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Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy

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Abstract

This article discusses the needs and challenges of developing good, science-based, simple methods for postharvest handling that can be made available in developing countries. Some of the traditional challenges have been successfully met (i.e. identifying causes and sources of losses for key crops, identifying many potential postharvest technologies of practical use for reducing losses), but many challenges remain. These include the characterization of indigenous crops in terms of their unique postharvest physiology (e.g. respiration rate, susceptibility to water loss, chilling sensitivity, ethylene sensitivity), ascertaining the differences between handling recommendations made for well-known varieties and the needs of local varieties of crops, and determining cost effectiveness of scale-appropriate postharvest technologies in each locale and for each crop. Key issues include building capacity at the local level in postharvest science, university teaching and extension, and continued adaptive research efforts to match emerging postharvest technologies to local needs as these continue to change over time. Development of appropriate postharvest technology relies upon many disciplines that are relevant to the overall success of horticulture, i.e. plant biology, engineering, agricultural economics, food processing, nutrition, food safety, and environmental conservation. The expanding pool of new information derived from postharvest research and outreach efforts in these areas can lead in many directions which are likely to have an impact on relieving poverty in developing countries.

Keywords: capacity building; extension; fresh produce; fruits; postharvest losses; quality; safety; vegetables

INTRODUCTION

The primary goals of research on postharvest biology and technology of fresh produce are to reduce losses in quantity and quality and to maintain safety between harvest and consumption sites. The strategies for attaining these goals include: (1) growing cultivars that have good flavor and nutritional quality plus long postharvest-life potential when harvested at optimum maturity; (2) using an integrated crop management system that maximizes yield without sacrificing quality; and (3) using optimal postharvest handling practices to maintain quality and safety of the food products. Recent studies and literature reviews confirm that postharvest losses are still high at the farm, wholesale and retail levels, and that not much improvement in the overall percentagof losses can be documented from the 1970s to the present, despite active horticultural education and research programs in many countries.

According to many studies, farmers have been losing between 30% and 40% of the value of their fruits and vegetables before they reach the final consumer.[1–8] These losses are observed at harvesting, during packing, transportation, in wholesale and retail markets, and during delays at different stages of handling. In Rwanda, Ghana, Benin and India, recent studies have generated similar findings, with losses ranging from 30% to 80%.[9] Physical and quality losses are mainly due to poor temperature management, use of poor quality packages, rough handling, and a general lack of education regarding the needs for maintaining quality and safety of perishables at the producer, wholesaler, and retailer levels.[9] Physical and quality losses in turn lead to loss of market value, concerns about food safety, and lower incomes for growers.

While researchers have identified many potentially useful postharvest technologies for use in developing countries, there is a lack of information regarding the costs and financial benefits of these postharvest technologies, since costs are rarely documented during research studies. Generally the adaptive research step between gathering laboratory findings and extension of the results is missing or local costs are simply not considered when investigating the technology and its field applications. Technically useful practices therefore tend to be disregarded since there is no information on costs or their potential financial returns in different developing regions.

Although extension services in developing countries are increasingly involved in providing educational programs and training activities on postharvest topics, often there is a lack of follow-through and support after the training. Those participating

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in postharvest training may be convinced and willing to implement improved practices, but cannot do so when needed supplies, tools or equipment are not locally available. Even when users are initially provided with these tools and supplies as part of a training program or development project, there tends to be a lack of local support and services once the programs end. Any adoption of changes in postharvest practices are then abandoned as repairs cannot be made when facilities, coolers, equipment or handling systems break down and tools or spare parts cannot be obtained locally or at reasonable cost.

CHALLENGES AND OPPORTUNITIES IN POSTHARVEST RESEARCH AND OUTREACH

Less than 5% of funding for horticultural research and extension (R&E) has been allocated to postharvest issues over the past 20 years,[10,11] as the historical focus has been on increasing production. In the 1990s the focus moved to marketing and more recently to value chain development. Still, Internet databases show that less than 1 in 2000 agricultural projects undertaken globally have focused on fresh produce handling and marketing, according to advanced searches during 2009 using AiDA,[12] USAID DEX,[13] World Bank Documents,[14] UNFAO inPHo,[15] and DEVEX databases.[16] While thousands of development projects have been launched in developing countries between 1990 and the present time by dozens of donor agencies, few have focused on agriculture (less than 6% according to the AiDA database; 25% according to the World bank), very few have focused upon horticulture (approximately 1% of the agricultural projects), and only 1/3 of these very few horticultural projects included a postharvest component. 'Postharvest' designations, when investigated further in these databases, generally turned out to be some kind of food processing. Most of the other horticulture projects appeared to focus upon increasing food production via various means such as improving irrigation systems, infrastructure projects, developing markets for processed or export products or strengthening capacity in extension work.

RESEARCH ACHIEVEMENTS AND NEEDS

Although the biological and environmental factors that contribute to postharvest losses are well understood and many technologies have been developed to reduce these losses,[17–19] they have not been implemented, in many cases, due to one or more of the following socioeconomic factors: (1) inadequate marketing systems; (2) inadequate transportation modes; (3) unavailability of needed materials, tools, and/or equipment; (4) lack of information; and (5) governmental regulations and legislations. Mrema and Rolle[20] reported that priorities within the postharvest sector of developing countries have evolved from a primarily technical focus geared towards the reduction of losses, to a more holistic approach designed to link on-farm activities to processing, marketing and distribution. Despite this evolution in trends, fundamental problems and concerns of the sector have remained relatively unchanged, with high postharvest losses, poor marketing systems, weak research and development capacity, and inadequacies in policies, infrastructure, extension services and information exchange cited as major constraints within the sector in developing regions of the world.[20]

Postharvest losses vary greatly among commodities and production areas and seasons. While it may not be economical or practical to completely eliminate postharvest losses, an acceptable loss level for each commodity and production area combination can be identified on the basis of cost–benefit analysis (return on investment determination). Since energy use is such an important component of relevance and practical applications for postharvest technologies for users in developing countries, it is important to consider the availability and cost of energy when assessing options.[21,22] Future postharvest research needs to build on existing knowledge, and be adaptive, applied, and suitable for small-scale users. A systematic analysis of the production and handling system for each commodity is the logical first step in identifying an appropriate strategy for reducing postharvest losses. Also, it is essential to determine the return on investment in each of the selected postharvest technologies. Scale is important because most farmers in developing countries operate on a small scale, both in terms of land area in production, and in the low volumes of crops harvested and handled on any given day. Such information can greatly facilitate convincing handlers and marketers of the value of adopting the recommended technologies.

Just a few examples of current research needs are local postharvest loss assessments, studies of reusable/recyclable packages, inexpensive and safer ripening systems, low-cost cooling methods, sanitation and food safety practices, bio-pesticides, and alternative energy sources for postharvest uses. Developing countries are tackling environmental issues in various ways, some of which will likely affect postharvest research. For example, a bill was passed in 2006 in Rwanda that banned the use of plastic bags. Alternative packaging materials for horticultural crops therefore need to be studied and locally assessed for feasibility and cost effectiveness. Possibilities include the use of cassava-based polymers, chicken feather polymers, or bio-degradable non-food starches.

Capacity building in postharvest research is an obvious need in many developing countries and can be achieved via internships, faculty exchanges, human resource development for staff in university laboratories and research centers, laboratory upgrades, improved access to web-based information, and mentoring. Leadership training is an important component in capacity building and, while it has been well characterized, is often neglected.[23] Although there are a few researchers in each developing country who carry out some postharvest research, there tends to be very little coordination among the postharvest researchers within each country or among countries within each region. Also lacking is interdisciplinary collaboration among production horticulturists, plant pathologists, entomologists, marketing economists, engineers, food technologist, consumer scientists, and others who may be involved in various aspects of the production and marketing systems. Such cooperation and collaboration are essential to establishing effective research and extension programs.

Although much of the information needed to properly handle foods of plant origin is known, there is a need to refine the requirements and recommendations for the particular cultivars of each commodity produced in a given area. Also, there are indigenous crops grown in developing countries about which we do not have enough information on their optimal postharvest handling conditions.

The terms 'commodity system', 'value chain' and 'supply chain' are used interchangeably to include production, collection, processing, wholesaling, and retailing as well as support functions, such as input supply, financial services, transport, packaging, and advertising. A systematic analysis of each commodity's production,

postharvest handling and marketing system is the logical first step in identifying an appropriate strategy for reducing postharvest losses. While value chain analysis typically considers five major components[24,25] that are common for all products (production, collection, processing, marketing and consumption), commodity systems assessment[26,27] includes these five components, and breaks the collection step down into many more individual components that are important for many horticultural crops (harvest, sorting, grading, cleaning, packing, cooling, storage, etc). Vellema[28] points out that while studies of postharvest innovation acknowledge the relevance of institutional and policy issues as well as the systemic nature of change, 'there is little connectivity between this literature and the scholarly work on technological innovation found in the social sciences and development studies'.

Studies of the causes and magnitude of postharvest losses can be very helpful in identifying priority areas of research and extension in each country. Such studies should include the socioeconomic constraints to use of recommended technologies in each situation and how to overcome these constraints. There is no standardized protocol for documenting postharvest losses, and each published study utilizes a wide variety of surveys, interviews and measurements, each focusing on a different set of variables. Cooling practices in general have been documented to be cost effective,[9,21,22,29] as have many small-scale storage practices,[9,22,30,31] but much more research is needed to determine the return on investment (ROI) of various postharvest technologies such as improved packaging, cooling, ethylene exclusion and/or scrubbing, treatment with 1-methylcyclopropene to inhibit ethylene action, modified atmosphere packaging, and decay control treatments. Such information can greatly enhance adoption of technologies with high ROI potential by produce handlers.

Food safety is a major concern of the produce industry and the regulatory agencies, such as the US Food and Drug Administration. Use of 'good agricultural practices' throughout the production system and use of 'good manufacturing practices' during all processing steps are highly recommended.[32,33] Future research areas include developing reliable indices of microbial quality and procedures for minimizing microbial contamination, and investigating how various postharvest handling treatments and conditions influence survival of human pathogens on produce.

More attention should be given to developing value-added products, such as fresh-cut fruits and vegetables and fresh juices, with superior flavor and nutritional quality that satisfy consumer preferences. Management and utilization of fruit and vegetable waste are garnering interest as a way to generate increased incomes. Studies have shown it is possible to utilize up to 100% of fresh produce by further processing the culls, peelings, seeds or trimmings typically discarded as waste, and manufacturing a variety of chemical and industrial by-products.[34,35]

Biotechnology is a tool that can be utilized, in an interdisciplinary approach, to address some of the concerns about quality attributes and the biological causes of deterioration of harvested produce.[36] Kader[37] proposed that priority should be given to the following goals: (1) to attain and maintain good flavor and nutritional quality to meet consumer demands and encourage greater consumption of fresh fruits and vegetables; (2) to introduce resistance to physiological disorders and/or decay-causing pathogens in order to reduce use of chemicals; and (3) to modify surface structure and/or composition of some commodities to reduce their microbial contamination potential. The challenge to molecular biologists is that many of the desired improvements require manipulation of more than one gene and, in some cases, target genes have not yet been identified.[37]

OUTREACH ACHIEVEMENTS AND NEEDS

Outreach or extension in the case of postharvest technology involves making the link between research and small-scale producers and marketers. In all countries, there is a need to improve the outreach efforts aimed at informing producers, handlers, marketers, and consumers about how to maintain quality and safety of food products. Recently there have been a few local success stories, including the use of information technology (IT) kiosks in India, cell phone text messages for providing market information in Rwanda, and formation of smallholder groups for direct marketing. A current study of existing Internet communication technologies and a wide variety of commercial services in Uganda, Indonesia and India indicate that farmers are willing to pay for IT-based advisory services, but their access to text-based messages is limited by high costs and illiteracy rates.[38] A variety of postharvest training of trainer (ToT) programs for extension workers were implemented as part of major development efforts in Egypt (USAID AERI – Hort Project 2004-07), Lebanon (USAID CEDARS 2003 – 7), and Indonesia (USDA Indo Cold Chain Project 2001-04). More recently, postharvest training was provided for horticultural extension workers, who were then hired by private sector companies (USAID GMED Project Maharashtra, India 2007-08), and a 2009-10 WFLO project funded by the Bill and Melinda Gates Foundation provided demonstrations of small-scale postharvest technologies with cost effectiveness information for horticultural growers and marketers in sub-Saharan Africa and South Asia.[39]

Extension efforts and training needs differ by target group, and there are often difficulties in reaching smallholder farmers, women, youth, middlemen/traders and processors. Traders and middlemen have been generally ignored although they have a large impact on the final quality of fresh produce and its potential market value. Future extension efforts should seek to include this group of men and women in programs aimed at reducing postharvest handling losses. Reaching women may be easier if training workshops were offered in or near the markets where they sell produce and/or shop for food. Extension programs should be planned around their free time and provide child care to allow them to better focus on the information and participate more actively.

Farmer or trader association or cooperatives are being widely promoted as a means of enhancing access to markets, but the formation and management of farmers' organizations is a complicated and difficult task. More comparative research is needed to identify 'workable models' and 'best practices' for facilitating collaborative marketing in developing countries.[40] Export marketing is especially dynamic as global competition in the sector can be extreme,[41] and farmers cannot be expected to adapt to the annual changes in demand, preferences, prices, regulations, and standards. New challenges will continually arise, and education programs must somehow keep pace.

In India a variety of government agencies through the extension services (Krishi Vigyan Kendras or KVKs), farm demonstrations and fairs are supposed to provide information on modern technology, but studies show that only a very small percentage of farmer households of marginal and small categories are able to access these services. In Uttar Pradesh (UP) state 0.8% of small and 1.2% of marginal farmers, and in Uttaranchal state 0.4% of small and 0.0%

of marginal farmers, have access to extension service workers as a source of information.[42]

Outreach efforts and training needs will also vary by crop and climate zone. Increased attention must be given to food safety issues for farmers in West Africa, since many vegetable producers are peri-urban farmers who use sewage water for irrigation. There is also widespread misuse of chemicals for pest management.[43] Promoting the use of bio-pesticides, such as neem (*Azadirachta indica*) extracts and other alternative practices to control insect pests instead of the use of chemicals, is important for controlling insects in cabbage in Ghana.

Reducing rough handling is a simple yet neglected practice for reducing mechanical damage in fruits such as mangoes. Mangoes grow on tall trees in West Africa and India, and the harvest is generally practiced by hitting the tree with a pole and letting fruits drop to the ground. Manual labor is available for handling fruits at the markets in Ghana (typically by drivers' mates or helpers) but these handlers lack training in loading and unloading of produce. The use of shade to reduce weight loss in leafy vegetables is another simple yet neglected practice. In India a simple shade structure for field packing results in 1% weight losses for spinach as compared to 5% weight loss when packed during the same time period under sun.[9] Other constraints, such as lack of proper sorting, lack of cleaning, washing or sanitation, rough handling, improper trimming, misuse of postharvest treatments (such as over-waxing and misuse of hot-water dips for pest management), inadequate concentrations of chlorine in wash water, use of inappropriate chemicals or misuse of registered pesticides and food additives, and lack of quality standardization and inspection, are major areas which need attention.

Simple packaging improvements, such as using inexpensive fiberboard liners in rough packages, can decrease bruising and abrasions during transport to market. In India, liners in rough plastic crates increased the market value of guava fruits by 12.5% compared to unlined packages during a 50 km trip to market.[9] In Ghana, simply halving the size of the typically large sacks used for transporting cabbage was able to reduce mechanical damage from 30% to less than 10%.[39] Other problems related to packaging material that can be targeted for outreach efforts include the use of flimsy or rough packing containers, overuse of packing materials intended to cushion produce, use of oversized packages, over-filling containers, and inadequate ventilation.

The problems associated with transportation include overloading of vehicles, use of bulk transport or poor-quality packaging, leading to compression damage, lack of adequate ventilation and cooling, and rough handling. In India it is a common sight to see the traders and laborers sitting on top of the packaged produce loaded on trucks.

Small- scale food processing offers another avenue for outreach efforts aimed at reducing postharvest losses. Solar drying has been widely studied and continues to be of particular interest to extension services due to its low cost. Whole tomato concentrate (WTC) consumes very little energy and time to prepare the product and has been shown to be more cost effective than processing of traditional products such as tomato purée. Sanni *et al.*[44] identified a variety of issues and strategies to ensure the development of user-friendly, fuel-efficient and durable equipment in Africa.

Postharvest Training of Trainers (ToT) programs for international audiences are funded on occasion by large agencies such as USAID and UNFAO, and postharvest workshops and short courses are offered by many universities. Efforts have typically been too short term in nature, too expensive, and too oriented to large-scale commercial horticultural businesses and export crops to be of much practical use to R&E professionals in developing countries. Postharvest ToT needs to be conducted locally and to begin with Commodity Systems Assessment[26,27] and/or Postharvest Systems Research[45] techniques to help trainees learn to identify local causes and sources of losses for the crops of interest. Postharvest ToT programs should include hands-on demonstrations of the many causes/sources of losses in horticultural crops (including temperature and relative humidity mismanagement, mechanical damage, pathogenic decay, ethylene exposure, etc.), exercises on data collection and farmer training needs assessment, postharvest tool kits, and audiovisual materials (posters, videos). Postharvest tool kits for trainees should include, at the minimum, a digital temperature probe, sling psychrometer, refractometer, firmness tester, digital scale, color charts, sizing rings, calipers, pH test strips, and chlorine test strips. Finally, ToT programs should be followed up with mentoring via live interactions with instructors during initial ToT programs, occasional training visits as follow-ups, and relatively low-cost ongoing mentoring via Internet chats, emails, and interactive websites.

There is a need in all developing countries to improve postharvest extension programs and to strengthen the connections between researchers, extension workers, and clientele groups of producers and handlers. All appropriate methods of communicating relevant information in a concise manner should be used. There are many opportunities for collaborative efforts in extension of postharvest information among many of the countries in each region, especially when they share a language.

The human element in postharvest handling of horticultural commodities is extremely important. Although labor costs are lower in developing countries, labor supervision, training, productivity, and management are generally better in developed countries. Effective training of workers and their supervisors along with delegation of responsibility and authority to the supervisors are more common in developed countries than in developing countries. The tendency in many operations in developing countries to limit authority for making any changes in the procedures to the owner or very few trusted persons often leads to poorly developed management and problem-solving expertise among the supervisors and reduced productivity of the workers.

In 2005 the Global Horticultural Assessment included both postharvest technology and capacity building among its priority recommendations,[46] and currently the USAID Horticulture Collaborative Research Support Project (initiated in October 2009) is providing funds for several new pilot projects that include postharvest components (http://hortcrsp.ucdavis.edu/). Recently the concept of promoting integrated postharvest training and services centers for postharvest outreach has emerged[47,48] and is underway in Cape Verde, with plans to implement similar centers in Rwanda and India. Such a center is designed to provide an integrated approach to postharvest management and aims at 100% utilization of production in one form or another. The center would be utilized as a training site for farmers, small traders and agri-entrepreneurs, and provide postharvest services to assorted clientele on a fee for service basis. Ideally it would be supported at both the national level (with participation by researchers and university faculty) and at the local level (by the extension service). The center should include all the infrastructure facilities desirable for improved postharvest management on a small scale such as collection, sorting/grading, packing house with appropriate technologies, inspection, low-cost cooling and cold storage, transport

vehicle, low-cost processing/preservation unit (canning or bottling, solar drying, etc.), and basic laboratory facilities for quality evaluation and monitoring food safety.

ADVOCACY ISSUES

Postharvest R&E has long been neglected in most developing countries. A survey of the current human, physical, and financial resources allocated to postharvest research and extension activities in every country should be conducted and the results should be used to develop an action plan for establishing an effective postharvest research and extension program to serve the needs of clientele groups in each country. In most cases, solutions to existing problems in the postharvest handling system require use of available information and implementation of existing appropriate technologies. Thus it is highly desirable to strengthen the connection between researchers and extensionists (both public and private consultants) to assure the smooth transfer of relevant information to those who need it. The most successful model is that where researchers and extensionists belong to the same organization and are co-located for maximum interactions and collaborations.

Establishing a Postharvest Working Group in each country can be very useful in providing a forum for communications among all those concerned with postharvest biology and technology research and extension. The next step is to establish a link among the various Postharvest Working Groups in each region to facilitate exchange of information and regional collaboration on training and other areas of mutual interest.

Funding for postharvest research and extension efforts should be enhanced. Although reducing postharvest losses of already produced food is more sustainable than increasing production to compensate for these losses, less than 5% of the funding of agricultural research internationally and in most countries is allocated to the postharvest research areas.[49] This situation must be changed to reach a better balance in allocation of resources between efforts towards increased production and those towards reducing postharvest losses. Goletti and Wolff[50] stated that 'while research on the improvement of agricultural production has received considerable attention and funding, until recently postharvest activities have not attracted much attention from international research organizations (CGIAR, FAO, ACIAR, IDRC, CTZ, CIRAD, NRI, USAID)'. They identified the following reasons to justify an increased commitment to postharvest research by the international agricultural system: (1) high internal rates of return; (2) international public good character; (3) effect on poverty; (4) effect on food security and health; and (5) effect on sustainable use of resources. More than 10 years ago Goletti and Wolff[50] drew the following conclusions, which are still relevant today:

> As the significant contribution of postharvest 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 postharvest topics cannot be justified. Since so far, relatively little has been invested in postharvest research, there is potential for large impacts as constraints and bottlenecks are removed. It would thus be desirable to re-examine current funding priorities and to allocate a larger proportion of resources to the postharvest area.[50]

A few local success stories have recently emerged from India on the advocacy front, where market regulatory revisions in some Indian states are beginning to have a positive effect on reducing postharvest losses. The National Horticultural Mission is the lead public sector organization (http://www.nhm.nic.in/), and the Global Cold Chain Alliance – India is an example of a new private industry professional organization (http://gcca.in/), and both are currently advocating strengthening the cold chain infrastructure. Decades ago, in response to food shortages, the Government of India under its Department of Agriculture and Cooperation established the Agricultural Produce Marketing Committee (APMC) governed by the APMC Act, which prohibits transactions for all agricultural commodities outside the regulated wholesale markets. According to the Act no direct marketing and direct procurement of agricultural produce can take place from farmers' fields, and the setting up of alternative markets is restricted. The APMC laws were created to ensure better prices for farmers through an open auction system, but instead it has led to the development of local vested interests and reduced marketing options for small farmers by limiting their access to emerging domestic retail and export markets. Recently the states of Punjab, Maharashtra, Bihar, and UP, among others, have amended the APMC Act in order to permit private companies such as RK Foodland, NDDB, Reliance Fresh, and ITC Ltd to set up their networks to procure goods. According to the Model Central APMC Act 2003, it is envisaged that eventually each state can amend the Act to allow farmers to sell their commodities anywhere they want to do so, and the wholesale market taxation system is proposed to be removed. This simple move to direct marketing of perishable crops allows quicker handling, fewer delays between harvest and marketing, less unnecessary transport of crops without cooling to/from central markets, and no extra unloading/loading/stacking of produce to be weighed and taxed, all of which have helped to reduce losses.

Advocacy needs in developing countries are many and include those mentioned (i.e. enhanced funding for R&E, updating laws governing markets) as well as micro-credit, interest rates, support for associations, extension programs for women, hiring and training more women as horticultural extension agents, access to high-quality planting materials/seeds, simple postharvest tools, supplies (especially improved packages), equipment, market information, etc. Prevailing interest rates at the banks in Ghana are currently so high (23–30%) that most farmers simply cannot afford to borrow money. In India there are government-operated websites as well as some private sources that provide current market price information which can be viewed and utilized by registered members. Tamil Nadu Agricultural University, Coimbatore: National Spot Exchange Ltd (http://www.nationalspotexchange.com) and the Directorate of Marketing and Inspection: Directorate of Marketing and Inspection, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India (http://agmarknet.nic.in) are just two examples of these new services.

Throughout the developing world, there are still many issues related to roads and transport, including whether roads exist at all, connect farms to markets, whether roads and vehicles are kept in good repair, etc. Road networks in Ghana are generally considered accessible but not all roads are passable to large vehicle traffic, especially during the rainy season. Transport delays are common within the local markets when trucks break down, and especially during the rainy season, all contributing to high postharvest losses.

Producers and handlers of foods of plant origin in each country should be encouraged to form a trade organization that can serve

their collective interests in promoting their products in domestic and international markets, supporting high-priority research and extension efforts, and representing their interests in dealing with governmental agencies, such as those responsible for food quality and safety regulations. Traders, including the many intermediaries who are currently ignored by traditional extension systems, should be invited to join these trade associations.

Marketing cooperatives should be encouraged among producers of major commodities in important production areas. Such organizations are especially needed in developing countries because of the relatively small farm size. Advantages of marketing cooperatives include: providing central accumulation points for the harvested commodity, reducing costs by purchasing harvesting and packing supplies and materials in quantity, providing for proper preparation for market and storage when needed, facilitating transportation to the markets, and acting as a common selling unit for the members, coordinating the marketing communication and advertising program, and distributing profits among members.[51]

The entry of modern retail players, both international and domestic, into developing countries and transition economies is bound to continue having major impacts on these countries' agri-food systems, as large-scale supermarket retail and wholesale operations demand large-volume and low-price produce that meets stringent quality and safety standards.[52] Given the small unit size of many producers in developing and transition economies the ability to ensure timely delivery of products of the right quality and quantity to intermediaries and processors is paramount. Grouping small-scale farmers into cooperatives, farmers' organizations or business units can help with this,[52] as well as serve to become a focal point for postharvest training efforts.

CONCLUSIONS AND RECOMMENDATIONS

Increasing investments in postharvest horticultural technology R&E is long overdue, and can have a major impact on reducing waste and increasing the food supply, leading to improved incomes without increasing production and wasting the expenditures on all the inputs required (land, water, seeds, fertilizers, pesticides, labor, etc.). The most useful technological changes in production, harvesting, and postharvest handling systems for horticultural perishables have resulted from interdisciplinary team approaches in research and extension programs. Maintaining quality, especially flavor and nutritional content, and ensuring safety (avoiding chemical and microbial contamination) must be the focus of future research and extension activities in all countries.

Four general recommendations are provided for meeting future challenges in postharvest R&E:

- An integrated approach for postharvest science and education from grade school through trade school or university could help to reduce global food losses, by integrating postharvest information into the general agricultural curriculum in each country or state and their extension services, with much more emphasis on preventing losses, maintaining quality and nutritional value after harvest and ensuring food safety.
- Establishing a Postharvest Working Group in each country could be very useful in providing a forum for communications among all those concerned with postharvest biology and technology research and outreach. A link among the various Postharvest Working Groups in each region would further facilitate exchange of information and regional collaboration on training and other areas of mutual interest, and help to reduce duplication of efforts.
- Capacity-building efforts undertaken in postharvest technology in developing countries must be more comprehensive, and include technical knowledge on handling practices, research skills, access to tools and supplies, cost/benefit information, extension skill development (training needs assessment, teaching methods, advocacy), Internet/Web access, and provision of follow-up mentoring for young scientists and extension workers after formal training programs have been completed.
- A central site for conducting postharvest research and offering local extension programs such as a 'Postharvest Training and Services Center' is recommended for each developing country. This site is where local R&E personnel could meet and conduct practical adaptive research aimed at testing innovations under local conditions, identifying issues regarding practicality, costs, potential returns, providing demonstrations of those innovations determined to be feasible (both technically and financially), providing comprehensive, hands-on training on improved postharvest practices, and providing information of practical use to women involved in horticulture.

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