Identification of Appropriate Postharvest Technologies for Small Scale Horticultural Farmers and Marketers in Sub-Saharan Africa and South Asia – Part 1. Postharvest Losses and Quality Assessments

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Abstract

Part 1 of 2. The objectives of the study were 1) to systematically assess and characterize postharvest losses for key horticultural crops in four countries using field based measurements at the farm, wholesale and retail markets, to increase the knowledge base and identify priority postharvest problems that currently limit market access for small farmers and rural marketers, 2) to identify and field test postharvest technology options that could solve priority postharvest problems by conducting field trials in Sub-Saharan Africa and South Asia, and 3) 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. A series of comprehensive postharvest assessments were undertaken in Ghana, Rwanda, Benin and India during 2009 to identify the % physical losses, quality changes and economic value of losses for 16 different crops. Based upon these assessments, supplemented by interviews of various players along the value chains, primary causes and sources of postharvest losses and quality problems were identified. Sampling, objective and subjective measurement of physical losses and quality parameters were conducted at the farm, wholesale and retail markets in each of the four countries by trained data collectors housed at 10 partner institutions. Ten (10) random samples were collected at each of the 3 levels of the value chain for each crop. Tomatoes were assessed in all 4 countries, mangoes in 3 countries, and other crops in one or two countries each. Sample sizes and quality parameters varied by crop type. Sorting was done to determine overall quality, % damaged, % decayed and % with other defects within each sample. Rating scales were developed for visually assessing quality, color changes, stage of ripeness, and degree of package protection. Objective measurements of firmness, SSC%, air temperature, pulp temperature and % RH were made using hand held tools in the field. Postharvest losses were related to one or more of 4 major factors: 1) high temperatures, 2) poor quality packages, 3) poor field sanitation and 4) time required to reach the market.

INTRODUCTION

Field observations over the past 40 years have reported that 40 to 50% of horticultural crops produced in developing countries are lost before they can be consumed, mainly because of high rates of bruising, water loss and subsequent decay during postharvest handling (Kitinoja, 2002; Ray and Ravi, 2005). Losses can also show up as decreased nutritional quality (loss of vitamins, development of health dangers such as myco-toxins) or decreased market value. The magnitude of these losses and their impact on farm income varies greatly from place to place and has often been difficult to calculate since losses are related to improper temperature management, and the postharvest handling chain includes all the steps between harvesting and consumption,

including sorting, cleaning, packing, cooling, storage, transport and processing. Reducing postharvest losses for fresh produce has been demonstrated to be an important part of sustainable agricultural development efforts meant to increase food availability (Kader, 2005), but during the past thirty years less than 5% of the funding provided for horticultural development efforts has gone toward postharvest projects, while more than 95% has gone toward trying to increase production (Kader and Rolle, 2004). Literature reviews undertaken in preparation for this study indicate that only one in 2000 agricultural development projects funded by major international agencies during the past 10 years has focused on postharvest horticulture (USAID, World Bank, UNFAO and DEVEX data bases). It was estimated that 10 to 20% of all farmers are producers of horticultural crops, sometimes in combination or rotation with field crops, and that horticultural cropping accounts for approximately 7% of the land in Sub-Saharan Africa (SSA) and 6% in South Asia that was used for agriculture in the year 2000 (AVRDC, 2005; FAOStats, 2004). Unpublished evaluation reports of several recently completed major projects (i.e., World Bank's Diversified Agricultural Support Project in UP, India; USAID's Agricultural Exports and Rural Incomes Horticulture component in Upper Egypt, USAID's Growth-oriented Micro-Enterprise Development in Maharashtra, India; JICA's sponsorship of the Horticulture Crops Development Authority in Kenya) identified significant failures resulting from over-reliance on production oriented activities, and the lack of adequate training on postharvest handling practices, slow or no development of appropriate postharvest infrastructure or neglect of other aspects of the postharvest chain during transport and marketing.

In 2008 staff of the Bill and Melinda Gates Foundation contacted us regarding some of our past publications (Kitinoja and Kader, 2002; Kitinoja and Gorny, 1999) and invited us to implement a one year long planning project that could document current levels of postharvest losses for small farmers in SSA and South Asia, then identify and test potential solutions. Although there are hundreds of horticultural crops produced in these regions, in most cases the major crops were easily identified by our local partners and were known as either common food crops, some with higher nutritional value than others, or as higher value crops (crops grown for sale to others or for processing to add value). After reviewing a wide range of possibilities, we selected 16 different crops falling into five general categories of crops grown in the four target countries of Ghana, Benin, Rwanda and India and selected several crops from each category in each country for a total of 28 crop/country data collection sites for inclusion in this study.

Crops Selected for Study in the Four Target Countries

1. India (in the States of Uttar Pradesh and Uttaranchal). Tomatoes (*Solanum lycopersicum*), eggplant (*Solanum melongena*), cucurbits (*Lagenaria leucantha*), bottle gourd (*Luffa cylindrica*, sponge gourd), okra (*Abelmoschus esculentus*), mangoes (*Mangifera indica* L.), litchi (*Litchi chinensis*).

2. Ghana (in and near the Cities of Kumasi and Tamale). Tomatoes (*Solanum lycopersicum*), eggplant (*Solanum melongena*), peppers (*Capsicum annuum*), okra (*Abelmoschus esculentus*), onions (*Allium cepa*), cabbage (*Brassica oleracea* var. *capitata*), mangoes (*Mangifera indica* L.), pineapples (*Ananas comosus*), plantains (*Musa* × *paradisiaca* L.).

3. Rwanda (near the City of Kigali). Tomatoes (*Solanum lycopersicum*), leafy greens (*Amaranthus* spp., amaranth leaves), bananas (*Musa acuminate*), pineapples (*Ananas comosus*).

4. Benin (in the Southern Coastal Zone). Tomatoes (*Solanum lycopersicum*), peppers (*Capsicum annuum*), leafy greens (*Amaranthus* spp., amaranth leaves; *Solanum macrocarpon*, African eggplant leaves), onions (*Allium cepa*), mangoes (*Mangifera indica* L.), pineapples (*Ananas comosus*), oranges (*Citrus sinensis*).

Tomatoes were assessed in all 4 target countries, mangoes in 3 countries, and the other crops in one or two countries each. Categories included: 1) subsistence crops, used as staple foods (plantains, bananas); 2) other crops important for the daily traditional diet,

found in common recipes (tomatoes, eggplant, cucurbits, okra, peppers, onions, cabbage); 3) high nutritional value crops (oranges, indigenous leafy crops); 4) high value crops with good potential for additional income generation (litchis, pineapples, mangoes); and 5) good potential for drying or added value processing (tomatoes, cucurbits, peppers, onions, mangoes, bananas, leafy vegetables).

One of the key factors in selecting the crops to be assessed in each of our four target countries were the local crop calendars, since our potential data collection period ran only from April through September 2009. Many of the most commonly produced vegetable crops could be readily assessed since they are harvested during 6 to 8 months of the year (i.e., tomatoes, peppers, eggplant, okra, cabbage), while a few crops are harvested throughout the entire year (i.e., leafy greens, bananas, plantains). Most tree fruits, however, tend to be harvested during a single season for a period of about one month to up to 4 months, depending upon the commodity. We would like to have included potatoes in UP, India, but the harvest period typically does not begin there until November.

OBJECTIVES OF THE STUDY

The objectives of the study were 1) to systematically assess and characterize the postharvest losses for key horticultural crops in four countries using field based measurements at the farm, wholesale and retail markets, in order to increase the knowledge base and identify priority postharvest problems that currently limit market access for small farmers and rural marketers, 2) to identify and field test specific postharvest technology options that could solve priority postharvest problems by conducting field trials in Sub-Saharan Africa and South Asia, and 3) to identify postharvest technology interventions that would specifically address the identified priority problems and serve to reduce food waste and market 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.

MATERIALS AND METHODS

Five workshops on postharvest loss and quality assessment methods were held in Africa and India during March through July 2009. Postharvest scientists and extension specialists from the University of California, Davis, joined the WFLO project team in providing two day long workshops for our local partners followed by field visits to practice the use of tools and protocols.

Data collection instruments and worksheets were developed and field-tested prior to implementation of five workshops. Each data collection worksheet was adjusted to fit the specific characteristics of the crop as it was to be assessed on the farm, at the wholesale and retail markets, and a set of three worksheets were used to create a protocol. The purpose of the five workshops was to finalize and field test the protocols that would be utilized to gather information on postharvest losses and quality problems throughout the production, postharvest supply chain and marketing period. Our local partners then helped to identify specific sites to be surveyed, people to be interviewed and observed and the timeline for data gathering via field visits and laboratory studies. Target number for these loss assessment workshops was 20 participants per country, but interest in the training was much higher than expected, and 236 persons were trained, including 102 from India, 67 in Ghana, 42 in Rwanda and 25 in Benin.

Data collection protocols included the following variables.

- 11 independent variables: country (India, Ghana, Benin, Rwanda); location in the value chain (farm, wholesale market, storage, retail market); relative perishability of the crop (very perishable i.e., litchis, ripe tomatoes, leafy greens, thin peel cucurbits or okra; moderately perishable i.e., breaker/turning tomatoes, eggplant, peppers, thick peel cucurbits, pineapples, bananas, plantains or mangoes; and less perishable i.e., cabbage, oranges or onions); time from harvest (hours); air temperature (°C); relative humidity %; pulp temperature (°C); initial quality rating at harvest (rating scale for no defects to

extreme defects); initial maturity or ripeness (on a scale of 5 or 6 depending upon the commodity); level of protection provided by the package (rating scale from none to excellent); weight of package (kg).

- 10 dependent variables (quality characteristics and loss measurements, which are somewhat different for each kind of crop): physical losses (% removed during sorting); price offered per unit, package or kg; quality rating (on a scale from no defects to extreme defects); % defects; % decay; % damage; maturity or ripeness rating (color charts provided visual ratings on a scale of 5 or 6 depending upon the crop); firmness (lbs-force or squeeze test depending upon the crop); SSC % (soluble solids content); weight loss %.

Sample sizes depended largely upon the size of the crop: 50 units were considered a sample of okra or litchi, 10 units were selected for each sample of cabbage or pineapples, and 20 units was the sample size for all the other crops. A finger of bananas or plantain, and a bunch of leafy greens was considered one unit.

Data Collection

Measurements were performed in the field on a variety of crops in the four target countries during April through September 2009. US team members briefly joined the local assessment teams in each target country during this period to participate in the process at each site, but the majority of the loss assessment efforts were carried out by our local partners at Amity University in India, KNUST, CSIR and Tamale PolyTechnic Institute in Ghana, ISAR, KIST and Umatara PolyTechnic in Rwanda, and IITA in Benin. Over 100 of the trainees and their local supervisors participated in the 6 month long data collection efforts.

Postharvest Tool Kits

The required tools for assessment were provided to 8 assessment teams. These included a refractometer, Effigi penetrometer, a sling psychrometer, digital scale, digital temperature probes, laser-guided infrared temperature sensor, color charts for key crops (used to assess maturity), sizing rings, calipers, quality rating scales (modified from those published by UC Davis's PTRIC program www.postharvest.ucdavis.edu), and color illustrations for identifying defects in key crops.

Assessments were carried out in three locations: at the farm, at the wholesale market and at the retail market for each crop in each country. Only onions in Ghana were stored for any significant period of time, so storage sites were not assessed for any of the other crops. Package protection ratings were revised by project leaders to reflect a common scale across all four countries, since the initial ratings were locally biased (for example a raffia basket or cloth sack in Benin was considered a high quality package and rated by the local team as a 4.0 on a of 5.0 point scale, whereas in the other 3 countries sacks and baskets were all rated as 2.0 or lower).

Ten random samples were obtained for each crop/location combination, for a total of 30 samples per crop in each country. Data analyses included descriptive statistics for each crop, correlations and regression analyses for key variables. Temperature differences were calculated for each sample (measured pulp temperature in °C compared to the handling temperature commonly recommended for extending shelf life), but % weight losses of samples could not be measured because of lack of accurate data on package weights.

Missing Data

In Ghana incomplete loss assessment data were collected in Kumasi for tomatoes and okra, therefore these data were not included in the analyses. Data collected in Ghana did not include farm level measurements for onions since these were not being harvested during the data collection period. Data collected in Benin did not include farm level measurements for any fruit crops or for onions since these crops were not being harvested during the data collection period. Pulp temperatures for amaranth leaves were not

measured at all in Rwanda for undisclosed reasons. In several cases, only 4 or 5 sets of data could be collected because of inclement weather or time of the season - for example when roads were washed out and a full set of data could not be gathered in Benin or Ghana (i.e., for leafy greens, mangoes, plantains and okra).

Of the 11 independent variables included in the protocols, two variables could not be successfully measured. Package weight was difficult to assess because weights were so high (with estimates ranging from 45 to 70 kg per sack) and teams did not have appropriate scales to weigh such packages. The variable "time from harvest" was documented at farm locations, but was largely unknown when measurements were made on random samples at wholesale or retail markets.

Of the 10 dependent variables included in the protocols, results reported for three variables are questionable or minimally useful. 1) Reported physical losses were based upon recall by produce handlers, and may or may not be reliable. Total physical losses are unknown, and estimates based upon the reported % of produce sorted out and discarded on the farm, wholesale market and retail market are largely estimates, and losses may be even higher than reported, since there are missing steps along the chain (i.e., during ripening, transport or overnight storage) where data on losses were not systematically collected. 2) Price offered per unit, piece, package or kg was reported haphazardly and cannot be converted to price per kg across locations or sites. Such a wide range of harvesting containers (various non-uniform sizes of bowls, buckets, sacks, heaps) and sales units (specific numbers of fruits, bunches, by the piece, in consumer packs, etc.) were in use even on a single farm or at a single marketplace, that our analyses could not be successfully completed for most crops. Only in 7 crops could economic losses be calculated using a full set of price per kg data. 3) Weight losses could not be determined for samples because in most cases the initial weights of packages were unknown. Only in Rwanda did loss assessment teams stay on the farm or at the retail market for a period of time long enough to take initial and final weight measurements for samples of leafy greens, bananas and pineapples.

RESULTS AND DISCUSSION

Sampling and measurement of postharvest losses and quality attributes at the farm, wholesale and retail markets, and interviews of key players along the value chains indicated a wide range of postharvest handling practices that contribute to high levels of physical and quality losses, as well as market value decreases, that need to be addressed in order to reduce waste and improve farmer incomes.

Postharvest losses were related to one or more of four major factors, well known to be important for maintaining quality and extending shelf life:

Temperature

Temperatures measured during harvest, handling, transport and marketing were much higher than those recommended for quality maintenance of the produce. Pulp temperatures for tomatoes in India were 10.2, 15.5 and 14.1°C higher than recommended when measured at the farm, wholesale market and retail market respectively (Table 1).

Pulp temperatures for the other crops were all similar to that reported for tomatoes, and typical pulp temperatures in SSA and India were 10 to 20°C higher than recommended temperatures. Mean air temperatures ranged from 27.9 to 38.3°C in India and from 25.3 to 33.5°C in SSA. Mean pulp temperatures for individual crops ranged from 25.1 to 35.9°C in India and from 21.1 to 34.7°C in SSA, which were typically 10 to 20 degrees higher than handling temperatures recommended for the crop. In a few cases, where temperate crops were studied (i.e., cabbage, onions, amaranth leaves, litchis), pulp temperatures were 25 to 30°C above the recommended lowest safe handling temperatures of 0 to 2°C.

The general lack of use of shade contributes to high pulp temperatures and high water losses. For a few crops, pulp temperatures were lower than air temperatures (tomatoes being packed under shade in India, pineapples handled in the early morning in

Rwanda, damaged cabbages in Ghana, observed to be wilting in the sun). Most other crops were left exposed to ambient conditions during the postharvest period. Mean pulp temperature for onions in sacks inside storage sheds in Tamale, Ghana was 31.2±0.8°C. Mean weight loss on the farm for 10 samples of leafy greens (amaranth packed in sacks) in Rwanda was 10.8±9.1% over a time period ranging from 30 to 240 minutes directly after harvest. Mean weight loss for leafy greens, pineapples and bananas at retail markets in Rwanda was 11.3±2.8, 3.4±2.4 and 8.8±5.9, respectively, during a period of 6 hours.

High temperatures are well known to result in increased rates of respiration, deterioration and water loss in fresh produce, leading to reduced market value and decreased nutritional value. Measured air and pulp temperatures in SSA and India were so much higher than the optimum postharvest handling temperatures recommended for maintaining optimum quality (USDA, 2004) that shelf life theoretically would be only one half or even one quarter of the potential.

Poor Quality Containers

Packages used for handling fresh produce in SSA and India were too big, too rough, and too flimsy to provide protection for fresh produce during handing and transport (Figs. 1-3). Across all crops and countries package protection ratings were uniformly low, 46% of crops were packed in large sacks or cloth bundles, 31% were packed in open baskets and 8% had no package at all. Even some of the most delicate, highly perishable crops were packed in sacks (i.e., leafy greens in Rwanda, okra in India), and many moderately perishable crops were packed in large sacks (eggplant in India, peppers in Ghana and Benin, pineapples in Rwanda). Only 15% of crops were packed in plastic or wooden crates, and even these containers were of inferior quality. The plastic crates used in India for mangoes and tomatoes were filthy and rough on the inside, causing abrasions, and wooden crates used for tomatoes in Ghana were made with no vents and for holding 60 to 70 kg of ripe fruits. These wooden crates were too large to provide protection, and much of the fruit on the bottom of the crates was crushed and typically discarded before sale.

The % mechanical damage for individual samples of cabbage handled in very large sacks in Ghana (N=30) ranged from 0 to 100% and was measured at 55±20.1% (farm), 32±25.7% (wholesale), and 45±27.6% (retail market). When baskets or sacks of leafy greens were sorted in the wholesale markets in Benin by our assessment teams, in more than half the samples, 100% of the 20 bunches per sample were damaged, and the mean level of mechanical damage overall was 89.5±35.9%. The % bananas in Rwanda sorted out and discarded before sale, which were handled in bunches or hands without any packages, was 14.8±21.0% (farm), 35.1±33.1% (wholesale) and 30.1±24.4% (retail market). There was too much missing data for plantains in Ghana to accurately calculate % damage, but reported ranges in the samples gathered were 10 to 50% (wholesale) and 10 to 30% (retail market).

Poor Field Sanitation

The general lack of field sanitation and lack of pre-sorting to remove decayed produce before packing promoted spread of fungal and bacterial diseases and insect pests during handling. Pre-sorting losses on the farm from decay and pest damage in the field were reported to be high for okra in India (18.5±7.4%), tomatoes in Ghana (12.9±13.3%) and for leafy greens (17.3±16.6%) and tomatoes (23.0±9.7%) in Benin. Even though the most obviously decayed or infested units had been sorted out and discarded, subsequent random samples assessed by data collectors indicated rates of decay on the farm ranging up to 100% after packing, with 47.1±47.6% of sampled bunches of leafy greens showed decay symptoms in Benin.

Use of unclean water for rehydrating leafy greens in Africa (by sprinkling leaves or standing bunches in pans of water) and okra in India (by soaking sacks of okra in water before transport) may also have contributed to decay problems later in the marketing chain.

Time to Reach Retail Markets

The time it takes to reach the retail market varied widely, and postharvest damage increased and was cumulative over time. While it was not possible to simply sum losses for a specific sample across the value chain, the general finding was that % physical damage during handling was very high. Physical damage was even higher for the most delicate crops (i.e., 34.3±40.3% on farm, 86.4±35.9% at wholesale and 73.8±26.0% at retail markets for leafy greens in Benin), for crops handled in a large sack that does not provide protection (i.e., cabbage in Ghana), or without any kind of package (8.5±12.7% on farm, 19.0±18.4% at wholesale and 22.0±14.4% at retail markets for bananas in Rwanda). Visual symptoms of losses and quality problems included wilting for leafy greens, softening in tomatoes and fruit crops, and bruising for many of the crops. There was considerable variation in physical damage found on individual farms, and the most obvious cause was due to rough handling.

For seven crops, adequate data were collected on market prices and price per kg that enabled calculation of the changes in retail market value caused by a decline in visual quality. For both amaranth leaves in Benin and pineapples in Rwanda, economic losses were estimated at 30%, based upon reduction in market value per kg of the produce sold when compared to the highest price per kg offered for higher quality produce on the same day in that market. In India, average losses in market value at the retail level as result of perceived decline in quality was 1% for tomatoes, 52% for cucurbits, 31% for okra, 20% for mangoes and 18% for litchis.

Relative perishability was expected to be a strong predictor of postharvest losses as produce moved over time from the farm to the markets, but no significant differences were found when highly perishable, moderately perishable and low perishability crops were handled at such high temperatures and in such poor quality packages. Although the exact time from harvest could not be accurately determined, the physical damage and rates of decay at wholesale and retail markets were as high for oranges, cabbage and onions as they were for crops considered more perishable. Mean pulp temperatures for oranges in Benin were 29.8±2.7°C (wholesale) and 28.2±1.5°C (retail market), and incidence of decay in samples were 13.1±25.5% (wholesale) and 30.8±41.1% (retail market). Mean pulp temperatures for onions during August and September in Ghana (for crops harvested in March) were 31.8±0.8°C (storage), 31.0±3.2°C (wholesale) and 33.5±3.0°C (retail market) and reject volume before sale at the retail market was 18±8.6%.

Many of these findings support earlier published studies reporting high levels of postharvest losses in developing countries that occur because of poor temperature management, handling damage, decay incidence and market value reduction in various crops (Roy, 1993; Ndunguru et al., 2000; Lana et al., 2002; Pandey et al., 2003; El-Assi, 2004; Prigojin et al., 2005; Udas et al., 2005; Bani et al., 2006; Kumar et al., 2006; Weinberger et al., 2008; Vayssieres et al., 2008). While the findings of this study are predictable given the known typical conditions of postharvest handling, documenting the losses in the four target countries for small farmers during 2009 was considered a key step for designing appropriate future loss prevention efforts. A major benefit of this study was enhancement of the expertise and increased awareness of the causes and extent of postharvest losses among all who participated in data collection and analyses.

Correlation and regression analyses among key variables were explored but were found to be non-significant, because of the consistently high handling temperatures, high levels of damage and losses found within each crop and to the high standard deviations found within each data set. Any anticipated minor effects of individual variables such as harvest maturity, firmness, SSC%, initial quality, relative perishability or RH% during handling were overwhelmed by the overriding influences of the very high handling temperatures and the very poor quality packages in use for all the crops.

Part 2 of this paper presents the results of field trials, cost benefit analyses and future research needs.

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Tables

Table 1. Recommended versus measured pulp temperatures for tomatoes at farm, wholesale market and retail market sites in 4 countries (N=30; 3 reps from 10 random samples per site).

Country	Recommended temperature	Mean pulp temperatures (°C) ± st. dev.		
		Farm	Wholesale market	Retail market
India	15	25.2±0.6	30.5±2.7	29.1±2.8
Ghana	15	31.2±2.7	30.2±2.5	32.5±2.6
Benin	15	28.5±1.7	29.1±1.2	30.6±2.7
Rwanda	15	30.1±3.0	22.1±1.2	23.4±2.3

Figures

Fig. 1. Poor quality packages - cloth sacks of eggplant in India (used fertilizer bag).

Fig. 2. Poor quality packages - enlarged sacks of cabbage in Ghana.

Fig. 3. Poor quality packages - huge sized wooden crates of ripe tomatoes in Ghana.