Appropriate Postharvest Technologies for Small Scale Horticultural Farmers and Marketers in Sub-Saharan Africa and South Asia – Part 2. Field Trial Results and Identification of Research Needs for Selected Crops

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Abstract

Part 2 of 2. Based upon findings on the causes of postharvest losses and quality problems for key horticultural crops in Sub-Saharan Africa (SSA) and South Asia, 32 potential postharvest technical solutions were identified and investigated further. An additional 28 options related to production, extension and marketing activities were identified but not tested during this project. The objective was to identify postharvest technology interventions that would specifically address the identified priority problems and serve to reduce food and value losses, and that are of appropriate scale, cost effective, easy to use on a trial basis and capable of generating increased incomes by at least 30% for small farmers. Field trials were conducted on 19 of these intervention options, and cost/benefit analyses were conducted on 21 cases of improved handling, packing, storage and processing practices in India, Nepal, Ghana, Rwanda, Cape Verde and Benin. In 81% (17) of cases, the postharvest technologies were determined to be cost effective and of appropriate scale for successful adoption and management by small scale horticultural producers and marketers in Africa and South Asia. Field assessments and preliminary field trials led to the identification of additional research needs for selected crops, and recommendations are provided for future studies in small scale postharvest technology.

INTRODUCTION

Part 1 (Kitinoja and Alhassan, 2012) provides the background, materials and methods for the postharvest loss assessments and the findings on the types, volumes and causes of postharvest losses and quality problems for key horticultural crops in Ghana, Rwanda, Benin and India. High temperatures during the postharvest period and the use of non-protective packages were a source of high levels of damage and deterioration, which greatly reduced the potential postharvest life of all the crops studied (Kitinoja and Alhassan, 2012).

RESULTS AND DISCUSSION

Based upon these findings, 32 potential postharvest technical solutions were identified and investigated further. These results should be considered preliminary, since the number of field trials undertaken was quite limited because of time and funding constraints.

The following list includes 19 individual technology topics identified as potential postharvest interventions for reducing postharvest losses and maintaining quality after harvest. Each of the topics includes a variety of options for specific interventions that were briefly assessed in various locations, and then, if found worthwhile based upon rough estimates of costs and potential benefits, were tested during field trials in several different countries. We were able to initially assess postharvest technology topics in only 8 of the 19 categories, which included 19 of the 32 potential intervention options in this list because of limited resources. As results from the postharvest assessments pointed to poor temperature management and poor quality packaging as the main sources of losses and quality problems, focus during field trials was on simple technologies that could reduce temperature or improve the quality of packages. We were also interested in technologies that could protect against insect damage, control decay, or help to reduce losses by adding value (i.e., processing and the use of improved packaging for processed products).

Postharvest Technology Topics and Related Options for Study

1. Improved containers or packages: plastic crates; liners for existing rough packages; smaller packages.
2. Improved field packing methods during harvest: sorting, sorting into sizes or different maturities and packing in the field; buckets for harvest (not tested); folding tables (not tested); gentle handling (not tested separately but considered part of all the other field trials); trimming and wrapping.
3. Providing shade (various ways to protect produce from the sun as it moved from farm to market): cloth covers, plastic net shelters, large umbrellas.
4. Insect control - pest management for fresh produce: hot water treatment.
5. Insect control - packaging upgrades for processed products: sealed plastic for dried products; sachets of chemical control, i.e., slow release phosphin (not tested); small scale CO_2 applications.
6. Low cost cooling - evaporative forced air cooling: reduce temperatures from ambient temperatures (which can be 30-35°C) to 12-15°C using natural evaporation of water (not tested).
7. Low cost cooling - hydro-cooling: use of deep well water if available (naturally colder).
8. Low energy cool storage practices: various sizes of the original Zero Energy Cool Chamber (ZECC) designed by S.K. Roy in India during the 1980s (Roy and Khurdiya, 1981; Pal and Roy, 1988; Roy and Pal, 1991); large walk-in closet design for ZECC (considered too expensive for this study); clay refrigerator (determined to function well, but too small for farm use); ventilated storage structures for onions (not tested since their design has been well documented and they are currently used in India).
9. Small-scale cool transport: insulated boxes. Not tested during this project, but plans were for the Millenium Challenge Corporation (MCC) project in Cape Verde to field test several models during 2010.
10. "Cool & Ship" portable forced air cooler: room sized air conditioner, plus CoolBot unit and insulated box is used to quickly cool 250 to 400 kg of produce (not tested).
11. Small-scale cold room equipped with CoolBot: CoolBot controller unit can allow user to utilize a common room sized A/C unit to cool an insulated room down to low temperatures with relatively high humidity.
12. Methods to slow ripening of fruits: ethylene scrubbers; 1-MCP treatments. Not tested, although desk and lab studies are underway at UC Davis. No sources for 1-MCP were identified in Africa, although studies have been recently conducted in India (Singh and Pal, 2008).
13. Methods to speed ripening of fruits: use of ethylene (as Ethrel or ethephon) rather than calcium carbide for ripening. Not tested since the use of ethylene rather than calcium carbide is a well-known practice. Calcium carbide has been banned in many countries.
14. Improved, low-cost, low-technology food processing methods - solar drying: improved direct solar drying; indirect solar drying methods.
15. Improved, low-cost, low-technology food processing methods: solar cookers for food processing - jams, pickles, hot water baths (not tested).
16. Low cost food processing methods - turning fresh horticultural produce into locally desirable snack foods: "combined methods" advocated by FAO for processing fruits

and tomatoes (blanching, acidification, lowering aW, adding anti-microbials); pickle making (mixed vegetables).

17. Use of water disinfection methods and other sanitation procedures (ways to reduce microbial contamination): hand washing; chlorinated wash water. Not tested, but desk studies are underway at UC Davis.
18. Curing root and tuber crops: field curing methods (natural air) vs. heated air. Not tested, since methods, protocols, cost for different crops (cassava, potatoes, sweet potatoes, yams, onions, garlic) are well known and should be further disseminated to reduce postharvest losses.
19. Alternative cooling technologies: Peltier refrigerator (not tested). Desk study is on-going at UC Davis.

An additional 28 options, related to production, extension and marketing activities, were identified during the assessments but not field tested during this project, since time and funds were limited. These included:

1. Production practices that affect postharvest losses and quality (i.e., quality of seeds/planting materials, choice of cultivars, planting timing, spacing/density, fertilization, weeding, irrigation, field sanitation, crop rotation, pruning, thinning, spraying, IPM practices, bagging fruits, GAPs);
2. Extension and training strategies for outreach and promotion of appropriate postharvest technologies (i.e., holistic approaches, provide training at reasonable cost, integrated postharvest management systems, developing local business models, expert systems for decision making support, role of micro-credit, value of a rent-to-own model for promoting postharvest technologies, and commercial approaches such as postharvest stores or shops); and
3. Marketing strategies that help maintain quality and reduce postharvest losses (i.e., market information systems, improving access to market information by using low cost systems, such as SMS text messages, role of farmers group formation, role of the intermediaries as partners).

A few of the postharvest technology options were initially identified as important, but planned field trials could not be completed when needed supplies or proper controls were found to be lacking. In Benin, difficulties in cooling produce after 52°C hot water dip treatments reduced efficacy of the hot water treatments undertaken at IITA. Even under these conditions, losses in oranges were reduced from 97.5% (control) to 70.0% when assessed at day 15 of ambient temperature storage after treatment. Small scale CO_2 applications could be tested only in the lab in the USA, where dry ice in sealed containers (i.e., allowing slow release of CO_2) was shown to kill many kinds of insects within 7 days. Field testing was not possible due to lack of information from African partners on availability and cost of local supplies. In Ghana, hydro-cooling of cabbage in field trials was unreliable because of poor quality water used in the studies. Initial tests indicated higher rates of decay were reported when hydro-cooling was used compared to no cooling.

Preliminary Results of Selected Field Trials

The final report on this project provides details on all 19 of the field trials conducted during the study, plus the cost/benefit analyses conducted on 21 related cases of improved handling, packing, storage and processing practices for various crops in India, Nepal, Ghana, Rwanda, Cape Verde and Benin. The objective was to identify postharvest technology interventions that would specifically address identified priority problems for specific crops and serve to reduce food and value losses, and that were of an appropriate scale, cost effective, easy to use on a trial basis and capable of generating increased incomes by at least 30% for small farmers.

All the field trials reduced postharvest losses, and overall, of the 21 cost/benefit analyses performed on the different categories of postharvest technology options, all 21 were profitable for small farmers, and 81% (17 technology/crop combinations) provided an increase in income of 33% or more. Assuming a baseline income of $ 600 per year (or less than $ 2 per day), potential profits were more than $ 200 per year. The technologies were assumed to be under-utilized in each of the cost/benefit analyses in order to make sure our calculations did not depend upon optimum usage.

Summaries of ten of these field trials are provided as case studies. Further testing is recommended for all cases, and studies involving additional crops, modifications of the technologies and/or different locations are encouraged.

1. Field Trial 1: Improved Containers or Packages: Liners for Rough Packages.

Description. In India we field tested lightweight corrugated fiber-board (CFB) liners for cartons and plastic crates. These liners were locally made and found to be inexpensive, reusable for several uses, and recyclable.

Preliminary Findings. Guava was transported over a distance of 50 km in inexpensive plastic crates, both with and without crate liners. No significant change in weight loss % was measured for the two treatments, but bruises were observed in 12.5% of the guavas transported in crates without liners.

Costs and Benefits. 50 sets of liners cost Rs 480 or US$ 9.50. Market value of the bruised guava fruits fell from Rs 40/kg to Rs 15/kg.

Return on Investment. Immediately profitable. For each 1 MT load (50 crates) of guava fruit transported, the additional profits were Rs 2645 (=US$ 52.60) or 5.5 times the cost of the initial investment. Total returns depend upon the number of times the liners are used for transport.

2. Field Trial 2: Improved Containers or Packages: Smaller Sized Packages.

Description. In Ghana a smaller package (half sized sacks) was tested at KNUST for use for transporting cabbages to market.

Preliminary Findings. Cabbage in large sacks (holding up to 70 kg) suffered 32% breakage and head splitting, while half sized sacks (approximate capacity 30 kg) resulted in less damage (23% breakage and head splitting,). Market value of the cabbage was the same for the undamaged heads (1.44 Ghanaian Cedis or $US 1.00/kg) but damaged heads were discarded as a total loss.

Costs and Benefits. 28 small sacks cost US$ 21, compared to the 14 large sacks which cost US$ 14. The small sacks cost US$ 0.75, slightly less than large sacks ($ 1.00 each) but twice as many small sacks are needed to carry the same volume of cabbage. More cabbage is available for sale when small sacks are used (77% of the initial volume) compared to only 68% of the initial volume for cabbage transported in large sacks.

Return on Investment. Immediately profitable. For each 1 MT load (28 small sacks) the additional profits were $US 83.00 compared to the traditional practice of using large sacks.

3. Field Trial 3: Improved Field Packing Methods during Harvest: Trimming and Wrapping.

Description. In India field trials were conducted with cling-wrapped cauliflower heads. Produce was trimmed and cling wrapped, packed in plastic crates and compared to the traditional practice of transporting bulk loads with stems and outer leaves attached to act as a cushion during transport.

Preliminary Findings. In Noida, a peri-urban area near New Delhi, farmers reported they sold cling wrapped cauliflower for Rs 20/head compared to those unwrapped, which sold for Rs 10/head, both of the same weight. In Unnao, a rural area designated as impoverished, prices for wrapped cauliflower heads increased by 25% from Rs 10 to 12.5/head.

Costs and Benefits. Cling film cost only Rs 0.2/head, and 50 plastic crates cost Rs 12,500 (Rs 250 or $ 5.00 each). In Noida, cling wrapped cauliflower sold for Rs 20/head in comparison to those unwrapped, which sold for Rs 10/head. Head weights averaged 0.5 kg. Transport costs were reduced and the leaves and stems that were left on the farm could also be sold or used as animal feed.

Return on Investment. Two uses of the plastic crates and liners will pay for the initial investment in Noida. Subsequently, for each 1000 kg of cauliflower harvested, wrapped and field packed in 50 plastic crates, 600 heads of 0.5 kg/head were sold at twice the price of the untrimmed/unwrapped cauliflower heads, for an additional profit of Rs 5960 or US$ 119.20 per load. In Unnao, 9 loads were required to pay for the initial investment, after which each subsequent 1 MT load provides farmers with an increased profit of Rs 1460 or US$ 29.50.

4. Field Trial 4: Field Packing under Thatched Roof Structure with Concrete Flooring.

Description. In Rwanda, unsorted vegetables are typically packed in traditional woven baskets and sold on the day of harvest to a buyer who comes to the farm. A field packing station was constructed on a farm near Kigali using local materials (wooden poles, thatch roof, concrete floor) and tomatoes were sorted, graded and packed into plastic crates under shade (Fig. 1).

Preliminary Findings. Weight losses under traditional conditions were 2.5% in 4 hours, compared to 0.5% in 4 hours under shade. Quality sorting and grading, plus the use of improved packages resulted in higher price/kg offered by the buyers coming to the farm.

Costs and Benefits. The cost of the structure was relatively high at $ 1161 (650,000 Rwandan francs) since it was built by local contractors, and the cost of 20 large plastic crates was US$ 48.00 ($ 2.40 each). If the farmer had built his own structure, the cost could have been reduced to $ 600. Market value of the higher quality field packed tomatoes was US$ 0.71/kg compared to $ 0.54/kg for the unsorted/ungraded fruits.

Return on Investment. Six uses of the field packing station for packing tomatoes will pay for the initial $ 1209 investment. Each subsequent 1 MT load provides an additional profit of $ 198 compared to the traditional practice.

5. Field Trial 5: Providing Shade with Plastic Shelters.

Description. In India, sturdy 70% PolyNet shade structures with curved poles made of galvanized iron pipes (Fig. 2) were designed and constructed in ten locations for farmers to use during sorting/ grading/packing, compared to the existing practice of no use of shade.

Preliminary Findings. Packing trials conducted during the cool winter season with spinach resulted in a reduction of weight loss from 5% (no shade) to 1% (under shade).

Costs and Benefits. PolyNet shade structures cost Rs 7000 ($ 140) each. Although market value for the spinach was the same (Rs 10/kg) the earnings were higher because of the higher volume available for sale by weight. Differences in weight loss would be higher for trials conducted during the hot summer months.

Return on Investment. 18 uses of the packing shelters for packing spinach during the winter months will pay for the initial investment. If the shade was used 4 or 5 times per week the payback period will be about one month. For each subsequent use, Rs 400 ($ 8.00) of additional profits will be generated compared to the traditional practice of no shade. Using the system with higher value crops or during summer, when there is a larger differential of weight loss during packing under shade versus sun, would lead to increased profits.

6. Field Trial 6: Low Energy Cool Storage Practices: Zero Energy Cool Chamber (Small Size).

Description. In India a 100 kg size cool chamber storage unit made of bricks and sand, and saturated with water to promote evaporative cooling was constructed and tested at six locations for temporary storage of a mixed load of vegetables during the hot season.

Preliminary Findings. Average weight losses were reduced from 30 to 10% and market value increased from an average of $ 1.00/kg to $ 1.20/kg. Produce temperatures were reduced to the point where produce could be safely stored for 5 to 6 days without signs of decay.

Costs and Benefits. The ZECC cost $ 100 each, and plastic crates cost $ 25 ($ 5.00 each). Market value of cooled/stored produce increased by 20% compared to selling at the offered price at the end of the day of harvest.

Return on Investment. Three uses pays for the initial investment of US$ 125. For each subsequent load of 100 kg kept in cool storage, profits would increase by US$ 40.50 compared to the traditional practice that requires selling on the day of harvest.

7. Field Trial 7: Low Energy Cool Storage Practices: Zero Energy Cool Chamber (Large Size).

Description. In India a 1 MT unit called a "walk-along" ZECC model (Fig. 3) was designed, constructed and field-tested in two locations. The unit can hold up to 50 plastic crates of produce in temporary cool storage.

Preliminary Findings. Weight losses for radish samples in India during the ZECC field trial were 7.35% by day 6 for produce stored inside the ZECC, compared to 13.57% for produce stored under ambient conditions. Weight losses for tomatoes in India during the ZECC field trial were determined to be 1.8% by day 6 for produce stored inside the ZECC, compared to 8.4% for produce stored under ambient conditions.

Costs and Benefits. The Walk-along model ZECC cost $ 1000 each, and 50 plastic crates cost $ 250 ($ 5.00 each). For tomatoes, weight losses decreased and market value increased from Rs 14/kg to Rs 20/kg when farmers were provided with more options for marketing.

Return on Investment. Eight uses of the 1 MT ZECC would pay for the initial investment. Each subsequent 1 MT load of tomatoes stored in the ZECC would provide an additional profit of US$ 140 compared to the traditional harvest day selling practice or ambient temperature storage overnight.

8. Field Trial 8: Low Energy Cool Storage Practices: Zero Energy Cool Chamber (Small Size).

Description. In Ghana a 200 kg size ZECC with thatched roof and concrete floor was designed, constructed in two locations and field tested for temporary storage of cabbage.

Preliminary Findings. Temperatures inside the units were measured on a daily basis and compared to the ambient conditions in a typical storage shed. The traditional level of postharvest losses for cabbages in Ghana is extremely high (60%), as a result of high weight loss when handled and stored at ambient temperatures (ranging from an average of 26°C in the morning to 33°C in the afternoon) and very low relative humidity (ranging from an average of 29% in the morning to 28% in the afternoon). Weight loss when handled and stored at in the ZECC was still high, but greatly reduced to 36% because temperatures were lower (ranging from an average of 22°C in the morning to 27°C in the afternoon) and relative humidity was higher in the cool chamber (ranging from an average of 62% in the morning to 56% in the afternoon).

Costs and Benefits. The Ghanaian version of the ZECC cost US$ 1040 to construct by local contractors. If the farmer did his/her own construction, costs could be reduced to $ 813. The volume of produce available for sale after 6 days of temporary storage at ambient conditions versus in the cool chamber increased from 40 to 62% of the harvested crop. There was no difference in market price per kg, although the visual quality of the cabbage kept in cool storage was better maintained over the 7 days of the field trial period.

Return on Investment. 18 uses of the 200 kg size ZECC would pay for the initial investment of $ 1040. Each subsequent 200 kg load will provide $ 58 in additional profit compared to the traditional practice of ambient temperature storage or immediate sale.

9. Field Trial 9: Small-Scale Cold Room Equipped with CoolBot Control Unit.

Description. A CoolBot unit can allow user to utilize a common room sized air conditioning unit to cool an insulated room down to very low temperatures while maintaining relatively high humidity (http://storeitcold.com). The field trials compared costs, different kinds of insulation materials, and power use to those for traditional sheds and walk-in cold rooms used in the USA, India and Ghana.

Preliminary Findings. In Ghana, the CoolBot cold room was compared to a traditional storage shed used for several months of storage for onions. Losses were reduced from 30 to 5% and market value increased from $ 0.50/kg for onions sold immediately after harvest to $ 2.00/kg for onions sold four months later during the off season.

Costs and Benefits. The costs for constructing an insulated 20-m^2 room of 6 MT capacity, equipped with a window style air conditioner (10,000 BTU) and a CoolBot controller ($ 300) totaled $ 4300. Recurring costs were $ 580 for electricity costs for initial cooling ($

80/MT at $ 0.09/kWh) and cold storage at 1°C for 4 months ($ 25/month at $ 0.09/kWh).
Return on Investment. Immediately profitable. The high value of stored onions sold during the off season provided a gross return of $ 10,820 compared to $ 2100 for onions sold immediately after harvest, for an additional profit of $ 8720 per 6 MT load. Even if a back-up 3.5 kW generator is required, the cost ($ 4900 plus fuel) could be covered by only 2 or 3 uses of the CoolBot equipped cold room.
10. Field Trial 10: Low Cost Food Processing Methods. This involved turning fresh horticultural produce into locally desirable snack foods with use of "combined methods" as described by FAO for processing fruits and tomatoes (blanching, acidification, lowering aW and adding anti-microbials).
Description. Improved canning/bottling using combined methods were field tested in India to determine if it was possible to increase food availability for rural families at low cost. Any processed product will also need simple low cost packaging to protect from insects, light, oxygen.
Preliminary Findings. during the peak of tomato production season in India there is a market glut, and prices offered to farmers fall to Rs 2/kg, while during the lean season the market price can climb as high as Rs 50/kg. Field trials documented that 10 kg of tomato fruit yielded 6 L of juice, which was processed to 2 L of puree. Concerns with traditional chemical treatments (food safety) mean training should be provided on recipe modifications, carefully measuring ingredients, choosing safe alternatives to dangerous chemicals used as food preservatives.
Costs and Benefits. the cost of buying tomatoes in the market during the field trials was Rs 16/kg. The cost of processing tomato puree (including produce, fuel, bottles and corks) was Rs 29 per bottle of 500 g, and market value was Rs 70.
Return on Investment. Immediately profitable, but yields were very low (4 bottles of puree that could be sold at a profit of less than US$ 1.00) and equipment for the field trial was provided by the local extension service (KVK). Processing at the village level would require additional investments such as purchase of pots, utensils, a stove and a crown corking machine - a future project might consider supplying these as part of the training process as a grant in kind to a women's association.

Costs and Benefits

For each of the field trials, we calculated both the payback period at 0% interest and the additional income if used at only 35 to 50% capacity, to ensure we were not over-reaching. Depreciation is implied in the lifespan of the technology, which is considered in each case. Since plastic crates can be used 100 times before they will need to be replaced, utilization at 50% capacity for a smallholder would mean they would use the plastic crates twice per month rather than once per week over the course of up to four years.

In most cases labor was included in the comparative cost of the technology. If labor costs do not need to be included in the cost of the technology (for example if the farmer provides his own labor or the food processor does not need to pay herself for her investment of time) the financial returns will be even higher than found in these preliminary field trials. When local materials can be substituted for purchased supplies (for example if a farmer can cut thatch to make the roof for a ZECC) the initial costs will be even lower.

In more than 80% of these preliminary field trials the postharvest technologies were determined to be cost effective and of appropriate scale for successful adoption and management by small scale horticultural producers and marketers in Africa and South Asia. Payback periods were very short for some technologies (i.e., immediate for the use of improved packages or processing methods, and a few weeks to 3 months for the use of shade structures or field packing). Payback periods were somewhat longer for the use of ZECCs for temporary cool storage (i.e., one to two months in India, 5 months in Ghana), and longest for the CoolBot technology which requires about one year to pay for the construction and operation of a high cost electric powered insulated cold room, and somewhat longer if a back-up generator is needed. In all cases, the useful life of the tested postharvest technologies was well beyond the payback period, and earnings could be generated for many months or years after the break-even point.

These low cost approaches to reducing losses are especially important since the vast majority of horticultural crops producers and marketers in Sub-Saharan Africa and many horticultural producers in South Asia are women. Since the 1970s the academic community has been studying and documenting evidence of the neglected role of women in agricultural development (United Nations Economic Commission for Africa, 1972; AFRACA, 1983; Mungate, 1983; Kamp, 1984; Kumar, 1987; Saito and Weidemann, 1990). Although they provide 60 to 90% of the farm work (Quisumbing et al., 1995), women usually lack technical knowledge, and often have poor access to current information, markets and credit, which all contribute to these observed high levels of postharvest losses. The packing and marketing of these horticultural crops is also dominated by women, and a recent assessment reported that in Africa over 50% of production and 80% of the labor for packing and marketing of horticultural crops was performed by women (GHI, no date. http://www.globalhort.org/success-stories/). Simple, inexpensive postharvest technologies that can be readily used by women can help to fill these gaps.

Many of the findings of this study support earlier published studies reporting high levels of postharvest losses due to poor temperature management, handling damage, decay incidence and market value loss. All this postharvest waste makes the lives of farmers, their families very difficult, as they often receive low prices for their foods, since marketing intermediaries know that the horticultural crops they purchase from growers are likely to lose a lot of their volume and value before they can be sold to market vendors or consumers. Our studies also indicated that many small farmers tend to be “price takers”, whereby they grow a horticultural commodity and offer it for sale to the highest wholesale bidder at the farm gate or in the marketplace on the day of harvest, mainly because they lack any other option. This practice of selling or “dumping” produce, sometimes at a loss, is not a successful marketing strategy, and usually means that farmers receive low prices because whenever they have produce for sale, often so does every other local farmer, leading to a glut of a particular kind of fresh produce in the market-place.

Implementing simple postharvest technologies, such as those identified and field tested in this study, can help small farmers successfully protect produce during handling, store produce for a short time or process perishable crops to more stable foods, enabling them to potentially get better prices by selling during off peak production times. Use of appropriate scale postharvest technologies can provide farmers with options other than immediate sale, and can reduce fruit and vegetable losses while enhancing farming sustainability by reducing demands on natural resources used to grow horticultural crops. When women are assisted to earn more money from the crops they produce, they tend to invest in their families by providing more food, preventative health care and education for their children (Haddad and Hoddinot, 1995).

Future Research Needs

We recommend that future projects continue this work in other settings as well as assess the potential technology options that were not tested during this study, especially since so many of those assessed in this preliminary study were demonstrated to reduce losses and to be cost effective for smallholder farmers in Sub-Saharan Africa and South Asia. In addition, the many options identified during the field assessments that are related to production, marketing and extension practices need to be further studied and field tested. Fieldwork to identify the types and sources of postharvest losses and these preliminary field trials on potential solutions led to the identification of additional research needs for fruit and vegetable crops.

Ten general recommendations are provided here for future studies in small scale postharvest technology for smallholder farmers and marketers.

1. Perform postharvest loss and quality assessments for the full range of horticultural crops in all developing countries, in various climate zones and during different seasons;
2. Conduct field trials and cost/benefit analyses of small scale postharvest technologies potentially suitable for reducing losses for horticultural crops in additional developing countries, in various climate zones and during different seasons;
3. Field test various coatings and heat treatments for pest management for fresh produce under developing country conditions (i.e., chitosan, waxes, edible films, forced hot air, hot water);
4. Identify and test protective packaging and packaging materials that can be reused and/or recycled (i.e., starch based polymers for alternatives to plastic bags, improved plastic crate designs);
5. Study effects of the size and shape of the Zero Energy Cool Chamber, including testing of locally made structures and construction materials (i.e., types of flooring, bricks, sand fill and shade coverings);
6. Design and test of variations of passively powered evaporative cool storage chambers or systems, including mobile systems;
7. Identify and test reliable low cost electric power sources for evaporative and Cool-Bot controlled cooling systems (i.e., solar powered, wind powered or other alternative energy sources);
8. Design and test of cost effective insulated cool boxes and package covers of varying sizes and types for use in maintaining cool temperatures during short distance transport (i.e., to be carried in wagons, or in the bed of a pick-up truck, or pulled as trailers);
9. Design and test of cost effective packaging methods for improved insect control in dried products (i.e., use of insecticide impregnated films, CO_2 flushes, use of dry ice, etc.);
10. Identify and test lower cost, safer food additives and preservatives for improved processed products (i.e., alternatives to salt and sulfites).

CONCLUSIONS

Historically, production agriculture and production horticulture have received the vast majority of attention in development efforts in Sub-Saharan Africa and South Asia. While increasing yields, planting improved seeds or growing new crops is very important, much of these investments will continue to be wasted whenever a crop is lost during postharvest handling before it can be eaten or sold. Therefore much more emphasis is needed on improving postharvest handling practices in order to reduce this waste and improve the health and welfare of families living in these regions.

With postharvest sorting losses at the farm, wholesale and retail markets commonly reaching 30 to 50% for many of the horticultural crops we studied during this project, and physical damage measuring as high as 50 to 89% for vegetable crops in the markets of Africa and India, this represents an enormous waste, not only of food, but also the land, water, fertilizers and human labor that went into producing the food. By working with farmers and handlers in the postharvest sector and investing in simple, low cost improvements, such as gentle handling, protective packages, shade and cooling, cool storage and cool transport, we can help farmers and marketers to reduce physical losses, maintain food quality and market value for a longer period of time. By protecting the food supply and extending the marketing period in cost effective ways, we can assist growers to gain the confidence to take responsibility for more of handling steps along the postharvest chain, both to better access their local and regional markets and to gain more profits from their horticultural farming efforts.

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Figures

Fig. 1. Field packing structure in Rwanda.

Fig. 2. PolyNet shade structure in India.

Fig. 3. The authors visit a large sized Zero Energy Cool Chamber in India (one metric ton capacity) during the field trials at Amity University.