrient content of a food. The effect of processing on the nutrient content of food depends on the sensitivity of the nutrient to various conditions prevailing during the processing, some of which include pH, light and oxygen. Sensitivity of nutrients to processing methods vary with the type of nutrient, with some nutrients increasing and others decreasing with different processing methods. The concentration of the nutrients in the food and its characteristics determine the level of nutrient retention. Most processes are heat-related and improve the digestibility of foods, making nutrients more available by sometimes inactivating the anti-nutrients found in food and thus increasing their bioavailability. This chapter discusses indigenous food processing methods and their effect on nutrients, with emphasis on zinc nutrition.

PROCESSING AND ZINC RETENTION

In many low-income countries diets are primarily composed of cereals and legumes which contain phytate (myo-inositol hexaphosphate), a compound known to inhibit zinc absorption [Calhoun *et al*., 1974]. These diets contain few animal-sourced foods which are rich in zinc and are free of phytates [Wallwork & Sandstead, 1990]. Dietary combinations of foods that have high levels of phytates are consumed mostly by rural populations and may have complexities regarding bioavailability and utilization of zinc. This calls for serious consideration of the assessment of the indigenous food preparation methods and diet combinations with implications

to zinc nutrition status.

Zinc inhibitors like phytates and fiber are present in higher amounts in plant foods, especially cereals and legumes, and influence zinc absorption. Although phytates have been singled out as the most potent dietary inhibitor of zinc bioavailability [Herzberg *et al*., 1990; Saha *et al*., 1994], other known inhibitors include oxalate, fiber, EDTA, and polyphenols such as tannins [Larsson *et al.,* 1996].

Most Kenyan diets are composed of cereals and legumes that have a high content of zinc inhibitors whose levels may be reduced through appropriate food processing technologies adopted by households. Maize as a cereal grain is a common staple in most Kenyan diets, and has very high phytate content [Fordyce *et al.,* 1987; Gibson, 1994]. When these staples are fermented, phytases are produced which break down phytates increasing the amount of available zinc. Figures 1-4 show some of the cereals, nuts and legumes consumed in local diets.

Figure 1. A Variety of Sorghum in the Market

Figure 2. A variety of beans sold in the market

Figure 3. Groundnuts in the market

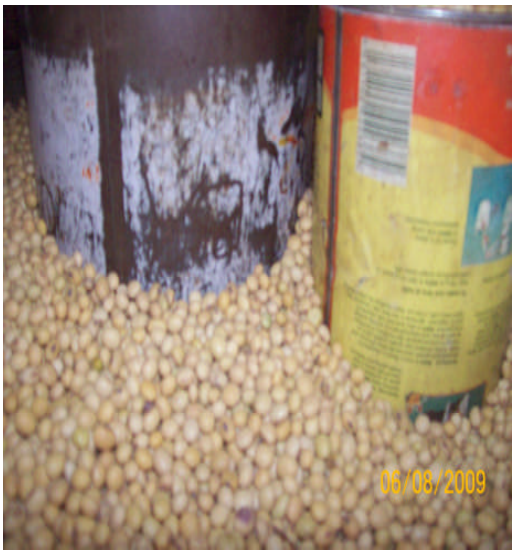

Figure 4. Soya beans in the market

Animal sources of food provide higher levels of zinc than plant foods, which are also high in phytic acid and other constituents that reduce the bioavailability of dietary zinc. Consumption of beef protein increases zinc absorption [Sadstead, 1991]. Plant foods that are rich in zinc include legumes, nuts, seeds and whole grains but they are also high in phytic acid, an inhibitor of zinc bioavailability. Unrefined cereal grains, classified as low-zinc bioavailability diets, have a high phytate-zinc ratio, a high level of energy in these high-phytate foods and low amounts of proteins [Etcheverry *et al.*, 2006] and compose the daily diets of many people.

ZINC ABSORPTION AND BIOAVAILABILITY

The balance between absorption facilitators and inhibitors, and the individual's zinc nutrition status determines the bioavailability of zinc from individual foods or from a meal [Cheryan, 1990; Cousins 1996; Kelsay, 1988]. Promoters of zinc absorption include amino acids such as histidine and cysteine [Kies *et al.*, 1983]. Diets have been classified into high, medium and low-zinc availability based on the absorption of energy from animal sources, the phytate-zinc molar ratio, the amounts of inorganic calcium salts and the methodologies of processing of cereals. Phytate-zinc molar ratio is used to estimate the likely absorption of zinc from a mixed diet. Diets with a phytate/zinc molar ratio greater than 15 have relatively low zinc bioavailability, those with phytate/zinc molar ratio between 5 and 15 have medium zinc bioavailability and those with a phytate/zinc molar ratio less than 5 have relatively good zinc bioavailability [Sandstrom, 1997]. Phytate/zinc molar ratio and calcium/phytate/zinc molar ratios play a major role in inhibiting zinc absorption such that zinc absorption is typically less than 15% in high phytate meals [WHO, 1996].

Several studies have reported on the fractional and net absorption of zinc under different dietary conditions [Sandstrom, 1980; Sandstrom & Cederblad, 1987; Flanagan, 1998]. Although fractional absorption decreases with higher intakes of zinc, the net absorption was greater when total consumption of zinc was increased. This increase was less dramatic in foods that had low phytate levels than in foods with higher phytate levels. Fractional absorption of zinc was further reduced when other minerals were included in the aqueous supplement. Absorption of zinc tripled when white bread was enriched with 3.1 mg zinc chloride to produce a total meal content of 3.5 mg zinc, but not when sufficient zinc was added to the same amount of phytate-containing wholemeal bread to produce a similar final zinc content. When meals containing chicken meat were enriched with 3.3 mg zinc per meal, fractional absorption fell by only a quarter and net absorption increased by 30-50%. Incubation of dough with yeast for 16 hours before baking reduced the phytate/zinc molar ratio of bread containing wheat bran from 17 to 4 and doubled the absorption of zinc. Zinc was absorbed most efficiently from aqueous solutions and from meals

containing animal products. Absorption was considerably less from phytate-containing meals. Fortification of foods with exogenous zinc generally produced a small reduction in fractional absorption, but a positive impact on net absorption. However, fortification of foods with a high phytate/zinc molar ratio had only a small effect on net zinc absorption [Sandstrom, 1987].

High fiber foods are often associated with diminished zinc absorption. However, refined foods that are low in fiber have substantially lower levels of zinc, so that while relative zinc absorption from low fiber foods is improved, the overall zinc absorption is greater from high fiber foods. For example, almost 40% of the zinc in white bread (refined) is absorbed, while only 17% of the zinc in whole grain bread is absorbed [Kannan, www.vegetariannutrition.net/articles/iron-zinc-Bioavailability-in-vegetarian-N.]. However, the total amount of zinc absorbed from whole grain bread is almost 50% more than that absorbed from white bread because whole grain bread contains more than three times the level of zinc found in white bread [Sandstrom, 1980]. These technologies are unavailable to the local communities.

INDIGENOUS KNOWLEDGE IN FOOD PROCESSING

Increased food production, availability of food supply and access are crucial to achieving major nutritional improvements. Wide application of proper technologies and approaches, and development of new concepts that should be transmitted to households and stakeholders, are necessary for promotion of dietary interventions in zinc deficiency states. Transfer of indigenous knowledge and skill in food processing, presentation and meal combinations from the older population to the younger, and building on their knowledge for production, processing and preservation of food is necessary for the control of zinc deficiency. There have been notable changes in food selection patterns and traditional methods for preparing and processing of indigenous foods with implications for nutrient retention and bioavailability. The traditional methods are a cheaper, acceptable, economically feasible and sustainable means for improved zinc status.

Use of traditional methods requires an understanding of the local dietary patterns, food beliefs, and food consumption patterns of the population to consider the general dietary compositions and combinations, and interactions between the diverse food constituents that antagonize zinc absorption and bioavailability. Such development must consider the cost of foods in terms of accessibility by the general population. Challenges in changing dietary habits, attitudes and practices must be appreciated. There are a range of dietary diversification and modification strategies that increase zinc content and bioavailability of plant-derived foods. Dietary approaches are based on promotion of increased consumption of zinc-rich diets and reduction in the intake of inhibitors of zinc absorption. Strategies to increase the zinc content of the diet are necessary in Kenya where diets are based on cereal staples.

Dietary diversification includes consumption of zinc rich foods, animal foods and local plants that have high zinc content and indigenous insects. However, zinc and phytate contents of local Kenyan plant foods have not been clearly assessed to identify suitable sources of absorbable zinc. Indigenous food processing methods and diet combinations usually reduce the levels of anti-nutrients in the plant diets, thus increasing nutrient bioavailability. Such methods include soaking, drying, fermentation, boiling and roasting. These methods are used in combination to both enhance organoleptic properties of food (thus increasing acceptability) and also promote nutrient complementation. Soaking of cereals and legumes has been used to reduce the phytate content of plant foods. For example, sprouting of beans can dephytinize food products and thus improve zinc bioavailability and also increase the vitamin C content [Yadav, 1994]. Drying has been used to preserve meat, fish, cereals, roots and tubers, fruits and green leafy vegetables. Meat and fish are dried over smoke which adds flavor besides increasing shelf life. Such dried fish has readily available zinc [Gibson and Hotz, 2001]. Amino-acid and cystein-containing peptides are released during digestion of cellular animal proteins, enhancing zinc absorption.

Soaking and germination have been used to process foods, reducing levels of anti-nutrients and increasing the nutrient quality of foods. Soaking oats followed by sprouting the oats reduces

phytate content and doubles the amount of absorbed zinc in comparison with untreated oats. Zinc content is improved when leavened products are used [Gibson, 1994]. Sorghum, for example, is soaked, germinated and eaten or ground to flour and added to ungerminated cereal flour, reducing the cereal viscosity and activating endogenous cereal phytases that break down phytate into lower inositol phosphates. Soaking and germination enhance enzymic hydrolysis of phytates. Cereal porridges have been prepared by combining germination and fermentation to improve flavor, digestibility of the products and increase the content of vitamin and minerals. The initial enzymic changes which precede germination result in both transfer and increase of the B-complex vitamins. It also breaks down the higher carbohydrates and other storage molecules such as calcium, magnesium and phytate [Akpapunam & Sefa-Dedeh, 1997].

Fermentation and drying have been used in combination. For example, cassava roots are peeled and grated into pulp, put into cloth bags and set in the sun to drain and ferment. Weights are added onto the bags to press out the moisture for 3-4 days. There is a degree of fermentation and souring. After complete draining, the material is sieved and put in shallow metal pots over a wood fire and is continuously stirred and turned, beating humpy sections to disintegrate them. The other example is maize flour which is soaked as a thick paste for 3-4 days at ambient temperatures to promote fermentation. The paste is roasted over low heat until golden-brown. It is then sun-dried to reduce the moisture content and to increase the peeping quality. Fermented products are low in soluble fiber and high in insoluble fiber. Organic acids such as acetic, lactic, citric, formic and butyric acids produced during fermentation potentiate zinc absorption by forming ligands with zinc. Microbial fermentation enhances zinc bioavailability through hydrolysis induced by microbial phytase enzymes. Reduction of phytates in the diet could also favor enhanced absorption of other minerals like calcium and iron. Fermentation reduces the phytate content by releasing endogenous phytases and incorporates yeast during the process [Kavas & Sedef, 1991].

Figure 5. Germinating Soya Beans

Figure 6. Germinating Sorghum in the Market

Figure 7. Flours from two sorghum varieties

Figure 8. Flours from different cassava varieties

Figure 9. Dried cassava varieties

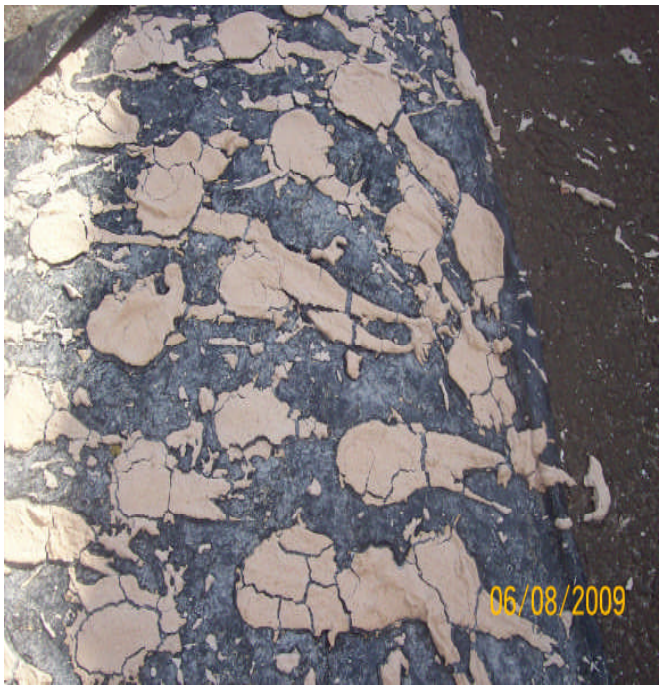

Figure 10. Fermented Wet Millet

IMPLICATIONS FOR RESEARCH AND PRACTICE

Diets in Kenya and other low-income countries are composed primarily of cereals and legumes that are high in phytates that inhibit zinc absorption. The high level of zinc inhibitors can be reduced through appropriate traditional food processing technologies adopted in households. The zinc and phytate content of local Kenyan plant foods has not been clearly assessed so as to identify suitable sources of absorbable zinc and possible suitable dietary combinations that can contribute towards the reduction of zinc deficiency. The adoption of non-Kenyan cultures, changing tastes, diets and lifestyles have negatively influenced the consumption of indigenous foods and contributed to the loss of indigenous knowledge and skills in food preparation, food combinations of nutritional value and food conservation. Time has also become a major constraint in food preparation with populations resorting to convenience and easy to prepare foods that are generally of low nutritional quality, monotonous and lack variety. Social networks have changed the traditional mode of knowledge transmission. There is also failure of knowledge transmission from generation to generation because of attitude formation relegating these methods into categories of primitive technologies. There is potential for creating awareness of the value of indigenous foods, and preparation and conservation methods. Recipe development offers the potential for increased product variety for the changing tastes and for improved marketability of the products. Indigenous food processing methods and diet combinations usually reduce the levels of zinc antagonists in the plant diets, thus increasing zinc bioavailability. Transfer of indigenous knowledge in food processing, preparation and diet combinations to communities needs to be profiled to identify processes that promote nutrient content and bioavailability for improved health and nutrient situation of rural populations whose diets are basically plant-based with high phytic contents that reduce the bioavailability of zinc. There is need for extensive study of dietary patterns of a population to initiate changes that seek to enhance nutrient content of food and bioavailability.

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