

100 Under \$100

Tools for Reducing Postharvest Losses



Betsy Teutsch, author 
and Lisa Kitinoja, technical editor



100 UNDER \$100: TOOLS FOR REDUCING POSTHARVEST LOSSES



A woman's cooperative in Mawali village, Lembeh Island, North Sulawesi, Indonesia, making snacks - Photo: ©IFAD/Susan Beccio

Betsy Teutsch, Author
Lisa Kitinoja, Technical Editor

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TECHNICAL EDITOR'S FOREWORD

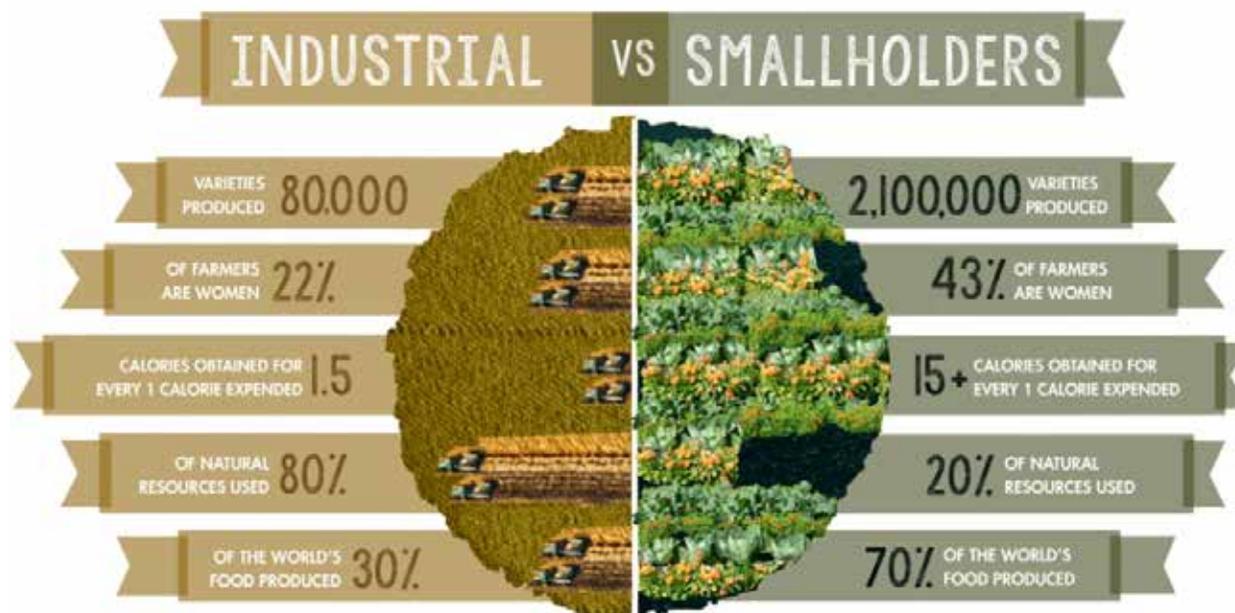
Recently, Food Loss and Waste (FLW) has become a global topic of keen interest, and reducing FLW is being promoted as a “[\\$700 billion business opportunity](https://on.bcg.com/2NTMRWm)” [\[on.bcg.com/2NTMRWm\]](https://on.bcg.com/2NTMRWm). Feeding Earth’s growing population will require both reducing the currently high levels of FLW and taking better care of our productive resources ([Stockholm Resilience Centre](https://bit.ly/2S788z6), 2018 [\[bit.ly/2S788z6\]](https://bit.ly/2S788z6)). The United Nations has included reducing FLW by 50% by 2030 in its Sustainable Development Goals (SDGs).

In the USA, since I first started working in this field in the early 1990s, there has been huge growth in the number of farmer markets, CSAs, and cottage scale food processing ventures. Worldwide, smallholder growers produce food using much less fertilizer, irrigation, diesel powered equipment (tractors, combines) and other inputs that require energy to manufacture (insecticides, herbicides, fungicides). They tend instead to use “people power” and manual labor for weeding, cultivation, harvesting and packing, which creates local jobs. Industrial farming has

the purpose of making money. Small-scale farming can be a source of income generation for families, but also provides

- improved nutrition
- ecological and environmental well-being
- energy efficiency
- balanced community development

My education in postharvest biology and technology began in 1980, and during my graduate school years I was privileged to work with Dr. Adel A. Kader at the University of California, Davis as a lab research assistant and as a teaching assistant. He mentored me for more than 30 years as I worked as a postharvest consultant, and introduced me to Dr. Awad M. Hussein (University of Alexandria, Egypt), the UC Davis postharvest faculty, and dozens of researchers and extension specialists in developing countries. Dr. Kader, Dr. Hussein, and many of my postharvest



Infographic: AGrowingCulture.org

mentors including Dr. S. K. Roy (IARI, India) and Win Winogron (managing director of Dole's banana-pine-apple operations in the Philippines and Thailand) have passed away, but some of their postharvest wisdom is being passed down via this new book.

If any of my friends have wondered why I chose to work in the difficult and challenging field of low resource food system development, the simple graphic on the previous page illustrates how important it is to support small scale and female farmers in their work and livelihoods.

As I come to the end of my career, I hope many others will pick up the “reducing postharvest loss for small-scale farmers, traders and marketers” banner and continue to help us move toward a cleaner and greener world.

Thank you to Betsy Teutsch for sharing her wonderful journey into the burgeoning field of postharvest training. While working with Betsy, I learned that we

are fellow Brandeis University graduates who share a love of global travel and environmental protection, and I enjoyed spending time digging through piles of old research studies, presentations, extension publications and travel photos. Thank you to my husband John, and my family and close colleagues Lizanne Wheeler and Hala Chahine-Tsouvalakis for their continuous support. Thank you to everyone who sent us photos or gave us permission to use their images. Thank you to the PEF Board of Directors for sponsoring this book project, and especially to Dr. Diane M. Barrett, Dr. Deirdre Holcroft, Dr. Majeed Mohammed, Bertha Mjawa, and Vijay Yadav Tokala for their reviews and editing of the early drafts. Finally, a grand thanks to Agribusiness Associates Inc, Postharvest Innovations LLC, and the Global Cold Chain Alliance for sponsoring the production of the e-book edition.

—Dr. Lisa Kitinoja, La Pine, Oregon - December 2018



Postharvest trainer Solange Musanaze training young people at the new Postharvest Resource and Training Center in Rwanda - photo: Bertha Mjawa

AUTHOR'S FOREWORD

Two years ago, I received a surprise call from Dr. Lisa Kitinoja. Her organization, The Postharvest Education Foundation (PEF), is featured in my book *100 Under \$100: Tools for Empowering Global Women* [100under100.org]; “Reducing Postharvest Losses” is Tool 67. She very much appreciated the book’s design and layout. She had an idea—taking PEF’s extensive database of postharvest tools and presenting them in the same format. Might I want to write a new book, *100 Under \$100: Tools for Reducing Postharvest Losses* with PEF?

Reducing postharvest losses can literally feed hundreds of millions of extra mouths, bring smallholder farming families up out of extreme poverty, and mitigate global warming utilizing affordable, accessible tools and techniques. What a privilege and opportunity to be invited to blend technical material, photos, and stories together in a lively, user-friendly book.

Hence, my immediate answer was yes, kicking off my immersion in postharvest loss reduction. My first and foremost thank you is to Dr. Kitinoja and the whole board of the PEF, whose patience, support, and vision never wavered. It didn’t take long to learn how central Dr. Kitinoja is in this field. She answered every question clearly and quickly, with a modesty and graciousness that one might not expect from a world-renowned expert. It has been a wonderful collaboration.

Thank you also to all the many content providers who have uploaded guides, manuals, books, and articles, making them available to anyone in the world with an internet connection. In this day and age, we increasingly take this for granted, but it remains miraculous. Additional shout-outs to journalists and feature writers who lift up smallholder farmer successes, making them compelling and tangible. Statistics and data (thanks, researchers!) are crucial, but it’s the stories that stick.

Photo search and curation is one of my favorite tasks. I am indebted to all the photographers whose

work we feature, each of whom posted photos available for public reuse. Flickr and Wikimedia’s Creative Commons collections are extensive and global, indispensable for such a project. IFAD and Photoshare granted me permission to utilize their photo assets, yielding spectacular images well-suited for the book, for which I am deeply grateful. USAID’s copyright-free photo collections added yet more gems. Dr. Lisa Kitinoja and other PEF members provided photos from their personal collections. The UN’s FAO, agricultural NGOs including AVRDC and ADMI, and educational institutions were a rich photo source as well. Many images come straight from Facebook, posted by initiatives and small farms. A few bloggers with perfect photos popped up in my endless searches. Tracking them down was challenging, but every one of them generously granted permission. All photos are credited and I extend my thanks to each and every photographer for enriching this book.

This book features many videos, effective teaching tools not only for readers but for this author. I literally watched people from all walks of life who have posted videos of themselves demonstrating useful skills and scientific concepts. (I screened ****dozens**** of onion and garlic braiding videos [Tool 17], not to mention all the ones demonstrating pineapple carving—way more than I needed to—because they were so much fun to watch.) What a vast peer-to-peer resource video sharing has become. I thank everyone who created and shared the videos we included. SAWBO-Animations are an especially valuable contribution to postharvest loss education and we have included all their videos related to postharvest techniques.

The PEF Board put in many hours looking over the book draft and curating featured resources for each entry, for which I am immensely grateful. It was exciting to include photos and content from [alumni](#)

of PEF's training programs [bit.ly/2nS8nAc]. These colleagues' contributions enhance the book and are proof of concept: expanding postharvest knowledge builds local capacity and closes the loop between information and end users. It is our fondest hope that this book will prove a useful tool of tools for agricultural extension agents all over the world.

Maureen Mecozzi of the World Vegetable Center AVRDC was especially helpful, as was Dr. Sarma Mohan of Tamil Nadu Agricultural University, India.

Thanks to Dr. Camille George, development engineer, and Dr. Lonny Grofman, Appropedia Founder and professor, for their support and ideas. Dr. Neil Hausmann of DowDuPont provided helpful information, as did Matt Utterback of eKitabu, for which I am also thankful.

I am grateful to my original publisher, She Writes Press, for providing me with an extraordinary book designer, Tabitha Lahr. It is wonderful to have another opportunity to work with Tabitha. Thanks also to Tim McGrath who created the book's elegant icons.

My husband David has been a patient, supportive companion and has learned far more about reducing postharvest losses than he ever expected. Thank you!

I fervently hope our children Zach, Becca, Nomi and Micah and grandchildren Shulamit, Sender, Eyal, and Nadav will live to see a planet that sustainably feeds all who are hungry, and that the visions presented in this book will become daily realities.

–Betsy Teutsch, Philadelphia, PA - December 2018



Hmong farmer May Young taking opo squash harvested in the morning on her farm in Sanger, California to be packed for the farmers market - USDA/Bob Nichols.

INTRODUCTION

Postharvest loss reduction is an enormous global challenge: 30 to 40% of crop yields go missing from farm to table. These losses, all along the value chain, hit hard. Smallholder farmers' pockets are emptier than they could be and there is less available food overall, exacerbating food insecurity. The planet loses as well, since all the seed, water, fertilizers, and other inputs, including transportation, that have already been consumed contribute to global warming, without producing any nutrition for our hungry world. Reducing postharvest losses increases agricultural efficiency, achieving more "calories per gallon/liter."

[The Postharvest Education Foundation \[postharvest.org\]](http://postharvest.org), founded and headed by Dr. Lisa Kitinoja, has worked tirelessly to educate and disseminate skills and postharvest tools for conserving the harvest. This book is a compilation of their vast resources, presented in an accessible and engaging format. Each entry features links to additional sources of helpful information. A great many of the 100 tools link to Dr. Kitinoja's renowned *Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops* [bit.ly/2oPluBv], written with Dr. Adel A. Kader and revised many times, the latest in 2015.

This book's photographs not only add visual interest; they also educate. We are enormously grateful to photographers from all over the world who have posted photos available for reusing freely. Read more about the photography in my Foreword.

Waste presents an opportunity. Reducing postharvest loss and waste by 50% is [Sustainable Development Goal 12.3 \[champions123.org\]](http://champions123.org) as well as #3 in the [DrawDown \[drawdown.org\]](http://drawdown.org) project ranking solutions to climate change. Our book focuses on postharvest losses. (We contrast losses with waste in an AfterWord Essay.)

Approximately 90% of agricultural investments are aimed at increasing farmer yield, leaving only 10%

devoted to postharvest handling, storage, and processing of the resulting crops. Investing in postharvest improvements therefore represents high potential for impacts and returns on investment:

- Raising farmers' income
- Expanding food supply and food security
- Building local capacity
- Developing regional value chains
- Increasing gender equality, since nearly half of smallholder farmers are female

100 Under \$100: Tools for Reducing Postharvest Losses, modeled after my earlier book [100 Under \\$100: Tools for Empowering Global Women \[100under100.org\]](http://100under100.org), zooms in on the value chain from farm through end-consumers [eaters!], encompassing a wide variety of techniques and tools. Some are tried and true, others are innovations. While some are relatively affordable and manageable by a smallholder farming household, others require farmer groups [Tool 87] or entrepreneurs. Each tool pays for itself—often after just one use—by reducing losses, effectively expanding the harvest. Once paid off, each reuse contributes directly to the bottom line.

Our target audience is the vast network of Agricultural Extension Workers [Tool 90] employed by governments, intergovernmental organizations, agribusinesses, and NGOs who work directly educating smallholder farmers. Others with an interest in agricultural innovation to alleviate poverty, eradicate hunger, and improve the health of people and planet will find these postharvest solutions inspiring, compelling, and accessible.

This book is designed to be interactive. The 100 tools are organized sequentially, following the value

chain. Many concepts reappear, as they are foundational postharvest loss reduction methods. Hence a tool like Reusable Plastic Crates stars in more than one entry, since RPCs are used throughout the journey of food from farm to table.

Each entry features icons to visually guide the reader's attention to themes and features.

Tools often interlink. When this is the case, we have added internal hyperlinks to quickly find a relevant section. We also link to the six AfterWord Essays which zoom in on specific larger topics. We have included many links to external websites, videos, and resources within entries, at the bottom of each tool, and in the book's Entry Notes at the end. For the convenience of those readers with limited internet access or those who choose to print out a copy of the book, a bit.ly link is included as well.

The Postharvest Education Foundation Board worked hard to locate and curate each entry's URLs providing additional helpful information. These include websites and videos as well as manuals and guides. The videos were not necessarily selected for their high production quality but rather for their accessibility; many of them are farmers or food processors "doing their thing", demonstrating techniques and ideas that can be replicated and adapted.

The URLs are all functional at the time of publication. We apologize for any trouble readers may have using the links in the future. Regrettably, it is inevitable that over time some of them will no longer be accessible. If a link no longer works, be sure to consult the final Entry Notes, which include detailed information about publications. Readers may find that the resource material is posted elsewhere on the internet.

The Sections follow the value chain:



Farm: Section 1 focuses on tools and methods for decreasing the amount of food lost at the source, smallholder farms.



Packinghouse: Section 2 describes best practices and methods to avoid food loss when crops are packed. Packing can take place directly in the field, or in specifically designated sheds or packinghouses.



Processing: Section 3 highlights value-added activities that both preserve food surpluses and add market value to the food itself.



Storage: Section 4 features tools to lengthen the shelf life of horticultural products (fruits and vegetables, root and tuber crops), and grains and pulses, thereby decreasing losses.



Transport: Section 5 delves into this reoccurring value chain challenge, reducing losses incurred when moving produce, both on short and long hauls.



Market: Section 6 explores improved marketing. Whether wholesale or retail, at the farm or local market or exported to far away cities, best practices decrease the quantity of foodstuffs lost at the market.



Legal and Financial: Section 7 views the larger economics of postharvest loss reduction, presenting financial and legal interventions to help solve underlying problems that contribute to food losses.

Each entry is identified by category of commodity:



Fruits and Vegetables and Grains and Pulses: Horticultural value chains differ from those of grain and pulses. Tools are identified by which commodities they are used for; in some cases, the tool is useful for both.

Super Tools reappearing throughout the value chain are specifically highlighted:

These are essentially three foundational principles that create the backbone of postharvest loss reduction, whose impacts are leveraged via the use of ICT, the fourth super tool.



Gentle Handling: From farm to table, taking care to avoid bruising and damage reduces food losses.



Temperature Management: Managing temperatures so foods do not spoil due to loss of moisture and/or rapid decay increases marketable quantities.



Sanitation: Careful monitoring of sanitation along the food chain decreases contamination. Since contaminants are easily spread from an infected fruit or vegetable to adjacent produce, thereby ruining a whole shipment, investing in sanitation can prevent large losses.



ICT (Information and Communication Technology): Digital tools maximize the quality and quantity of food that actually reaches consumers.

Highlighted Features and Benefit Icons:



Eco-Benefits: All postharvest loss reductions provide environmental benefit. This logo points to specific eco-value, both local and global. In some cases, it reflects harm reduction such as eliminating pesticide use. In other cases, it might reflect carbon footprint shrinking like decreased transport or reusable packing.



Do-It-Yourself: These tools can be fabricated locally, using available materials and common equipment. Some of them are applicable to small farmers in the industrialized world, as well. Where possible, links to plans are included.



Female Friendly: Women comprise nearly half of the farmers worldwide, generally clustered at the lowest-income generating

end of the value supply chain. Female-friendly tools can help women perform tedious jobs more quickly and redeploy their time-savings elsewhere. They also offer opportunities for women-owned microenterprises, moving up the supply chain and increasing income.



Worker Health: Throughout the whole value chain, from farmers wielding heavy tools and harvesting by hand (often with babies on their backs) to workers in packing, processing, transport, and marketing, all workers benefit from improved tools that reduce physical strain and lessen repetitive stress injuries.



Technology Transfer: In our connected world, ideas flow from locale to locale. This icon points to great examples of technology transfer in ways that may surprise readers.



Consumer: This icon notes methods for cafeterias, food purveyors, or end-user households to decrease the amount of food that spoils before consumption.

Resources for the URLs are at the end of each entry:



- A first stop for authoritative information is [Small-Scale Postharvest Handling Practices: A Manual For Horticultural Crops](#) (5th edition) by Lisa Kitiñoja and Adel A. Kader, published by UC Davis [[bit.ly/2oPluBv](#)]. This 283-page book will be challenging to open with slow internet; for that reason, we cite it but do not hyperlink it in the body of the book. When we quote it, we cite it as simply “Kitiñoja and Kader (2015)” with a page number. It is linked in the back Resources, and free to download.
 - The FAO’s website is another classic resource. Their [Postharvest Compendium](#) [[bit.ly/2NRMyzh](#)] includes manuals for many crops.
 - Another generally useful resource with crop specifics is the [UC Davis Postharvest Library](#) available in twelve languages [[bit.ly/2VruZdh](#)] and [Produce Facts](#) [[bit.ly/2oN5XmH](#)] covering 132 horticultural crops.
 - Penn State Extension’s [Best Practices for Keeping Produce Fresh](#) – <https://extension.psu.edu/keeping-produce-fresh-best-practices-for-producers> [[bit.ly/2OzbN6n](#)] is a comprehensive guide with excellent, instructive photographs.
- PEF has posted digital documents referenced in this volume, [100 Under \\$100 Resources and References 2018](#) [[bit.ly/2BUKfVr](#)], via Google Drive as primary resources for readers.

We would love to hear your anecdotes and success stories and share your on-the-ground photos and videos, illustrating affordable Tools for Reducing Postharvest Losses. Please send them to PEF via email at postharvest@postharvest.org.

Follow us on Twitter @PostharvestOrg and please “Like” our book’s [Facebook](#) page [[bit.ly/2E5ljew](#)] to follow and share book news and updates.



Section 1

FARMING

1. Planning Tools
2. Low Tunnels, High Tunnels, and Greenhouses
3. Trellising
4. Pruning and Thinning
5. Hand-Held Cutting Tools: Knives, Clippers, and Secateurs
6. Crop Maturity Indicator: Refractometer
7. Crop Maturity Indicator: Color Charts
8. Harvesting Bags
9. Smooth Buckets and Containers
10. Digging Tools for Roots and Tubers
11. Pole Pickers for Tree Fruits
12. Reusable Plastic Crates and Liners
13. Field Handcarts
14. Pre-Sorting Harvested Crops at the Farm
15. Field Packing
16. Curing Roots and Tubers
17. Curing Bulbs: Garlic and Onions
18. Tarpaulins and Ground Cloths for Air Drying Crops
19. Mechanical Threshing
20. Shelling



Picking poles [Tool 11] cushion fruits, reducing losses at this organic mango farm in Colombia - Photo: Fruandes (www.facebook.com/fruandes)

FARMING: INTRODUCTION



Farmer Aleya Begum tending betel leaf trellising in Char Samaiya, Bangladesh - ©IFAD/G.M.B.Akash

“In both developed and developing countries, more than 500 million, or nine out of ten, farms are managed by families, making family farms the predominant form of agriculture. They not only produce about 80% of the world’s food but also serve as custodians of about 70–80% of farm land.”

–FAO [[link to Infographic - bit.ly/2PCGDeM](https://bit.ly/2PCGDeM)]

These smallholder family farmers are our target population, along with the millions of agricultural extension agents who serve them, educating and demonstrating how growers can improve their food security, land stewardship, and productivity.

The farm is where it all happens. Smallholder farmers make a myriad of decisions daily and seasonally,

with many variables to consider. This stressful livelihood requires immense physical labor; postharvest activity planning takes a backseat. Living from hand to mouth, quite literally, usually means a lack of savings to invest in the many tools that actually expand food’s shelf life and family income.

FAMILY FARMERS FEEDING THE WORLD, CARING FOR THE EARTH

WHY IS FAMILY FARMING IMPORTANT?



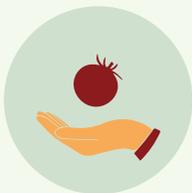
More than **90%** of farms are run by an **individual** or a **family** and rely primarily on family labour



Family farms occupy around **70-80%** of farm land

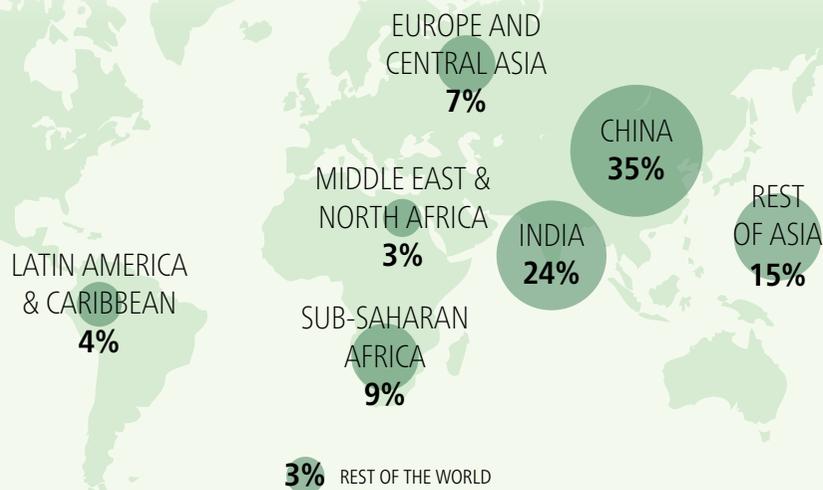


Family farms produce about **80%** of the world's food



Due to the variety of food they produce, family farmers also strongly contribute to **food security**

WHERE ARE THE WORLD'S FARMS?



HOW BIG OR SMALL ARE FAMILY FARMS?

72% are smaller than one hectare



6% are bigger than five hectares

22% other sizes



57% of Rwanda's farms cover **less than half a hectare**



47% of India's farms cover **less than half a hectare**

FAMILY FARMING IS VITAL TO LOCAL ECONOMIES



Family farming represents an opportunity to **boost local economies**



especially when combined with **specific policies** aimed at social protection and the well-being of communities



Largest share of **investment in agriculture** comes from farmers

FAMILY FARMING IS KEY TO SUSTAINABLE AGRICULTURAL PRODUCTION



Agriculture is responsible for **70%** of global freshwater withdrawals worldwide



Agriculture **conserves biodiversity**



Agriculture produces valuable **ecosystem services**

Family farms are part of the solution to the hunger problem

fao.org/family-farming-2014



Food and Agriculture Organization of the United Nations



©FAO - December 2014

SECTION ONE: FARMING presents 20 tools for farmers to reduce farm-based losses. They utilize a combination of the four postharvest Super Tools, each contributing to maximized yields during growing and immediately into harvest. Some of these are pre-harvest, utilized during the growing season. If crops are lost unnecessarily during the growing season, or production practices cause quality problems, that is considered postharvest loss.

Quicker processing of crops that are traditionally handled in the fields postharvest reduces losses. Basically, any method that

- Reduces the number of times a harvested crop is moved
- Lowers the heat in the crop (due to field heat, hot weather or sun exposure), or
- Decreases crop exposure to pathogens and pests improves the bottom line yield.

From an efficiency standpoint, performing tasks like grading at the farm make sense. Moving rejects forward increases the chances they will later be discarded. Improving farm performance is crucial to reducing postharvest losses later in the value chain.



Gentle Handling: Utilizing specialized harvest tools that handle plants more surgically and gently reduces losses significantly. Protective structures for growing [Tool 2], well-designed cutting tools [Tool 5], and Picking Poles to cushion dropping fruit [Tool 11] are all examples of tools that reduce losses by avoiding punctures and bruises that spoil fruit and vegetables. Reusable Plastic Crates [Tool 12] have been widely adopted; not only do they lower costs, but they prevent the all too common problem of fruits or vegetables at the bottom of traditional containers being crushed.



Temperature Management: Reducing heat exposure decreases moisture loss, a leading cause of product decline. Protective structures block out wind and direct sunlight [Tool 2]. Wheeled carts [Tool 13] move produce quickly and smoothly from Field Packing [Tool 15], reducing heat exposure. Anything that quickly removes field heat increases the chances of expanding marketable yields.



Sanitation: Adhering to strict sanitation protocols controls the spread of pathogens and pests, voracious competitors for the harvest. While “sanitation” brings water and disinfectants to mind, any tool which reduces pathogen/pest contamination promotes sanitation. Lifting and protecting plants from ground contamination via Trellising [Tool 3] and Pruning [Tool 4] and drying on Tarps [Tool 18] may be surprising sanitation upgrades, but they do the job. Quicker crop processing provided by Mechanical Threshing [Tool 19] and Shellers [Tool 20] likewise reduces the exposure of crops, compared to those left in the field to dry.



ICT: Utilizing modern information technology helps apply up-to-the-minute information that farmers lacked in the past. Collecting a farm’s individualized data and using it to inform decisions and improve work flow reduces losses [Tool 1] as do specialized testing tools like Refractometers [Tool 6] for optimizing harvest timing.



Gender sensitive mapping of household farming systems in Cauca, Colombia - Photo: Mariola Acosta, Visiting Researcher Gender and Climate Change, CIAT/CCAFS

Planning Tools: Calendars and Budgeting

Measurement, data gathering, and recordkeeping help farmers plan how to best deploy their time and resources strategically to maximize crop yields and implement postharvest activities.



1 Farmers have observed nature and worked their lands for thousands of years, accumulating vast experience, but until modern times, their extensive knowledge was largely stored in collective memory and shared orally.

Tracking and recording information provide the basis for future planning. Modern smallholder farmers have many tools at their disposal to help them manage their time and resources more strategically. Every growing season is an experiment, since variables always impact yields, but sharing information helps everyone.

The cropping calendar [online tool at the FAO \[bit.ly/2MserHy\]](https://www.fao.org/2MserHy) features micro-targeted information on over 130 crops from amaranth to zucchini, in over 283 agro-ecological zones of 44 countries. It provides information on planting and harvesting periods. Agricultural extension services often have data that is even more local, generated by farmers and farmers' groups [Tool 87].

This information can be integrated into an individual or farmers' group planning, since diversifying the crops raised will dilute farmers' risks as well as expand their harvesting and marketing opportunities. An advance work flow plan allows farmers to predict how they will allot their time and resources, creating a budget and a calendar for

- Labor
- Financial outlay for inputs
- Plans for repayment of loans [Tool 95]

Farmers need to make strategic decisions about what to grow. More information about anticipated market demand allows for raising crops that will fetch the highest prices rather than just guessing and repeating past experiences. This is the approach of [Sasakawa \[www.saa-safe.org\]](http://www.saa-safe.org), an African NGO working to raise incomes for smallholder farmers. "If you want to enter into competitive markets you need to find out



Farmers budgeting farm activities to create a decision-making tool - Photo: Andrée Nenkam, CGIAR

what the customers want. The value chain in Sasakawa is now driven by the market,” reports SAA’s Leony Halos-Kim. Contracting with a purchaser [Tool 97] in advance reduces much of the guesswork and risk, though contracts can vary widely in terms of fairness to farmers.

Decisions about harvest timing are critical, as well. Staggered harvest schedules improve work flow for farmers. Small-scale producers have the option to harvest

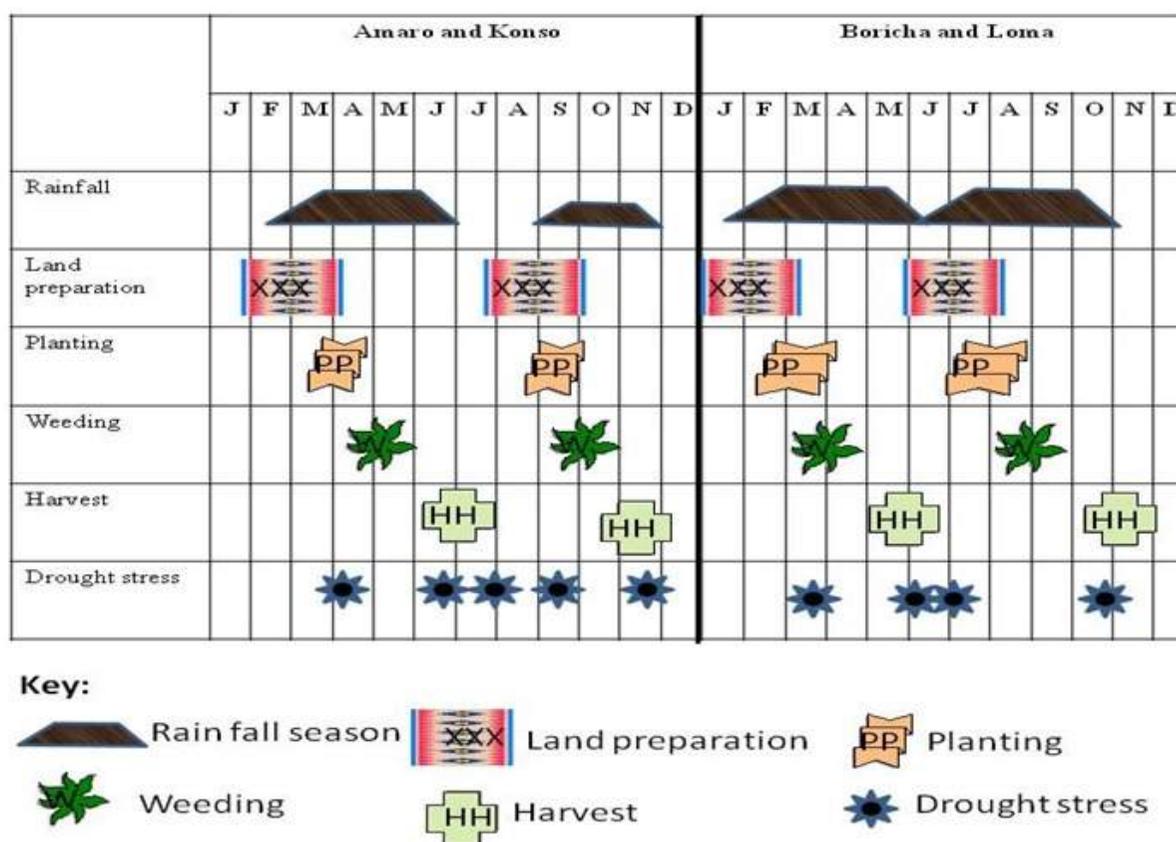
- Earlier, when vegetables are more delicate, adding value.
- Later, when fruits are riper and more flavorful.
- More frequently, with multiple harvests to gather produce at its optimal stage of maturity.

The single harvest method results in many under-ripe as well as over-ripe plants, adding up to sizable postharvest losses.

Sharing information expands knowledge base. Women’s experiences and wisdom have traditionally been undervalued. Including women in the planning process adds important workflow considerations in male-female smallholder farms, and women’s farmer groups offer an effective method of capturing gender perspective.

Climate disruption is wreaking havoc for smallholder farmers; many efforts are engaged in helping plan for droughts, irregular rains, and unpredictable weather, and the resulting eco-agro challenges and opportunities.

Many smallholder farmers have low literacy, but it is possible for farmers to create a schedule with relatively simple pictographs and charts. Pictured [below] is a [calendar from](#)



Ethiopian farmers’ bean cropping calendar - Photo: Asrat Asfaw, ResearchGate

[ResearchGate \[bit.ly/2xFikFH\]](https://www.researchgate.net/publication/312121212) showing bean crops in Ethiopia, created by local farmers.

ICT is adding immensely in capturing and disseminating important information from seed and input acquisition all the way to storage and marketing.

- Apps provide information on weather, pests, prices, and markets
- Excel spread sheet tools help farmer groups input, track, and analyze data
- Videos [SAWBO-animations.org, for example] and downloadable guides are readily available

- Local interactive radio provides two-way communication links

Gnima Koma, smallholder rice, maize, and sesame farmer in the Sédhiou region of southern Senegal, has become a database manager for her local farmers' association. "With the support of USAID agricultural projects, I am now able to ensure proper monitoring of our activities. I produce my reports more easily, I can operate the GPS, produce maps and analyze the data, and I feel quite comfortable with computer-based tools."



FAO's 130+ Crop Calendars [\[bit.ly/2MSerHy\]](https://www.fao.org/3/a/2MserHy)



Attra.ncat.org Webinar on Crop Planning [\[bit.ly/2Wmlhwh\]](https://www.attra.ncat.org/webinars/2Wmlhwh)



Small Tunnel Farming in Honduras - Photo: World Renew

Low Tunnels, High Tunnels, and Greenhouses

Protective structures help launch crops early and/or extend their growing season; staggering harvests decreases wasted crops by minimizing harvest-time over-supply. Tunnels decrease pest exposure and can be reused for postharvest crop drying.



2

Protective structures trap heat from the sun to create microclimates for plants. While the original innovation, immense glass greenhouses, trapped heat in order to grow tropical flowers in cold Northern climates, the technique has evolved to include plastic low and high plastic tunnels and poly greenhouses, providing many additional benefits.

In various climates structures protect against:

- Cold and extreme heat
- Wind
- Rain
- Insects and infestation

These protections yield additional benefits and possibilities, particularly growing crops in seasons when it was previously impossible, like during the rainy season. During dry seasons, or in dry climates, when drip irrigation is used with crops under protective structures, they add an entire bonus plant growing cycle using water very frugally. When fresh produce supplies run low and are therefore in especially high demand, marketing this added crop expands food supply and income.

Tunnels are labor intensive and require purchasing materials, but they allow farmers to begin the growing seasons earlier and harvest ahead of the normal crop season. Extended season crops grown under cover provide multiple benefits, including

- Fetching higher prices, more than offsetting the costs
- Improving crop quality and consistency in terms of size, color and shape, decreasing culls
- Improving nutrition, providing vegetables earlier (and in some regions, later) in the season for farmers' families as well as the public
- Staggering harvests to reduce losses; produce marketed early and late in the season has less competition, and scheduled planting avoids peak-harvest gluts
- Expanding productive employment seasons for farmers
- Using less water, helpful when it is scarce
- Requiring less weeding
- Consuming far fewer herbicides and pesticides
 - Reducing health harms for farmers themselves
 - Reducing health risks for consumers
 - Reducing local air, soil, and water pollution
 - Reducing costs



Farmers in Nepal using trellising, drip irrigation, and a high tunnel to expand their production - Photo: © Winrock International



A farmer in Nepal tends his trellised tomatoes under a plastic tarp, creating a modified greenhouse [Tool 3] - Photo: Neil Palmer (CIAT/CCAFS)—See this up close in Tool 3, Trellising.

Farmers can use low tunnels to raise ambient temperature around 8°C, higher during the day rather than at night. These are also called polytunnels, since they are constructed of a U-shaped metal or bamboo posts that support 6' wide polyethylene sheeting. Other names include hoop tunnels, grow tunnels, hoop frames, and caterpillar tunnels, describing their low-slung appearance.

High tunnels require more materials, making them costlier. Added benefits include

- Crop intensification, growing more on these small plots, especially when combined with vertical trellising [Tool 3]
- Farmers can work standing up inside the tunnels, instead of crouching
- Protecting workers from extreme heat (if the structures are ventilated) and inclement weather

Greenhouses [see also Tool 44, where they can be used to dry grain] made of heavy plastic are more permanent than low or high tunnels but accomplish the same purpose. They are used to start seedlings for transplanting, getting a jump on the growing season. Greenhouses last for many seasons, as do many high tunnels. They generally require the use of drip-irrigation, requiring equipment but saving on water use and labor. Torn plastic can be patched, extending its life.

Greenhouses and high tunnels are also used to dry maize and other crops postharvest [Tool 44], with added ventilation to remove moisture. In locations where they can be used both pre and post-growing season, they provide double benefits, making them a desirable investment and speeding the payback.

Plastic is difficult to dispose of responsibly in developing world settings; figuring out an end-of-season plan for non-reusable tunnels is challenging.

In Peshawar, Pakistan, Izhar Mehmood reports: “Working at one of his farms, [tomato farmer] Zafarullah, 50, says “tunnel farming has changed my fortune. I now have 12 tunnel farms on an area that once used to be a single field.”

Successful low tunnel farming crops include

- Strawberries
- Cucumbers
- Carrots
- Lettuces
- Peppers

Vine crops that are trellised underneath high tunnels include

- Cucumbers
- Gourds
- Melons
- Squashes
- Beans

Detailed information is available at the [SlideShare presentation \[bit.ly/2Mno3ZX\]](#) by Allah Dad Khan, Peshawar, Natural Resource Management Specialist IUCN Pakistan.

The **greenhouse gas effect** describes planet earth wrapped in a “blanket” of CO₂ and other emitted gases, trapping heat inside the earth’s atmosphere. While this is a negative impact, the same concept used judiciously by farmers is very beneficial when it extends the growing season.



Penn State High Tunnel Production Manual [\[bit.ly/2MPdDmV\]](#)



Texas A & M Low Tunnel Strawberry Production [\[bit.ly/2NkyzS5\]](#)



Large Scale Green Pepper and Cucumber Tunnel Farming in Pakistan [\[bit.ly/2wMI1Vv\]](#)



FairPlanet Seed Pilot Project in Ethiopia testing tomatoes - Photo: Aviv Havron

Trellising

Trellising provides plants with physical support to grow vertically and/or horizontally. Lifting them off the ground decreases damage, expands yields, and eases tending and harvesting.



3 Trellising provides a supportive structure for growing plants, lifting them and “training” them to grow up off the ground, providing multiple benefits:

- Providing more sunlight and airflow, enhancing growth
- Reducing the amount of contamination from ground contact
- Decreasing pest infestation, and thereby reducing the amount of pesticides required
- Improving farmers’ ability to see, tend, and harvest maturing fruits or vegetables, rather than the plants being hidden beneath foliage, decreasing lost or damaged harvest
- Allowing for intensive vertical cultivation; trellising is often combined with high tunnels (#2), further multiplying yields
- Protecting plants from accidental trampling

Trellises can be of varying degrees of sturdiness, depending on the crop, typically constructed of wood with string or wire:

- Simple wire or string stretched between two stakes to provide a training line for light-weight crops like beans
- Medium-weight to support tomato vines

- Sturdy construction to provide sufficient support for heavy plants like melons

They also range in height:

- Low trellises for ground crops like strawberries or raspberries
- Medium height trellises for lighter vine climbing crops like tomatoes or beans
- Taller, for heavy fruits or vegetables to hang from, like melons, gourds, climbing squash, grapes, or chayote



Afghani farmer Said Agha is delighted with the expansion of his grape harvest due to trellising - Photo: Afghanistan USAID Afghanistan



Enid Kansiime trellising at the [KadAfrica \[kadafrica.org\]](https://kadamfric.org) Passion Fruit Estate in Kabarole, Western Uganda - Photo: KadAfrica, Michaela Schulz

This photo demonstrates a very simple trellising technique: two pieces of twine twisted and tied horizontally to poles, so they can be used to hold a growing plant thread. The topmost growing tip can be threaded between the two strands of twine. This is passion fruit but it would also be suitable for light-weight vining crops like beans or peas.

A recent [study of tomato losses in Rwanda \[bit.ly/2yIcWSC\]](https://bit.ly/2yIcWSC) showed the lack of trellises contributed to huge losses on the farm—from pest attacks, trampled plants, and “lost fruits” not noticed until they are rotten.

Afghanistan grows over twenty varieties of grapes and hopes to return to being a major global supplier of raisins, dried grapes. Trellising, rather than the traditional method of ground cultivation, has multiplied yields and income.

“Said Agha is one of many grape farmers who used the traditional [vines on the ground] method. He was losing 50 percent of product due to poor ventilation and physical damage of the grapes lying on the ground. Now, with the help of USAID, he has trellised his vineyard and this year, he is expecting his income to increase by 50 percent.”



University of Minnesota Extension: Trellises and Cages [\[bit.ly/2wPcFfw\]](https://bit.ly/2wPcFfw)



Gardener’s Supply Article: How Plants Climb [\[bit.ly/2Q4JwWN\]](https://bit.ly/2Q4JwWN)



Cattle Panel DIY Tomato Trellis [\[bit.ly/2Q5U47P\]](https://bit.ly/2Q5U47P)



Butiti Sitein Kyenjojo tends passion fruit using a heavy-duty trellis, in Western Uganda - Photo: [KadAfrica \[kadafrica.org\]](http://KadAfrica.org)/ Eric Kaduru



Farmer tending his trellised tomatoes in Nepal; his greenhouse is featured in Protective Structures, Tool 2 - Photo: Neil Palmer (CIAT/CAAFS).



Farmer Haji Abdurrahman prunes cashew trees in Lombok, an island in Eastern Indonesia - Photo: IFAD/Robert Grossman

Pruning and Thinning

Pruning, the strategic removal of branches and leaves, and thinning, the culling of smaller fruits, intensifies the growth and quality of the remaining fruits, resulting in fewer postharvest rejects.



4 Pruning and thinning are farmers’ age-old method of harnessing the natural growth of plants to maximize production. It may seem paradoxical that cutting back growth has beneficial effects, but by allowing the plant or tree to redirect its growth energy, more of that power can be utilized for growing edible fruit rather than excess branches and leaves. When it’s clear that fruits are substandard or damaged, removing them as quickly as possible focuses the plant’s growth energy into healthy, full-size specimens. This “editing” reduces postharvest loss.

Intensive planting combined with extensive pruning, so the trees look more like large hedges, has taken off in mango growing regions and upended traditional growth. Left unpruned or lightly pruned, mango trees grow very tall. Their production expands as the tree matures, but the mangoes are far out of reach, making it difficult to harvest them. Consequently, many mangoes are over-ripe when they are shaken out of the trees, and/or fall and are bruised, resulting in rotting ends that later disqualify them from the standards set by processors and importers.

Aggressive pruning produces a doughnut-shaped, short tree, easily accessible to farmers while tending the crop and later when harvesting.

Branches of saplings are “trained” so they extend out symmetrically. Branches are cut back, leaving three or four, which are in turn cut back to another three or four, until the tree grows neatly and horizontally. The canopy is cut out as well, so the

tree lacks a crown. The inner space created allows for better sun access and air ventilation, decreasing the spread of fungus.

Many benefits result:

- Chemical application is greatly reduced, since it is not wasted on inessential branches and foliage
 - Saving farmers money
 - Decreasing workers’ pesticide exposure
 - Reducing environmental run-off and damage
- Accessibility of all the trees’ growth facilitates identification and removal of diseased or infected leaves or fruits, preventing any spread
- Trees produce more healthy, harvestable crop with fewer rejects—up to four times more than conventional production
- Fruit production is synchronized, making harvesting more efficient and decreasing the likelihood of fruit being harvested too early or late
- Harvesting is more easily managed, since the fruit is all accessible by foot and ladders, aiding its gentle handling and making it safer for workers



Mango harvesting—Creative Commons /A.A. Seif ICIPE and Infonet-biovision.org

Old trees can be pruned to the new configuration but if they are too mature, it is preferable to cut them down and start over, staggering their replacement. Many smaller trees can fit in the site of one old-style mango tree.

When trees and plants are pruned, it is important to remove the trimmed leaves and branches from the field. They attract bugs and pests which can spread disease back to the trees.

Crops that benefit from pruning and thinning include:

- Mangoes
- Grapes
- Tree fruits
- Cashews
- Guavas
- Bananas

Many resources online teach pruning techniques. Videos are especially effective for this purpose; the Ministry of Food and Agriculture of Ghana has posted [several](#) [\[bit.ly/2MeJo8Q\]](https://bit.ly/2MeJo8Q)



Biovision Farmer Communication Programme [\[bit.ly/2Rskdyd\]](https://bit.ly/2Rskdyd)



UC Davis—Pruning Trees [\[bit.ly/2wNOlad\]](https://bit.ly/2wNOlad)



UC Davis—Pruning Pistachio Orchards [\[bit.ly/2oM9pOI\]](https://bit.ly/2oM9pOI)



USDA High Density Peach Tree Cultivation [\[bit.ly/2oKwQrr\]](https://bit.ly/2oKwQrr)



High Density Mango Production in Ghana [\[bit.ly/2MUSYoj\]](https://bit.ly/2MUSYoj)



Orley Blanquiceth growing cacao in Colombia - Photo: Thomas Cristofolletti, USAID

Knives, Clippers, and Secateurs

Sharp, clean, well-designed tools minimize damage to plants and are beneficial for workers. Gentle handling can reduce the amount of mechanical harm such as bruising or gouging.



5

Pickers taking care to harvest plants gently will have a higher rate of desirable plants to sell. Many refinements have been made over time to improve the effectiveness of cutting tools, themselves an improvement over simply snapping fruits and vegetables off their stems.

Secateurs are short handled, one-handed pruning shears for use on plants. Invented in the 19th century, they have been continually refined since then and are safe and comfortable to use. They have a spring that opens them automatically, making them easier on the user, along with a safety lock.

Injuries predispose produce to decay, increased water loss, and increased respiratory and ethylene production rates, leading to quick deterioration. In general, harvesting by machine will cause more damage than harvesting by hand. (Kitinoya and Kader, 2015, p 18)

Tools come in a variety of price ranges and quality. They are an investment but can pay for themselves by decreasing damage and the resulting discards. In just one season of egg-plant harvesting in Jessore, Bangladesh, the cost of the secateurs was recouped.



Trimming and trellising instruction by a program field technician in Cambodia's USAID HARVEST/Fintrac initiative - Photo: USAID



Jose Blanquiceth cuts the cocoa pods to extract the wet beans in Isla de la Amargura, Caceres, Antioquia in Colombia - Photo: Thomas Cristofolletti/USAID

CASE STUDY Example: Secateurs for Brinjal (Eggplant) Harvest

The use of secateurs was reported to have been adopted by nearly all the CCBA trained farmers. The secateurs cost about 180 taka each and have a long useful life if kept clean when in storage between seasons. The high market price for brinjal is 40 taka/kg and lowest price is 5-7 taka toward the end of May. (\$US1 = 83 taka)

CROP: BRINJAL COUNTRY/REGION: JESSORE, BANGLADESH

| Assumption: Harvest 1000 kg over the course of the season | | |
|--|--|------------------------------------|
| | Current / Traditional Practice | New / Improved Practice |
| Describe: | Pulling fruit from plant: damages both individual fruit and plants | Using secateurs to harvest brinjal |
| COST | | |
| \$2 per pair of secateurs (4) | | \$2 x 4 = \$8 |
| Relative cost | 0 | + \$8 |
| EXPECTED BENEFITS | | |
| % losses | 5-10% | 0% |
| Amount for sale | 900-950 kg | 1000 kg |
| Value/kg (average price) | \$0.30 / kg | \$0.32 / kg |
| Total market value | Relative \$270 to \$285 | \$320 |
| Market value minus costs | (\$285-0) Maximum of \$285 | \$320-8 \$312 |
| Relative profit for the season | | (\$312-\$285) \$27 |
| Return on Investment | | Less than one season |

Source: Kitinoja and Wheeler (2016) POSTHARVEST IMPACT/OUTCOME ASSESSMENT: ADOPTION OF IMPROVED HARVEST AND POSTHARVEST PRACTICES AND LESSONS LEARNED IN THE COLD CHAIN BANGLADESH ALLIANCE (CCBA) PROJECT [\[bit.ly/2Sj59D0\]](https://bit.ly/2Sj59D0)

Tools last many years when maintained by oiling after use, to prevent rusting. The higher the quality tool, the more times it can be sharpened.

In addition to being regularly oiled and well-sharpened, tools need to be kept clean. Blades should be dipped in sanitizing solution periodically through the harvest season, to avoid passing any pathogens from one plant to another.

Spurs, stems, and protrusions with sharp edges should be carefully trimmed to prevent damage to adjoining fruits during transport.

Well-designed tools leverage human power, requiring less hand-strength and force. This makes them an important gender parity tool. And they help all harvesters avoid repetitive stress injuries.



Wikipedia on Pruning Shears [\[bit.ly/2wMnZds\]](https://bit.ly/2wMnZds)



Gardening equipment catalog [\[bit.ly/2wN6mtS\]](https://bit.ly/2wN6mtS)



Secateurs Rose Cutting Demo [\[bit.ly/2Cqs2RS\]](https://bit.ly/2Cqs2RS)



Dr. Adel A. Kader (co-author of *Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops*) demonstrating the use a refractometer during a postharvest training program in Ghana - Photo: Heidi Reichert, USDA

Crop Maturity Indicator: Refractometer

Accurately determining the optimal time to harvest decreases the amount of produce rejected for being under-ripe or over-ripe. This increases food supply, quality, and profits.



6 Each fruit/vegetable has an optimal time for harvesting, balancing its present degree of maturity against the future. For plants that keep on ripening on their journey to market, timing is essential in order to avoid harvesting and transporting too early or too late.

Close observation of physical color and shape, smelling, and pressing on plants are traditional methods for determining ripeness, both for growers and for purchasers. But farmers can utilize more precise tools to provide additional information about the crucial decision of when to harvest.

Sugar content of fruits and vegetables is an accurate indicator of ripeness. A liquefied sample of the plant can be tested in an inexpensive refractometer, yielding a reading that measures the amount of sugar.

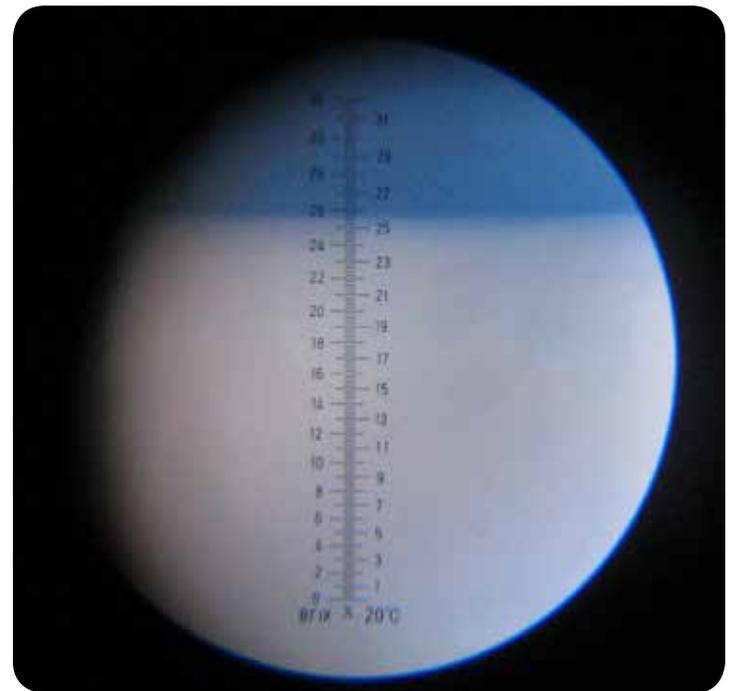
Refractometers, available for around \$25, are popular with winemakers and brewers but can be used by any farmer for measuring sweetness. Inside the device is a series of prisms and mirrors that refract light. In this case, it measures the density of sugar in the sample.

Using a garlic press, the farmer takes pulp and squeezes a few drops of juice onto the glass plate, creating a slide much like a microscope. A drop-down shield spreads and protects the sample and then, when held up to natural light, a measurement is discernible. Refractometers must be calibrated for accurate readings and washed and dried carefully between uses.

What is measured is called a Brix score. Degrees Brix (symbol

°Bx) is the sugar content of an aqueous solution. One-degree Brix is equivalent to one gram of sucrose in 100 grams of solution and represents the strength of the solution as percentage by mass, so a Brix of 6 means the fruit is 6% soluble solids (mainly sugars) content.

Buyers know in advance what Brix score they require, depending on their products' designated pathway to market—



Optimum refractometer reading for these grapes is between 25 and 26 which is indicated where the dark area on the scale meets the light area. This refractometer's range is 0 to 32 °Bx - Photo: Flickr/Dom Sagolla

fruits sold for eating will have different requirements than those headed for processing. Postharvest losses are reduced when farmers know in advance what buyers' requirements are and can supply fruit that complies.

Take mangoes, for example. A tree's output matures at different times; when around 50% of the fruits are at optimal ripeness, about 25% are under-ripe and the remaining 25% is over-ripe. Harvesting them all at the same time will result in losing half the crop. "The fruits which are not matured yet will never ripen since they lack the nutrients from the mother plant while the over-ripened mangoes will spoil very quickly. In addition, leaving over-ripened mangoes on the trees is dangerous: they attract birds, fruit flies and diseases onto the farm," advises **TECA** [bit.ly/2V86hPx]. Staggered harvesting based on measuring optimal ripeness can greatly reduce product loss.

Adolf Ferdinand Wenceslaus Brix (1798-1870) was a German mathematician and engineer. The unit for specific gravity of liquids, degree Brix (°Bx), is named after him.

Testing a mango's ripeness requires slicing a representative mango, scoring its flesh to produce juice, and testing its Brix on the refractometer. You can watch agronomist Daniel Komayire demonstrate to mango farmers in Ghana how this is done on this [video](https://bit.ly/2nFSNaR). [bit.ly/2nFSNaR]



Refractometer Calibration, Use and Maintenance [bit.ly/2oKowI9]



Wikipedia article on Refractometers [bit.ly/2oLsOPN]



How to Use a Refractometer [bit.ly/2wRiXvs]



Identifying the mango's maturity level in Ghana - Photo: from J.P.F. Films, Ghana—[Agric Films Ghana](https://www.agricfilmsghana.com) [bit.ly/2nFSNaR]

Crop Maturity Indicator: Color Charts

Determining when it's optimal to harvest decreases farmers' crop losses. Color charts are readily accessible and give clear indications of optimal maturity of fruits and vegetables.

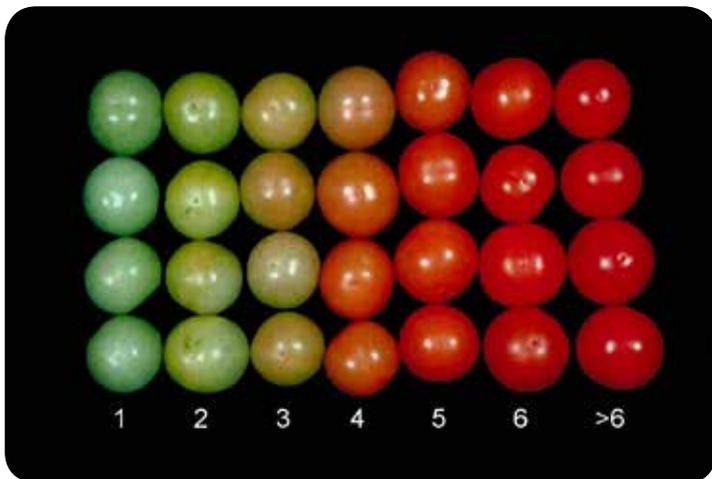


7 There are many methods for confirming plants' maturation. Using color charts for determining when to harvest for best quality and nutritional value is effective and utilizes knowledge collected and organized by farmers and agriculture specialists. For produce that continues to ripen and deepen in color after picking, knowing when to pick to fetch the highest prices is a smart strategy.

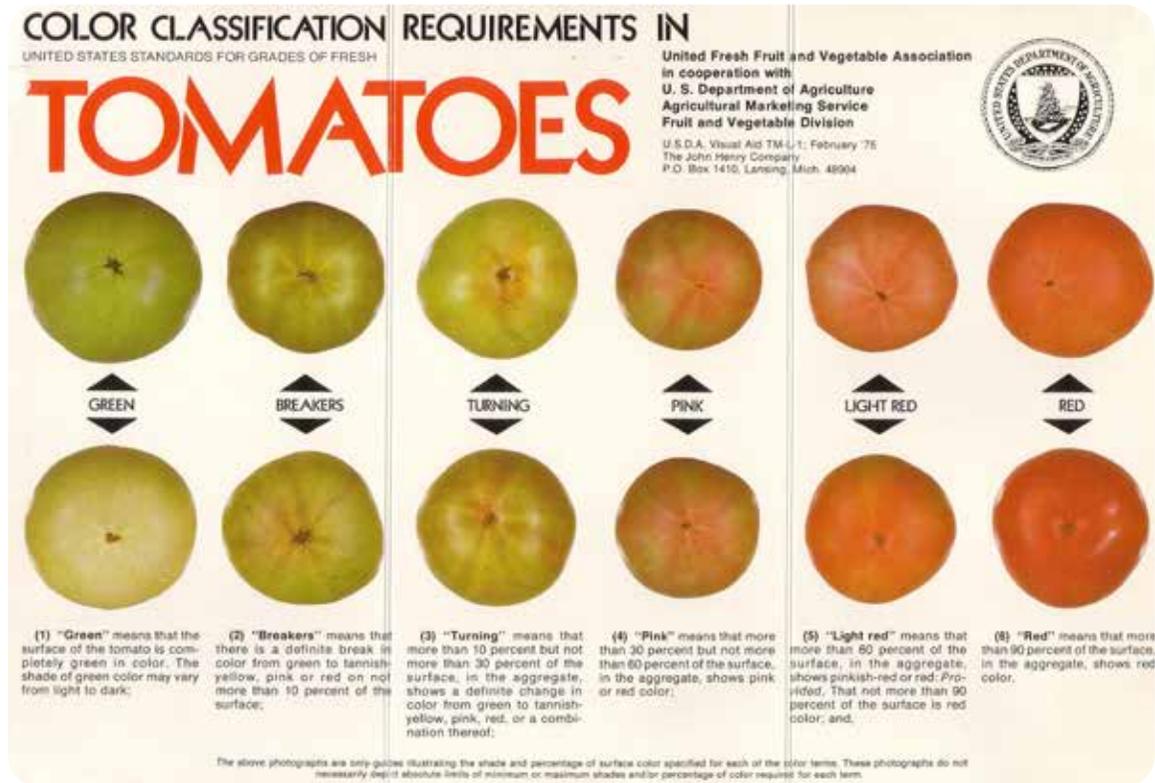
Fruits' and vegetables' colors develop and intensify as they ripen, but color evaluation is highly subjective. Memory is notoriously unreliable. Variables like lighting and moisture can alter viewers' impressions. Therefore, a printed reference chart cuts down on guesswork. Charts can be purchased or accessed online for most every plant sold on the commercial market.

For specialty items like rare local varieties, exotics, or heirlooms, or if purchased charts are not readily available, farmers can make their own by photographing their crops over time, printing the images, and laminating the sheets. Instructions are in the box below.

To make your own color charts, good quality digital photos of selected fresh produce set against a solid, uniformly colored background can be collected to represent the 4 to 7 color stages of any type of crop. Sometimes it is possible to collect all the representative colors of the crop on one day, and take one photo, but most of the time each photo must be taken during a specific time during the ripening period. A computer program that allows you to size and set the individual photos into a common frame, and using a high-quality photo printing service, will enhance the quality of the final product. Lamination of the printed image will ensure it is protected from rain, moisture or dirt when used in the field.—**Postharvest Innovation Series Number 4** [bit.ly/2R69w3p]—2017.



Cherry Tomato Maturity and Ripeness - Photo: Adel A. Kader, UC Davis



Color reproduction can vary considerably, so images may not be precisely accurate, but they will reflect the relative progression of color maturation. Pre-existing charts can be printed from the internet, but again, the challenge of color reproduction remains. For local fruits or vegetables of unusual colors, you can include simple guidance such as such as “harvest at 10% of full color”, or “harvest at 20% of full color” will suffice.

Printed charts are available through a variety of sources. UC Davis provides color charts in their series of [Produce Facts \[bit.ly/2HCBRuB\]](https://bit.ly/2HCBRuB) for fruits.

Creating a color chart of crop maturation on one’s own farm is the basis for efficient, well-informed, individualized planning for following years, as described in Tool 1: Calendars.

Tomatoes are particularly well-suited to color-based harvest decisions, a proxy for the number of days away the crop is from peak maturity, the ideal state for arrival at the market. If the tomatoes are harvested too early, they will not be ripe enough to command the highest prices when they arrive at the market. If they are harvested too late, they will be over-ripe and lose value. Naturally this requires calculating how many days away the markets are.



UC Agriculture and Natural Resources Tomato Color Chart [\[bit.ly/2wNGaPI\]](https://bit.ly/2wNGaPI)



UC Agriculture and Natural Resources Pineapple Color Chart [\[bit.ly/2w0bb63\]](https://bit.ly/2w0bb63)



Munsell Color System [\[bit.ly/2PHeDXb\]](https://bit.ly/2PHeDXb)



UC Davis—How to use a Color Chart [\[bit.ly/2Cq8b5b\]](https://bit.ly/2Cq8b5b)



Pickers using specially designed kiwi harvesting bags at Honeyfield Orchards in New Zealand: the left picker's bag is empty, the middle picker's is full, and the picker on the right is discharging his kiwi load by untying and releasing the bag's bottom - Photo: Alison H. Honeyfield

Harvesting Bags

With ergonomically designed shoulder bags, pickers can collect produce more gently; the bags' drop-down bottoms ease their loads into bins, greatly reducing damage to fruits and vegetables.



8

Fruit pickers must work fast. They are often paid by the weight or quantity of their picking, and windows of peak ripeness are short. They frequently climb high up on stools or ladders. While tossing fruit to the ground is the quickest method, it causes high rates of bruised fruits. These projectiles can also bruise the crop that has already been collected.

Hand-held collecting pails slow workers down and are awkward to hold and move. A good solution, harvesting bags, strap on and free both hands. Apron fronts to support the picking sack, hanging at waist level, maximize efficiency. Continual refinements over time have resulted in many different designs, but even very basic picking bags vastly decrease damage.

Picking bags, sometimes called harvesting sacks, can have added features for worker comfort, health, and efficiency. Adjustable and/or padded shoulder straps help distribute the weight of heavy full loads. Hence, they also minimize workers' physical strain, conserving stamina.

Many commercial versions are available but harvesting sacks can be fabricated locally out of canvas, a plastic tarp, or heavy nylon, with a few hooks, buckles, or large buttons for adjusting the size and creating a bottom that opens to discharge the bags' contents into bins. Stiff tubing or strong wire at a bag's top front edge keeps it open for easy access.

Bags must be washed at the end of each day, to make sure no contamination is carried forward.

A decelerating chute made of a fabric sleeve fabricated from canvas can further cushion fruit dropped from a picking bag into a bin.

Local fabrication provides jobs for seamstresses and brings down the cost. It is also a gender benefit, since most commercially manufactured agricultural equipment is currently sized for males. A skilled seamstress can modify commercial designs and adapt them for local preferences.

Lots of kiwis need picking in New Zealand. Pickers "raining" down kiwi fruits from the orchard canopy into their bags causes bruising, much of which is internal and only appears months later when the fruit is in storage. Designers at [HarvestWear](https://www.harvestwear.com) [bit.ly/2MJqeUy] tested out improvements, like extra cushioning and an interior slide tray that gently funnels the fruit into the bag. The decrease in spoiled kiwifruits pays for the added cost and then yields dividends.

Benefits: Reducing damage and postharvest losses from a typical 15% when roughly handling crops at harvest to less than 5% can provide a boost in potential income. The following examples provide a range of benefits depending upon market value of the crop, for a 1000 kg load.

| Crop | Market value per kg | Value when 15% is damaged during a typical rough harvest and is discarded in the packinghouse during sorting/packing | Value when packing bags are used and only 5% is damaged during sorting/packing | Potential increase in income per load |
|---------------|---------------------|--|--|---------------------------------------|
| Okra | \$0.50 | \$425 | \$475 | \$50 |
| Chili peppers | \$1.00 | \$850 | \$950 | \$100 |
| Mangoes | \$2.00 | \$1700 | \$1900 | \$200 |

If the cost of a harvesting bag is \$25, the investment in 2 bags will be repaid immediately after use with one load of 1000 kg of produce, even when the price is low, and with each subsequent use an extra profit of \$50 is generated. When the market price of the produce being harvested is higher, an immediate profit is obtained from the first day of use.

Data from **Postharvest Innovation Plan Series Number 3** [bit.ly/2NMABXw], 2017

Data collected by Kitinoja and her team demonstrate that harvesting bags pay for themselves after a single harvest, but of course they last many more years after payback (see table above). Commercial prices start at around \$25; bags can be made locally for under \$10. Fancier features, more padding, and stronger harness-style straps cost more but provide added benefits.

Companies selling a wide variety of picking bags include:

DuroKon durokon.com

Frostproof.com frostproof.com/picking-bags/

Harris Seeds Company harrisseed.com

Bags are sized according to the crop. For example:

Small: for delicate crops like peas and okra

Medium: for medium weight produce like tomatoes, cucumbers, and peppers

Large: for citrus fruit (a load can weigh up to 80 pounds)



Pennsylvania Apple Harvesters Using Harvest Bags [bit.ly/2M2zW3f]



Teresa Maina and Judith Achieng harvest sorghum in Apondo, Kenya, using a smooth plastic container - Photo: One Acre Fund/ Kelvin Owino

Smooth Buckets and Containers

Rigid containers with smooth interiors should be used for crop collection. Produce at the bottom of soft bags and baskets is often crushed. Baskets' rough interiors can further damage their contents.



9

It may come as a surprise that traditional rustic bags and baskets—agricultural mainstays—are actually active culprits in causing extensive postharvest losses.

The interiors of hand-woven bags and baskets are rough and jagged, and those loose ends snag, abrade, and puncture harvested produce. These wounds result in decay, water loss, and quick spoiling.

People may like the bags and baskets because of their flexibility and low-cost, but when collecting crops, that lack of support damages the contents. When the weight of a full container's contents pushes down, it squeezes the bottom of the load. Think tomato paste....

Obviously, traditions evolved in times when contemporary materials were not readily available. Metal pails solve many of these problems. Plastic containers do as well, with the added advantage of being lighter and cheaper.

Their additional advantages include:

- They are easily washed and dried between uses, a sanitary advantage in reducing pathogen spread.
- When using baskets or sacks, their porous nature makes their contents vulnerable to invasion and infestation. Buckets and other rigid, impermeable containers reduce this problem.

- From an environmental standpoint, some might think that using natural materials would be better than non-biodegradable, fossil-fuel based plastics. Balanced against the food waste which is reduced by smooth plastics, they are environmentally positive. Also, high-quality plastic receptacles can be used reused indefinitely; many are repurposed packaging from construction products. Natural fiber bags and baskets can rip, ravel, become moldy and degrade, especially when wet; their biodegradability can actually be a negative.

Due to their rigidity, buckets can be uncomfortable to carry. With shoulder straps and a shape contoured to the torso, they become an effective picking basket, with smaller volume than a picking bag [Tool 8], better-suited for smaller, delicate crops.



Orchard View Farms cherry harvester in Columbia Gorge, Oregon, using a strapped bucket - Photo: Andrea Johnson /Flickr



Foraging in the forest for food in Luwingu Zambia - Photo: Joe Nkadaani/CIFOR

Other precautions pickers can take to prevent damage to fruits and vegetables during the harvest:

- Remove rings and bracelets
- Trim fingernails
- Wash hands frequently
- Don't wear gloves—they are often very dirty and can spread pathogens



Cherry Harvesters Emptying Their Buckets [\[bit.ly/2oLYlvh\]](https://bit.ly/2oLYlvh)



Commercial Tomato Harvesting with Plastic Tubs in Florida [\[bit.ly/2Qai4GT\]](https://bit.ly/2Qai4GT)



Working on a family farm, digging potatoes in Dharmpur village, Nepal - Photo: ©IFAD/Fulvio Zanettini

Digging Tools for Roots and Tubers

Careful digging using appropriate tools reduces damage to roots and tubers during harvest.



10

Roots and tubers have sustained humans from the early days of hunter-gatherer culture. The image of women combing forests, leaning on trusty digging sticks and lifting out edible plants to sustain themselves and their families, is based in reality. A digging stick is still an effective tool.

In general, hand-harvesting results in less damage than mechanized. However, when digging for crops, it is important not to use tools with sharp points or edges. Once tubers are punctured or bruised, they are vulnerable to pathogens that will fester through the long trek from field to table, spreading decay throughout extended storage.

Careful digging with traditional digging sticks or short hoes to harvest roots and tubers involves gently removing top soil to find the roots/tubers. It is important not to dig randomly with a sharp-edged tool.

After the soil is loosened and the tubers are visible, traditionally a stick is pushed underneath to lift the crop up and out. Harvesters are better off using a wide-tined curved rake, dubbed a potato hook, to lift the potatoes; the soil falls through the rake. Using sharp shovels or pitchforks without caution can damage the crop.



Lifting spuds up with a potato hook rake in Connecticut - Photo: Jane Wallor



This farmer is digging up potatoes with a wooden hoe in Kongoussi, Burkina Faso. Traditional back-breaking labor is made easier by using a longer hoe, allowing vertical posture while harvesting - Photo: Ollivier Girard/CIFOR

The work is physically challenging, requiring bending over and kneeling in the fields to gather the crop. Modern use of longer-handled hoes allows harvesters to stand erect, with less body strain.

After gentle digging, roots and tubers must be cured before storage or marketing [Tool 16].



UC Agriculture and Natural Resources: Hand Tool Guide [\[bit.ly/2Ntbhdbj\]](https://bit.ly/2Ntbhdbj)



UC-Davis, Master Gardeners: Garden Tool Safety [\[bit.ly/2wQju0oJ\]](https://bit.ly/2wQju0oJ)



FAO Roots/Tubers Directory [\[bit.ly/2NTxcqMj\]](https://bit.ly/2NTxcqMj)



University of Utah: How to Harvest Potatoes [\[bit.ly/2wOQoiSj\]](https://bit.ly/2wOQoiSj)



Tadine Village, Mare Island, New Caledonia - Photo: Tom McGrath

Pole Pickers for Tree Fruits

Tools that allow for gentle plucking of fruit high on trees, picked at its optimum degree of ripeness, greatly reduce fruits lost due to over-ripeness or bruising.



11

Fruit-bearing trees have sustained people since the dawn of human life. Once established, trees propagate fruit without requiring farmers to sow, plant, or tend. Trees grow larger each fruiting cycle, increasing their output for a generation or more.

Humans have developed many methods of gathering fruit.

- The easiest method is simply enlisting gravity, letting ripe fruits drop. Fallen fruit is very ripe, often post-peak, and will quickly spoil. Hitting the ground bruises fruit, adding more likelihood of spoilage.
- A more proactive approach, shaking or hitting the tree to cause the fruit to drop—“beating the bushes”—also has a high damage rate. Working in pairs, with one worker cutting fruit and the other catching it with a tarp or bag and guiding it into a receptacle, reduces damage.
- Plucking reachable fruit and gently placing it in bins is effective but limited to a picker’s reach. “Low hanging fruit”, an expression popular with organizational development professionals, describes realistically accomplished goals.

People the world over have devised clever collection pole pickers to harvest high-hanging fruit at its prime, cradling its descent.

Fashioned from locally available materials, a simple tool like the large tin can and wooden pole used on the South Pacific island of Maré, New Caledonia, gets the job done.

Catching baskets made of net, wire, or plastic can handle the fruit more gently. A blade, kept sharp, or prongs to pluck the fruit from the stem is a useful upgrade.

An inverted plastic bottle makes a good receptacle. The narrow “funnel” end can be left open for small twigs and debris to drop through. Directions are posted at [\[bit.ly/2OYmZu9\]](https://bit.ly/2OYmZu9).

A hoop used as a catching basket rim and cutting edges can be fashioned from sheet metal, steel tubing or recycled scrap metal. [Kitinoja and Kader, 2015, p. 24-25]

Bill Birdsall posted his design for a net basket pole picker on [Instructables](https://www.instructables.com/) [\[bit.ly/2QaLl4w\]](https://bit.ly/2QaLl4w). The “finger” shape of the basket’s rim helps the fruit drop in the basket and not bounce when picked.

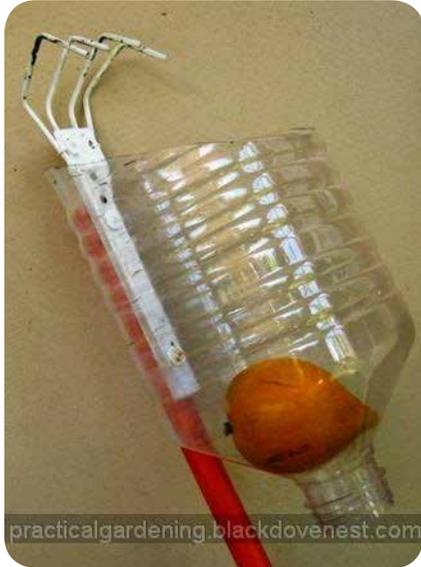
- Bamboo is readily available and works well for making poles. Telescoping poles, available commercially, are easier to transport, but are more expensive.
- Sturdier tools are needed for harvesting large quantities of fruit. An American urban orchard gleaning

project's favored design posted at [Instructables \[bit.ly/2MGs9J1\]](https://www.instructables.com/2MGs9J1/) is a commercial pronged wire basket.

- Painting the front of the basket white provides contrast so pickers can more easily discern what they are picking from 20 feet (6 meters) away.

- Adding foam to cushion the bottom of the basket is a further upgrade.

Picking poles are much safer for workers than climbing rickety ladders in search of high-hanging fruit.



Plastic bottles work, too - Photo: Practicalgardening.blackdovenest.com



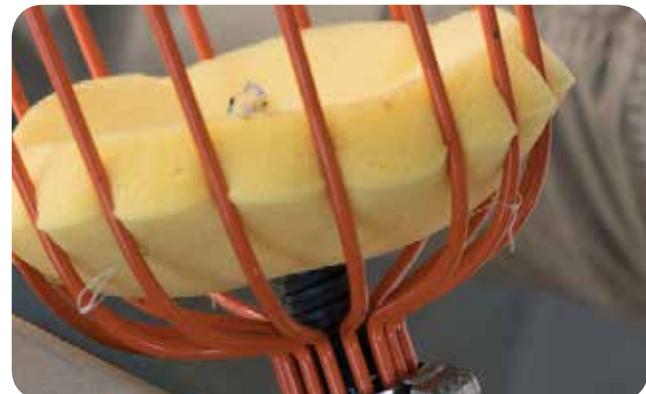
The finger shape on the net's rim guides the fruit into the basket - Photo: John Birdsall



Cloth bag fruit picker, Jimma University, Ethiopia - Photo: Lisa Kitinoja



Painting the front of the basket helps pickers to see what is going into the basket from a distance - Photo: NeighborhoodFruit



Foam lining added to cushion fruit - Photo: The Urban Farmers, Lafayette, CA



Instructables: Making a Net Fruit Picker [\[bit.ly/2QaL14w\]](https://www.instructables.com/2QaL14w/)



Instructables: Making a Fruit Pole Picker [\[bit.ly/2wOfyNQ\]](https://www.instructables.com/2wOfyNQ/)



Homemade Apple Long Sock Tunnel Picker [\[bit.ly/2NXCim0\]](https://www.instructables.com/2NXCim0/)



Farmers in Khatlon province, Tajikistan, packing tomatoes collected from their greenhouses - Photo: USAID/Sayora Khalimova

Reusable Plastic Crates and Liners

Rigid, stacking, reusable plastic crates greatly reduce damage to picked crops. Adding liners to assure no rough edges damage fruits and vegetables further reduces losses.



12 Reusable plastic crates, RPCs, available in a wide variety of designs, play a central role in reducing postharvest losses all along the value chain, starting at the farm where produce is picked. While they require an initial investment, the payback of outlay is generally very quick, and they can then be reused at least 150 times.

They also prevent a great deal of waste generated by single-use options. Since they are stronger than flimsy boxes, better protecting the fruits and vegetables, they are a win-win upgrade.

Returning RPCs back to the farms after they have traveled all the way through transport, storage, and marketing is a

significant challenge. Different models for accomplishing this task are emerging, based a rental rather than ownership model. In time, digital tags could allow owners to track them, creating a rental reuse system.

An added problem is that buyers determine what packaging they require from farmers. In Uganda, for example, Eric Kaduru of KadAfrica.org reports that despite his awareness that reusable plastic crates are far superior for packing and transporting their passion fruit crop to market, and would significantly reduce their losses, purchasers require crops to be delivered in polypropylene sacks. The result is unnecessary loss of produce and lower net income for KadAfrica, and all other farmers bringing produce to market in their region.



KadAfrica's passion fruit harvest loaded in the field in RPCs - Photo: Eric Kaduru, KadAfrica

Poor quality containers include

- Cloth bundles
- Jute, mesh or polypropylene sacks
- Woven baskets, especially if they are large sizes and/or have rough interiors
- Flimsy, low-quality crates made of thin plastic or Styrofoam

“RPCs can also be used to replace expensive single-use fiberboard cartons, as well as locally made crates that are constructed

“RPCs required 39 percent less total energy, created 95 percent less solid waste, and generated 29 percent less total greenhouse gas emissions than corrugated display-ready containers.” ([PackagingRevolution.net White Paper, 2012](#))

—[\[bit.ly/2BUKfVr\]](#)

from rough wooden planks or palm ribs. Many of these packages use natural resources to manufacture and wind up either being transported to landfills or decomposing underfoot as debris in marketplaces after one or two uses.” ([Kitinoja-2013](#)) [\[bit.ly/2B6vQXN\]](#)

Reusable, heavy plastic is actually preferable to natural material, since it can be reused so many times, as opposed to just one or two uses for those made of natural materials.

High density polyethylene (HDPE) crates are available in three styles:

1. Stackable but not collapsible. These remain in the same facility and are reused each season.
2. Nesting crates, formatted with bottoms smaller than the tops so one fits inside the other when oriented in the same direction, but stackable when oriented in opposite directions.
3. Collapsible crates.

Nesting and collapsing crates save space, making them more economical to return to farms for the next season.

If crates have rough interiors, low-cost paper or fiberboard liners can be added to reduce friction and the resulting abrasion to loads.

“While there are many factors to consider before making any large investment, a simple cost and benefit calculator worksheet developed by PEF can be used to plug in estimated local costs and expected economic benefits for small scale operators to check the numbers before making any investments.” A sample spreadsheet is provided in Appendix A, and an Excel file spreadsheet is available for download from the PEF website.

—[Kitinoja-2013](#) [\[bit.ly/2B6vQXN\]](#)

Business models for full circle RPC distribution are evolving. One problem is that people find plastic crates extremely useful and pilferage is high. In time, perhaps there will be embedded IDs to track each RPC’s movement. This already exist for pallets [Tool 64] in some countries.

Shipping RPCs to remote locales can make them very high in price, but they are still a worthwhile investment.

RPCs are easy to clean between uses, important for maintaining high sanitation standards throughout the value chain.



The Postharvest Education Foundation’s White Paper on Reusable Plastic Crate Systems, on which this entry is based [\[bit.ly/2Q8qiWV\]](#)



UC Davis Agriculture and Natural Resources: Comparing Packaging Materials, Including RPCs [\[bit.ly/2NiTMvZ\]](#)



Benefits of RPCs [\[bit.ly/2NtXlu1\]](#)



Jen Tobener from Our Table Cooperative in Sherwood, Oregon, wheels freshly harvested vegetables in a cart designed by Josh Volk - Photo: Josh Volk, Slow Hand Farm

Field Handcarts

Using wheeled carts to move harvested produce from field to packing house saves physical labor and allows for smoother passage, damaging less of the crop.



13

No one should underestimate the benefit of utilizing wheels. Farming in general, and harvesting in specific, exacts an enormous energy toll on farm workers. Using even simple, handmade mini-carts saves a great deal of bending and lifting and minimizes the number of times crates need to be moved. This automatically reduces damages to harvested produce, which is vulnerable every time it is handled.

A wheeled cart not only greatly eases the work of carrying bins of produce; it also eliminates the need for workers to bend over to the ground to pick up heavy loads. Designing a cart to be a convenient height is a significant “up”-grade. Wheels also decrease gender disparity and reduce physical strain for all workers.

“Small carts or small mobile field packing stations can be designed to be moved along with the packers and to provide shade for packing operations.”—Kitinoja and Kader 2015, p. 19.

Adding a shade to a cart provides the benefits of two super-tools for reducing postharvest losses, gentle handling and heat reduction/cooling of the newly harvested plants.

Carts can be purchased, but prices exceed most smallholder farm budgets. They can be assembled locally from scrap wood, used bike tires, and basic parts. There are many plans online.

Simple harvest carts include:

1. One-wheelers (wheelbarrows)
2. Two-wheelers
3. Wheeled flatbed wagons, with or without sides.

Heavier, larger carts go up in size and price. Obviously, they should be matched to the weight of the loads they will move.

Josh Volk, a creator of handcarts for small American farms, describes his design: “The standard flatbed design for the cart is slightly forward of the wheels which helps keep the cart from tipping while it is standing in the field, but allows the majority of heavy loads to be carried by the wheels, not the operator.”

A classic wheelbarrow is also a useful tool for harvest, but as its interior is not flat, it doesn’t allow for stacking crates efficiently. A modified two-wheel option is more like a small wagon.



Plans for this aluminum harvest cart are available online; linked at end of this entry - Photo: John Hendrickson, Center for Integrated Agricultural Systems, University of Wisconsin

Options to consider when fabricating a cart:

- **Width** – If a farm is committed to a specific size of crates, the cart can be designed to fit them.

The pictured cart was designed to accommodate readily available floral RPCs used for export from Holland. While they are sturdy enough for reuse, returning them to Europe is prohibitive. They are popular for harvest collection in the USA, where this was designed.

If the pathways on a farm are narrower, the cart can be narrower, as well.

- **Height** – higher will save the strain of bending but may make it less stable. Two additional wheels can add stability. Some carts are high enough to roll over the crops.

- **Materials** – aluminum is lighter weight and easier to maneuver, but wood may be more readily available. Local welders may be more adept at working with steel.
- **Tires** – used or new bicycle tires work well.
- **Shape** – flat is easiest, but if the cart will be used on slopes, side barriers prevent loads from sliding off the surface.



Rolling wagon from Full Cellar Farm in Gresham, Oregon - Photo: Emily Cooper



Full Cellar Farm's cart wheels are 4 feet apart, straddling its beds - Photo: Emily Cooper



Farm Handcarts slowhandfarm.com/blog



Aluminum Farm Cart plans [\[bit.ly/2CqsgbF\]](http://bit.ly/2CqsgbF)



Canadian DIY Bike Cart "Experiment" [\[bit.ly/2MVWKab\]](http://bit.ly/2MVWKab)



Laborer sorting green peppers into smooth buckets [Tool 9] in a polyhouse [Tool 2], Manoli Village, Sonipat District in Haryana, India - Photo: Katrin Park / International Food Policy Research Institute

Pre-Sorting Harvested Crops at the Farm

Culling decaying or irregular produce at the farm allows it to be redeployed, conserving the resources that would be used to transport it, and prevents it from contaminating healthy produce.



14

A certain percentage of every harvest includes “irregulars”, produce that is visibly

- Decayed
- Split
- Bruised
- Munched on by pests
- Infested
- Discolored
- Too small
- Oddly shaped
- Too ripe or too soft

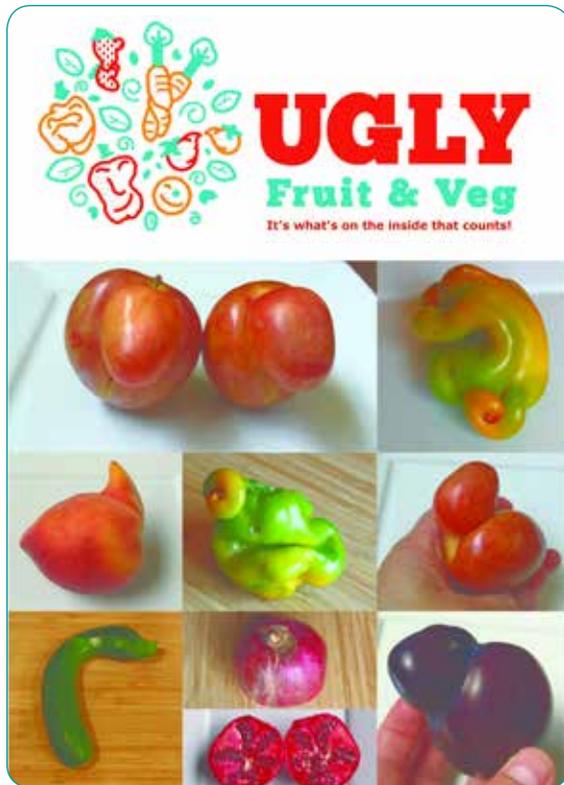
Inspecting and culling or diverting the rejects up front at the farm, rather than at a later step in the value chain, has many economic and ecological advantages:

- Averting the spread of pathogens from infected to healthy plants, especially when no postharvest pesticides are used

- Conserving material and financial resources that would be expended to wash, pack, cool, package, and transport them further along the value chain
- Quickly deploying edible but commercially rejected plants at the farm

Decayed produce must be disposed of responsibly, but there are many uses for culls if workers perform some targeted trimming. The value that has already been invested in growing them, including inputs and labor, can still provide benefits. Typically, edible rejects are

- Processed into other kinds of products like jams or dried foods, also improving food security and/or generating income
- Eaten by the family or farm workers, improving food security
- Fed to animals
- Composted and/or used as fertilizer, enriching the farm’s soil. Composting will kill most fungi; but dangerous pathogens (like the fungi that produce aflatoxins) must be burned to be completely destroyed.



#UglyFruitAndVeg, a twitter hashtag, features submitted photos of curiously shaped fruits and vegetables that don't make the commercial cut but are equally nutritious - Photo: www.UglyFruitsAndVeg



DC Central Kitchen gleans at Butler's Orchard to utilize rather than waste their reject apples. "To produce 5,000 healthy meals for our 80 partner agencies every day, we transform 3,000 pounds of food that would have otherwise been wasted. That includes . . . misshapen or blemished produce from local farms." - Text and photo: DC Central Kitchen, Washington, DC

Pulses and grains, like fruits and vegetables, should be carefully inspected immediately after they are harvested. Decayed kernels must be removed.

Tempting as it is to hide inferior crops out of sight at the bottom or interior of the container, this classic ploy backfires. Decayed crops spread pathogens through the whole lot, causing losses that are not apparent until the shipments are opened; the value of the whole delivery is ultimately greatly diminished.

It is especially important to remove any moldy or pest-

infested beans or grains that will be stored long term, since closed containers are an ideal environment for pathogen development. Sometimes, when opened, 100% dust is revealed: insects have feasted on the entire contents. Hermetically sealed storage suffocates pests, but it is still important to remove any infested grains or kernels before bagging. Hermetic sealing prevents deterioration but does not improve food's quality.

Consuming plants with cosmetic imperfections that render them commercially non-viable is important in decreasing global food waste. Food waste is a serious environmental problem, as well as a moral challenge in our world where so many people are malnourished and hungry. "Ugly" or "imperfect" fruits and vegetables are now being promoted and sold as such. This raises awareness of the value of these nutritious but funny-looking fruits and vegetables, hashtagged #UglyFruitAndVeg.



UC Davis Postharvest Fact Sheets for Fruits and Vegetables [\[bit.ly/2oN5XmH\]](https://bit.ly/2oN5XmH)



Champions 12.3—Global Campaign for Reducing Food Loss and Waste [\[bit.ly/2N84bGD\]](https://bit.ly/2N84bGD)



ImperfectProduce.com's Marketing in San Francisco [\[bit.ly/2oKWD2P\]](https://bit.ly/2oKWD2P)



Silverlands Namibia field packing grapes from lined reusable plastic crates (Tool 12) into retail packaging - Photo: FreshPlaza/Nichola McGregor

Field Packing

Packing directly into retail packages in the field during the harvest maintains quality and minimizes damage and contamination. This both expands the saleable harvest and raises its value.



15 OHIO, “Only Handle It Once”, is a mantra of efficiency. It is the basic principle of field packing, whereby functions that are typically performed in a packinghouse are moved directly to the field where harvesting is taking place.

This means moving necessary equipment and items to the field:

- Clean working surfaces
- Trimming or washing equipment, like buckets for chlorine wash [Tool 22]
- Designated packaging materials, preferably approved by ultimate wholesale or retail buyers

If produce is washed, it must also be dried before packing, usually by allowing it to sit for a few minutes on a clean surface to drain and air dry. An important addition to field packing is a [sunshade \[bit.ly/2P58Vih\]](https://bit.ly/2P58Vih) to minimize heat and water loss once the crops are cut from the plants. Shade also improves working conditions for workers.

Field packing offers multiple benefits:

- Each time harvested plants are handled they are vulnerable to damage. Putting them directly into protective packaging as soon as possible minimizes the number of times they are moved and protects them from the very beginning and throughout their journey to market.

- When they are trimmed and placed in well-designed protective packaging, their exposure to soil and air-borne pathogens is likewise limited.
- Under a protective sunshade, plants’ direct sunlight exposure is decreased, and the air is cooler. This removes some of the field heat and lessens water loss.
- Farmers avoid the expense of maintaining the packinghouse.



Demonstration of field packing for tomatoes in Tanzania by Lizanne Wheeler; the PVC tubes held by the worker in the foreground were used to make sizing rings [Tool 30] - Photo: Patrick Brown

“Field packing allows your produce to be handled just once, right after it is harvested. At every step it can stay in its packaging because it is already cleaned, sorted, and well-protected. Less handling means less damage and minimal loss of quality.”

—Postharvest Innovation Plan Series
Number 13: **Field Packing** [\[bit.ly/2MsnjD6\]](https://bit.ly/2MsnjD6)

- Packers get the job done more quickly; the added efficiency is better for the produce and easier on workers. Packing season is stressful and intense.
- Labor costs are decreased, since redundant efforts are eliminated.

“Every evening by 6 o’clock our workers are at home and they can cook, wash clothes and see the kids, while some of the packhouse workers don’t get home

until 10 or 11 at night and are back up at 4 in morning and they can pack 7 days a week. It is a rested person who comes back to work the next day here. I am going to change to 100% field packing next season, this is the last year I will pack in the packhouse.”

—Andre Vermaak, Silverlands Grapes, Namibia

A simple hand cart [Tool 13] can be used to bring empty containers into the field during the harvest. Two or three different containers can be field packed at the same time, allowing the harvester to sort by colors [Tool 7] or grade into different sizes [Tool 14] as she moves along the row. A larger, mobile cart with a roof attached for shade can be pushed along the edge of the field.

Field packing pays for itself by reducing losses as well as reducing expenses. Adding up the costs and savings of a typical grape packing enterprise **demonstrates** [\[bit.ly/2MsnjD6\]](https://bit.ly/2MsnjD6) that field packing of 1000 lbs of table grapes valued at \$0.50 per lb provides a daily return of \$56 more than using a pack-in-house. The investment in the shaded packing station can be recovered in less than three days.



Strawberry Field Packing Directly into Clamshells [\[bit.ly/2wMYEzS\]](https://bit.ly/2wMYEzS)



Field Packing Lettuce into Two Different Containers with a Rig [\[bit.ly/2wPiXMn\]](https://bit.ly/2wPiXMn)



“Cut and Come Again” Method [\[bit.ly/2Nt6FUo\]](https://bit.ly/2Nt6FUo)



Amare Bihonegh, a farmer in the Tach Gyint district of the Amhara Region of Ethiopia, with his properly cured and stored potatoes - Photo: Kebede Lulie, Food for the Hungry

Curing Roots and Tubers

Curing, the process of keeping roots and tubers warm and moist for a few days before long term storage, facilitates their natural self-healing. This reduces water loss and protects them from disease, prolonging their shelf life.



16

Roots and tubers—yams, potatoes, cassavas, cocoyams, taro, and sweet potatoes—have the capacity to literally grow a second skin after harvest, under the correct temperature and relative humidity conditions. This **curing** allows them to heal wounds, nicks, and abrasions resulting from the digging process of harvesting them, protecting them from water loss and infestation.

Once the wounds have healed over, the roots and tubers are far less vulnerable to pathogens. Since an infected plant will spread its decay to the rest of the stored load, the whole lot is safer. When fully cured, they can be stored for long periods of time, typically 6-9 months, in a cool space (around 55°F/ 15°C). Cured roots and tubers can be held back and sold for a higher weight, since their rate of water loss is much lower than uncured crops. Farmers can time their sales to catch rising prices.

Storage time for uncured roots and tubers is much shorter, forcing early sales at lower prices and exposing them to decay.

Curing can be done outdoors by piling the produce in the field and covering it with dead plant materials or straw, but optimal curing conditions are a room or structure with

- Added heat, about 85° F/30 °C
- High humidity of around 90-95%
- Good ventilation, to avoid condensation

If outdoor conditions are not suitable for natural curing, the expenditure for fuel required to achieve the optimal heat is costly, although it will pay back in longer storage and reduced losses.

Curing with Heated Air:

“The most uniform distribution of heat is obtained when heat is introduced near the floor level of a curing structure. Heaters can be placed on the floor near the bins of produce, or heat can be ducted in from outside the curing room. A high relative humidity can be obtained by wetting the floor or by using an evaporative cooler in the room without introducing outside air.

If heaters are located near the ceiling, then ceiling fans can be used to help redistribute the heat down into the room of produce. Bulk bins must be stacked to allow a gap of 10 to 15 cm. (4 to 6 inches) between rows for adequate air circulation.”

—Kitinoja and Kader (2015), p. 34

Field Curing is a lower tech option:

“Yams and other tropical root and tuber crops can be cured outdoors if piled in a partially shaded area. Cut grasses or straw can be used as insulating materials and the pile should be covered with canvas, burlap or woven grass mats. Curing requires high temperature and high relative humidity, and this covering will trap self-generated heat and moisture. Never use plastic covers, as the pile can then become too hot, which will harm the produce. The stack should be left for about four days (yams) or five days (cassava, sweet potatoes,

or cocoyams) and then checked to feel the peel of the produce. If the peel is firmly attached and does not slip when pressed sideways using light finger pressure, the curing process is complete.”

—Kitinoja and Kader (2015), p. 32.

In the case of sweet potatoes, curing improves flavor, as it facilitates starches converting to sugars. Orange-flesh sweet potatoes are being promoted globally for nutritional purposes; information about curing is available at the [Sweet Potato Knowledge Portal \[sweetpotatoknowledge.org\]](https://sweetpotatoknowledge.org).



CGIAR Potato Guide, beautifully illustrated [\[bit.ly/2wPGFsJ\]](https://bit.ly/2wPGFsJ)



Purdue Extension: Rosie Lerner's Sweet Potato Tips [\[bit.ly/2Dpam9x\]](https://bit.ly/2Dpam9x)



New PEF White Paper on Curing [\[bit.ly/2QTyzqw\]](https://bit.ly/2QTyzqw)



Duryodhan Hati from Kalimati village in Nuapada district, Odisha, India, has successfully increased the storage time for his onions, following WorldVeg practices - Photo: World Vegetable Center

Curing Bulbs: Garlic and Onions

Curing bulbs to dry their outer peeling and neck tissue protects them from water loss and decay during handling, storage and marketing. This decreases losses and expands income.



17

A mainstay of cuisines everywhere, onions win the world-wide distribution award—they are grown and eaten in more countries than any other vegetable. Hence improving the value chain for onions and other tasty bulbs like garlic, leeks, and shallots benefits farmers and consumers the world over.

Bulbs have the ability, like roots and tubers [Tool 16], to self-seal when handled correctly postharvest. Facilitating this forming of a protective outer later is known as **curing**. For bulbs, the outer skins dry in place and the neck gradually closes tightly, forming a protective casing. Compared to uncured bulbs, cured bulbs:

- Lose less water during storage
- Better resist decay
- Have a significantly longer storage life
- Expand farmer income, due to the three factors listed above

Bulb curing is quicker than root and tuber curing and does not require high temperature. If bulbs are grown during the dry season, they can be cured in the open field following the harvest. The dried tops of the bulbs are used to cover and shade the plants, protecting them from excess heat and sunburn (which causes the tissues to look bleached out and pale) which can damage them.

To expedite drying, bulbs must be kept at low relative humidity. Leaving space between bulbs improves air circulation, and faster, more even drying.

Onions and garlic can also be cured in breathable sacks (jute, burlap, or similar — but not plastic). They are then covered with dry grass or straw to prevent sunburn.



Onions curing in California in burlap sacks - Photo: Lisa Kitinoja



Onions curing in mesh sacks in Egypt - Photo: Lisa Kitinoja



Hanging onion and pepper braids at the Lima, Peru Mercado de Sequillo - Photo: Betsy Teutsch



Garlic field drying on a pallet covered with chicken wire - [KitchenGardeners.org](https://www.kitchengardeners.org) Video



Vendor at Dolac Market shows off her garlic braid in Zagreb, Croatia - Photo: Betsy Teutsch



Well-cured onions at market - Photo: Lisa Kitinoja

In emergencies, like heavy rain or flooding, which would make field curing and drying impossible, and curing facilities are unavailable, a tent can be used.

Once cured, onions need to be stored in a shaded, ventilated area. Dedicated onion storage sheds feature raised structures to guard against rodent and insect pests. Bottom and side ventilation promote beneficial air circulation throughout the structure.

Maximum storage time for well-cured bulbs is 6-9 months, depending on the variety and climate, generally well before the next harvest is available (in regions with multiple crops a year.)

Detailed instructions are available in the Small-Scale Post-harvest Manual, Kitinoja and Kader (2015) p. 36.

The World Vegetable Center has been working on [improving the postharvest value chain for onion farmers in India \[bit.ly/2W8OHKS\]](#). Without curing, onions are marketed immediately postharvest, causing gluts and driving down prices. Curing bulbs evens out the supply and averts surpluses left to rot, raising income.

“Previously I wouldn’t store onions as I didn’t know about postharvest handling and used to sell my crop immediately after harvest,” Mr. Duryodhan Hati [photo above] from Kalimati village in Nuapada district said. “World Veg staff trained us about proper harvesting, curing, sorting and storage techniques and this year I’ve been storing my onions for the past two months and not a single onion has spoiled till now. I’m expecting a storage life of 2-3 more months to get a better price.”

Once cured, an attractive way to add market value to both onion and garlic bulbs is by leaving the stems intact and braiding them to create artistic bunches for hanging. This improves air circulation and they last longer; variety of sizes can be worked into the design, a good use for smaller bulbs. Hanging the braids from a kiosk’s sunshade adds visual interest and raises eye level at markets, attracting buyers. Using two colors of onions is especially attractive. There are many videos demonstrating bulb braiding techniques posted online.

Check out a model onion storage structure in Tool 65.



Postharvest Innovations Plan Series #19: Curing Bulb Crops [\[bit.ly/2NUSDHM\]](#)



Braiding Garlic and Onions [\[bit.ly/2MVcSnn\]](#)



Braiding Garlic for the Market or Home Storage [\[bit.ly/2MbaXLq\]](#)



Utah State University Extension: Harvesting and Curing Onions [\[bit.ly/2NPgvg2\]](#)



Beneficiaries of TAO's work in Oyam District, northern Uganda, drying seeds to meet market standards - Photo: Trust for Africa's Orphans

Tarpaulins and Ground Cloths for Air Drying Crops

Grains, pulses, and vegetable seeds should be dried before packing, processing, or storage. Using a waterproof ground cover—not the traditional practice of drying directly on the ground—reduces losses and enhances food safety.



18 Unlike horticultural crops—where the goal is to **avoid** water losses after harvesting—grains, pulses, nuts, and seeds need to be dried. If they are stored while still moist, they are at high risk of decay due to mold growth. Moisture also promotes germination, whereby the grains sprout.

Traditionally farmers dry their grains, pulses, seeds, and nuts directly on the ground; a modern variation is to lay crops to dry along roadsides taking advantage of flat grading. This practice exposes the drying product to a great deal of dust and pollution. While it is generally difficult to change people's customs, simply performing this same task on affordable groundcovers has a large beneficial impact.

Inexpensive **tarpaulins** (“tarps”) are simply thick non-woven polypropylene drop cloths. Tarps

- Create a barrier that prevents contamination from ground-based pathogens and toxins, as well as insects and other pests with easy access to the drying foods
- Block contact with soil moisture, speeding the drying process
- Provide a large surface area for the sun and wind to act more quickly to evaporate moisture

- Ease moving the dried crop, since tarps can be lifted and their load can be funneled into storage containers

The use of inexpensive tarpaulins pays back quickly. They can be cleaned and reused for many harvests. Natural drying utilizes sun and wind; no fuels or energy are required, making it environmentally friendly.

The product should be stirred or raked frequently to ensure evenly distributed drying.



Ester Samuel, of Lemu, Balaka, Malawi, spreads her drying white maize flour on a ground cloth - Photo: T. Samson/CIMMYT



Agri-business inspector examining crops grown by farmers benefiting from TAO's projects in northern Uganda, checking for mold or insect damage - Photo: Trust for Africa's Orphans

Sun drying is challenging during rainy seasons or in very humid climates. A second tarp can be used to cover drying grains during short periods of rain.

[Trust for Africa's Orphans' \[trustforafricasorphans.org.uk\]](http://trustforafricasorphans.org.uk) work in Oyam District, northern Uganda, features two key agri-business projects. One aspect is the store built to enable produce to be stored dry and securely for sale in bulk at higher prices; the other the tarpaulin provided to dry seeds, so they meet the high standards expected by commercial buyers. [Pictured here].



FAO's Postharvest Grain Portal [\[bit.ly/2wOL4vW\]](http://bit.ly/2wOL4vW)



International Rice Research Institute: Sun Drying Rice [\[bit.ly/2oMWSdR\]](http://bit.ly/2oMWSdR)



Women during hands-on training using a mechanical thresher learning first-hand how the equipment, which is easy to operate and much less work, can also save time and reduce threshing losses. The chaff flies off and the grain drops into a collection pan at the machine's bottom - Photo: ADM Institute for the Prevention of Postharvest Loss

Mechanical Threshing

Small-scale mechanical threshers radically speed the process of separating grains from chaff. This liberates labor and slashes the time the crop is exposed to rain, insect, and rodent attack in the field.



19

Traditional hand threshing is tedious, heavy, time-consuming physical labor. Workers must hoist sheaves and then forcefully beat them on the ground to loosen the grains from the straw. When farmers use animals to trample the plants, they can speed the threshing, but this causes a lot of damage and food contamination.

Mechanized threshers are too costly for an individual smallholder farm to own, but when a farmer co-op or group [Tool 87] purchases one jointly with microloans [Tool 95], it is available to all its members. They receive training in the technique, and also how to rapidly assemble and dismantle their thresher to move it from farm to farm. Farmer groups can also generate income by renting the device out to non-members, benefiting an even larger number of smallholder farmers.

Hence mechanized threshers can be paid for with

- Higher volumes of grain capture per hour or per day
- Reinvesting farmers' resulting time dividends elsewhere
- Direct revenue from outside users
- Reduced losses due to getting the job done faster, shrinking damages in the field from water, microorganisms, rodents, and insects

A trio of designers, Richard Trimble, Donna Cohn, and Susan Hanna, recently won a **Chasing Genius** [bit.ly/2pweA5s] award to produce 50 of their solar-powered pearl millet threshers developed in Niger and Hampshire College.

When a farmer group owns its own device, members no longer need to wait for a more distant threshing service to arrive, decreasing their crops' exposure to risks such as unexpected rain. This increases efficiency, following a calendar [Tool 1] set up in advance of how to budget time and labor.

The basic threshing device is a rotating cylinder with bristles, like a giant circular hair brush. Farmers hold sheaves over the rotating drum, which pulls off the grains and sends the chaff flying. The shaft is turned by a foot treadle or by a small engine. The grains are too heavy to be air-borne and drop into the pan at the bottom of the device.

CTI, [Compatible Technology International](https://bit.ly/2KNTHLj) [bit.ly/2KNTHLj], recently introduced a human-powered pearl millet mechanical processor in Senegal in partnership with USAID. Traditionally pearl millet, a West African staple, is

threshed by pounding it with an oar-sized pestle in a mortar sitting on the ground—back-breaking work. CTI co-designed a mechanical pearl millet processing machine along with end-users.

Their innovation

- Combines stripping, threshing, and winnowing (separating the grain from the chaff)—Voila! Clean grain free of debris drops into a collection bin
- Processes five times faster than by hand. What took days now takes hours; what took hours is accomplished in minutes, especially since it also strips and winnows
- Requires no fuel, making it eco-friendly
- Benefits women in particular since they are tasked with processing the pearl millet; this liberates their time for other tasks, including helping other women's farmer group members with their crop processing, or managing the business of renting the equipment to non-members



CTI's co-created crank-operated pearl millet thresher/winnowing in Senegal - Photo: CTI

Power for rotating the mechanical thresher's drum can also be provided by pedaling a bicycle drivetrain. FarmHacks has posted [Open Source instructions for a pedal-powered thresher \[bit.ly/2KOo4Bi\]](https://bit.ly/2KOo4Bi); it can be adapted for different types of beans and grains.



Sasakawa Africa Association's Agro-Processing for Smallholders [\[bit.ly/2wS2vLX\]](https://bit.ly/2wS2vLX)



MSU Bicycle Powered Legume Thresher Prototype [\[bit.ly/2wS2vLX\]](https://bit.ly/2wS2vLX)



Village Introduction of a Paddy Thresher [\[bit.ly/2NmkrQ\]](https://bit.ly/2NmkrQ)

Kansas State University's Postharvest Innovation Lab on Twitter [@PHLInnovLab](https://twitter.com/PHLInnovLab)



PEF graduate Ibrahim Seid demonstrates a \$1 [tool that shells 20 kg/hour](https://bit.ly/2vF9ibd) [bit.ly/2vF9ibd], at the Agricultural Mechanization Research Center in Ethiopia - Photo: Mekbib Heilegebrile Seife - PEF Graduate, Ethiopia, 2012

20

Maize is the most widely produced cereal crop in the world, the top food choice in Southern and Eastern Africa, Central America, and Mexico. According to CropTrust.org, this cereal, which originated in Mexico, is now grown in at least 164 countries around the world with a total production of more than 1 billion metric tons in 2013. If post-harvest loss is an estimated 30-40%, 300+ million tons of maize goes missing annually.

The maize value chain is complex. Though smallholder farmers primarily raise maize for household consumption rather than market sales, surplus maize is utilized in a wide variety of ways:

- Direct consumption (fresh sweet corn, as a vegetable)
- Milled into maize flour (cornmeal) for a wide variety of traditional foods
- Food additives like corn sweetener, alcohol, and oil
- Alcohol for direct consumption
- Animal consumption
- Ethanol for fuel

Once maize is harvested, it must be dried before shelling. (Sweet corn eaten fresh is actually highly perishable immature corn.) Maize is husked and stored, but sometimes farmers leave it in the fields to dry. These ripe ears are directly exposed to rain and hungry rodents; much of this portion of the crop is lost.

Shelling

Speeding up maize shelling, peeling its dried kernels off the cobs, shortens the crop's exposure to the elements while in the field. It also frees workers to redeploy their time more productively.



When the maize cobs' moisture level [Tool 45] is in the 13%-14% range, shelling can commence. Shelling is done on the farm, since it would be unwieldy and inefficient to move tons of cobs. The dried kernels come off when hand pressure is applied. This tedious task, hand shelling, is the traditional norm. It is often women and children who perform this repetitive, stressful work but since they are not compensated, it is often unaccounted for in farm labor measurements.

Speeding up the task through the use of well-designed hand tools is cheap and effective, diminishing the time the harvest is vulnerable and expanding marketable or edible yield. Shellers are commercially manufactured but easily fabricated locally. Plans are posted [online](https://bit.ly/2MdAmZC) [bit.ly/2MdAmZC]; many [versions](https://bit.ly/2MsGYCV) [bit.ly/2MsGYCV] are popular. Some are made from refashioned tin cans or PVC pipe, like the one



Rotary sheller attached to a PortalBike pedaling set-up in Nepal - Photo: PortalBike



Maize sheller demonstration in the Dubha village of India's Muzaffarpur District: Women traditionally shell maize with their hands (top), a time-consuming process that causes painful blisters. Under a Cereal Systems Initiatives for South Asia (CSISA) project, a simple and inexpensive manual hand sheller was introduced (bottom). Photo: Madhulika Singh/CIMMYT

popularized by the Agricultural Mechanization Research Center above. Sizes can be adjusted for the type of maize and the size of the shellers' hands.

The many hours saved by using hand-held shellers can be reallocated to harvesting more maize or other vital tasks. Children would normally be expected to stay out of school to help, so mechanizing this task supports their education.

Crank-operated rotary shellers are even faster. They are purchased free-standing and clamped to a working surface

with a makeshift collection bin. Check out these videos: [\[bit.ly/2MfSP7G\]](https://bit.ly/2MfSP7G) and [\[bit.ly/2P6sqqG\]](https://bit.ly/2P6sqqG).

[MayaPedal \[mayapedal.org\]](https://mayapedal.org) in Guatemala and [PortalBike \[portalbikes.org\]](https://portalbikes.org) in Nepal have developed bicycle-powered shellers. Their portability allows for a micro-business, whereby workers pedal their rotary sheller from farm to farm performing the task even faster, for a fee. This equipment could be owned by a co-op [Tool 87] or an individual entrepreneur.



Evaluation of Rotary Adjustable Maize Sheller in Ethiopia [\[bit.ly/2NU7DFX\]](https://bit.ly/2NU7DFX)



Rotary Maize Sheller in Action [\[bit.ly/2NmI6JQ\]](https://bit.ly/2NmI6JQ)



Demo of a Hand-Held Maize Sheller [\[bit.ly/2MV46eb\]](https://bit.ly/2MV46eb)



Section 2

PACKINGHOUSE

21. Cleaning the Produce
22. Chlorinated Wash
23. Digital Temperature Probe
24. Hot Water Treatments
25. Preservative Paste Treatments
26. Trimming Produce
27. Waxing
28. Sorting Tables / Manual Sorting
29. Color Charts
30. Sizing Rings and Mechanical Sizers
31. Packing by Hand
32. Packing Cartons, Crates, and Boxes
33. Interior Package Lining and Cushioning for Reducing Produce Injuries
34. Plastic Liners and Packaging to Retain Moisture
35. Packaging Enclosures and Modifications
36. MAP (Modified Atmospheric Packaging)
37. Hand Dollies and Hand Pallet Jacks
38. Evaporative Pre-Cooling
39. Pre-cooling: Hydro-Cooling with Cold Water and Ice



El Salvadoran farmers packing their vegetables - ©IFAD/Carla Francescutti

PACKINGHOUSE: INTRODUCTION



Packing fresh vegetables in Guguletu, Cape Town, South Africa - Photo: AUSAID SOUTH AFRICA

Once the crop is harvested, unless it will be consumed directly at the farm, it heads to the packinghouse. Relocating packing functions directly to the harvest field [Tool 15] minimizes the number of times produce is moved and speeds the packing process, reducing exposure to ambient heat. Freestanding packinghouses are

still a norm; upgrading in-house protocols will reduce losses.

Again, the four postharvest Super Tools come into play, contributing to loss reductions during packing. Of course, they work in tandem. Adopting loss reduction strategies provides multiple, interlocking benefits.



Gentle Handling: Taking care to avoid bruising and damage reduces food losses. Trimming the sharp edges and stems of plants prevents them from puncturing other plants [Tool

26], thus preventing pathogen spread. Packing by hand [Tool 31] and using well-designed boxes [Tool 32] with appropriate cushioning [Tool 33] are more ways to keep produce and customers happy. Hand dollies and pallet jacks [Tool 37] reduce friction and jostling, more gentle handling examples.



Temperature Management: Managing temperatures so foods do not spoil due to loss of moisture and/or rapid decay increases marketable quantities. At the packinghouse stage,

removing as much field heat as possible slows the natural deterioration of products; hydro-cooling [Tools 28 + 29] accomplishes this. Waxing [Tool 27] doesn't lower temperature, but reduces plants' water loss, adding to shelf life.

Tools that might be integrated into packinghouse protocol are also featured in subsequent sections. Evaporative coolers [Tools 70 and 71] are featured in the Section 4: Storage. Additional cooling tools [Tools 80 and 81] are included in Section 5: Transportation.



Sanitation: Cleaning produce [Tool 21] adds to its value but also prevents the spread of pathogens. Various treatments like Hot Water Dips [Tool 24] and Preservation Paste [Tool 25] kill

pathogens and/or prevent their maturation. Plastic films [Tool 34-35] protect produce from pathogen invasion as well as moisture loss.



ICT: Increasingly, digital technology aids in packinghouse functions. Digital Temperature Probes [Tool 23] test for a variety of variables, determining the correct next step for produce. Sized

and graded produce [Tools 29 and 30] can be marketed via apps connecting buyers and sellers posting their offerings and/or requests.

Weights, measures, and scales, covered in Tool 84, are also an important packinghouse tool.

The *USDA Agricultural Marketing Service Equipment Catalog for Fresh and Processed Products Inspections* [\[bit.ly/2QRF1aKJ\]](http://bit.ly/2QRF1aKJ) is a useful resource for packinghouse equipment.



Dianna Grant of East New York Farms! Youth Internship program washes bok choy at the United Community Centers Youth Farm in Brooklyn, N.Y - Photo: East New York Farms!

Cleaning the Produce

Washing fresh produce provides triple benefit: it removes pathogens that can degrade their host, prevents the spread of contagions to surrounding produce, and adds value. People pay more for cleaned produce.



21 Cleaning fruits and vegetables typically involves either dry brushing or washing, depending upon the type of produce. Note: some produce should NOT be washed.

Dry Brushing Produce

For some commodities, such as kiwifruits, peppers, citrus fruits and avocados, dry brushing may be sufficient to clean the produce. - Kitinoja and Kader (2015) p. 37.

WASH before cooling and packing: tomatoes, cucumbers, leafy greens

WASH to remove latex and reduce staining: mangoes, bananas

WASH after storage: sweet potatoes, potatoes, carrots

DRY BRUSH after curing or storage: onions, garlic, kiwifruit

DO NOT WASH: green beans, melons, cabbage, okra, peas, peppers, summer squash

—Kitinoja and Kader (2015), p. 38

The University of Florida recommends keeping brush speeds below 100 rpm to prevent damage and abrasions. Being able to clean without using water can minimize the need for chlorine wash water and reduce costs overall.

Washing Stations

A simple washing station comprised of a large sink or other receptacle and a hose with a spray nozzle facilitates washing, adding value to produce sold at the market and reducing pathogen damage.



FAO's Packhouse Manual features brushing and hand removal of damaged tomato fruits before grading - Photo: S. Horvitz, INTA E.E.A. Balcarce [bit.ly/2nzeWY8]



Philadelphia's Weavers Way Farm's retrofitted washing machine used as a giant salad spinner - Photo: Emma Dosch



Spray washing radishes at Bay Branch Farm in Cleveland, OH - Photo: Bay Branch Farm

Packinghouse washing adds to fruit and vegetables' commercial value as well as decreasing losses by cleaning off some of the surface agents that infect and degrade produce. Increased prices for prepped, washed/dried produce pay for the investments quickly, though washing hygienically is challenging in a packinghouse without running water.

The sink water's sanitation level must be managed, or this washing prep can have the opposite effect: spreading contamination from infected produce to healthy plants and reducing their value—see Chlorinated Water [Tool 22] procedures in the next entry.

Repurposed equipment that can do this job well include

- A large, freestanding sink with legs or placed on a table
- An old bath or wash tub
- A PVC plastic tank or tray with drainage holes

A spray nozzle on a hose can simply be held over produce placed on a wire mesh or vented plastic shallow tray; the water drips through and drains directly.

An upgraded version of a washing station, made of sheet metal, can be fabricated locally. Plans for a galvanized sheet metal tank for washing produce are posted [here \[bit.ly/2WM4TiA\]](https://bit.ly/2WM4TiA). A simple tray with holes can be used to allow the washed produce to drain and air dry before packing.

More elaborate plans (though still far less expensive than commercially produced washing stations) have also been developed by the [Leopold Center for Sustainable Agriculture \[bit.ly/2P6f5ib\]](https://bit.ly/2P6f5ib).

The chart below, based on theoretical price data published by Postharvest Innovations LLC (2017), shows the beneficial impact of washing produce prior to taking it to market. The costs for washing can be very low if running water is available for spraying produce after harvest or can cost up to \$300 to

| Crop-1000 kg load | Market value without washing before packing | Market value if washed before packing | Potential increase in profit per 1000 kg load |
|------------------------|---|---------------------------------------|---|
| Carrots | \$0.40 per kg \$400 per load | \$0.55 per kg \$550 per load | \$150 |
| Cucumbers | \$0.90 per kg \$900 per load | \$1.00 per kg \$1000 per load | \$100 |
| Leafy green vegetables | \$1.00 per kg \$1000 per load | \$1.50 per kg \$1500 per load | \$500 |

Source: [Postharvest Innovations Plan Series - Number 9](https://bit.ly/2NLExHQ) (2017) [bit.ly/2NLExHQ]

provide a large washing tank and chlorinated water recirculation system. Either way, the investment pays for itself quickly, especially when leafy greens are prepped through washing. Once paid for, washing stations keep on benefiting the bottom line without additional costs; they can help finance additional upgrades. They are well-suited for farmer co-ops [Tool 87] pooling resources.

Washed produce has enhanced cosmetic appeal and buyers are willing to pay extra for this labor-saving convenience.

Washed leafy greens are also a cash crop for American small farms. Simple air drying does not remove enough moisture from leafy greens—they require some shaking and spinning. Many [videos \[bit.ly/2MHDfy9\]](https://bit.ly/2MHDfy9) are posted online showing the conversion of old washing machines into giant salad spinners—the only working control necessary is an on/off switch for the spinner. Electricity, or another manner of running the mechanism, is required. One hack is to run the washing machine by attaching it to a bicycle, utilizing pedal power.



Washing Machine Salad Spinner [\[bit.ly/2Hh7prv\]](https://bit.ly/2Hh7prv)



SmallPlateFarm's DIY Washing Station [\[bit.ly/2M5uKvr\]](https://bit.ly/2M5uKvr)



Small Farm Greens Washing with Spinner Baskets and Washing Machine Spinner [\[bit.ly/2M7LBOr\]](https://bit.ly/2M7LBOr)



Washing aji dulce (sweet peppers) at U Mass Amherst's Research Farm - Photo: Zoraia Barros

Chlorinated Wash

Washing water-tolerant fruits and vegetables with chlorinated water at the packinghouse reduces the spread of surface pathogens, averting postharvest losses.



22

Produce is routinely washed in the packinghouse to remove field dirt and debris, unless it cannot handle water [see Kitinoja and Kader (2015) p. 38 for a list.]

Rinsing off any loose soil and debris improves aesthetic appearance and enhances food's market value, but if the wash water is dirty, pathogens will just spread from infected items to healthy ones, contaminating them all.

Washing should, therefore, only be done if the water is clean. If no potable water is available, it is better to skip the washing process.

Chlorination is an easily implemented, quick, inexpensive, and readily available treatment. When chlorine (powered or liquid) is dissolved in the washing water, it disinfects the harvested produce, halting the spread of bacteria. Chlorine is generally recognized as safe.

Chlorine is the familiar smell of swimming pools. Chlorine is also used to treat municipal drinking water and in households where pre-treated water is unavailable.

Chlorine kills pathogens on the surface but does not penetrate the fruit or vegetables' tissues. When sodium hypo-chlorite is mixed with water it produces hypochlorous acid (HOCl), the active compound that kills microorganisms.

Chlorine needs to be measured carefully to be maximally effective. The desired chlorine level is measured in parts per million, **ppm**. In the packinghouse, using **150-200 ppm** free chlorine solution prevents contamination (about 2 ml of chlorine bleach per liter of clean water). Inexpensive [chlorine](#)



Preparing to use test strips for chlorine wash of cilantro directly in the field, U Mass Amherst - Photo: Zoraia Barros

test strips [bit.ly/2MghTLV] are a low-tech way to check the chlorine levels.

- If chlorine concentration is too high, it can corrode equipment and will emit unpleasant smells.
- If chlorine levels are too low, it will not properly disinfect.

The pH (level of acid or base) needs to be monitored as well. The **pH range of 6.5-7.5** is optimal for sanitizing. Inexpensive and **readily available** [bit.ly/2vFhlzl], **pH test strips** (*not Litmus paper!—it simply turns red or blue, and doesn't provide enough detail*) can be used to test the pH of the water.

Chlorine ppm and pH both need to be monitored and adjusted as needed, generally hourly, throughout the process. Wash tanks need to be cleared of debris which lock up chlorine and adversely affect the treatment, and water needs to be filtered or changed.

While a chlorine wash is generally a packinghouse function, it can also take place directly at the farm after the harvest (as pictured), provided the concentrations can be properly monitored and maintained.

There is an app for this: Sensorex's **water testing probe** [bit.ly/2MHFu4x]. Under \$100, it attaches to a smart phone and can perform pH tests, along with many other water testing functions. Over time this can save money that would have been spent on one-time paper strip tests.

What kinds of organisms can cause decay that spoils harvested food?

Here are common terms:

MICROORGANISMS – microscopic organisms, especially bacterium, virus, or fungus.

PATHOGEN – a bacterium, virus, or other microorganism that can cause disease.

MICROBES – microorganisms, especially bacterium causing disease or fermentation.

BACTERIUM – members of a large group of unicellular microorganisms that have cell walls but lack organelles and an organized nucleus, including some that can cause disease.

FUNGI – FUNGUS – any of a group of unicellular or multicellular spore-producing organisms feeding on organic matter, including molds, yeast, mushrooms, and toadstools.

For farmers and processors meeting American organic certification standards, which fetch higher prices, a clear water rinse following the chlorine is required, to reassure people there is no detectible chlorine residue.



UC Davis: Chlorinated Wash Water Procedures [bit.ly/2Q8Hnt0]



Penn State Extension: Using Sanitizers in Wash Water, 3-Video Series (with background, strategies, and techniques) [bit.ly/2NXn3tj]



Cornell University Extension: Washing Station Procedures [bit.ly/2MSV01F]



Urban Farmer Curtis Stone's Washing Set-Up [bit.ly/2Ah2q6K]



Digital Temperature Probe

Digital temperature probes provide accurate, quick measurements of pulp, air, and container temperatures, facilitating decisions about when to provide cooling to prevent losses and quality problems for fruits and vegetables.



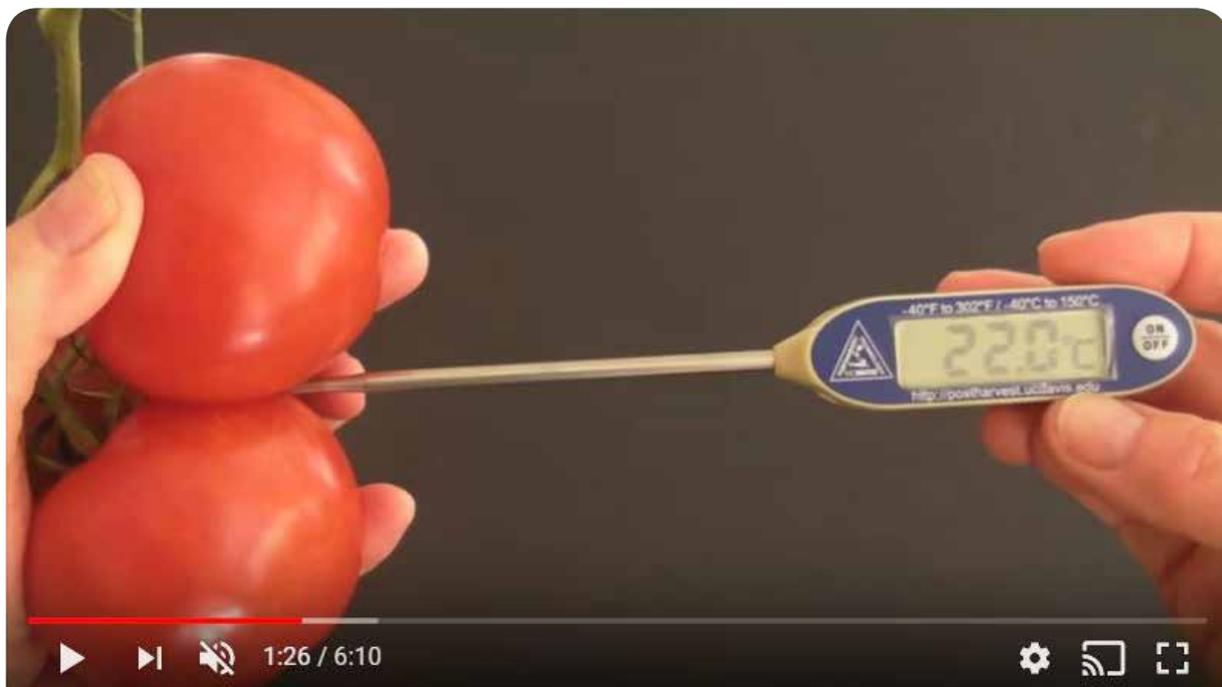
A [commercially available digital](https://bit.ly/2vHxslx) temperature probe [\[bit.ly/2vHxslx\]](https://bit.ly/2vHxslx)

23

The pulp temperature of produce can be checked within 10 seconds by inserting the tip of the probe into the item, but this naturally damages it. To avoid damaging produce, an accurate reading of the internal temperature can be obtained by holding the tip of the probe BETWEEN two items for 15 seconds. Knowing the temperature of the fresh

produce being handled, packed, and stored enables farmers, traders, and marketers to protect the foods from excessive heat, which will in turn prevent rapid deterioration.

Each type of produce has a “lowest safe temperature” for extending its shelf life. Postharvest handling requires knowing what these temperatures are and trying to maintain the best



How to Measure Temperature and Relative Humidity

[Video \[bit.ly/2NTaeQs\]](https://bit.ly/2NTaeQs) by Dr. Diane Barrett

environment for the produce. You can look up these recommended temperatures online for more than 200 crops at the [UCDavis Postharvest site \[bit.ly/2HCBRuB\]](https://bit.ly/2HCBRuB).

Battery-operated, affordable Digital Temperature Probes

- Can be field-calibrated using ice water, allowing farmers to customize the information they gather
- Are waterproof so can be washed with soap and water for thorough cleaning and sanitization
- Fit comfortably in the hand or pocket, and are lightweight, inexpensive tools (priced at about \$25)
- Are calibrated by putting the probe in crushed ice and setting it to 0°C or boiling water and setting it to 100°C
- Operate via a watch-type battery, with the battery lasting about one year with typical use.



QA Supplies [\[bit.ly/2MTOhnT\]](https://bit.ly/2MTOhnT)



UC Davis: How to Measure Temperature and Relative Humidity by Diane M. Barrett, PEF Board Member [\[bit.ly/2NTaeQs\]](https://bit.ly/2NTaeQs)



Hot water treatment of papayas - Postharvest Handling of Mango, UC Davis, slideplayer.com/slide/6299318/

Hot Water Treatments

Hot water treatments that kill insects and fungal pests, followed by cold water sprays, expand the quantity of high-quality fruits and vegetables available for market consumption.



24

We humans are always in competition with insects, fruit flies, and microorganisms who also feed on ripe fruit and vegetables. Carefully monitored hot water treatments (also called **HWD**—hot water dip) can eliminate most of these pests for certain types of produce, but it can also damage the fruits or vegetables. Hot water injury can actually create losses if it is not carefully counteracted by an immediate cooling bath or cold-water spray. And of course, the hot water itself needs to be from a potable water source that is known to be pathogen-free.

Hot water treatment times vary according to the specific insect or pest being targeted (see chart on next page).

Accessing the energy required for heating the water to the desired temperature is challenging in low resource areas with constrained fuel and energy access. Controlling the temperature of the water without the aid of sophisticated heat management technology is an additional challenge but a digital temperature probe [Tool 23] does the job well. Plus, the cold-water treatment must be ready to go immediately so the hot water treatment doesn't damage the produce.

Non-experts may be curious: Why doesn't hot water treatment "stew" the fruits or vegetables? The answer is the peel of the treated fruits is quite thick, and/or the time of the treatment is quite short.

For some crops, such as mangoes, hot water treatment is required for export according to the protocol of the receiving country. This is form of quarantine to ward against fruit flies and other insects entering across borders. Hot water treatments followed immediately by hydro-cooling have been performed safely for many decades, without any reductions to the quality of the fruit.

Mangoes are India's most important commercial crop. A hot water treatment design such as the one at the Indian Institute of [Horticultural Research in Bangalore \[bit.ly/2B8f5eR\]](https://bit.ly/2B8f5eR) is a large metal vat with electric heaters into which crates of mangoes are submerged. Their installation of solar water heating equipment has significantly lowered their energy costs.

Heat Treatment Reduces Anthracnose Incidence and Severity on Mangoes



Postharvest Handling of Mango, UC Davis, slideplayer.com/slide/6299318/

Hot Water Treatments

| Commodity | Pathogens | Temperature (°C) | Time (min) | Possible Injuries |
|---------------|---|------------------|------------|----------------------|
| Apple | Gloeosporium sp. Penicillium expansum | 45 | 10 | Reduced storage life |
| Grapefruit | Phytophthora citrophthora | 48 | 3 | |
| Green Beans | Pythium butleri Sclerotinia sclerotiorum | 52 | 0.5 | |
| Lemon | Penicillium digitatum Phytophthora sp. | 52 | 5-10 | |
| Mango | Anthracoese Collectotrichum gloeosporioides | 52 | 5 | No stem rot control |
| Melon | Fungi | 57-63 | 0.5 | |
| Orange | Diplodia sp Phomopsis sp. Phytophthra sp. | 53 | 5 | Poor de-greening |
| Papaya | Fungi | 48 | 20 | |
| Papaya* | Anthracoese Colletotrichum | 42 49 | 30 20 | |
| Peach | Monolinia fruticola Rhizopus stolonifer | 52 | 2.5 | Motile skin |
| Pepper (bell) | Erwini sp. | 53 | 1.5 | Slight spotting |

* papaya anthracnose control requires both treatments, 30 minutes at 42 °C followed by 20 min at 49 °C.
—Kitinoja and Kader (2015), p. 108

Hot water treatment dips can be heated using wood or coal fires, propane, natural gas, or electric or solar water heaters.

Temperature requirements vary by the commodity being treated, but typically range from 40°C to 52°C, requiring 9.2 to 14.7 kWh of energy to raise 400 L of water from ambient temperatures of 20°C to 25°C via resistance heating.

Solar water heating can reduce substantially the electricity or propane requirements, saving 80 to 90% of the fuel that would otherwise be required. Simple

flat plate solar collectors with single glazing can be made locally and are commercially widely available in most of the world.

Storing the water that will be used for hot water dips inside a large outdoor tank that is painted black and deliberately left exposed to the sun can increase the ambient temperature of the water to 30°C and reduce subsequent heating costs by 30% or more.

—[Empowering Agriculture: Energy Options for Horticulture \[bit.ly/2Mh3eAj\]](#)
—Winrock and USAID, 2009



UCANR Technical Review of Postharvest Treatments [\[bit.ly/2wTosuf\]](https://bit.ly/2wTosuf)



USAID Mango Postharvest Training, featuring Mangoes (including the hot water treatment) [\[bit.ly/2Qfx6LR\]](https://bit.ly/2Qfx6LR)



Triptych showing rotting cabbage, upper left. Lower left, workers use paint brushes to apply preservative pastes on the butt stem end of cabbages. Right, a comparison of different treatments - Photo: World Vegetable Center

Preservative Paste Treatments

Readily available, inexpensive treatments—baking soda and powdered lime, among others—can be applied to retard or eradicate decay on some fruits and vegetables.



25 Common pests can be blocked from the produce they frequent with some very simple interventions, essentially spreading a paste on the general surface or at the point of microorganism entry, like the butt end of cruciferous vegetables.

Bicarbonate salts for postharvest decay prevention have been used on fresh peppers, melons, potatoes, carrots, and citrus fruits. These salts are very inexpensive, safe to use, readily available, and accepted as “certified organic” and “chemical free” for marketing purposes.

Bicarbonate salts include:

- Bicarbonate of soda, commonly known as baking soda (NaHCO_3)
- Potassium bicarbonate (KHCO_3)

They are applied by spraying or painting onto the butt end’s cut surface, or the butt end is dipped into a clear liquid solution.

Alum, as aluminum potassium sulfate is nicknamed, is also an effective preservative due to its astringent properties. Lime powder is, too, due to its natural drying properties, which are similar to alum; gardeners who use lime will recall how it immediately dries the skin. Cabbage is at risk for microbial infections resulting in browning and bacterial soft rot. Its shelf life can be prolonged by applying a paste on the butt stem end immediately after harvesting of one of the following:

- **Lime powder paste**—made by mixing lime, CaCO_3 , in water at a ratio of 1:1. [Note this is lime as in limestone, available in powdered form, not the green citrus fruit lime, which is called by the same name.] Use of powdered lime can reduce losses due to soft rot in cabbage from the typical amount of

20% trimming losses to 0% (Economic Analysis of Postharvest Technologies for Vegetables, [Acedo and Weinberger in AVRDC 2008](#)) [bit.ly/2yY6zea]

- Alum powder paste—a mix of 15 grams of Alum, $KAl(SO_4)_2$, potassium aluminum sulphate in 100 ml of water. If a weighing scale is not available, prepare the solution by adding and dissolving alum into a small volume of water until such time that the alum will not dissolve anymore (the solution is saturated).

After treatment of the butt-end of the cabbage heads, the produce should be allowed to dry for 20 to 30 minutes before packing.

The shelf life of the treated cabbage was significantly extended (14-15 days) over untreated control (6-7days). [Postharvest Handling of Cabbage and Chili in Asian Countries, p. 29](#) [bit.ly/2w2P22X]

The World Vegetable Center gives instructions for a variety of preservative pastes [bit.ly/2w6XoGv]:

Bacterial soft rot is the most serious postharvest problem of cabbages and other crucifers in the humid tropics. The disease usually starts at the cut butt end

of cabbage. It can be prevented or minimized by simply applying lime paste, 15% alum or guava leaf extract at the butt before packing and handling. The techniques are very simple and cheap, but extremely effective—sometimes eliminating the problem completely—and can yield high returns.

In addition to lime or alum treatment, they recommend guava leaf treatment.

- Prepare guava leaf extract by extracting pure extract from mature leaves of guava (slice the leaves and extract juice using mortar and pestle) and add water at 1:1 mixture.
- Apply the lime paste, alum solution, or guava leaf extract at the cut butt end of cabbage using any suitable, clean applicator such as
 - soft, fine brush
 - natural cotton puff
 - cotton cloth
- Allow to dry before packing and subsequent handling.

Application method for bicarbonate salts; chlorinated water is optional:

| Method | Rate | Followed By |
|---|---|----------------|
| Overhead spray or dip 2% solution | Use 2 g in 100 mL water or 20 g per liter | |
| Overhead spray or dip 3% solution. Rinse in water | Use 3 g in 100 mL water or 30 g per liter | Rinse in water |

–Kitinoja and Kader (2015), p. 100



AVRDC's Manual on Cabbage and Chili [bit.ly/2oQ5oc0]



AVRDC's page on Paste Preservation [bit.ly/2MUZBjV]



Demonstration of the amount of post-trimming cauliflower plant waste, in India - Photo: Sunil Saran

26

Trimmed produce is more compact and generally more visually appealing. Cutting off exterior leaves with damage or rot decreases the plants' risk for the interior spread of pathogens or their spreading to neighboring plants. Fruits and vegetables' tough, woody, spikey stems and branches that are no longer necessary to the plant can damage other plants in the force and jostling of transit.

Cruciferous vegetables are prime candidates for a trim. Their leaves are large, tough, and expansive; their stems are thick and strong. Most plants are trimmed first in the field. At the packinghouse, more outer leaves are removed and stalks are cut to create a flat base.

Trimming excess outer leaves and any visible leaves with signs of decay (during the harvest and/or in the packinghouse) protects that plant as well as any other adjacent plants in transit. That way the decay is halted from spreading through a full container.

Transporting more compact products increases energy efficiency and lowers costs. It also reduces the the resources consumed in packaging. If a container heads to storage, reduced volume also consumes less space and energy for temperature control, another saving.

Trimming is done by expert workers with large, sharp knives. It is important to make sure the knives are washed and dried often, just as one would at home in a kitchen.

Large urban fruit and vegetable markets in the Global South generally lack waste management systems, resulting in the trashing of vast quantities of organic waste. This not only fails to capture the benefit of the waste, but it creates environmental and health hazards in slums where the dumps or landfills are located.

Trimming Produce

Trimming plants protects them from pathogen infection that can spread and prevents adjacent produce from contact injuries. It allows waste to be gathered, composted, and used as fertilizer and saves energy during transport by compacting volume.



Hence, trimming locally facilitates

- Composting the vegetable and fruit waste, turning it into a soil-enriching asset
- Feeding it to farm animals
- Supplying feedstock for a biodigester, a useful investment. Organic waste is dumped into the tank or balloon where it breaks it down, ultimately producing methane gas to fuel equipment. The remaining slurry is used as a soil amendment for local farms.



Artfully trimmed purple cauliflower from a Wisconsin CSA - Photo: Hermit Creek Farm

Sometimes vendors at Farmers Markets leave stems or leaves intact, adding to the natural, visual appeal and impressive size of their offerings. Conventional wholesale/retail supply chains prioritize food packing's compactness over natural aesthetics. The decreased volume saves space and lowers costs all along the value chain.

Over-trimming can cause waste and loss of edible food, so care should be taken to trim away only the inedible portions of the produce. Some vegetables that require serious trimming due to their long stems and large or spikey leaves include:

- Cauliflower
- Broccoli
- Cabbage
- Artichokes
- Pineapple
- Head lettuce, romaine lettuce



Untrimmed purple artichokes, violetta carciofi, at a Farmers Market; in some cultures, artichokes stems are peeled and cooked - Photo: Michael Horne/Flickr

Trimming losses for many types of leafy vegetables can be reduced by using the **“cut and come again”** [\[bit.ly/2nzgDEP\]](https://bit.ly/2nzgDEP) method of harvesting. It works well with leafy vegetables such as chard, spinach, kale, leaf lettuces, and some cole crops like broccoli and broccoli rabe.



“Cut and Come Again” Trimming [\[bit.ly/2Nt6FUo\]](https://bit.ly/2Nt6FUo)



Produce Nerd’s Cauliflower Field Packing [\[bit.ly/2OtW2yI\]](https://bit.ly/2OtW2yI)



Hand waxing mangoes in Guyana - permission requested - Photo: Guyana Ministry of Fisheries, Crops and Livestock

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For fruits and vegetables requiring packinghouse washing treatment, there is an unintended negative consequence: natural surface coatings are removed along with dirt. This can contribute to quicker moisture loss and shriveling and it increases their vulnerability to microorganisms.

Food grade wax coatings help avert moisture loss, add back additional anti-microbial protection, and expand shelf life length, reducing postharvest losses. They also add visual, cosmetic appeal: waxed fruits and vegetables are shinier, more attractive products. The most commonly waxed fruits are citrus, but other candidates for postharvest waxing include

- **Fruits:** apples, avocados, bananas, breadfruits, carambolas, coconuts, guavas, grapefruits, lemons, limes, mangoes, melons, oranges, papayas, passion fruits, peaches, pineapples, tangerines
- **Vegetables:** bell peppers, bitter melons, cassava, cucumbers, eggplants (also known as aubergine or brinjal), potatoes, pumpkins, rutabagas, sweet potatoes, tomatoes, turnips, yams

Waxes are typically applied by dipping, brushing or spraying. The amount of wax applied per item is miniscule; a whole outer coating is applied with just a drop or two of wax in water mixed with an emulsifier like biodegradable soap or lecithin.

Plants must be dry when they go through the waxing process. Melted wax can be daubed on plants directly or they can be dipped, for about a second, into a container of liquid paraffin

Waxing

For fruits and vegetables benefitting from a vapor barrier, a thin food grade wax coating extends their shelf life of by reducing water loss during handling and marketing. This reduces postharvest losses.



solution. In a mechanized packing line, waxing is done by saturated brush rollers or sprayed.

The most common waxes are paraffin, Brazilian carnauba, and shellac, a natural product made from insect exoskeletons.

While there is no evidence that waxed fruits and vegetables prevent any harm to consumers, some purchasers are uncomfortable with the synthetic appearance of waxing. For organic certified produce, the wax must be certified organic as well. There have been consumer campaigns railing against waxing, presuming it is only for cosmetic reasons. Understanding that it averts postharvest waste is a compelling counter argument.

Cassava, the staple of hundreds of millions of people, spoils quickly postharvest—within just a few days. This forces cassava farmers to sell as soon as possible, resulting in a great deal of lost income and food wasted due to glutted markets. Waxed cassava



Sharon Acheng of Makerere University holds a waxed (left) and a non-waxed cassava root in Uganda - Photo by S. Quinn/CIP



Exported waxed cassava in a grocery bin in Great Britain - Photo: Wikimedia/Jeffery Martin

roots can last up to a month, greatly extending opportunities for marketing locally, regionally, and internationally. This is a standard procedure in the Caribbean; a number of [NGOs are working to transfer this technology to Africa \[bit.ly/2OyVk1U\]](#), starting in Uganda.

The project has demonstrated the value of waxed cassava: urban consumers were willing to pay US\$.71 per kg for the waxed roots versus US\$.31-0.42 per kg for non-waxed roots.



Waxed citrus at retail in France - Photo: Deirdre Holcroft

The cost of waxing per root is just **1.6¢**, making waxing an enormous return on investment. Buyers are willing to pay a premium for waxed cassavas that last longer in their larders.

Gum Arabic shows promise as an environmentally friendly, safe [micro-coating agent \[bit.ly/2Mh6AmI\]](#); it could replace paraffin, a fossil-fuel passed produce. Gum Arabic is sourced in Africa; it could be another value chain to add to agricultural activity.

When an item has lost 5% or more of its original weight it will be visually noticeable. This amount of moisture loss typically lowers the grade of the product or makes it completely unmarketable. The longer produce is expected to be stored, the more important waxing becomes in reducing weight loss. Application of a thin layer of wax coating can reduce product weight loss by 30 to 40%.

—[Postharvest Handling Technical Series, \[bit.ly/2wa7KFY\]](#) Guyana



Guyana Waxing Manual [\[bit.ly/2wRiYQv\]](#)



Science Tech Entrepreneur: Preservation of Fruits by Waxing [\[bit.ly/2Nves3I\]](#)



Best Food Fact: Wax on Apples [\[bit.ly/2WWCRQW\]](#)



Product Marketing Association—PMA: How to Label Wax or Resin Coatings [\[bit.ly/2oQ2zHY\]](#)



Workers sort coffee cherries in Santa Domingo, with culls going into buckets - IFAD/Joanne Levitan

Sorting Tables / Manual Sorting

Hand culling and sorting on a raised surface increases the value of products and prevents decay from spreading to healthy commodities. Sorting tables can be used for field packing or in packinghouses.



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Hand sorting to inspect for damaged, diseased, or otherwise problematic fruits and vegetables (or grains and pulses), as well as pulling out “foreign objects”, results in less product damage than mechanical sorting. Performing this function, known as culling, as soon as possible after harvest means less is expended on the rejects, increasing efficiency and saving resources. Edible rejects can be salvaged and eaten at the farm or given to workers or local families rather than wasted altogether.

Trained workers can sort manually without any advanced equipment and do a better job than automated processes.

Hand sorting is frequently done on the ground when workers are **field packing** [bit.ly/2OzMJMu] or on the floor of a packinghouse. Raising the sorting process to table height is more hygienic, preventing ground or floor contamination from pathogens and pests. It is also more comfortable for workers.

A well-designed sorting table speeds the job and decreases workers’ physical stress:

- Good lighting is important, especially since a field packinghouse should be shaded [bit.ly/2P58Vih] to decrease hot sun shining on harvested crops.
- For indoor packinghouses, LEDs are extremely energy efficient and increasingly affordable, providing bright light without adding any heat. LEDs can run on solar charging.

- A foam rubber pad on the floor eases worker fatigue.
- Compartmentalizing the table to follow the work flow speeds the process. A canvas-bottomed or cushioned portion of the table allows the produce to gently rest before sorting. Two or three bins for easy categorizing are useful. For some commodities, sorting can be combined with grading, both by size [Tool 30] and by color [Tool 29], adding efficiency and reducing the number of times the produce is handled.



Women manually sorting chickpeas in a state-of-the-art plant in Adama, Ethiopia, facilitated by the USAID-funded program Agribusiness Market Development Program - Photo: Nicholas Parkinson, Communications Manager, ACDI VOCA

If the typical 20% damage caused by field and packing operations taking place on the ground is reduced to 5% damage when using the raised table, a **100% return of investment** can be expected with the first use.

–[Postharvest Innovations Plan Series Number 5 \[bit.ly/2OBwfU7\]](https://bit.ly/2OBwfU7)

| | With use of a sorting/grading/packing table | Traditional handling on the ground in the orchard |
|---------------------------|--|---|
| Costs | \$100 to build | \$0 |
| Benefits | 5% of the fruits are damaged | 20% of the fruits are damaged. Explains Kitinoja, “With traditional field sorting, commodities tend to be left on the ground, piled up too high, handled roughly, and dumped from one place or container to another, all causing damage. We observed tomatoes being handled 25 times by various people while being moved from place to place in the field during collection, piling, sorting, and packing into huge baskets.” |
| Value per kg | 95% High-quality = \$1.00 per kg (\$900) 5% Poor quality = \$0.30 per kg (\$15) | 80% High-quality = \$1.00 per kg (\$800) 20% Poor quality = \$0.30 per kg (\$60) |
| Total market value | \$965 | \$860 |

Each subsequent use of the table will result in a further \$105 profit compared to traditional handling and packing of guava in the orchard.

Example: Improved Handling and Packing of 1000 kg of Guava fruits - [Postharvest Innovations Plan Series Number 5 \[bit.ly/2PBVwOE\]](https://bit.ly/2PBVwOE)

Cheap eyeglasses are available through a variety of sources; workers needing vision correction are obviously more effective when they obtain affordable prescription glasses. Magnifiers are available without prescription and can reduce eye strain.



Postharvest Innovations Plan Series #5: Sorting/Grading Packing Table [\[bit.ly/2oPV0ks\]](https://bit.ly/2oPV0ks)



FAO.org: Packing House Operations [\[bit.ly/2U0iy3f\]](https://bit.ly/2U0iy3f)

Color Charts for Sorting and Grading

Sorting and grading separate out top quality produce. At peak maturity and free of decay, it will have a longer shelf life and sell for a higher price in the marketplace. Lower quality fruits and vegetables are sold for reduced prices instead of discarded, decreasing waste.



Sorting tomatoes by color chart, courtesy of [Kowafresh \[Kowafresh.com\]](http://Kowafresh.com), a logistics B2B postharvest African company - Photo: Ademola Adebawale/Kowafresh 2015

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The theory behind sorting and grading is simple: consolidating fruits and vegetables by size, ripeness (color is a proxy for stage of ripeness), and general quality allows micro-targeting for specific markets. Wholesale buyers pay a premium for pre-selected top-grade foods so their customers don't need to waste time picking out the best produce [Tool 82]) or waiting for foods to ripen.

Likewise, produce of lesser quality—smaller size, surface

blemished, oddly shaped [Tool 14], or what have you—can also be grouped together and sold for lower prices instead of discarded.

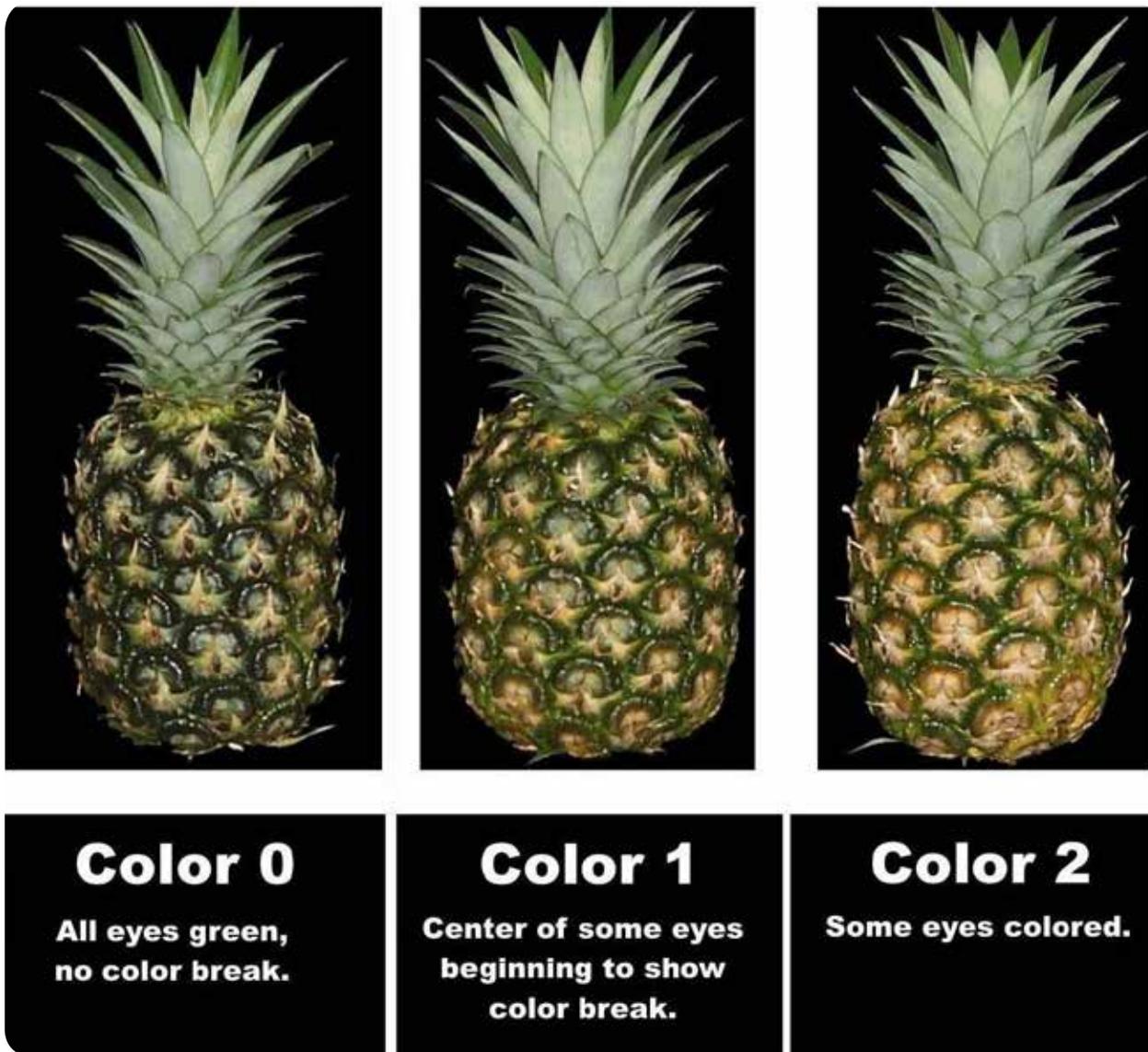
In my Philadelphia neighborhood, a market features cheaper produce of just this type; I make a point of purchasing their very small avocados. In typical grocery stores, the large, higher-priced avocados are more than my family of two typically eats, and the excess goes to waste. Since I prefer the smaller



Highest quality okra pods are in the green zone. If they extend into the red zone, they are classified as 2nd quality and sold for a lower price - Photo: IFAD/ Irshad Khan



Workers sort and grade the morning's okra harvest by size, near a field not far from the village of Si Pin Thayar in Myanmar - Photo: IFAD/ Irshad Khan



Hispacori's packinghouse chart for assessing ripeness in San Jose, Costa Rica - Photo: Hispacori.com/Facebook

single portion avocados, I get a good deal and the discount store has created a market for cute little “mini-avocados”. Win-win.

Color is an objective indicator of a plant's degree of ripeness. Grouping shipments by their maturity level means that sellers can be confident of the consistency of the lots they purchase. If fruit or vegetable batches are at different stages of maturity, some will spoil before the others are peak, lowering the value of the whole lot. Likewise, plants that are further away from peak ripeness do not satisfy customers' demand for food that can be consumed immediately, so they are best off grouped together and sold to people planning ahead or left to ripen and then brought to market.

Experienced packinghouse workers can discern the maturation level by visually scanning the plants. More specific guidance is provided by color charts created for each type of fruit or vegetable; these are available from sources below. This is an automated process in industrial packinghouses, with expensive equipment that quantifies color and tries to approximate the human eye.

Grading charts are also available for sizing, another aspect of quality. In the case of okra, pictured, first quality pods need to be smaller, not larger. Smaller size correlates to their being of a preferred tenderness; longer pods are tough and fibrous.

Maturity – minimum 11.5% SS = 6% color



Papaya's range of color during ripening, interior and exterior—high-quality papayas are typically harvested when they reach 50% color - Photo: Postharvest Handling of Mango - UC Davis slideplayer.com/slide/6299318/



Postharvest Innovations Plan Series #4: Color Charts for Sorting [\[bit.ly/2R69w3p\]](https://bit.ly/2R69w3p)



OECD (Organisation for Economic Co-operation and Development) International Standards [\[bit.ly/2Ufq5QR\]](https://bit.ly/2Ufq5QR)



USDA Agricultural Marketing Service Equipment Catalog for Fresh and Processed Products Inspections [\[bit.ly/2QRFlaK\]](https://bit.ly/2QRFlaK)



UC Davis, PEF Board Member Dr. Diane Barrett: Sorting by Color to Increase Market Value [\[bit.ly/2Cq8b5b\]](https://bit.ly/2Cq8b5b)



UC Davis Manuals and CDs—#23A Produce Quality Rating Scales and Color Charts [\[bit.ly/2P50TsN\]](https://bit.ly/2P50TsN)

#25 Avocado Handbook [\[bit.ly/2P4dBI3\]](https://bit.ly/2P4dBI3)



Diverging potato sorter in Bolivia: smaller potatoes drop in between the narrow poles at the base, and larger potatoes make it to the widest - FAO/Katia Iversen

Sizing Rings and Mechanical Sizers

Grading foods by prescribed sizes (“sizing”) increases value chain efficiencies. Sized commodities feed the supply and demand for graded produce, lowest through highest.



30

For most commodities, the largest are the most prized: unblemished, ripe but not over-ripe, and well-shaped. International standards are established to rate most every agricultural commodity commercially produced. While experienced workers can make fairly accurate judgments, mechanical aids take the guesswork out of sizing.

Sizing adds value by selecting the “crème de la crème” of the crop that will fetch premium prices both in in-country urban markets and for out-of-country export. Lower grade fruits and vegetables, when mixed with the highest quality, reduce the value of the combined lot. Sizing can be done during field packing, or later in the packinghouse.

Creating a designated lower-value grade creates a market for these nutritious but less desirable foods. When mixed with higher quality offerings, they are typically rejected and ultimately wasted, in addition to lowering the value of the whole lot. Lower grade commodities can be sold

- For food processing, where size or appearance is irrelevant
- To local markets, where rural people have less income to spend on fresh foods
- To government, IGO, or NGO school lunch or other feeding programs
- To consumers educated to [accept lower aesthetic quality](https://vimeo.com/98441820) [vimeo.com/98441820]

The USDA and EU provide international standards for sizing many different crops:

UNECE (UN Economic Commission for Europe) [Fresh Fruit and Vegetable Standards](https://bit.ly/2Rbl1aU) [bit.ly/2Rbl1aU]

European Commission—Fruits and Vegetables: [Marketing Standards](https://bit.ly/2N9xrNd) [bit.ly/2N9xrNd]

USDA (US Department of Agriculture) [Agricultural Marketing Service Fruit Standards](https://bit.ly/2NNtaUV) [bit.ly/2NNtaUV]

USDA (US Department of Agriculture) [Agricultural Marketing Service Vegetable Standards](https://bit.ly/2N9KWfN) [bit.ly/2N9KWfN]

A variety of cellphone apps [Tool 93] connect sellers to buyers, who specify their desired color, size, or other specifications, creating market efficiencies, often with added content to educate farmers. Agromarketday.com in Uganda and Farmerline.co in Ghana are examples of digital platforms that offer all kinds of information to their networks.

Fruits and vegetables below the minimum standards can be eaten at the farm, gifted to workers, fed to animals, or composted.

An example comparing graded to ungraded loads of onions shows how much more valuable they are with the investment of labor and simple grading/sizing tools, together costing around \$50.

The price for **ungraded** mixed load of onions = \$0.50 per kg
 1000 kg of **ungraded** onions = **\$500.**

Prices for **graded** onions, per kg:

| | | | |
|---------------|----------------|---------------|-------------------|
| Small - \$.30 | Medium - \$.50 | Large - \$.70 | Colossal - \$1.00 |
|---------------|----------------|---------------|-------------------|

See how an average 1000 kg **graded** load generates \$630, compared to the \$500 it would have brought in ungraded:

| | | | | |
|------------------|--------------------|-------------------|----------------------|----------------------|
| 10% small = \$30 | 30% medium = \$150 | 50% large = \$350 | 10% Colossal = \$100 | Total = \$630 |
|------------------|--------------------|-------------------|----------------------|----------------------|

The farmer who grades her load will therefore earn an additional \$80, after subtracting \$50 for labor and tools, from the \$630 net = \$580 vs the \$500 the load would have generated had she not invested the time in grading. That equals nearly a 14% premium.

In some countries, the prime produce is exported; local populations rarely see top quality foods produced in their own nation.

Labor is expended for each load, but the tools can be reused for subsequent sorting at no additional cost. Of course, if the whole lot consists of smalls and mediums, with virtually no large or colossal onions, it wouldn't be worth grading. (When farmers know that premium produce fetches top dollar, they are more motivated to maximize their efforts to produce high quality crops.)

Automated grading tools can damage produce, so gentler hand-sizing reduces losses. Handheld sizing rings are calibrated according to specific measures. They are available commercially but can be fabricated locally as well, using wire and round molds. —Kitinoja and Kader (2015) p. 65

Diverging bar sorters, incredibly clever, are suited for hard, round commodities. The bars, close to each another at the base, radiate outwards (slanted downwards, so gravity does the work), with the distance between them fanning out over the expanse. Smaller orbs drop through at the beginning, with the

larger ones falling into successive bins below; the largest make it to the end. The photos featured are a tourist attraction at the Valhalla Macadamia nut farm in Antigua, Guatemala, where visitors can test out the locally fabricated sizer.



DIY citrus sizing rings designed by El Zeta; instructions are available online [bit.ly/2vFI05W] - Photo: El Zeta



Worker dumps macadamia nuts at the top of the diverging bar sorter at Valhalla in Antigua, Guatemala - Photo: Marni Davis



Ben Miller rolling macadamia nuts down the diverging bar sizer – Photo: Nathan Shelburne



Side view showing collection bags for six sizes of macadamia nuts - Photo: Marni Davis



Postharvest Innovations Plan Series #2: Sizing Rings [\[bit.ly/2Nsfiyn\]](https://bit.ly/2Nsfiyn)



Infoagro.com: Using a Sizer [\[bit.ly/2MaDRLI\]](https://bit.ly/2MaDRLI)



El Zeta's DIY Fruit Sizer (in Spanish) [\[bit.ly/2Cwn4D2\]](https://bit.ly/2Cwn4D2)



Handpackers move so swiftly the camera captures their motion; this woman is packing oranges in Lebanon - Photo: Hala Chahine

Packing by Hand

Packing by hand rather than machine results in less damage to fruits and vegetables, reducing postharvest losses. Workers can add aesthetic value, as well.



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Packing by hand is the norm in low-resource field packing and packinghouses. But even in more commercialized settings with advanced equipment, packing by hand is still preferable because automated packers damage more of the fruits and vegetables than humans do.

If the produce will be stored and shipped, packing is just a practical matter. If the fruit or vegetables are going directly to retail markets, hand-arranging can add aesthetic value to the packaging.

Workers must keep their hands clean and their fingernails

short, as long nails can damage produce. Sometimes packers wear cotton gloves to minimize damaging fruit. Gloves get dirty and spread pathogens so it's important to be vigilant in keeping them clean.

Hand packing allows the packaging of riper fruits; these command higher prices if they arrive at the market safely before over-ripening.

Workers are more comfortable packing at table level [Tool 28] rather than on the ground, and it is more hygienic as well. Good lighting is important as well, to reduce eye strain.



A farmer in Pakistan uses new packaging techniques to protect and extend the shelf life of his produce - Photo: Farrukh Mirza, Winrock International



Hand packing allows workers to create aesthetically pleasing arrangements like these edible nasturtium flowers packed in protective clamshell packaging at Caoba Organic Farmers Market, Antigua, Guatemala - Photo: Dina Tanners



Handpacking dragon fruit in Viet Nam - Photo: Safety-Fruits.com



Postharvest Innovations Plan Series #13: Field Packing [\[bit.ly/2wV2OoJ\]](https://bit.ly/2wV2OoJ)



Grape Field Sorting and Hand Packing [\[bit.ly/2M3miNr\]](https://bit.ly/2M3miNr)



Hand Packing Oranges in Valencia, Spain [\[bit.ly/2wQk7He\]](https://bit.ly/2wQk7He)



Scottish green grocer reusing shipping cartons and pallets for a visually interesting retail display - Photo: SwaloPhoto/Flickr

Packing Cartons, Crates, and Boxes

Well-designed, sturdy, ventilated packing boxes protect produce. They can be supplemented with interior cushioning, further guarding against injury in transit. Uniform boxes stack efficiently for storage and transportation.



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For surviving undamaged in transit and storage, stabilizing and protecting fruits and vegetables in sturdy containers is crucial. A wide variety of styles and types of boxes are available, manufactured from many different materials including fiberboard, wood, and plastic. A checklist for evaluating appropriate packaging helps choosing among options and can be accessed in the resources section. - Kitinoja and Kader (2015), p. 82-83.

Boxes can be wood or fiberboard. Crates can be wood, bamboo, or plastic. Containers for storing and shipping produce must balance a number of characteristics to perform the job well:

- **Large vs. small** - If containers are too large, when filled they become prohibitively heavy. This leads to boxes being dropped, increasing the likelihood of damage to the contents as well as worker injuries. Containers that are too small are inefficient.

Field trials conducted in Africa and India during 2009-10 showed that decreasing the size of huge packages (sacks, wooden crates, and baskets) could decrease losses by 30% (*Appropriate Postharvest Technology Project* - Saran, Roy and Kitinoja, 2012).
- **Stable vs. lightweight**—Cartons that are too light often collapse, destroying their contents. If they are too heavy, they add unnecessary weight and expense.

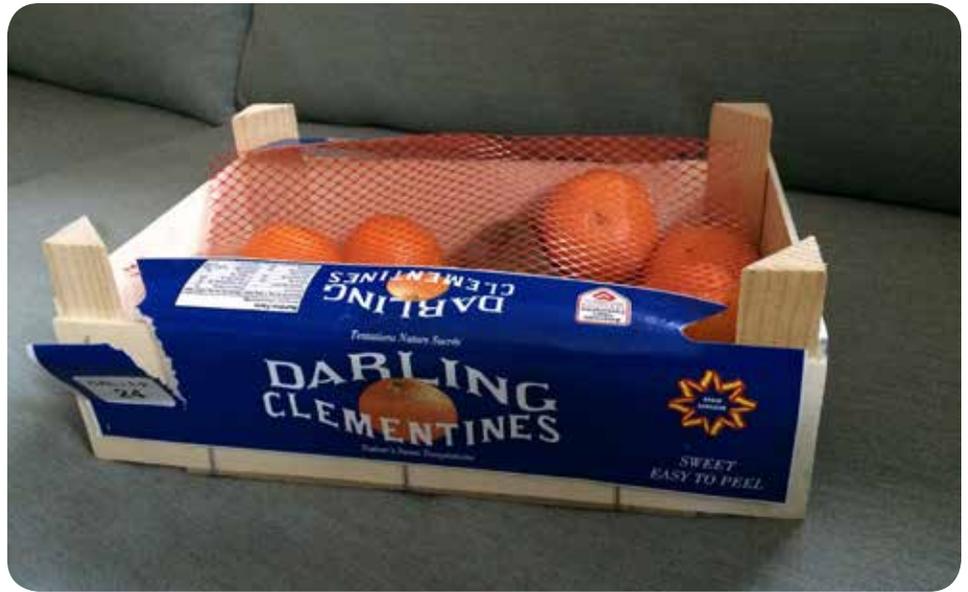
- **Solid vs. permeable** - Stored plants need protection but they also need to breathe; boxes must have at least 5% venting per side. If they are too loosely constructed, though, they will be unstable.
- **Affordable vs. reliable** - Well-designed packaging usually costs more. It enhances efficiency, reduces labor, and adds market appeal. Cheap, poorly made packaging can backfire, causing food losses. Over-packaging adds to costs, though, creating excessive waste, and is environmentally irresponsible.
- **Environmentally sustainable vs. disposable**—Some inexpensive materials, like corrugated cardboard, can be reused or composted. Plastic recycling is frequently non-existent in the Global South, creating immense pollution problems. Some materials are created from recycled content; others use virgin materials, another factor to consider. Sometimes virgin materials are preferred over reused, though, for their perceived higher hygienic properties.

In value chains for eco-conscious products like organic foods, using sustainable packaging could add value. This topic is explored in the AfterWord Essay on Plastics.

Containers need to stand up to humid conditions in storage; packaging choices need to take that into account. The fact that cardboard



Plastic crates for packing fresh produce in Rwanda - Photo: Lisa Kitinoja



A traditional stackable, open-top clementine crate with triangular corner reinforcement columns - Photo: Betsy Teutsch



A brightly printed branded Guatemalan corrugated plastic produce box pulled from the recycling bin of a food pantry near my Philadelphia house - Photo: Betsy Teutsch



First a sturdy cardboard watermelon container, now a pumpkin stand - Photo: Robert S. /Flickr



Open tomato cartons with hand grip holes that ease workers' moving tasks, efficiently stacked on pallets - Photo: Mike Krzeszak/Flickr

Half-sized crates were developed and tested in 2013 for a UC Davis Horticulture Innovation Lab project in Tanzania. These smaller wooden crates were compared to large, rough crates currently in use for packing and transporting ripe tomatoes. By using smaller crates, damage was reduced to less than half. Sanding the inner surfaces to reduce roughness will further decrease damage.

—Kitinoja and Kader (2015)

and fiberboard degrade naturally is a benefit when it has already performed its duty, but if it collapses and ruins the whole load it stores, it is a culprit in postharvest losses.

Boxes and cartons are available commercially in a huge range of styles. Transporting packaging supplies to remote areas is very costly. In such cases, if appropriate raw materials and labor are available locally, workers can use templates to create their own shipping containers.—Kitinoja and Kader (2015)—
Chapter 4.

For local sales, RPCs (reusable plastic crates) [Tool 12] can be used. Stackable, vented plastic crates can be used to pack perishable crops, are easy to clean, and can be used 150 times or more. Heavy duty crates with fewer vents can be used to pack melons, carrots, and crops that do not require much ventilation.

Adding bracing at corners of cartons is another strategy to decrease losses. Corner braces also provide a stacking mechanism for boxes with open or netted tops.

Traditional containers such as bags, sacks, and baskets do not give enough support, crushing foods at the bottom.

Wire-bound crates are commonly used for melons, beans, eggplant, greens, peppers, squash, and citrus fruits. Specialized style cartons are available for grapes, for asparagus, for tomatoes, and others.

Packaging is an opportunity for branding. Cartons designed for eventual use at the retail level are a form of advertising; attractive design and communications improve the product. Lisa Kitinoja observes that high-quality containers always add value—sometimes they cost more than the produce packed inside.

Corrugated plastic cartons, a newly expanding offering, lend themselves to bold, high-definition, high-contrast graphics.



North Carolina State Extension's Packaging Requirement for Fresh Fruits and Vegetables: A Manual [\[bit.ly/2MXhEpD\]](https://bit.ly/2MXhEpD)



FAO's Comprehensive Packaging Analysis [\[bit.ly/2QcRugo\]](https://bit.ly/2QcRugo)



Uline Packaging www.uline.com



Assembling a Die-Cut Cauliflower Carton [\[bit.ly/2oYmq7X\]](https://bit.ly/2oYmq7X)



Worker washing papayas before packing them in newspaper-lined wire and slat crates, La Roya, Peru - Photo: CIFAR/CGIAR/ Juan Carlos Huayllapuma

Interior Package Lining and Cushioning for Reducing Produce Injuries

Lining the containers and padding individual fruits and vegetables to stabilize and protect them from injuries in transit and storage significantly reduces losses.



33 Gentle handling, one of postharvest loss reduction's Super Tools, makes a huge difference in the packing, transit, and storage of fruit and vegetable containers. Stabilizing the load inside sturdy boxes [Tool 32] with prefabricated padding or locally available materials like straw or newspaper—if the ink does not contain toxic ingredients—prevents damages. Bruised plants can decay, leading to ruining either individual plants or spreading pathogens to the entire load.

Lining rough interiors of plastic, cardboard, or wood crates not only prevents against injuries from the force of transit, it also minimizes abrasions and bruises that can be inflicted by hard edges or sharp, spiky splinters. Cardboard does the job; adding vent holes helps control temperature. Newspaper is free and can be composted when transport is complete.

Manufactures offer a wide range of specialized packing inserts. Trays, cups, wraps, liners, and pads are available made from molded pulp, plastic, cardboard, and polystyrene foam. Some are made from recycled materials.

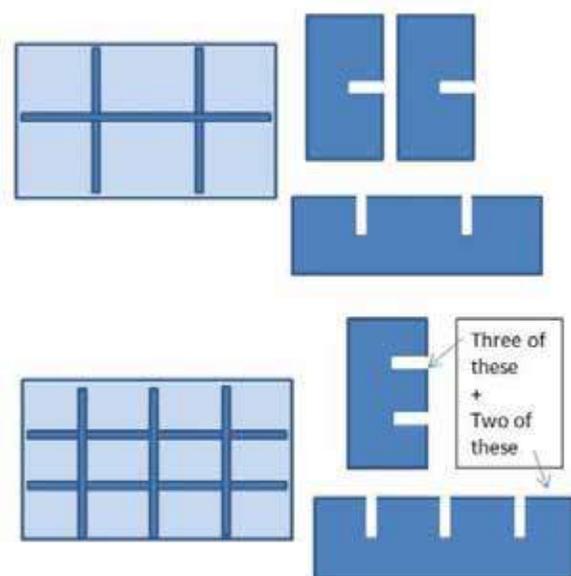
Most packing becomes trash at the end of the line, so it's important to use no more than necessary. Shredded newspaper accomplished much of the same benefit, though it is less aesthetically appealing when the foods are unpacked, especially if they go straight to a retail market.

Dividers perform a similar function, especially for large, heavy items like melons. They can be constructed like

“tic-tac-toe” grids by notching cardboard strips and connecting them face-up to face-down.

Even though padding and dividers can add volume that expands box size and expense, cushioning quickly pays for itself and then generates profits. The table presented shows savings from reducing damaged produce. If a cushioned shipment's higher quality generates even better prices, the increases would be larger than demonstrated here.

Some simple designs for dividers:



Courtesy of Postharvest Innovation Plan Series Number 17

| 1000 kg of Guava fruits | Typical large package or container | Same large package or container with Dividers | Potential Increase in Profits |
|---|--|--|--|
|  | Market price: \$1.50/kg 83 cartons @ \$1.00 15% discards due to abrasions, cuts, bruises, compression damage during shipping | Market price: \$1.50/kg 100 cartons @ \$1.00 100 dividers @ \$0.20 No mechanical damage | $\$1380 - 1192 = \mathbf{\$188}$ |
| | Market value: 850 kg x \$1.50 = \$1275 Net: \$1275 - \$83 = \$1192 | Market value: 1000 kg x \$1.50 = \$1500 Net: \$1500 - \$120 = \$1380 | Using dividers generate a 16% added profit - \$188 |

(Photo above) Guava seller in Kolhapur - Evgeni Zoltov

Source: [Postharvest Innovations Plan Series Number 17 \[bit.ly/2nzNo4U\]](https://www.postharvestinnovations.com/postharvest-innovations-plan-series-number-17)



Belle-de-coeur tomatoes nestled in a crushed purple paper bed, immobilizing and protecting them in their sturdy carton and showing them off at their destination - Photo: PXHERE.com



Bubble wrap on the bottom of a strawberry clamshell for protection - Photo: Deirdre Holcroft



Postharvest Innovations Plan Series #17: Package Liners and Dividers [\[bit.ly/2oS3Yhc\]](https://www.postharvestinnovations.com/postharvest-innovations-plan-series-number-17)



Banana packing in Cienaga, Magdalena, Colombia - Photo: J. Stephen Conn/Flickr

Plastic Liners and Packaging to Retain Moisture

Plastic packaging materials designed to decrease water loss are used both as carton liners and as individual enclosures for some large fruits and vegetables. This also provides cushioning.



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Water retention is a basic principle of reducing post-harvest losses.

At the time of harvest the water content of fruits and vegetables is very high and produce has a fresh appearance and crisp texture. Harvesting removes the plant from its water supply and the product begins to lose weight. This loss of water has an immediate economic effect in that it reduces saleable weight. Continued water loss causes wilting and/or shriveling. Consequently, reducing water loss improves produce appearance, quality, shelf life, and profitability.

—Deirdre Holcroft

Plastic does a great job at retaining water, though its inability to biodegrade is causing enormous global challenges. Plastic—a synthetic material—is prized for its

- Light weight
- Low cost
- Flexibility
- Strength
- Transparency, translucency, or opacity as desired

- Water-resistance
- Endless color range, plus ease of printing

Plastic has transformed life on earth, including agriculture and food distribution. In its many forms, plastic is gradually replacing traditional materials. Its properties help extend the life of fruits, vegetables, and flowers. Plastic is used to both line bulk containers and to wrap individual plants.

When containers of harvested vegetables and fruits plants are lined with plastic, it creates a vapor barrier, resulting in a micro-environment with higher relative humidity. It also can help cushion the load.

Polyethylene liners are added to shipping containers in cherry boxes, and polyethylene bags are used for

It is important to keep produce stored in polyethylene-lined cartons cool, to prevent damage due to carbon dioxide accumulation from increased respiration rates which can cause anaerobic conditions and off odors and flavors.

—Kitinoja and Kader (2015) p. 100



Packinghouse workers in Lushoto, Tanzania, showing off their packaged produce (net bags and vented plastic bags) - Photo: Esther Mwaisango - PEF graduate, Tanzania, 2012

bananas destined for distant markets. Using a polyethylene liner in a fiberboard carton can help protect produce and reduce water loss in commodities such as cherries, nectarines, kiwifruits, bananas, plums, leafy green, and herbs. Water vapor given off by the product is contained within the liner, increasing the relative humidity around the product and decreasing the rate of water loss.

The liner can also reduce abrasion damage that results from fruit rubbing against the inside of the box.

—Kitinoja and Kader (2015) p. 100

Plastic in its many forms is used for prepacking individual items in a larger carton, providing

- Moisture retention
- Protection from exterior moisture
- Cushioning
- Easier, efficient transfer from packinghouse to retail markets
- Communications: producers or wholesale buyers can print information and branding on the wrapper

- A restraint to retail customers' handling which can damage plants.

A wide variety of individual plastic packaging is available:

- Bags—unsealed (sealed packaging is covered in tool 36). Sometimes, like for cauliflower, the bags are taped but are not air-tight
- Vented bags—to reduce condensation; too much water can be damaging
- Clamshells have many desirable attributes (though watch out for sharp edges!)
 - Lightweight yet protective
 - Combining an attractive box with the waterproof quality of PET plastic
 - Transparent, so contents are visible
 - Stackable
 - Some can be opened and reclosed without destroying the packaging; if desired, they can be sealed shut

- Molded shapes can be designed to help display, stabilize, and protect the contents
- Rigidity allows for packages to stand vertically or be suspended, making eye-catching displays
- Sleeves—used for flowers and herbs

Utilizing plastic as efficiently as possible, yet trying to solve the global problem of single-use plastic waste is an immense challenge. Plastic's appeal is in large part its being water resistant. This becomes a problem once its job is complete. Precisely because it is non-biodegradable, it persists for centuries, as litter that over time breaks into small, environmentally toxic micro-particles.



Carrots in a carton lined with plastic to aid their moisture retention - Photo: Lisa Kitinoja



Postharvest Innovations Plan Series #17: Package Liners and Dividers [\[bit.ly/2oS3Yhc\]](https://bit.ly/2oS3Yhc)



Banana Packing in Ecuador [\[bit.ly/2wPHxgX\]](https://bit.ly/2wPHxgX)

Packing Grapes

Step 1: Start with an empty box



Step 2: Add a liner



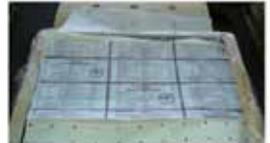
Step 3: Place the grapes in the box



Step 4: Add absorption material



Step 5: Add a TOP SO2 pad



Step 6: Fold the liner



Step 7: Close the box



Sulfur-infused pads can cover the whole surface area of table grape crates - Photo: [Eduardo Maldonado \[bit.ly/2BUKfVr\]](https://bit.ly/2BUKfVr)

35

1. Screening package vents to prevent insect damage for mangoes

Wire mesh screens can be added to packages to block the vent holes and prevent insects from entering the packages to lay eggs. Wire mesh is sometimes accepted as an alternative treatment to the use of chemical fumigation with pesticides for exported fruits. Wire mesh is cut locally to fit the inside of the cartons.

2. Sulfur-infused pads to reduce fungal decay in table grapes

Table grapes, non-climacteric fruit, do not continue to ripen after harvest; they are picked and packed at optimal maturity and packaged to maintain quality. Stored grapes are susceptible to molds and fungi. Adding slow-release pads of sulfur dioxide (SO₂) inhibits gray mold caused by the fungus *Botrytis cinerea*. This innovation goes all the way back to 1925. The technology commonly used now is the DR (dual release) pad, invented in the 1960s by Dr. K. E. Nelson. It gives an initial high release of SO₂ followed by slow release. Moisture within the package of grapes is absorbed by the pads and reacts with the sulfite, [releasing SO₂ \[bit.ly/2JILIEf\]](https://bit.ly/2JILIEf).

Packaging Enclosures and Modifications

Specific products are available to meet the packing needs of various fruits. Inexpensive additives and modifications reduce losses.



If too much SO₂ is released it can cause bleaching. The goal is to achieve the best distribution throughout the container as possible. (ibid.) The sulfur dioxide continues to be released for several months.

3. Ethylene absorbing pads to slow ripening

Ethylene is a naturally produced plant growth hormone, C₂H₄ or H₂C=CH₂. It is a colorless flammable gas with a faint, sweet, musky odor when pure.

Ancients noticed that gashing figs would stimulate their ripening; what caused this was the release of ethylene stimulated by the wounding. In the mid-19th Century it was observed that plants near gas lights had disturbed growth patterns. By early 20th Century, the link between ethylene and plant growth and aging was confirmed.

Ethylene is responsible for the changes in texture, softening, color, and other processes involved in plant ripening. It also controls senescence, plant deterioration. Controlling the effects of ethylene allows for slowing or speeding the ripening of ethylene-sensitive fruits and vegetables.

In packing and shipping, it is desirable to slow the ripening process for many fruits including bananas, tomatoes,

and pears. It is also important to reduce yellowing of ethylene sensitive vegetables, like cucumbers shipped with tomatoes. This is done by inserting ethylene absorbing sachets or filters, also called ethylene scavengers, into the shipping container. The most effective in-box ethylene absorbers are potassium permanganate or palladium.

It is important to be attentive when packing and shipping

a mixed load of fruits [Tool 68]. Some fruits, such as apples and pears, emit ethylene when they ripen and it can speed ripening in ethylene-sensitive plants. This may be detrimental, though the very same procedure—adding ethylene to speed ripening—can be used strategically when that is what marketers intend [Tool 85] when storing or marketing.



The Produce Nerd: Why Is Sulfur Dioxide Applied to Grapes? [\[bit.ly/2wWI7t8\]](https://bit.ly/2wWI7t8)



How to Use Uvasys (Sulphur Dioxide Pack) for Grapes [\[bit.ly/2Cx4tH9\]](https://bit.ly/2Cx4tH9)



Ethylene Control and Ethylene Filters [\[bit.ly/2QeGwXR\]](https://bit.ly/2QeGwXR)



Shrink wrapping cauliflower in India - Photo: S. K. Roy

MAP (Modified Atmospheric Packaging) and Shrink Wrapping

Modified Atmosphere Packaging (MAP), used with refrigeration, encapsulates produce in a thin plastic film. This reduces water loss and increases carbon dioxide while reducing oxygen, extending quality. Simple-to-use shrink film is a similar technology and can also reduce losses.



36

MAP is a form of packaging that usually reduces the oxygen and increases the carbon dioxide in a package, which can extend the shelf life of fresh produce. MAP can also alter the water vapor content or relative humidity.

MAP is usually high tech and can be used for large shipping containers, pallets, boxes, and individual packages. A simpler form of MAP is shrink-wrapping produce, which reduces water loss and slows respiration. Most MAP requires reliable refrigeration to maintain the desired atmosphere within the package.

MAP can be created by either packaging produce within a sealed container, usually a plastic bag, and allowing the natural respiration which uses oxygen and gives off to carbon dioxide to reduce the oxygen and increase the carbon dioxide in that package. Alternatively, MAP can be created by sealing a package and adding nitrogen or a prescribed gas mixture, a high-tech option. The atmosphere in the bag will continue to change as a result of respiration.

Typically, oxygen concentrations should be below 8% and carbon dioxide concentrations should be above 1% to have an effect on produce. The correct range of oxygen and carbon dioxide for the different fruits and vegetables is available in USDA Handbook 66, [The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks](#) [[bit.ly/2CBr2VPJ](#)]

and in [Produce Facts](#) [[bit.ly/2HCBRuB](#)] from UC Davis.

Plastic film packaging is widely used in produce packaging, but often the main benefit is reduced water loss, as optimum levels of oxygen and carbon dioxide are not always achieved.

Plastic encapsulating comes in different forms and will be familiar to customers who shop in supermarkets with elaborate refrigerated displays. Some products are directly coated in plastic with no added packaging; others are bagged. Some fruits and vegetables are plastic-wrapped on plastic trays.

Modified atmosphere packaging should always be considered as a supplement to proper temperature and relative humidity management. The differences between beneficial and harmful concentrations of oxygen and carbon dioxide for each kind of produce are relatively small, so great care must be taken when using these technologies.

—Kitinoja and Kader (2015) p 64

There are two main types of plastic film used in MAP, engineered polymers and micro-perforated film. The engineered polymers have specific permeabilities particularly to oxygen (called the oxygen transmission rate OTR). These must be matched with the respiration rate, weight, and optimum atmosphere for the product being packed. These are used where produce needs low oxygen and low carbon dioxide.

Micro-perforated films have very small holes in the package which allow oxygen, carbon dioxide, and water vapor to move in and out. The number of holes depends on respiration rate, weight, and acceptable atmosphere for the produce being packed. The sum of oxygen and carbon dioxide adds up to 21% in a micro-perforated bag and often the carbon dioxide is quite high e.g. 5-10% oxygen + 16-11% carbon dioxide. Produce being packed in this must be able to tolerate moderate to high carbon dioxide concentrations. - For more information, see Chapter 5 of Kitinoja and Gorny (1999) [bit.ly/2P9A1rq].

Mushrooms in 8 oz. trays bound in plastic film, long English cucumbers encased in plastic, and bagged iceberg lettuce are featured in most produce departments, even where the majority of produce is sold loose.

Individual Shrink Wrap (ISW) is considered excess packaging by some, but for specific types of foods it reduces waste by

- Keeping produce fresh by creating an oxygen barrier, extending shelf life, preventing discoloration, and maintaining appeal
- Providing protection from toxins and consumer handling while maintaining visibility
- Protecting foods from surface damage
- Providing confidence in the plant's food safety, as opposed to unpackaged produce, perceived by some as less hygienic
- Improving communication, since the wrapper can provide information

Some plants sealed in plastic film produce excess moisture, so they need to be wrapped in perforated plastic to allow ventilation.

“At the retail market, the shelf life of traditionally handled cauliflower was 5 days. With the improved practice, the shelf life of cauliflower increased to 8 days due to the wrapping of individual curds with plastic film. As a result, retailers are able to increase

their volume of sales and returns because of the extended period of 3 days over which good quality produce can be displayed for sale.”

—SlideShare/FAO [bit.ly/2w73pD5] -

Dr Abul Hasnat M Solaiman



Low-tech: using plastic film and tape to pack green eggplant in plastic crates in Bangladesh - Photo: Md Razu Ahmed - PEF Graduate, Bangladesh, 2015



Danish Technological Institute Guide to Packaging Fresh Fruits and Vegetables [\[bit.ly/2J4VG00\]](https://bit.ly/2J4VG00)



USDA Handbook 66 (792 pages): The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks [\[bit.ly/2wXSKLo\]](https://bit.ly/2wXSKLo)



MAP Bags for Melons [\[bit.ly/2CvED6h\]](https://bit.ly/2CvED6h)



Handling coffee bags in Ethiopia is eased by the use of a hand cart - Photo: ACIDI/VOCA

Hand Dollies and Hand Pallet Jacks

Utilizing basic tools—wheels, axle, and leverage—handcarts and pallet jacks allow workers to move tall stacks of crates and other heavy loads without damage to the food, or to themselves.



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Packinghouse workers move a wide variety of containers. The more standardized and coordinated the equipment and systems in the value chain are, the more efficient the movement of foods. Standardizing carton size, on uniform-sized pallets, is an example of an innovation that decreases exertion and increases efficiency.

Once produce is packed into cartons or crates, they need to be stacked for staging, where they are moved to storage or sent off to markets. Increasingly, these stacks of containers are stored on pallets [Tool 64], described in the Storage section of this book.

Utilizing handcarts or pallet jacks

- Greatly magnifies how many containers workers can move at a time, since they are rolling them rather than hoisting and carrying them
- Decreases the dropping of containers, protecting containers and their contents
- Reduces the numbers of times individual containers are moved, decreasing opportunities for mechanical damage and bruising of produce from vibration during transport, compression in a box, or impacts
- Improves gender parity, since women and men can both handle large loads

- Reduces worker strain and injury
- Requires no fuel or electricity

Pallet jacks, the costlier tool, typically consist of twin forks designed to slide underneath raised pallets. The prongs lift off the floor manually when the hydraulic jack is pumped (similar to a tire-changing jack), raising the pallet. Pallets and the containers standing are only elevated a few inches and then rolled. Their contents are barely jostled and their ride forward is smooth.



From [WikiHow's 6-step directions](https://www.wikihow.com/6-steps-to-Operating-a-Manual-Pallet-Jack) [bit.ly/2Gpxhyo] for operating a manual pallet jack - Photo: WikiHow

Some pallet jacks also include a scale, making it easier to weigh pallets and log this information into the record books directly before shipping.

A hand dolly, also called a hand cart or trolley, is a simpler, less expensive mechanism. It is L-shaped, with handlebars and a ledge at the bottom and wheels at the base. It is useful for carrying heavy loads, though pallet jacks can handle much heavier amounts. Their load is lifted, angled, and rolled.

Instructables.com features a simple conversion of a broken supermarket cart into a [serviceable hand cart \[bit.ly/2KONfnj\]](https://www.instructables.com/Serviceable-Hand-Cart/) with an hour and a half of labor. It can be used as a two-wheel angled load carrier or a four-wheeled flatbed. Old supermarket carts can be purchased in used appliance shops.



Tim Anderson's hand dolly fashioned from a trashed supermarket cart doubles as a flatbed - Photo: Tim Anderson/Instructables



A hand dolly moves a heavy crate of red onions easily - Photo: Lisa Kitinoja



Worker with a pallet jack moving mango in reusable plastic crates at Kibbutz Matsuva, Israel; cross-stacking adds strength to the stacks - Photo: Max Nathans/Flickr



DIY Hand Dolly [\[bit.ly/2wY1VwI\]](https://www.instructables.com/Serviceable-Hand-Cart/)



Desert cooler cabinet managed by Esa Abiso, cooling tomatoes in Ethiopia - Photo: Esa Abiso - PEF Graduate, Ethiopia, 2014

Evaporative Pre-Cooling

Removing field heat after harvest is a crucial step towards extending plants' viability. Evaporative cooling is a low-tech approach for lowering temperatures and preserving quality during packing.



38

Temperature management—keeping harvested produce at optimal low temperatures during its journey from harvest to consumption—is energy intensive. In low resource regions without accessible, affordable electricity for powering refrigeration (referred to as the **cold chain**), lower tech approaches for reducing produce temperature are required. They do not duplicate refrigeration, but any degree of temperature decrease expands the length produce can be preserved, making them quite effective. These eco-friendly strategies can also be deployed along with refrigeration for decreasing energy consumption.

Cooling techniques used, in the absence of refrigeration, along the value chain include

- Harvesting in the morning, to take advantage of lower temperatures
- Erecting a [sunshade in the field \[bit.ly/2P58Vih\]](https://bit.ly/2P58Vih) to protect harvested commodities
- Forced-air cooling (pulling or pushing cold air through stored crates using a high-powered fan)
- Water and ice cooling
- Transporting produce at night or early morning, when temperatures are lower

Evaporative cooling, also known as swamp or desert cooling, exploits the fact that a water from a saturated mat will evaporate and remove heat from surrounding space when warm air blows through it. Using evaporative cooling in the packinghouse works best with low to moderate relative humidity; adding so much humidity to the air makes it feel like a swamp.

For storage, for markets, and for end users without reliable refrigeration, small [pot-in-pot evaporative coolers \[bit.ly/2Mdf3qV\]](https://bit.ly/2Mdf3qV) larger ZECCs [Tool 71] and a new product, [Evaptainers](#) [Tool 74] preserve produce for many more days than if it is left at ambient air temperature. Water is continually added to replace what has evaporated.

“A desert cooler is simply a cabinet of shelves, covered with a cover made of wet burlap or jute cloth. The desert cool storage cabinet can be made in any size with local materials, such as bamboo, teak or other types of wood that have been oiled to prevent mold growth. It can be made in any size or shape to fit the available space.”

—Lisa Kitinoja

In the packinghouse, an evaporative cooling chamber can be as simple as a ventilated box or as large as a whole room with cover mats that can be saturated. Fans help push the air and increase efficiency.

| | | Air temperature (°C) | | | | | | | | | Air temperature (°F) | | | | | | | | |
|-----------------------|----|----------------------|-----|------|------|------|------|------|------|------|----------------------|------|------|------|------|------|------|-------|-------|
| | | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 41 | 50 | 59 | 68 | 77 | 86 | 95 | 104 | 113 |
| Relative Humidity (%) | 10 | -1.8 | 1.5 | 4.6 | 7.5 | 10.3 | 13.1 | 15.7 | 18.3 | 20.9 | 28.8 | 34.6 | 40.2 | 45.5 | 50.6 | 55.5 | 60.3 | 65.0 | 69.7 |
| | 20 | -1.0 | 2.5 | 5.9 | 9.2 | 12.4 | 15.6 | 18.7 | 21.8 | 25.0 | 30.3 | 36.5 | 42.6 | 48.5 | 54.3 | 60.0 | 65.7 | 71.3 | 77.0 |
| | 30 | -0.2 | 3.5 | 7.2 | 10.8 | 14.3 | 17.9 | 21.4 | 24.9 | 28.5 | 31.6 | 38.4 | 44.9 | 51.4 | 57.8 | 64.1 | 70.5 | 76.9 | 83.3 |
| | 40 | 0.6 | 4.5 | 8.4 | 12.3 | 16.1 | 20.0 | 23.8 | 27.7 | 31.6 | 33.0 | 40.2 | 47.2 | 54.1 | 61.0 | 67.9 | 74.8 | 81.9 | 88.9 |
| | 50 | 1.3 | 5.5 | 9.6 | 13.7 | 17.8 | 21.9 | 26.0 | 30.2 | 34.4 | 34.4 | 41.9 | 49.3 | 56.7 | 64.1 | 71.5 | 78.9 | 86.4 | 93.9 |
| | 60 | 2.1 | 6.5 | 10.8 | 15.1 | 19.4 | 23.8 | 28.1 | 32.5 | 36.9 | 35.8 | 43.6 | 51.4 | 59.2 | 66.9 | 74.8 | 82.6 | 90.5 | 98.4 |
| | 70 | 2.9 | 7.3 | 11.9 | 16.4 | 20.9 | 25.5 | 30.0 | 34.6 | 39.2 | 37.1 | 45.1 | 53.4 | 61.5 | 69.6 | 77.8 | 86.0 | 94.2 | 102.5 |
| | 80 | 3.6 | 8.3 | 13.0 | 17.7 | 22.4 | 27.1 | 31.8 | 36.5 | 41.3 | 38.4 | 46.9 | 55.3 | 63.8 | 72.2 | 80.7 | 89.2 | 97.7 | 106.3 |
| | 90 | 4.3 | 9.2 | 14.0 | 18.9 | 23.7 | 28.6 | 33.4 | 38.3 | 43.2 | 39.7 | 48.6 | 57.2 | 65.9 | 74.7 | 83.4 | 92.2 | 101.0 | 109.7 |

Tables of wet bulb temperatures in Celsius (left) and Fahrenheit (right) associated with air temperatures and relative humidity (%). Wet bulb temperature is the lowest temperature that can be achieved with evaporative cooling. Blue shaded areas represent the potential lower temperature that can be achieved using evaporative cooling at a given temperature and RH%. Notice that at RH 80% or above, not much cooling is possible.



Mini-evaporative cooler for leafy greens in packinghouse, Ethiopia - Photo: Lizanne Wheeler

Cooling provides the following benefits for perishable horticultural foods:

- Reduces respiration: lessens perishability
- Reduces transpiration: lessens water loss, less shriveling
- Reduces ethylene production: slows ripening
- Increases resistance to ethylene action
- Decreases activity of microorganisms
- Reduces browning and loss of texture, flavor and nutrients
- Delays ripening and natural senescence

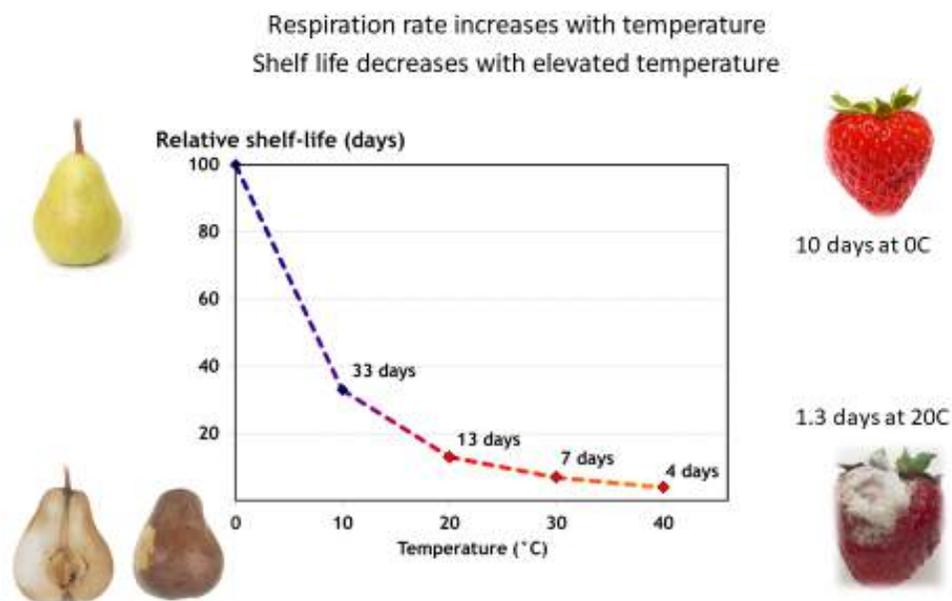
– **Kitinoja White Paper PEF 2013**
[\[bit.ly/1WEsmxN\]](http://bit.ly/1WEsmxN)

Some fruits can be damaged if they are overchilled, so achieving a sufficiently cool temperature with low-tech tools avoids that problem.

This table shows that even modest amounts of cooling relative to ambient temperature are beneficial. Respiration rate

and most other physiological activities are 2 to 3 times faster with every 10°C (18°F) increase in temperature. (This is called a Q10 coefficient). Therefore, if a crop with a Q10 of 3 lasts 100 days at 0°C (32°F), it will only last 33 days at 10°C (50°F), 13 days at 20°C (68°F) and 7 days at 30°C (86°F).

Respiration



Water Relations in Harvested Fresh Produce, PEF (2015) [\[bit.ly/2RVicuV\]](http://bit.ly/2RVicuV)

Household refrigerators are generally set to 2-6°C (37-43°F).

| Food | Storage Potential | | | |
|------------------------|-------------------------------|---------------------------------|--------------------------------|---------------------------------|
| Fresh Green Vegetables | 1 month at 0°C/32°F | 2 weeks at 10°C/50°F | 1 week at 20°C/68°F | Less than 2 days at 30°C/86°F |
| Potatoes | 5-10 months at 4 to 12°C/54°F | Less than 2 months at 22°C/72°F | Less than 1 month at 32°C/90°F | Less than 2 weeks at 42°C/108°F |
| Mangoes | 2-3 weeks at 13°C/55°F | 1 week at 23°C/73°F | 4 days at 33°C/91°F | 2 days at 43°C/109°F |
| Apples | 3-6 months at minus 1°C/30°F | 2 months at 10°C/50°F | 1 month at 20°C/68°F | A few weeks at 30°C/86°F |

-Kitinaja White Paper PEF, 2013 [\[bit.ly/1WEsmxN\]](http://bit.ly/1WEsmxN)



Postharvest Innovations Plan Series #7: Large ZECC [\[bit.ly/2CwJuny\]](https://bit.ly/2CwJuny)



Postharvest Innovations Plan Series #6: Small ZECC [\[bit.ly/2CAaTFj\]](https://bit.ly/2CAaTFj)



PEF White Paper: Use of Cold Chains for Reducing Food Losses in Developing Countries
[\[bit.ly/2NZEvgG\]](https://bit.ly/2NZEvgG)



UC Davis Lecture: Temperature Management: Cooling and Storage [\[bit.ly/2wVGrjQ\]](https://bit.ly/2wVGrjQ)



Charcoal Cooler for Women's Cooperative [\[bit.ly/2Nv9Ydx\]](https://bit.ly/2Nv9Ydx)



DIY Fan and Wet Towel Evap Cooler [\[bit.ly/2Qdfksq\]](https://bit.ly/2Qdfksq)



Cooling down the broccoli after bringing it in from the field at Wisconsin's Vermont Valley Farm - Photo: Dream Lens Media

Pre-cooling: Hydro-Cooling with Cold Water and Ice

Removing field heat as quickly as possible upon harvesting slows plant deterioration. Cold water and ice are efficient absorbers of field heat, decreasing losses by extending fruit and vegetable shelf life.



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Plants absorb heat; as daytime temperatures soar, so do plants' temperatures. Harvesting early in the day is an effective strategy for keeping plants cooler, as is storing recently harvested plants under a [sunshade in the field](https://bit.ly/2P58Vih) [bit.ly/2P58Vih]. Once plants arrive at the packing-house, lowering their temperature to slow their respiration rate is a task of immediate, pressing importance.

Using cold water or ice in various forms is an efficient method for reducing field heat because transmitting heat from solids to liquids is faster than transmitting heat from solids to

gas. Since the ambient atmosphere (that is, the air!) is gaseous, water absorbs heat much more quickly than surrounding air and does so without any loss of plant weight. (Plants are mostly water.) Cold water and/or ice are more effective than air conditioning at quick removal of heat.

Hydro-cooling (using cold water) is commonly used for vegetables, such as asparagus, celery, sweet corn, radishes, and carrots, but it is seldom used for fruits. - [FAO](https://bit.ly/2MgCQGz) [bit.ly/2MgCQGz]

Cooling plants in water offers an opportunity to wash them at the same time. Water must be chlorinated [Tool 22] to



Ice block ready for transport in India - Photo: Lisa Kitinoja



Icing greens to remove field heat in India - Photo: Mihir Mohanta

“Water can remove heat about 15 times faster than air, although the actual efficiency of hydro-cooling systems is lower. Hydro-cooling typically cools produce 5 to 10 times faster than forced-air cooling. The rate of cooling in a hydrocooler is strongly related to the amount of contact that occurs between the cool water and the product being cooled. For this reason, tank and flume hydrocoolers are more efficient than shower hydrocoolers, and loose produce is cooled fastest, followed by produce in bulk bins, then individual packages, then palletized produce.”

—edis.ifas.ufl.edu/hs1270

kill bacteria [bit.ly/2P5T579]. Reusing the water is environmentally and economically wise, but it must be disinfected again before reuse.

The simplest approach for hydro-cooling is placing freshly harvested plants in a large vat of cold water. Another method

is to spray cold water on plants. If plants are already in reusable plastic crates, the whole containers with their contents can be plunged into the cold bath. In fact, that is a good reason to consider RPCs, if they are not already integrated into postharvest activities. Utilizing the same container eliminates moving produce from one bin to another, decreasing its vulnerability from a move. It also reduces work load.

The World Vegetable Center/AVRDC has promoted a collapsible unit that can be assembled as a hydro-cooling tool. Their [video \[bit.ly/2KPPyX7\]](http://bit.ly/2KPPyX7), in Swahili with English subtitles, demonstrates low-tech pre-cooling.

Ice is generally delivered to the packinghouse and used as ice chips, crushed, or in slurries (“Slurpy”, to Americans). The World Vegetable Center has also shared a simple technique, [ice bottles wrapped in newspaper \(p. 57\) \[bit.ly/2nylFS9\]](http://bit.ly/2nylFS9), an effective low-tech process. “The ice bottle technique is an innovative way to avoid direct contact of ice with the produce. The ice bottles (2 per pack of 25 kg vegetable) are wrapped with newsprint and placed in the package. Temperatures are reduced to 20°-25°C (68°-77°F) from 35°C-40°C (95°F-104°F) in packs of produce sealed in the afternoon and transported the following morning.” After use, the bottles can be refrozen again and again.



North Carolina State Extension’s Tips for Hydro-Cooling [bit.ly/2Qeclue]



AVRDC: Low-Cost Cooling Methods (Swahili with English subtitles) [bit.ly/2wTHu3K]



An Industrial Conveyor Hydrocooler [bit.ly/2pVy5oa]



Section 3

FOOD PROCESSING AND VALUE ADDITION

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Clients from the Honduras MERCADO project participating in a plantain chip production training - Photo: Fintrac Inc

FOOD PROCESSING AND VALUE ADDITION: INTRODUCTION



Haitian smallholder farmers holding moringa leaves and cacao pods along with the new products made from each: Kuli Kuli's Moringa Green Energy shots and Taza Chocolate's Stone Ground Haiti bar - Photo: Sebastian Petion

Food processing, adding value to crops, generally has higher profit margins than the farming itself. Farmers typically earn only about 10% to 20% of the total value of the food that reaches consumers. Many techniques, highlighted in this section, are suited for small-scale food processing businesses creating desirable, marketable products. Value addition activities are a win-win, generating economic activity as well as reducing post-harvest food losses.

An overabundance of postharvest yield arriving directly to local markets can result in plummeting prices. When supplies exceed demand, some crops go begging and spoil before purchase; farmers and potential consumers lose out. In some locales there is no incentive to even gather available excess ripe fruits, like mangoes, and they are left to rot. Creating robust postharvest food processing can absorb this low-cost harvest surplus and even create a market for heretofore unharvested foods.

Food processing utilizes the abundance of produce at harvest time and helps preserve food so it can be eaten later and sent further afield. Value addition generally results in lighter, more compact products that reduce storage and transport costs. If they do not need to be kept chilled, their shelf life is further expanded, reducing losses.

Women do the lion's share of food preparation in rural areas. Utilizing their cooking skills for food businesses is a logical step, but it's a big jump. Many factors go into a successful value addition initiative; small businesses, be they started by individuals or co-ops, require skills beyond the food preparation itself. Workers starting a food processing enterprise need training and support to

- Acquire appropriate machinery and supplies
- Access larger markets: local, regional, and international
- Learn business bookkeeping
- Access financing [Tool 95] and manage cash flow
- Meet market standards for food safety
- Arrange for necessary supervision
- Acquire any required licenses or certifications

- Create worker safety protocols
- Manage inventory and distribution challenges
- Develop branding and marketing skills

Tools interlock, of course. Typically, value addition activities are temporary set-ups, processing the harvest when it's abundant. But if food processing groups expand their storage capacity with options like metal silos [Tool 60] or cool storage [Tool 71], they can also extend their value addition activities beyond harvest season. Buying when commodity prices are low and storing them allows businesses to remain open and process their products for longer periods, expanding employment and increasing profits.

PracticalAction.org provides a wealth of training materials on food processing, including both the science and practical techniques. Check out Practical Action [Food Preservation Part One \[bit.ly/BwEb9X\]](https://bit.ly/BwEb9X) and [Part Two \[bit.ly/2vIm0Gd\]](https://bit.ly/2vIm0Gd). They are useful both for trainers in educational settings and for food processing practitioners.

Ultimately value addition activities create an enormous variety of quality foods that people enjoy eating. Consumers appreciate their availability and convenience and are willing to pay for their perceived value. Bon appétit!

Processed products must be packaged and stored properly in order to achieve their potential shelf life of up to one year. Dried products must be packaged in air-tight containers (glass or plastic bottles or sealed plastic bags). Canned and bottled products must be adequately heat-processed using clean, high-quality containers that provide good seals. Dried and canned or bottled products are best stored in a cool, dark place. Kitinoja and Kader (2015), p 241



Workers at Caboa Organic Farm in Antigua, Guatemala, follow sanitation guidelines and suit up for food preparation - Photo: Dina Tanners

Sanitation

Sanitation is a super tool for reducing postharvest losses. Maintaining clean, food-safe environments for processing edibles is crucial for avoiding waste due to product contamination.



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Maintaining high sanitation standards is crucial from the farm onwards all the way up through the value chain.

“Sanitation” refers more generally to cleanliness: washing surfaces with water, sweeping the floors, and the like.

“Sanitizing” is the use of chemical agents like chlorine and detergent for disinfection. This kills microorganisms.

Workers must be sure to wash their hands with soap and water after using the toilet as well as washing their hands between tasks. Work surfaces, utensils, and tools must also be washed and sanitized frequently to avoid spreading germs.

Workers typically wear clean aprons and hairnets, hats, or scarves. Some companies provide uniforms for their crew, professionalizing hygienic attire and addressing the problem that employees frequently lack access to sanitary water for laundering their work clothes. In some venues, especially in Asia, workers add face masks. Sometimes disposable gloves are worn, in part to protect workers and in part to guarantee cleanliness.

Frequent handwashing also protects workers from spreading germs to one another and to the foods being handled. When workers are healthier, it is a benefit both to the workers and to the processing facility.

Obviously, containers in which products are packaged must be sanitary and food-safe.

Equipment, whether used indoors or outdoors for drying,

must be kept clean. “Trays made from stainless steel, plastic or nylon are much easier to keep clean than are wooden trays... Use a strong detergent and a stiff brush to scrub the trays, screens or mats clean. Allow them to dry in the sun before using them to dry product.”—Kitinoja and Kader (2015), p 241

If food processing takes place in a space with dirt floors, “A good material for settling dust on earthen floors is calcium chloride (CaCl₂). When spread on the earth it absorbs moisture from the air and keeps the soil moist. Rake the calcium chloride into the surface at a rate of ½ pound per square yard (250 ml per square meter).”

To reduce mold growth on utensils during the off-season they should be thoroughly washed with soapy water, rinsed, dried, and stored in a well-ventilated area.

There are three main categories of contamination in food processing:

- **Physical foreign objects**—anything from splinters and shards to screws or staples
- **Chemical toxins**—ranging from insecticides to cleaning agents or heavy metals
- **Human pathogens**—spread from infected people with viruses, bacteria, parasites, or other pathogens

Utmost care must be taken to observe protocols and safety measures guaranteeing product integrity.

Concerns about food safety when handling fresh fruits and vegetables have increased over the past decades. Recent outbreaks of food-borne disease have been associated with berries, tomatoes, leafy greens, fresh herbs and cut fruits. Wholesale buyers and consumers are increasingly interested in the use of handling practices that will ensure food safety.

It is the responsibility of growers and postharvest handlers to document their food safety practices in order to protect fresh produce from contamination. Retailers, such as large supermarket chains, are demanding compliance with food safety practices from their suppliers. It is nearly impossible to export produce to Europe or the U.S. without documenting its safe handling from the farm to the market.

–Kitinoja and Kader (2015), p 255



Trimming green beans in Tanzania in a state-of-the-art processing plant - Photo: Feed The Future/Fintrac



Signs at Caboa Organic Farm in Antigua, Guatemala: (Top left) "Wash your boots before entering", (Top right) "Wash your fingernails and maintain personal hygiene in this area", and (Bottom) "Wash your hands before entering to work" - Photo: Dina Tanners



Cornell University's Good Agricultural Practices Program: "Food Safety Begins on the Farm"

[\[bit.ly/2yLyqOZ\]](https://bit.ly/2yLyqOZ)



Hand Washing Poster [\[bit.ly/2wVm1Xo\]](https://bit.ly/2wVm1Xo)



SAWBO Animation: How to Wash Your Hands [\[bit.ly/2Qsi4Cp\]](https://bit.ly/2Qsi4Cp)



A women's group sponsored by CDC, Centro Desenvolvimento Comunitario, making bananas, cassava, and sweet potato chips in the district of Baucau, Timor Leste (South East Asia) - Photo: UNMIT/ Martine Perret.

Graters, Choppers, and Slicers

Well-designed tools for processing harvested foods ease and speed workers' tasks and add to product value.



41 Food processing ranges from simple to complex. Appropriately designed tools for grating, chopping, and slicing are the foundation for food processing enterprises, absorbing harvest yields as quickly as possible to capture fresh, high-quality ingredients.

For some foods, a single step is required to create a saleable commodity. Fresh ginger, for example, can be bottled and sold all over the world after just being grated.

In contrast, cassava, the third largest staple crop in the world, requires a series of at least ten steps from tuber to HQCF,

high-quality cassava flour. The process includes peeling, washing, grating, pressing, disintegration, sifting, drying, milling, screening, packaging, and storage, according to [The Cassava: Adding Value for Africa \(C:AVA\) Project \[cava.nri.org\]](http://cava.nri.org). Left on its own, cassava degrades within a day or two of harvesting; processing must take place immediately, adding to the challenge.

Food can be processed for the local market, like slicing and frying chips. Or commodities can be transported to another processor as part of a multi-ingredient end product, like chopping



Workers at Fruandes, a FairTrade Organic B Corp, processing yellow dragon fruit at their workspace in Ibagué, Colombia - Photo: Fruandes



Workers shred, dry, and press coconut to make virgin coconut oil at a Women in Business Development model farm in Nuu Station, Samoa - © IFAD/Susan Beccio

mangoes that are then sent on to juice processors or used as pulp in cakes and candy.

Trends in the modern world—expanding urban centers, women entering the workforce in ever greater numbers, and rising incomes—increase demand for labor-saving prepared foods. Processed foods are not only a convenience; they allow access to out-of-season products or those from faraway locales.

Food professionals track marketing opportunities and trends across the global food supply system, from local to international. When this information is available to local farmers and farmer co-ops, they can take advantage of lucrative market trends in their planning. For example, Esoko.com provides smallholder farmers with vital market information via cellphone in Ghana, Kenya, and Tanzania.

The closer food prep is to the original food source, the more efficient it is, with less opportunity for spoilage. Local labor is readily available if financing [Tool 95] can be found for launching small microenterprises. Women's co-ops are well-suited for such initiatives, after some basic business training.

Trimming [Tool 26] and eliminating waste portions of produce lightens its weight and contracts its transportation footprint. This lowers costs and provides eco-benefits as well. Of course, the waste should be managed in an ecologically responsible manner.

Any chef will tell you that great food preparation is all about high-quality knives. Or, for a broader perspective, tools that grate, chop, and slice. Safety is always a consideration when workers are wielding sharp tools. To guard against cross-contamination, these tools must be washed frequently.

Popular techniques for common products include:

Grating: ginger, garlic, onions, turmeric

Slicing: mangoes, bananas, peaches, apples

Chopping: most vegetables (before drying or cooking to make sauces)

Mincing: garlic, onions



Representative Food Preparation Options from Walmart [\[bit.ly/2CovJ92\]](http://bit.ly/2CovJ92)



Typical Commercial Chopper [\[bit.ly/2MWpZcU\]](http://bit.ly/2MWpZcU)



Isabelle opens her street side fresh fruit drink stand for the season, featuring a Chav Rub juice presser in Zihuatenejo, Mexico - Photo: Ted McGrath

Fruit Presses

Juice is delicious and nutritious, requiring fairly simple processing. Retail juice vendors press each order directly for customers; if they have refrigeration, they can bottle their surplus.



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Who doesn't like juice? A wide variety of fruits and also some vegetables lend themselves to juicing, extracting their liquid with manual tools. Juice is enjoyed with natural pulp as well as strained. Fruits and vegetables generally are around 80-90% water.

Sanitation is crucial in the juice extraction process. The fruits must be reliably pathogen free. The juice press parts must be cleaned frequently, as well as the knives, cutting board, and any peeling utensils. Of course, bottling equipment as well as

bottles must be sterile; workers must adhere to strict hygiene protocols, as well.

A simple mechanical juice press is the centerpiece of a microenterprise. Juice press vendors are common sights at markets, producing pressed drinks on demand. In this setting, sanitation is important but the product is consumed on the spot rather than bottled for sale elsewhere.

Juice vendors need a trusty supply of ripe, juicy fruits or vegetables like carrots. This consumes some of the surplus of fruit



A Mysore, India, juice vendor features gleaming, easy-to-clean stainless-steel counters and pots, displaying attention to high-quality sanitation; his clean white shirt also broadcasts "reliable cleanliness" - Photo: Beth Kanter/Cambodia4Kids/Flickr



The sugar cane vendor up close, straining the drink before serving it in a disposable cup, giving added confidence of food safety; clean glasses are also available - Photo: Beth Kanter/Cambodia4Kids/Flickr



A jovial juice presser in San Antonio Aguas Calientes, Guatemala - Photo: Betsy Teutsch

- Pineapple
- Sugar cane
- Carrots

Pressing juice for a waiting buyer adds a performative element; vendors often enhance the process with playful drama to achieve a competitive edge, especially if there are other fruit juice pressers in the market.

Another strategy for attracting customers is maintaining high publicly visible sanitation, increasing customer confidence in the juice's food safety—especially important for tourists warned about street foods. Note this travel anecdote from Flickr:

There were several sugar cane vendoras. Rufina picked out the cleanest one and had him press some juice. She pointed out that he wasn't selling from a pitcher of pressed juice that was sitting around.... Next door was a vendor who was dirty - and was annoyed that we didn't purchase from him. Wonder if he has learned anything from watching the competition.

—Beth Kantor, Cambodia4Kids

at harvest time. Juices are easier to consume than whole pieces of messy fruit; people pay to not only quench their thirst but for the convenience of the vendor peeling and prepping the fruit.

Fruits, strained of seeds, and veggies commonly pressed at juice stands include:

- Citrus fruits: orange, grapefruit, tangerine, lime
- Pomegranate

Rufina, as quoted above, is right to eschew juice sitting around in an open pitcher. Fresh-squeezed juice left outdoors in hot climates quickly becomes a hazard to human health.

Bottled fresh-pressed juices must be iced or refrigerated. In the United States, such products require labels stating “WARNING: This product has not been pasteurized and therefore may contain harmful bacteria that can cause serious illness in children, the elderly, and persons with weakened immune systems.”



Heavy Duty Modern Juice Press [\[bit.ly/2Ou8IsD\]](https://bit.ly/2Ou8IsD)



Chav Rub Presser (Mexico) pictured [\[bit.ly/2S9VGi2\]](https://bit.ly/2S9VGi2)



Traditional 20 Liter Barrel Style Fruit Press [\[bit.ly/2NIGKb2\]](https://bit.ly/2NIGKb2)

Pedal Powered Machines

Pedal power greatly leverages human effort. In off-grid, low resource regions, bike power can replace work that is performed electronically in industrialized regions, facilitating a wide variety of food processing.



Tanzanian prototype of pedal-powered coffee bean dehuller - Photo: MIT D-Lab (permission requested)



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Hand grinding, shelling, dehulling, juicing, and slicing are labor-intensive tasks, limited by the lack of time, body-strength, or available laborers. Processing harvested foods is time-bound; an absence of mechanized crop processing contributes to postharvest losses and perpetuates poverty. By adapting the power of bicycle technology and deploying it via pedal-driven machines, smallholder farming communities, women’s groups, and farmer co-ops [Tool 87] can create local microenterprises to process their own commodities. These turn formerly lost crops into assets.

Bike-pedaled machine technology is freely shared for local mechanics and tinkerers to adapt to local needs. Used parts and invented tweaks are the norm, utilizing reused bicycle parts and locally available attachments for milling or shelling. Necessity is the mother of invention; tinkerers create their own solutions using imagination, input, instructions available via the internet, and trial and error.

Where coffee growing is the main agricultural activity, bikes provide power to small coffee farmers, helping them compete with more industrialized competitors. Mechanizing tasks previously performed by hand speeds the process and frees up farmers to redeploy their labor to other income-generating activities or training. It also reduces body strain from doing tedious, repetitive manual tasks.

Bikes are powered by pedaling. Since humans have far stronger leg muscles than arm muscles, harnessing that added

power via bicycle allows for tasks to be done much more quickly. It also is an opportunity for children and older people to contribute labor, with “all legs on deck” during the harvest.

In Nepal, PortalBikes fabricates and sells bikes for cargo transport along with an attachment to turn them into machines for postharvest processing. In addition to their maize sheller attachment, they also sell an [adapter](http://portalbikes.org/pto-features) [portalbikes.org/pto-features] dubbed the “PTO”—Power Take Off, a term associated with farm tractors. It facilitates attaching a pre-existing hand grinder for maize, wheat, or coffee to their bikes. “If it rotates, chances are pretty good you can power it with a Portal PTO.”—PortalBike

Based in Guatemala, MayaPedal has been fabricating bike-powered machines for many years, gradually refining its techniques and freely disseminating [instructions](http://mayapedal.org/Mill.pdf) [mayapedal.org/Mill.pdf].

Pedal power can be harnessed for countless applications which would otherwise require electricity (which may not be available) or hand power (which is far more effort). *Bicimáquinas* are easy and enjoyable to use. They can be built using locally available materials and can be easily adapted to suit the needs of local people. They free the user from rising energy costs, can be used anywhere, produce no pollution, and provide healthy exercise.

—MayaPedal.org, San Andreas Itzapa, Guatemala

MayaPedal powers blenders with its *bicimáquinas*. This can be value-addition drink microenterprise for non-electrified settings.

Pedal-power has also been deployed in small farms in higher resource areas valuing sustainability and wanting to avoid the expense of costlier high-tech equipment.



MayaPedal www.mayapedal.org



Michigan State University Pilot Bean Dehuller [\[bit.ly/2QB4789\]](https://bit.ly/2QB4789)



GAIA Earth Pedal-Powered Machine Videos [\[bit.ly/201c9Cu\]](https://bit.ly/201c9Cu)



Fintrac has introduced solar drying structures shared by farming families, in Honduras - Photo: Fintrac

Low-Cost Grain Dryers

Grains, pulses, and crops such as nuts and coffee beans must be dried prior to storage. Low-cost ventilated dryers improve upon traditional air-drying practices. Solar air-drying decreases losses and saves time.



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Grains and pulses can be stored for long periods of time if they are sufficiently dried; thorough drying prevents

- Early germination while in storage
- Mold growth
- Insect invasion

Moisture content measurement is covered in Tool 45.

One traditional method of crop drying is leaving the grains on the stalks in the field, letting nature take its course. This requires no labor or tools, but prevents the land being prepared for the next planting and leaves the yield vulnerable to

- Insect infestation
- Mold
- Animals
- Theft
- Adverse weather conditions - rain or storms can damage the plants

An improved technique is to spread the yield out on a drying surface like a tarp [Tool 18]. (While roadsides are also frequently used, they are not recommended due to the obvious dirty air and pollution from traffic fumes.) This method is labor intensive, requiring workers to turn and stir the grain frequently. Since night air adds moisture back, grains need to be taken in for the evening. Sudden rain requires collecting the grain and protecting it. But compared to field drying, this technique decreases losses and expands income.

Smallholder farmers can speed this process, with less labor, by adopting low-cost, mechanical drying techniques that remove water from wet grains by blowing heated air through the grain. [IRRI \[bit.ly/2OzfXuz\]](https://bit.ly/2OzfXuz) reports that the benefits include:

- Better control over the temperature and moisture content
- A speedier process, since drying can be done day or night (and can be done day and night)
- Less labor required, since the grain doesn't need to be moved due to weather concerns
- More even drying of grain
- Higher milling yield

SAWBO-Animations has produced a video on **building a DIY high velocity** [\[bit.ly/2MMi9ic\]](https://bit.ly/2MMi9ic) solar grain dryer along with a second video demonstrating the **drying process** [\[bit.ly/2nC7cEY\]](https://bit.ly/2nC7cEY). Using natural convection, the unit requires just a tarp, clear plastic, wood, nails, stones, and direct sun. It is designed to dry the volume of grain raised by a smallholder farmer. After each of several intervals of two to three hours grains need to be stirred and re-spread. Moisture content needs to be tested to determine if the process is complete.

A larger solar dryer designed to be shared by a handful of farmers was introduced by **Fintrac in Honduras** [\[bit.ly/2vFU6ur\]](https://bit.ly/2vFU6ur). Built of PVC tubing, it is a high poly tunnel [Tool 2] (like those used for greenhouse season extension or vertical cultivation) with drying platforms built of screening,

increasing air circulation. It can be used for maize cobs, grains, coffee, beans, and even allspice. It costs around \$400 to make, from locally available materials. A farmer who builds one can rent out her drying services to nearby farmers, or a group [Tool 87] can build one collectively.

With only simple modifications farmers can use this structure twice during the growing season: first as a greenhouse [Tool 2] and then as a ventilated drying space. The design can be kept warmer or cooler, depending on air flow and how much venting is provided. Hence the investment pays back at both the beginning of the season and in postharvest dividends, speeding the return on investment. Future uses require little additional expense while contributing to profits.



SAWBO-Animations' rendering of a DIY high velocity solar grain dryer. Grains are spread on the ground tarp and the clear plastic is rolled on top. Air flows in through the bottom where the large rocks raise the clear plastic; moist heat flows out through the chimney—Illustration: [SAWBO Animations \[SAWBO-animations.org\]](https://www.sawbo-animations.org)



Stretching screening on drying frames for a high tunnel solar grain dryer
- Photo: Fintrac



Maize cobs or shelled maize can be dried, as well as coffee, beans, and allspice - Photo: Fintrac



FAO Grain Storage Techniques [\[bit.ly/2oTjqt6\]](https://bit.ly/2oTjqt6)



Fintrac: Story of the Low-Cost Solar Dryer [\[bit.ly/2MZSeYq\]](https://bit.ly/2MZSeYq)



SAWBO: How to Build a Solar Grain Dryer [\[bit.ly/2HHrf0A\]](https://bit.ly/2HHrf0A)



Training farmers to use moisture meters, empowering them to barter with grain traders, Kotwali, Bihar, India - Photo: ADMI Institute for the Prevention of Postharvest Loss

Low-Cost Moisture Meters

Moisture content assessment, determining when grains and pulses are at a safe moisture level for storage, improves stored product quality and reduces losses.



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When storing grains, it is crucial to confirm their moisture content is at correct levels for their commodity. Moisture content can be measured digitally or tested with low-tech methods. If grains are stored before attaining the recommended level of moisture content, the excess moisture can damage the crop.

“Natural respiration of stored, wet grain will generate heat, in particular when it is stored in sacks in bulk. Heat will provide excellent growth conditions for molds, insects and deteriorate quality.” - IRRI [bit.ly/2vH8nam] Aflatoxin is just such a mold, and its contamination of peanut and maize crops is highly toxic to humans and causes huge losses for farmers.

- Cereal grains’ moisture content must be 14% or less
- Beans and pulses’ moisture content must 12% or less

A wide variety of digital moisture meters are available. [Dr. Paul Armstrong \[bit.ly/2nnuI9P\]](http://bit.ly/2nnuI9P) has developed an effective grain moisture meter for the developing world, the **USDA EMC Meter 4.0**, measuring Equilibrium Moisture Content (EMC), at around \$75.

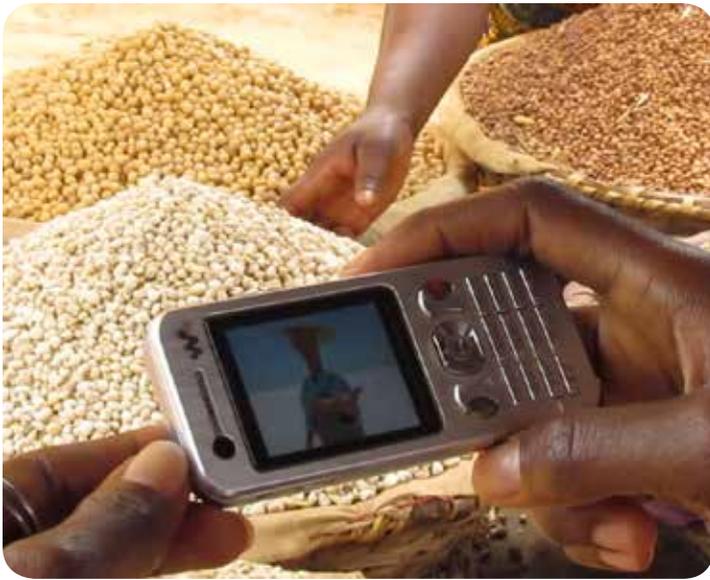
A low-cost innovation developed by the Horticulture Innovation Lab at UC Davis measures EMC, Equilibrium Moisture Content, via a credit-card size [DryCard \[bit.ly/2KUFvAs\]](http://bit.ly/2KUFvAs). It will cost around \$.25 and can be reused many times for testing

A simple and reliable technique to test if maize grain is dry enough to be loaded into metal silos for storage: the grain is placed in a dry clear glass bottle with dry salt, and shaken vigorously for three minutes. If the salt sticks to the sides of the bottle due to moisture from the grain, it is not yet dry enough to be stored.

–CIMMYT [bit.ly/2P2yksW]



Low-tech moisture measurement recommended by CIMMYT - Photo: CIMMYT



Watching a Sawbo animation about grain drying in Benin - Photo: Feed The Future, Marta Rossinelli

humidity, proxy for the water activity of stored commodities. If the humidity of the surrounding air is below 65%, molds cannot grow. Samples are tested by placing a small quantity into a sealed

bag or jar along with the card. After an hour or so, the cobalt chloride humidity indicator strip will turn blue if humidity is safe (beneath 65%), or turn pink, indicating the crop is too wet for storage.

According to Dr. Lisa Kitinoja, sometimes if the peanut crop is suspected of harboring aflatoxins, it will be discarded just to stay safe. With this test card, the growers/sellers can provide visible evidence the food has been dried enough to be safe to eat, reducing losses of food and income. Given how inexpensive the DryCards are, it makes them a very affordable investment for growers.

An even lower tech solution is demonstrated by [SAWBO Animations \[bit.ly/2MivoKr\]](#). Shaking dried salt in a closely sealed 750 ml glass bottle to test for safe grain or bean moisture levels for storage (instructions are in the box):

Yes, there's an app for that.... A Canadian husband and wife team have collaborated on a grain moisture meter for smartphones. "The Grain Moisture app is available for iPhones or iPads. Find it in the iTunes store by searching for "Grain Moisture." Cost: \$2.79.



ADM Institute [\[bit.ly/2oS2Fi0\]](https://bit.ly/2oS2Fi0)



Panomex Scoop Grain Moisture Meter [\[bit.ly/200JWMk\]](https://bit.ly/200JWMk)



GrainPro Moisture Meter's Instructional Video [\[bit.ly/2wRazvC\]](https://bit.ly/2wRazvC)



DryCard: "Innovator of the Year" [\[bit.ly/2OtjQpq\]](https://bit.ly/2OtjQpq)



Demonstrating improved solar drying of two varieties of chilies in Northern Ghana - Photo: Kristi Tabaj

Direct Solar Drying for Fruits and Vegetables

Harnessing the sun's free heat to dry fruits and vegetables improves on air drying: it's speedier and protects commodities from pests, toxins, and rain. And it creates flavorful, nutritious products.



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Drying fruits is an ancient technique. It is what happens when moist fruits are left out in the sun: plums become prunes and grapes become raisins. But successfully drying fruits is not guaranteed. Ambient air can be too humid for them to dry, it can rain, and foods left out to dry in the open are vulnerable to birds, pests, dirt, and toxins.



Stacks of okra trays dry on net trays in Garango, Burkina Faso - Photo: ©IFAD/Aubrey Wade

Utilizing low-tech direct solar dryers speeds up the process and is expanding the number of fruits and vegetables that can be dried for storage and future sale. Grains are dried using similar technology [Tool 2 + Tool 44].

Added benefits of quicker, low-cost solar drying include:

- Processing when harvest gluts lower prices
- Capturing fruits formerly left to rot on the trees
- Decreasing food weight and volume by up to 95%, lowering transport, packaging, and storage costs
- Protecting food from bacteria, yeast, and mold growth in storage due to removing moisture, while intensifying flavors
- Utilizing the sun, a free source of energy
- Speeding the process, decreasing labor invested per drying load
- Creating marketable, nutritious products for postharvest sale

Direct solar dryers are typically screened trays set into a frame, allowing 360° air circulation under a light-weight structure that supports a polyethylene sheet roof and siding. A smaller unit may feature a Plexiglas or glass cover that lifts up.



Faruq bin Yamin's passive solar dryer hack from Bangladesh - Photo: Md. Faruq bin Hossain Yamin, PEF 2012 Grad, Bangladesh



A group member of the FAO TeleFood project dries chilies in a stainless-steel solar dryer with a glass cover and slide-out tray in Nepal -©FAO/ Diana Giampiero

Convection of air is the natural movement of warming air as it rises, with an intake and outlet. The clear plastic cover traps the air while letting the sun rays in, raising the air temperature. As the air moves, it pulls out heat and moisture, gradually drying the foods.

“First and quite importantly is that these dryers save time, saving them 2.5 days of the 5 days it would normally take to dry the peppers [roadside]. This has ensured that they get their peppers on time to get to the market and they do a better bid because they now have cleaner peppers ensuring they sell at a 20% premium.”

— [Amina Bako, pepper farmer, Kaduna, Nigeria \[bit.ly/2UStCkg\]](#)

Postharvest educator Faruq bin Yamin from Bangladesh (PEF 2012 Grad, Bangladesh) posted his passive solar dryer on Facebook. Its vertical drying tunnel is constructed from four hanging baskets inside netting; the black mesh absorbs heat and warms the air trapped inside. He reports: “Outside temperature, 31°C and inside the dryer, 43-45°C, very simple and easy to make, low-cost, no need to transfer during rain, portable. Cost to make: \$3-4 US.” It can be used for herbs, fruits, or vegetables. His colleagues posted their enthusiasm about introducing his hack to Ethiopia. Larger versions are becoming popular in the United States, in part for drying homegrown marijuana.

Simple sun drying can be utilized by laying the fruits or vegetables on a frame of stretched mosquito or other netting covered with a thin, lightweight, white or light-colored

inexpensive fabric like cheesecloth or muslin. The cover allows ventilation while protecting the drying food from pests and dirt.

Dried fruits, vegetables, spices, or herbs are a good basis upon which to build a drying, packaging, and marketing micro-enterprise. Women's co-ops [Tool 87] are well-suited to utilize dehydration to create nutritious products. As a side benefit,

their own families' diets are improved by dried commodities consumed off-season.

Postharvest.org and the Horticultural Innovation Lab recommend placing a [solar reflecting sheet \[bit.ly/2nAWe2t\]](https://bit.ly/2nAWe2t) next to the solar dryer to increase solarization on cloudy days.



Postharvest Innovations Plan Series #11: Inexpensive Direct Solar Dryers [\[bit.ly/2wXkO2m\]](https://bit.ly/2wXkO2m)



Fruits of the Nile, Woman-Owned Solar Dried Banana Business in Uganda [\[bit.ly/2wWDqyZ\]](https://bit.ly/2wWDqyZ)



This book's author Betsy Teutsch tests slide-out racks in the drying chamber of Caoba Organic Farm's indirect solar dehydrator, Antigua, Guatemala - Photo: Dina Tanners

Indirect Solar Drying

Indirect solar drying utilizes an empty warming chamber connected to a tall racked unit topped with a vent. Captured air flows through the heating chamber and rises through the racks, drying foods.



47 Indirect solar dryers and direct solar dryers work on the same principal: when air is warmed, it expands and rises. Air contained in a closed drying unit heated by direct sunlight gradually increases in temperature and volume. By venting the dryer with an air intake at the bottom and an air vent up top, natural convection removes moisture from the foods.

Indirect solar dryers are different from direct solar dryers [Tool 46] in that they separate the heating chamber from the drying foods. The air is heated at the lower level, with no products present, and the warm air is routed up through adjacent, covered racks of food, venting out to the top of the stack. This shelters the drying products from direct sunlight. Protecting commodities from over-heating and sunburn damage that result in darkening and loss of quality makes indirect solar drying a significant improvement over direct solar drying.

The solar collector for heating air is similar to a solar box oven, a slanted construction whose interior is often painted black to absorb more solarization. The indirect solar example featured is lined with black corrugated material, increasing surface area for added heat absorption. It is covered with a transparent plastic, Plexiglas, or glass top. A reflector can be angled to direct more solar rays into the box.

The adjacent drying chamber or cabinet typically has four to six slide-out racks. If they are made of mesh (wire, food grade

As a rule, you'll need one square meter of tray area to dry about 2 kg of fruits or vegetables, and drying will take one day or more, depending upon the weather.

—Kitinoja and Kader (2015) via [Postharvest Innovations Plan Series Number 12](#)
[bit.ly/2nBKFb4]

plastic or cloth) air exposure is increased, speeding up the drying process. Fruits and vegetables should be placed only one layer high, in uniformly sized pieces. A chimney or turbine at the top of the drying stack will speed airflow, since it helps the warm, moist air to rise and escape the dryer, allowing space for additional fresh, dry air to enter.

“Using solar drying—direct or indirect—to process surplus fruits and vegetables that cannot be marketed or eaten before their shelf life is expended can enhance food security for small-scale farmers and marketers. Drying valuable perishable crops for later sale or use can be an inexpensive way to extend the storage potential and marketing period of these food products.”

—Postharvest Innovations Plan Series 12 (see above)



An indirect solar drying unit, Thailand - Photo: Lizanne Wheeler



Indirect solar dryer viewed from the front; note chimney for faster air movement and the corrugated black surface in the heating chamber - Photo: Lizanne Wheeler



Postharvest Educator Kodimah Issifu's "simple mixed mode solar drier" [\[bit.ly/2pYWY2D\]](https://bit.ly/2pYWY2D) for preservation of my veggies in glut. Thanks to Emmanuel Ayua for the design." Issifu estimates it cost around \$40 in materials. The black trapezoid base provides more solarization surface for heat collection, to warm the inner air flow through the chamber and up through the stack - Photo: Kodimah Issifu - PEF Graduate, Ghana, 2014 - posted on Facebook



A close-up of pepper slices and spinach leaves in a solar drying cabinet - Photo: Lizanne Wheeler

Cheetah Development in East Africa has introduced a [flat horizontal direct solar dryer](https://bit.ly/2OAgT1X) that swivels to vertical (with its contents held in place), utilizing some of

the benefit of the indirect style of vertical air outlet. The swivel feature speeds solar heat capture by rotating it first to the east and then to the west, following the sun's arc.



World Vegetable Center article [\[bit.ly/2oQbNDU\]](https://bit.ly/2oQbNDU)



Postharvest Innovations Plan Series #12: Improved Indirect Solar Dryers [\[bit.ly/2NuFXKQ\]](https://bit.ly/2NuFXKQ)



FAO on Solar Drying [\[bit.ly/2CBHg6v\]](https://bit.ly/2CBHg6v)



UC Davis Horticultural Innovation Center's Solar Chimney Dryer [\[bit.ly/2CwNogj\]](https://bit.ly/2CwNogj) and Manual [\[bit.ly/2oSG9pv\]](https://bit.ly/2oSG9pv)



Academic Study and Review of Indirect Solar Drying Techniques [\[bit.ly/2QaOtNL\]](https://bit.ly/2QaOtNL)



UC Davis Chimney Solar Dryer: 3 parts [\[bit.ly/2Qe7YVA\]](https://bit.ly/2Qe7YVA), [\[bit.ly/2QhezOV\]](https://bit.ly/2QhezOV), and [\[bit.ly/2NuGLPS\]](https://bit.ly/2NuGLPS)



A low-cost farm level dryer being tested at a farmer's house in Savannakhet Province, Lao PDR - Photo: IRRI

Drying: Heat-Assisted, Forced Air, and Natural Freezing

In humid regions or during cloudy or rainy stretches, heat-assisted forced air drying does the job, augmenting or replacing air or solar drying. In cold climates, natural freeze-drying preserves foods.



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Heat-assisted drying of food commodities provides a back-up for traditional direct sun drying or solar-powered drying when cloudy or rainy periods block direct sunlight. Sun drying in open air is not a viable option in a humid locale. Drying is accomplished by moisture moving from the drying food into the air; if it is sufficiently humid, the fruits and vegetables will not dehydrate. In humid areas, heat-assisted drying is often the norm.

Fuel is used to heat air and power a fan to pull the warm air through a drying chamber. The heat can be generated by wood, propane, electricity, or an oven. The fan can be powered by the electricity grid or solar power.

For a cheaper, greener approach, [eco-briquettes](#) fabricated from waste products can be used to fuel the heating [[bit.ly/2pYP216](#)]. Eco-briquette micro-enterprises provide local jobs and replace fossil fuel, lowering carbon emissions as well as costs.

[ADMI Institute for the Prevention of Postharvest Loss](#) [[postharvestinstitute.illinois.edu](#)] has tested a small-holder SSR rice dryer in Asia [pictured above]. It is a raised circular cylinder with a round vent in its center through which heat is moved, by fan, removing moisture and drying the grain. It has been well-accepted by farmers. IRRI's Rice Knowledge Bank, Center, has posted details. [[bit.ly/2NuBA2j](#)]. SSR stands for a Vietnamese term meaning "low-cost".

In contrast to preserving foods by drying them, ancient

Incas dwelling high, high in the Andes mastered a method of freeze-drying potatoes. By the 13th Century dried potatoes known as *chuño* had become a staple.

In high altitude environments, often over 12,000 feet, families spread potatoes out in the open for at least 3 nights during June and July, the coldest time of year, with night temperatures below freezing. The freezing process breaks down the cell structure and cell walls. The potatoes are left in the hot sun during the day, and the accumulated water is squeezed out—sometimes by stomping on the potatoes, a family activity. This produces black *chuño*.



Black *chuño*, white *chuño*, and spinach at Cusco, Peru's Central Market – Photo: Betsy Teutsch

White chuño [bit.ly/2MFAeyk] takes more processing. After several cycles of night freezing and daytime sunning, whole potatoes are soaked in nearly freezing water in stream or rivers for many days. Their skins are removed, leaving the hard, white potatoes with a multi-year shelf life. *Chuño* easily flakes into potato flour, an important ingredient for Peruvian specialties like soup. *Chuño* can also be prepared by soaking the dried potatoes to reconstitute them.

Initially a strategy for preserving surplus potatoes for emergencies, *chuño* is said to have sustained the Inca's vast armies. In present day South America, it is sold in the markets next to fresh

potatoes; locals purchase *chuño* to prepare popular traditional dishes. Clearly its value is no longer just as a back-up supply of sustenance. It is popular in and of itself.

Chuño production is a significant value addition opportunity for farmers in these high altitudes. It stores almost indefinitely, is light-weight, can be sold year-round, and provides steady income. Though *chuño* is processed in June, it was available at every urban market we saw on a January visit to Peru. Storing products and slowly releasing them for sale post-season smoothes growers' income. As supplies dwindle, prices will rise.



IRRI Rice Knowledge Bank Vietnamese Low-Cost Drier [bit.ly/2NuBA2j]



Home Electric Dehydrator [bit.ly/2wU1zXM]



The Process of Making *Chuño* (in Spanish) [bit.ly/2wZDZYu]



Chilies are blanched for five minutes and then sun dried for five days before storing in Myanmar's central Dry Zone - Photo: Soneva Foundation

Pre-Treatments: Blanching and Steaming + Honey and Ascorbic Acid Drips

Steaming or blanching, quick immersion in boiling water to stop enzymatic reactions, is an appropriate pre-treatment for some commodities. This helps preserve color and extends shelf life.



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Some produce requires blanching before freezing or drying. Blanching, using steam or a boiling water bath, halts certain enzymatic reactions in the product and helps retain color and flavor after processing. Always rinse blanched produce under very cold water or dip blanched produce into an ice water bath to stop the cooking process and quickly bring the temperature down. —Kitinoja and Kader (2015) p. 236

Blanching can also remove strong or unpleasant flavors, like in the case of cabbage. For foods that require softening, like potatoes, longer blanching makes them easier to consume. Fruits don't require blanching before processing. They can be frozen, dried or canned without pre-treatments.

For blanching, use one gallon of water per pound (8 L per kg) of produce. Add one minute for each 2000 ft. (600 m) altitude if you live at elevations over 4000 ft. (1200 m).

It is important for produce to be blanched or steamed as quickly and minimally as possible to get the job done; foods then should be immersed in cold water—sometimes referred to as “shocking”—to stop the process immediately upon completion of their necessary exposure to hot water treatment.

For foods damaged by direct immersion in hot water, indirect steaming is recommended. This includes leafy green vegetables that tend to leach color and flavor into boiling water.

Commodity Blanching: minutes in boiling water

| | |
|------------------------|------------------------------|
| Broccoli | 3 |
| Green Beans | 3 |
| Cabbage (wedges) | 5 |
| Carrots | 5 |
| Cauliflower | 3 (add 4 teaspoons of salt) |
| Collard Greens | 3 |
| Corn (Sweet) | 7 |
| Eggplant | 4 (add ½ cup of lemon juice) |
| Leafy Greens | 2 |
| Mushrooms | 3 to 5 |
| Peas | 2 |
| Potatoes (New) | 4 to 10 or until soft |
| Pumpkin | 2 to 3 or until soft |
| Sweet Potatoes | 15 to 20 or until soft |
| Zucchini/Summer Squash | 3 |

—Kitinoja and Kader (2015), p. 236



Sweet corn shocked in ice after blanching, before freezing - Photo: Pirate Johnny/Flickr

Blanching is resource intensive, requiring clean water, energy for boiling/steaming, and ice or other cooling treatments that follow the hot water immersion. To use water and fuel frugally, several batches can be blanched in the same boiling water bath. Or use the same steamer over and over again until the water runs out by boiling off.

Onions, garlic, and green peppers should not be blanched.

For fruit: some fruits' shelf life is increased and aesthetics are maintained by pre-drying treatments with one of these options:

- **Sulfur**—commonly used for dried apples, pears, peaches and apricots. **Sulfuring** [burn one tablespoon of sulfur powder per lb or 12g per kg of fruit] or **sulphiting** [dip fruit in a 1% potassium meta-bisulfite solution for one minute] helps prevent darkening, loss of flavor and loss of vitamin C. Because some people are allergic to sulfuring, it must be clearly marked—Kitinoja and Kader (2015) p. 244
- **Ascorbic acid (Vitamin C)** treatment prevents browning. Use 30 mL ascorbic acid powder in one liter (2 tablespoons in one quart) of lukewarm water. Slice the fruits directly into the solution, remove with slotted spoon, drain well and pat dry. (Ibid)
- **Honey** dips extend fruits shelf life; adding honey also adds calories and extra sweetness. Vegan diets prohibit honey, so it is important to label its presence.



Clemson University Fruit Drying Guide [\[bit.ly/2Nnm4FJ\]](https://bit.ly/2Nnm4FJ)



National Center for Home Food Preservation Drying Factsheets [\[bit.ly/2NrmzOY\]](https://bit.ly/2NrmzOY)



University of Minnesota Extension: Drying Fruit [\[bit.ly/2NtIsNn\]](https://bit.ly/2NtIsNn)



Workers attach fruit preserve labels in Meghri Cannery in the south of Armenia, primarily for export - Photo: IFAD/Joanne Levitan

Canning and Bottling—Boiling Water Bath and Pressure Canners

Canning is ideal for producing jams, jellies, and pickles. High acid foods are processed in a lower temperature water bath; lower acid foods require higher temperatures achieved by pressure cookers.



50 “Putting up” foods, preparing them in a safe manner that allows extended shelf life, has been part of food processing since canning techniques were refined in the 19th Century. Indeed, one whole genre of fruit spreads is called “preserves”, honoring this strategy of conserving high-quality foods for later consumption. While the process requires energy for heating and other resources like water, glass containers (which can be safely sanitized for reuse), lids, and labels, once canning is complete, foods can be reliably stored at room temperature for a year or more.

The hot water bath technique is used to prepare high acid foods. Because high acid content helps kill bacteria, the temperature only needs to reach a 212° boiling point (100°C). High acid foods include

- Fruits and fruit juices
- Jams and jellies
- Salsas
- Tomatoes with added acid
- Pickles and relishes
- Chutneys
- Vinegars
- Condiments

Bottling juices and vinegars is a similar process requiring heat processing in a boiling water bath.

The first step is chopping [Tool 41] or blending and then preparing the foods according to the chosen recipe or formula.

The prepared commodity or mixture is ladled into sterilized jars. They are then capped and placed in a boiling water bath, in a deep pot with a rack for raising the jars, with a loose cover. The pot must be deep enough for the containers of foodstuffs to be fully submerged and not much larger than the burner to ensure evenly distributed heat. Directions are widely available online. Home canning remains popular with frugal homemakers in the industrialized world, and as the basis for artisan microenterprises.

There are three types of jars and lids:

- **Ball jar and lid**, with a rubber seal and closing mechanism
- **Zinc lid**, with a rubber seal
- **Two-piece lid** with no rubber seal, the most commonly used

Jars must not be filled to capacity, nor can too much extra space be left at the top, before sealing.

The temperature must be raised to 240° for processing low acid foods like vegetables to kill all micro-organisms.

Reaching this temperature requires using a pressure cooker for canning, inexpensive and readily available in the Global South. Instant Pots, a popular new appliance, are not recommended for canning.

Low acid foods include:

- Green vegetables
- Potatoes
- Soy beans and soy-based food products (tempe, miso, tofu)

While food for canning should be fresh and high-quality, the technique accommodates fruits and vegetables that are below wholesale/retail grade [Tool 14]: undersized, cosmetically flawed, and/or misshapen. Bruises can be trimmed away. Canning, therefore, is an effective strategy for creating value from foods that might otherwise be wasted. Processing surplus fruit that is often left to rot can yield an income-generating product.

Canning and bottling create value addition microenterprise opportunities by absorbing seasonal surpluses when prices



Arusha, Tanzania women's group sells their jellies made from a variety of fruits; customers who return the bottle receive a discount on their next purchase - Photo: Odette Ngulu - PEF Graduate, Tanzania, 2012

are low. This reduces losses, since an overabundance of harvest can lower its value to the point that some portion goes to waste. Often launched by women's groups [Tool 87], such enterprises require expertise in business management, branding [Tool 88], and marketing.



USDA Canning Guide [\[bit.ly/2QAScXJ\]](https://bit.ly/2QAScXJ)



National Center for Home Food Preservation [\[bit.ly/2N2XDOC\]](https://bit.ly/2N2XDOC)



Homesteader's Basics for New Canners [\[bit.ly/2MfU2Hr\]](https://bit.ly/2MfU2Hr)



Cornell University Canning Introduction [\[bit.ly/2Qe3Vc1\]](https://bit.ly/2Qe3Vc1)



Pectin's Role in Making Jam and Jelly [\[bit.ly/2MoKgTy\]](https://bit.ly/2MoKgTy)



Berkeley, CA Small Batch Jam Company's Kickstarter Fundraising Video (they met their goal!) [\[kck.st/2NITxdW\]](https://kck.st/2NITxdW)



Fruit leathers and other packaged dried fruits treats at the Yerevan, Armenia, Market - Photo: Shaun Dumphy/WikiMedia

Fruit Leathers and Osmotic Fruit Dehydration

Fruit leathering and osmotic dehydration expand the options for dried fruit processing. Long shelf life and nutritious deliciousness make them popular domestically, with potential for export.



51

Dried fruit [bit.ly/2w8R4hM] is an ancient treat. Value addition, beyond the simple air/sun drying of fruits, generates many dried fruit specialties. Their popularity is derived from their attractiveness, sweet taste, long shelf life, plus being lighter weight and less messy than fresh fruits. They are compact, dense in calories, and easily transported, ideal for traveling or for nutritious snacking.

Fruits that lend themselves to drying like dates, figs, and raisins, are sold in their simple, unadorned, dried state. Creative food artisans add ground nuts, shredded coconut, and other flavorings to expand dried fruit offerings. These are labor-intensive



Labor-intensive, artistically presented dried treats at the Istanbul Spice Market tempt buyers - Photo: Betsy Teutsch

but their added appeal increases value. Dried fruit does not spoil like fresh fruit, so vendors worry less about inventory loss.

Fruits with high water content, like citrus and guava, typically discolor when they are dried, resulting in an unattractive brownish, tough product. When sliced to maximize surface area and suspended in a sugar solution, a process known as osmotic dehydration, they excrete water through their permeable surfaces while absorbing sugar. When dried afterwards, they remain sweetened and preserved by the sugar. (The syrup solution displaces the water lost by the fruits.) Osmotic dehydration yields a chewy, plump, sweet, colorful product with a long shelf life.

Osmotic dehydration can be followed by solar dehydration, a two-step process called osmo-dehydration. “In **osmo-solar dehydration** [bit.ly/2MesHdx] fruits are initially subjected to osmosis by dipping in sugar syrup (osmotic agent); then the fruits are dried in a solar dryer until the acceptable moisture content is achieved.” Of course, any food processing technique that utilizes solar energy is eco-friendly.

About 7-8 kg ripe guava fruits are required to make one kg of osmo-air dried slices; shelf life of product is six months to one year under ambient conditions.

—**India Institute of Horticultural Research**
[bit.ly/2KQUTgS]



Osmotically dehydrated guava - Photo: ICAR (permission requested)



Fruit leather processing in India, with plastic sheets separating each disk - Photo: S. K. Roy

Osmotic dehydration's benefits include

- Retaining fruits' and vegetables' shape, natural qualities, and wholesomeness
- Minimizing energy consumption
- Inhibiting enzymatic browning and improving the flavor and texture characteristic of the product
- Retaining the natural product color since it is immersed in solution, and not exposed to oxygen
- Reducing the products' volume and weight
- Reducing the dehydration time

Fruit leather [bit.ly/2MnZEDy] is popular around the world, as well. Mango, apricot, and banana are the most common, but mixtures are also marketed.

- Fruit is puréed by hand or, if electricity is present, with an appropriate appliance, to create pulp
- The pulp is strained to remove seeds and fiber
- Additional ingredients and flavorings can be incorporated and chemical preservatives, if desired, are added
- The puree is heated to 90°C (194°F) to kill microorganisms, preferably in a double boiler to avoid burning
- Puree is poured in thin layers onto lined trays and dried until it has a final moisture content of 15-25%. Then it is cut, pounded, or rolled.



FAO Fruit Drying Guidelines [bit.ly/2CAc3RI]



Journal of Food Science and Technology Osmotic Fruit Drying [bit.ly/2FuyqJ8]



FAO Fruit Leather Guide [bit.ly/2wW7fQb]



Osmotic Papaya Drying [bit.ly/2QhIvM0]



Many herbs, spices, and vegetables can be preserved in edible oils -
Photo: HomeRemediesLog.com

Preserving Herbs and Dried Vegetables in Edible Oil

Spices and herbs have been important in international trade since ancient days. Preserving spices, dried herbs, and dried or roasted vegetables in edible oil creates high value products sought domestically and globally.



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Spices, herbs, and vegetables can be preserved in edible oils; the oil protects the food from exposure to air, requires no heating, and creates a product with a very long shelf life. Crafted from oils with distinctive flavors and bottled attractively, this technique yields a high value, compact product suitable for international trade. Popular food products include sun dried tomatoes in olive oil, dried red chilies in oil, roasted peppers in olive oil, and oils flavored with garlic. The information in this entry is based on the FAO's 2005 publication [Herbs, Spices and Essential Oils: Post-harvest Operations in Developing Countries \[bit.ly/2Bq0le2\]](http://bit.ly/2Bq0le2).

In India, many fruits are heavily spiced and then covered with mustard oil for long term storage at ambient temperature.

Typically, the base is olive oil, sesame oil, or mustard oil. Processing is simple—clean the dried products, add them to a glass, metal or food grade plastic container, cover them with the selected oil, and seal the container.

In terms of world trade value, the most important spice crops from the tropical regions are

- Pepper
- Capsicums
- Nutmeg/mace
- Cardamom
- Allspice/pimento
- Vanilla
- Cloves
- Ginger
- Cinnamon and cassia
- Turmeric
- Saffron

The most important non-tropical spice crops are:

- Coriander
- Cumin
- Mustard
- Sesame seeds

The most important non-tropical herbs are:

- Sage
- Oregano
- Thyme
- Bay
- Mints
- Cilantro

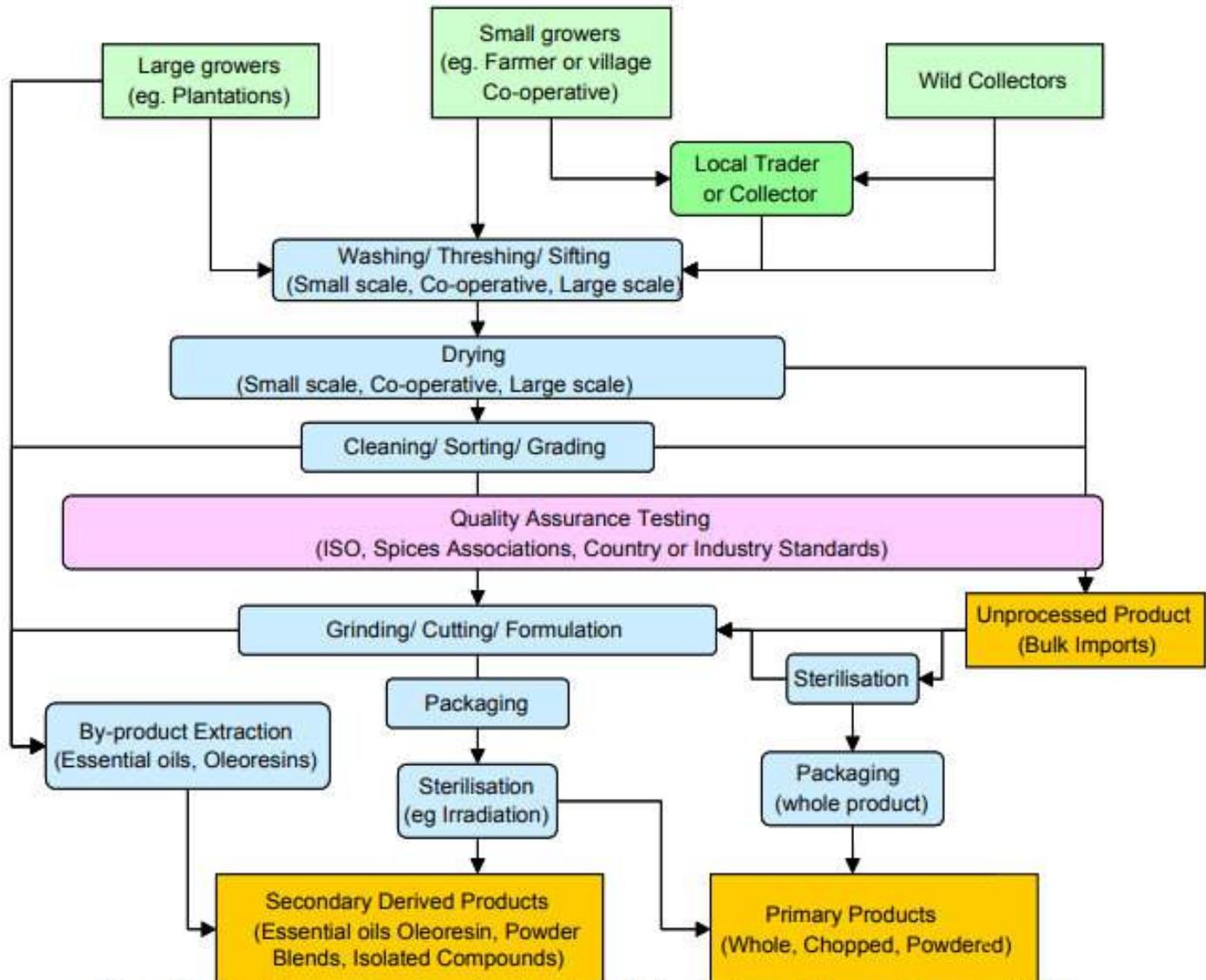


Figure 5: Post harvest processing and products produced from spices and herbs

Many steps are involved in the spice value chain; chart reads from top to bottom—FAO Herbs, Spices and Essential Oils, p. 12



FAO's Herbs, Spices, and Essential Oils [\[bit.ly/2Ns20lu\]](https://bit.ly/2Ns20lu)



Csiro.au's Preservation of Vegetables and Herbs in Oil [\[bit.ly/2O47Qqm\]](https://bit.ly/2O47Qqm)



Preserving Vegetables in Olive Oil [\[bit.ly/2N16wli\]](https://bit.ly/2N16wli)



Roadside sales of fresh-brewed beer made from marula, a local fruit, and presented in reused bottles in Mpumalanga, South Africa - Photo: Darlene Kasten

Fermentation

Fermentation, an ancient preparation method for many delicious foods, adds value by increasing the nutritional quality of the food as well as extending the duration of its safe consumption, in conjunction with canning.



53 Fermentation is universally known and has been used by peoples for thousands of years to transform commodities into desirable foods and beverages. The process of fermentation kills microorganisms, creating food that is safe to eat. The transformation brought about by fermentation also enhances the nutritional value of the foods by rendering them more readily digestible and adding beneficial [vitamins and micronutrients](#) [bit.ly/2MeMVE9].

The basic process of lacto-fermentation, a chemical reaction, occurs when the lactic acid bacteria (LAB) naturally present in foods converts that food's carbohydrates (sugars) to

lactic acid; food is preserved by the resulting lowered acidity, or pH. By leveraging this reaction, the lactic acid bacteria—beneficial microorganisms—kill lethal bacteria, like molds, that cause food to spoil.

Lactic acid production is promoted by the absence of the oxygen; thus, creating anaerobic, oxygen free, space improves intentional fermentation processing of foods. Foods suspended in their natural liquid create an anaerobic solution.

Because the chemical reaction of fermentation itself kills undesirable bacteria, the fermentation processing tools do not need the level of sterilization required for canning. Fermentation



Seoul, Korea's National Kimchi Making and Sharing Festival, 2014 - Photo: Jeon Han/Korean Culture and Information Service

Fermentation can improve the nutritional value of leafy vegetables, but salted or fermented vegetables have a shelf life of only 1-3 days at ambient temperature. Using preservative solutions combined with bottling and pasteurization (heat processing) extends shelf life.

—World Vegetable Center [bit.ly/2MHx3pQ]

Once their fermentation is complete, fermented vegetables should be consumed “fresh” as soon as possible, or heat processed/canned for long term storage or sale.

—Lisa Kitinoja

is most effective when the ambient temperature is in the 60-70 range, challenging in hot climates. Fermentation takes longer at higher ambient temperatures but the process still occurs. Erecting a sunshade [bit.ly/2P58Vih] if outdoors to protect the product from additional heat helps.

Fermenting foods are placed in clean, closed containers at room temperature for days to weeks, depending on the desired results, while fermentation does its magic. The foam and bubbles that begin to form are carbon dioxide (CO₂) gas escaping. No heat or cold chain is required, making fermentation an eco-friendly, low-tech, frugal process.

Fermented foods with intense flavors, such as sriracha (fermented peppers) are popular condiments, complementing blander vegetables and staple grains.

Brewing beer is a popular fermentation microenterprise, often the domain of women. Across the world, alcoholic drinks are created from available grains including sorghum, rice, and millet. Fruit is often added, and of course fermented grapes become wine.

Fermentation is one of the many steps in processing cocoa beans, on the way to their becoming chocolate.

Fermented cabbage is an Asian staple, kimchi. Fermented soybeans are the basis of both tempeh, a firm-textured chewy cake with high protein content, and miso, a concentrate used as the basis for soups.

Animals also like feeding on fermented food. Modern silage, grasses that are raised and mowed for animal feed, are fermented during storage in the silo. This preserves quality by the beneficial lactic acid bacteria killing off dangerous microorganisms. Like fermented foods for human consumption, fermentation improves the silage's taste and digestibility, and enhances its vitamin content.

In the high-tech industrialized world, there is a renewed interest in traditional fermentation processes and an appreciation for the role of fermented foods in counteracting an ultra-sterilized food system. There is a myriad of online information and many recipes available.



Kansas State Extension Fermentation Guide [bit.ly/2oUPpJM]



Sampling of Pickle Recipes [armagazine.com/2wVQ5mw]



***The Art of Fermentation* by Sandor Ellix Katz** [bit.ly/2RXcbOg]



Brothers Green Complete Beginner's Guide to Fermenting Foods at Home [bit.ly/2Nt6mZt]



Packaging a newly introduced product, quick-cooking beans, in Kenya - Photo: CIAT [\[bit.ly/2nBvvCR\]](https://bit.ly/2nBvvCR)

Processing Grains and Pulses

Grains and pulses (grain legumes) such as peas, lentils, and peanuts (groundnuts), are worldwide dietary staples. Value addition for beans and pulses yields quality nutrition and convenience.



54 Beans and pulses are cultivated across the world, valued for their nutritional value as well as flavor. Farmers appreciate their drought tolerance and ability to add nitrogen to soil. Typically, they are food crops, not cash crops, relegated to female farmers. Developing their commercial potential provides expanded business opportunities.

Cooking time for beans and pulses varies. Small lentils cook quickly while large beans require lengthy cooking to achieve tenderness. An [initiative in Kenya and Uganda \[bit.ly/2N8FgHF\]](https://bit.ly/2N8FgHF) is developing a variety of pre-cooked beans, lowering cooking time from two hours down to just 15 minutes. This saves end-users time as well as money, by reducing the fuel required for cooking. They are also creating and marketing bean-based snacks. In Tanzania, peanuts are fried in a coating of QPM (quality protein maize) meal [Tool 55], a double delivery of healthy food.

As incomes rise and the human population urbanizes, the market for prepared food expands. The effects of increased animal protein production taxes our planet, giving bean and pulse meat substitutes an ever more important role to play in combating climate change. Indeed, a popular new American company, BeyondMeat.com, creates products with pea protein. Their vegetarian burgers are flying off the shelves.

Soy beans are typically raised for their oil, but other processed soy products are central to Asian cuisine and have spread worldwide:

Soy milk—liquid extracted from cooked soy beans, a popular substitute for cow’s milk and a substitute for human milk, in baby formulas

Tofu—soy milk boiled with an added coagulating agent until curds separate. Pressed curds become soy bean cakes, a flexible high protein solid

Miso—fermented soy and grain

Tempeh—an Indonesian staple made by fermenting [Tool 53] soy beans and compressing them into a solid block

Edamame—fresh green soy beans, a nutritious snack boiled or steamed



Traditional tofu pressing in Haikou, Hainan, China - Photo: Anna Frodesiak/Wikimedia



Rinsing soybeans in Lombok, Indonesia - Photo: Candice and Jarrett/
Flickr



Tofu pressing in Lombok, Indonesia - Photo: Candace and Jarrett/Flickr

“Pulse ingredients are gaining in popularity because they appeal to both food manufacturers and consumers on several levels. First, food products with pulse ingredients can be labeled as non-GMO, gluten-free and low allergen, giving them broad market appeal. Second, pulse production has a small carbon footprint and contributes to sustainable food production, thereby appealing to environmentally conscious consumers. Third, their high protein and nutritional properties dovetail nicely with the growing interest in healthy foods. For these reasons, more and more new food products are featuring pulse ingredients.”

—Murad Al-Katib, Global Pulse Convention 2016

Chickpeas are growing in popularity, eaten as a snack and also puréed and spiced to become hummus. The global hummus market is growing by [8%](https://bit.ly/2GKVctp) [\[bit.ly/2GKVctp\]](https://bit.ly/2GKVctp) a year and producers are expanding the hummus preparation method to other types of beans. By 2022, it is predicted that over a billion dollars of hummus will be consumed annually.

Ethiopians prepare a pre-cooked chickpea powder with local spices, ready to be re-hydrated and eaten as a warm paste with the national bread known as injera. In the Middle East, such a chickpea paste is shaped into small balls and fried and eaten with condiments in a pita bread—falafel.

Rice can be parboiled to reduce the damage that can occur during de-hulling, and has the side benefit of reducing the time it requires to cook. One of PEF's graduate e-learners, Mekbib Heilegebrile Seife (Ethiopia, 2012) has developed a training manual on the utilization of this simple processing method.

CGIAR is coordinating a 10-year [Grain Legume](https://bit.ly/2PapR7k) [\[bit.ly/2PapR7k\]](https://bit.ly/2PapR7k) campaign, promoting their cultivation to expand their nutritional, ecological, and economic impact. Their targeted eight: chickpea, cowpea, common bean, fava bean, groundnut, lentil, pigeon pea, and soybean.



Article: Pre-Cooked Beans Pilot Project [\[reut.rs/2N8FgHF\]](https://reut.rs/2N8FgHF)



The Process of Making Tofu [\[bit.ly/2NAglae\]](https://bit.ly/2NAglae)



Tofu Making in Vietnam [\[bit.ly/2x9Edg0\]](https://bit.ly/2x9Edg0)



Nutrition expert passing out samples of foods made with QPM to promote its adoption - Photo: Odette Ngulu - PEF Graduate, Tanzania, 2012

Micronutrient-Fortified Foods, Biofortified Foods, and Edible Insects

Biofortified foods, fortified ingredients, and novel protein sources offer opportunities for creating products that improve traditional foods, generate new sources of income, and promote health.



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Globally, nearly a billion children and adults are hungry and undernourished; many simply don't have enough food, and others who consume sufficient calories nevertheless suffer from micronutrient deficiency. Deficits of essential micronutrients (vitamins, trace minerals, etc) are detrimental to human health and development.

Micronutrient deficiencies can be addressed through

- Food fortification [bit.ly/2xcHxHk], adding micronutrients during the processing stage.
- Biofortification, developing and growing food staples with higher nutritional value.
- Processing insects as a source of protein and nourishment.

In general, food processing contributes value and extends shelf life, a critical strategy for reducing food losses. Using processing techniques that boost traditional food's lack of high-quality nutrition adds extra value.

Introducing nutritionally-enhanced crops and processing them into desirable products is a complex value chain challenge.

Farmers need training and encouragement to raise and process new nutritionally-enhanced foods but will only gamble on them if they are confident there will be purchasers. Hence, simultaneous marketing and educational efforts must be implemented for creating demand.

Micronutrient [bit.ly/2OxXZZt] fortification is a post-harvest processing activity. For example, flour has long been fortified with folic acid to prevent neural tube defects. Only 70% of the world's population lives in countries requiring fortification. Fortification is only accessed by eating processed foods, in any event, bypassing many remote rural populations.

For over a decade a coordinated initiative has encouraged farmers to phase out less nutritious foods and instead grow orange flesh sweet potatoes, chock full of vitamin A. Orange-fleshed sweet potatoes are easy to grow and drought tolerant. The [Sweet Potato Knowledge Portal \[sweetpotatoknowledge.org\]](http://Sweet Potato Knowledge Portal [sweetpotatoknowledge.org]) provides resources throughout the OFSP value chain. [Sweet potato juice \[bit.ly/2nDOsEJ\]](http://Sweet potato juice [bit.ly/2nDOsEJ]), anyone?

Quality Protein Maize (QPM) offers 90 percent the nutritional value of skim milk, the standard for adequate nutrition value.

Conventional flour can be supplemented or replaced by foods processed into flour form:

- **Sweet potato flour** [bit.ly/2MF87iz] is easy to substitute for a portion of conventional flours in existing recipes, and new products are being developed to deploy OFSPs' value. These provide economic opportunities as well as healthier food, a win-win.
- Cricket flour is exactly what it sounds like—crickets, finely ground. It is extremely high in protein and can be added to baked foods to enhance nutritional content. **Crickets** [bit.ly/2nCLnWh] are rich in proteins, zinc, iron, copper, calcium and low in calories. A **product** [bittyfoods.com] combining cassava, cricket, and coconut can be substituted 1:1 for conventional flour. **Farming insects** [bit.ly/1ixCI5P] is an income generating opportunity; those unfazed by eating insects enjoy these eco-friendly, nutritious baked goods and **snacks** [exoprotein.com].
- **High-quality Cassava Flour (HQCF)** [bit.ly/2Mh6Aml] is nutritious, gluten-free (a plus for

contemporary marketing) and preserves the value of surplus cassava, since once harvested it rapidly spoils. It can replace imported wheat, creating a local market and lowering the price of food. **High-quality cassava flour** [bit.ly/2OzpaTY] stays white, while traditionally processed cassava flour turns brown.

- Dried plantain flour adds nutrients when substituted for a percentage of conventional flour. In Rwanda they flavor it with powdered onions, garlic, and chili peppers.

Diets overly dependent on conventional maize lack nutrients essential for human health and development. QPM, quality protein maize, was bred by Surinder Vasal and Evangelina Villegas at the **International Maize and Wheat Improvement Center (CIMMYT)** [CIMMYT.org] in the late 1990s to address this problem. Their innovation features twice as many essential amino acids, lysine and tryptophan, as well as enhanced protein content. QPM has been well-accepted by consumers, improving diets around the world. They were awarded the 2000 World Food Prize for this contribution to global nutrition. QPM is considered a biofortified food, because its nutritional profile has been improved using conventional breeding techniques.



WHO's Guide to Food Fortifications with Micronutrients (376 pages) [bit.ly/2xcHxHk]



GAIN: Global Alliance for Improved Nutrition on Fortified Foods [bit.ly/2Oqd1mT]



Academic Review: Quality Protein Maize (QPM) Flour [bit.ly/2p2K6YQ]



Edible Insect Products [bit.ly/2Quuytk]



Cooking with Crickets and Cricket Flour [bit.ly/2x3ZjwO]

Odette Ngulu, a 2012 PEF graduate, is a Postharvest Educator in Tanzania. Part of her job is to promote the use of nutritionally superior products like QPM, quality protein maize. Developing demand for a new crop along with its introduction is vital, or farmers will be stuck with harvested foods no one wants to purchase.

At fairs and trainings, Ngulu demonstrates foods that utilize QPM flour [bit.ly/2MhgNyX] and also shares samples. Check out her QPM cake and appreciate how challenging it is to regulate a charcoal open fire oven.



Demonstrating how to bake a delicious cake with QPM, Hai Region, Tanzania - Photo: Odette Ngulu - PEF Graduate, Tanzania, 2012



The cake is set to bake over a three stone charcoal fire—Hai Region, Tanzania - Photo: Odette Ngulu - PEF Graduate, Tanzania, 2012

Quality Protein Maize (QPM) Cake

Ingredients:

- 3 C. QPM flour (QPM is the texture of masa, very finely ground flour)
- 1 C. wheat flour
- 1½ C. sugar
- 1 C. butter
- 6 eggs (medium size)
- 7 tsp baking powder
- 1 tsp vanilla essence/ grated rind of 1 lemon / any desired spice
- 2 C. fresh milk /coconut milk

Method

1. Preheat oven to 180°C
2. Mix QPM flour, wheat flour, baking powder and sift together twice to ensure even distribution of the baking powder
3. Grease large baking tin and lightly dust with flour
4. Cream butter and sugar until light and fluffy
5. Add beaten eggs with vanilla gradually, beating well after each addition
6. Fold in flour and milk alternately to give a soft consistency
7. Pour the mixture into the greased baking tin
8. Bake at 180°C for 45-50 minutes until cake is well-risen and evenly golden brown.

A fine skewer stuck into the center will come out clean if the cake is finished.



QPM Cake cooling - Photo: Odette Ngulu - PEF Graduate, Tanzania, 2012



Section 4

STORAGE

56. Storage Sanitation
57. Make Your Own Hermetic Sealing Grain and Seed Storage Containers
58. Hermetic Sealing Triple-Bag Storage
59. Hermetic Sealing Free-Standing Dried Grain Containers
60. Hermetic Sealing Metal Silos and Cans
61. Natural Material Hermetic Sealing: Mud and Earth Clay Silos
62. Oxygen Absorbers and Dry Ice
63. Green Pesticides: Natural Treatments for Food Storage
64. Pallets: Benefits and Best Practices
65. Improved Storage Structure Design
66. Best Practices for Storage Room Stacking
67. Improved Storage Area Ventilation Systems: Fans and Turbines
68. Compatibility and Temperature Management for Fruit and Vegetable Storage
69. Ethylene Management
70. Evaporative Cooling Structures: Charcoal Coolers
71. Evaporative Cooling: ZECC, Zero Energy Cool Chambers
72. Solar Cold Micro-Room Sub-Contracting
73. Natural Underground Cooling
74. Vegetable and Fruit Storage Innovations: Evaptiners and Wakati Storage Chambers
75. Pest Traps: Insects and Rodents



Artisan Benjamin Njue demonstrating how to make metal silos in Embu, Kenya -
Photo: A. Wamalwa/CIMMYT

STORAGE: INTRODUCTION



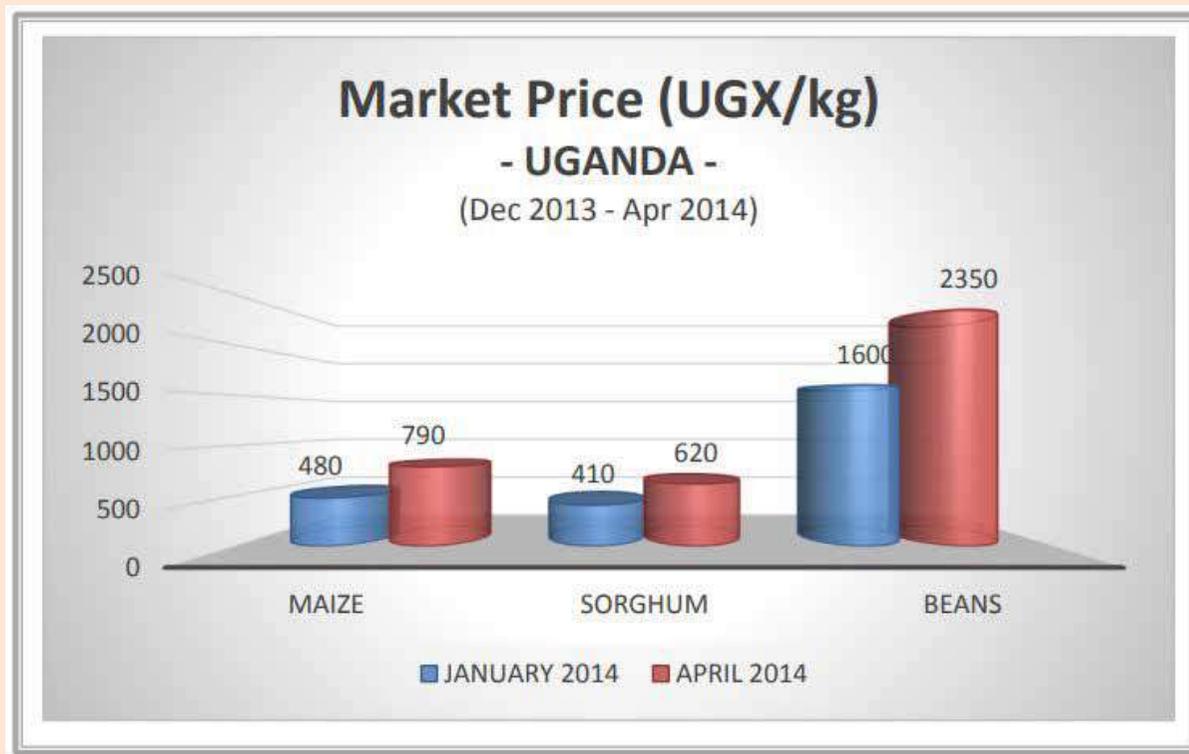
PICS Bag Opening Ceremony in Malawi, 2017; pristine grains featured in the eight close-ups are the aerial views of the bags standing in the center photo - Photo: PICS 3 Project/Facebook

A chain is only as strong as its weakest link, a truism for value chains everywhere. Reliable storage is a boon for both farmers as well as consumers. Preparing produce for successful storage allows for its deferred reentry back into the chain. This offers triple benefits:

- Decreased losses
- Increased revenue
- More calories for a hungry world

Mastering technology for storing food provided evolutionary advantages. Modern technology and research have improved on ancient methods, allowing more farmers and food handlers to preserve food and provide value.

People's ability to strategize and think ahead, when applied to food provisions, allow for survival during droughts and other catastrophes. Joseph's biblical innovation of storehouses in ancient Egypt, to put away grain in good years and save them for lean times, is a paradigm.



Market price increases achieved through four months of improved storage - [WFP \(the World Food Programme\)](http://bit.ly/2yVJCqD) [bit.ly/2yVJCqD]

Today we grow enough food to feed the whole world but, tragically, much of it spoils due to lack of reliable storage capacity.

For smallholder farmers, improved storage can help the family break out of food insecurity. Typically, families struggle during the Hunger Season, when their food supplies dwindle but the new crops are not yet producing. Lowering their food losses even by 10-15% can make a huge difference in families' health and security. In some cases, it can turn a farming family from one that runs out of provisions at the end of the season, when prices are highest, to a family that has a surplus to sell.

Modern technology focuses a great deal of attention on expanding yields. It is imperative to also expand storage capacity. This section features many ways for doing just that.

Storage is an investment; it must be used strategically. Only high-quality food, free of decay and damage, should be prepared for storage, and the storage

environment should be well-insulated, ventilated, and suited to the specific food's requirements in terms of temperature and humidity.

Traditional crop storage methods—typically using woven sacks or porous storage structures—do little to protect the food supply against invasion by insects, rodents, and pathogens. When pests consume stored crops, it results in the loss of the inputs purchased or procured as well as the labor and capital expended to plant, grow, harvest, and process the now lost crop.

The realistic threat of stored food spoiling is a poverty trap that perpetuates itself.

- Farmers may be motivated to sell their crops up front at harvest time when supplies are at the max and prices are at their lowest.
- Farmers whose food supplies are diminished due to storage loss must purchase food late in the season when it's the most expensive (or go without).

When farmers are confident of safe storage for their surplus beyond their household needs, they can sell strategically and increase their income significantly.

“It is worth noting there is another level of farmer who traditionally has minimal excess grain beyond the family’s consumption requirements, who utilizing the new storage technologies will have the option of trading (at a time of their choosing) surplus grain created through reduced postharvest losses. **To these families, this would represent a 100% gain in household income.**”

–WFP.org [bolding ours] [\[bit.ly/2OxSHx0\]](https://bit.ly/2OxSHx0)

If improved storage is widely adopted by smallholder farmers, prices will actually become more stable as end of season price hikes will decrease, providing overall communal benefit.

While an individual smallholder farming family might erect a small storage structure on their land, in most cases a larger structure would be owned either by a farmer group [Tool 87] or a commercial entity. Co-ops can share the expense of an improved storage structure and, if space is available, rent to others and generate revenue. Renting space in a reliable storage structure entails some up-front expense for farmers, rather than selling at the earliest opportunity, but the potential for higher payments later in the season is significant and they can more than recoup the initial outlay.

Infestation damage by pests adds extra labor for women who must sort through the grains, separating edible from inedible. Hermetic storage, leaving grains in pristine condition, eliminates this tedious, time-consuming task, paying women a time dividend.

References are listed at the end of the book, but for those focused on general grain and seed storage, these are comprehensive resources:



The Improved Seed Storage Project: Overview of Briefs and Case Studies [\[bit.ly/2MvxVgo\]](https://bit.ly/2MvxVgo)



FAO Guide: Appropriate Seed and Grain Storage Systems for Small-scale Farmers [\[bit.ly/2OhsRh3\]](https://bit.ly/2OhsRh3)



HCGA Grain Storage Guide [\[bit.ly/2NJQKAT\]](https://bit.ly/2NJQKAT)



A well-designed, clean, ventilated storage structure owned jointly by a rice cooperative in Burundi: their storage receipt system allows farmers to borrow against the rice they store and also to claim the profit when the rice is sold, or else take the rice back later in the year. - Photo: ©IFAD/Susan Beccio

Storage Sanitation

Adhering to strict sanitation protocols in storage spaces, from the smallest bin to the largest warehouse, reduces the spread of crop-destroying pests and pathogens.



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Sanitation is a super tool for reducing postharvest losses, from farm to end consumer. There are always pathogens, rodents, and insect pests looking for energy sources. The challenge is to protect stored food from these invaders. Prevention is more effective than post-invasion remedies.

Sanitation generally refers to superficial cleaning. Wiping counters, walls, and other surfaces, sweeping up debris, and washing hands to as to not spread anything from a decayed plant to healthy one all are routinely necessary. Checking for ripped containers that spill contents, thereby attracting pests, is another daily sanitation precaution. Workers themselves can take added measures both for their own protection and to avoid cross-contamination. These can include wearing clean uniforms, hairnets, shoe covering, gloves (disposable or washable—it is important to keep washable gloves clean, so they don't add to the problem), and particularly in Asia, facemasks.

Sanitizing involves intensified treatments on surfaces with disinfectant like detergent or a chlorine solution. For example, if the contents of a bag are found to be infested or decaying, the product must be disposed of prudently: feeding it to animals if that's a safe option or destroyed. The bag must be disinfected before reuse. (Bags like [PICS bags \[bit.ly/2P3vlep\]](https://bit.ly/2P3vlep) [Tool 58] are designed to be reused; they do not require disinfection except in the very rare case of their contents spoiling.)

Dedicated storage spaces range from small rooms assigned

for storage but not designed for that purpose to state-of-the-art warehouses. Each commodity is stored in an appropriate style of container to protect it. Therefore, optimizing storage requires quality product, appropriate storage containers or packaging, and a protective structure for housing stockpiled food.

The area surrounding the designated storage space should be kept free of garbage, waste, and weeds to avoid attracting rodents and pests. A closed storage structure is vital, with ventilation to avoid heat build-up. (Storing food out in the open invites pests for dinner.) “Rat guards can be made from simple materials such as old tin cans or pieces of sheet metal fashioned to fit the extended legs of storage structures. If desired, more elaborate technologies can be used. Concrete floors will help prevent rodent entry, as will screens on windows, vents and drains [Tool 66].” —Kitinoja and Kader (2015) p. 151

Between seasons, the storage room is usually emptied of its contents. This is the time to thoroughly clean all floors, ceilings, walls, pallets, reusable plastic crates, and other equipment.

SAWBO Animations promotes the mnemonic **DICE** for grain treatment pre-storage: **D**ry, **I**nspect, **C**lean, and **E**xamine. Their [DICE video \[bit.ly/2QAxcxE\]](https://bit.ly/2QAxcxE) outlines all these steps, as well as reinforcing precautions for reducing grain losses covered here and elsewhere.

Tips for [Sanitation Success \[bit.ly/2KRdVPE\]](https://bit.ly/2KRdVPE), from the FAO:

- Do not mix new grain with old
- Old infested material should be removed or thoroughly fumigated
- Clean the storage structures, machinery and disinfect bags and baskets by sunning or chemical treatment (washing, drying)
- Large structures will require chemical treatment (fumigation) while smoke may be adequate in small stores

Insect traps [Tool 75] help reduce infestation. Naturally they must be emptied or replaced when they have successfully captured bugs.



Nestor Agutor, who runs a convenience store, refilling a maize basin in his storage room in Atchannou, Benin; using a pallet under the sacks would help keep the product and storage room clean and also provide ventilation to improve shelf life - Photo: ©IFAD/Andrew Esiebo/Panos



FAO Manual on Grain Handling and Storage [\[bit.ly/2QuXYaz\]](https://bit.ly/2QuXYaz)



IPM (Integrated Pest Management) for Grain Storage [\[bit.ly/2NEH9LV\]](https://bit.ly/2NEH9LV)



SAWBO-Animations: DICE Grain Inspection [\[bit.ly/2QAxcxE\]](https://bit.ly/2QAxcxE)



SAWBO-Animations: Grain Storage [\[bit.ly/2MsLCfP\]](https://bit.ly/2MsLCfP)



Market in Ghana offering a variety of used jerry cans and large reusable containers; these are well-suited for DIY hermetic grain storage bins - Photo: Carsten ten Brink/Flickr

Make Your Own Hermetic Sealing Grain and Seed Storage Containers

Low-cost or free hermetic storage for small quantities of seeds and dried grains can be accomplished by utilizing locally available containers, new or used.



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While hermetic sealed containers are not new, they are at long last being embraced in developing countries where they can play a vital in reducing postharvest losses.

Hermetically sealing a non-porous container creates oxygen-free storage. Microscopic insect infestations and molds are deprived of the oxygen they require for maturation. Hence, they die off naturally, without pesticides. This lowers costs and eliminates toxic chemical exposure for eco-systems, farmers, food handlers, and end users. It also reduces the speed at which insect populations develop pesticide resistance.

Large plastic jerrycans or other heavy plastic discarded screw-top product containers make excellent, free hermetic storage. There is a thriving trade in reselling new as well as used containers in the Global South.

The red flag for repurposing these containers for hermetic seed/grain storage is that no jerry can or other container that has stored pesticides, other toxic chemicals, or fuel oil should be reused to store grain or seeds: **it is impossible to reliably clean the residue, rendering them dangerous for food storage.**

“The most common locally available containers include simple water bottles and recycled vegetable oil containers. The 5 and 20-liter vegetable oil containers are quite popular in villages throughout Africa and are typically used to store water and local beverages.”—Dieudonne Baributsa

Here are directions for storing crops for seed, eating, or sale, from [SAWBO Animation's video \[bit.ly/2OAPXPD\]](https://www.sawbo.org/animation/video) with added details:

1. Make sure the grains or pulses to be stored are of high-quality [**DICE**, Tool 56]. Hermetic storage preserves quality but does not improve it.
2. Grains/pulses must be dried according to [established guidelines \[bit.ly/2OzZYfN\]](https://www.sawbo.org/guidelines).
3. The container must be clean, dry, and air tight. The minimum recommended size is 5 liters but the optimal size is 10 to 20 liters.
4. Carefully pour in the grains/pulses/seeds. Shake contents to settle.
5. Fill as full as possible. If the handle is hollow, it should be filled too, maximally displacing air.
6. Cover the opening with a clean thin sheet of plastic, folded to add a second layer, and screw the top in place.
7. Mark the date, contents, and intended purpose of your stored commodity.

8. Do not open the container for at least a month, to guarantee bruchids or other bugs or molds are inactive. They will die naturally due to oxygen deprivation, so it is crucial not to let any air in.
9. If the contents will be used as seeds, plant within 6 months to guarantee the highest rate of germination.
10. If the contents will be used for food, the shelf life is a year or longer.
11. Once the container is opened, contents must be consumed within a few weeks; once the hermetic seal is broken the contents will deteriorate.



A cross-section of a jerry can used for hermetic sealed storage - Photo: SAWBO-Animations

According to IRRI's Rice Knowledge Bank, porous material like that of a clay pot can be used, but it needs to be sealed, e.g. using latex paint in the inside and the outside. They highlight problems farmers can run into with do-it-yourself hermetic storage:

- Intermittent opening and closing allow oxygen re-entry, leading to the rapid re-infestation of insects that hatch from eggs or larvae.
- If containers are only partially filled, the empty air space to grain ratio may not allow oxygen levels to drop to a level that will control insects—[IRRI \[bit.ly/2MJOLsA\]](https://www.irri.org/2017/02/20/irri-researchers-reveal-how-to-keep-grain-fresh-for-longer/)



World Food Program's Training Manual for Improving Grain Postharvest Handling and Storage (248 pages) [\[bit.ly/2OmaPdP\]](https://www.wfp.org/publications/2017/02/20/world-food-program-training-manual-for-improving-grain-postharvest-handling-and-storage)



SAWBO-Animations: DIY Hermetic Storage [\[bit.ly/2Ndd6eV\]](https://www.sawbo.org/2017/02/20/sawbo-animations-diy-hermetic-storage/)



SAWBO-Animations: DICE Grain Inspection [\[bit.ly/2QAxcxE\]](https://www.sawbo.org/2017/02/20/sawbo-animations-dice-grain-inspection/)



An early Open-The-Bag PICS event; note the PICS-branded toga fabric and illustrated directions on the bags - Photo: IITA/Flickr

Hermetic Sealing Storage Bags: PICS Bags and More

Hermetic sealed grain bags create non-porous storage impermeable to air and moisture. This oxygen-deficient micro-environment offers pesticide-free protection from internal infestation.



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The PICS hermetic sealed triple bagging system, a form of portable large bag hermetic sealing, has been an enormous success since its introduction over a decade ago in West and Central Africa. A project of Purdue University and the Bill & Melinda Gates Foundation, PICS stood for Purdue Improved Cowpea Storage. With funding from Gates Foundation, Purdue University has initiated PICS project in West African countries in collaboration with [national and international organizations](https://www.nationalandinternationalorganizations.com) [bit.ly/2MJfntU].

Cowpeas, popular in West Africa, are also known as black-eyed peas. Typically a women's crop, they are notorious for quick postharvest spoilage from bruchid infestation. Microscopic larvae mature in conventional bag storage; within a few weeks, the bagged cowpeas swarm with insects, rendering the contents useless. While nutritious, cowpeas had little market potential due to their short shelf life.

The PICS project worked with smallholder farmers to develop a triple bag design and technique, and to develop a bag supply chain. Triple bagging involves

- Filling the first of two High Density Polyethylene (HDPE) inner bags
- Squeezing out any air in the bag and twist-tying it closed

- Placing it in a second HDPE bag, squeezing out the air, and twist-tying it
- Placing it in a third outer woven polypropylene bag, and twist-tying it

The contents' quality is safe for up to one year.

A key component of the PICS adoption success is the Open-The-Bag Ceremony. At fairs and other public gatherings, agricultural extension workers [Tool 90] demonstrate how to use the bags, filling them on the spot, and marking them with the date. Many months later the PICS bag is opened to great fanfare. Villagers expecting to see a swarming load of worthless, well-fed insects are astonished when the opened PICS bag reveals an interior full of pristine cowpeas.

Building on the cowpea success, the PICS project ran trials on other crops. They were equally effective. PICS now stands for "Purdue Improved Crop Bags" and, along with other effective similar brands such as GrainPro, are used for

- Cowpeas
- Maize [bit.ly/2KPif6Q]
- Sorghum
- Wheat

- Rice
- Common beans
- Mungbeans
- Groundnuts
- Millet

Purdue University has initiated the third phase of the Purdue Improved Crop Storage (PICS3) project and expanded to different regions of Africa and some parts of Asia, funded by the Bill & Melinda Gates Foundation, [with several partner organizations \[bit.ly/2BjJ5of\]](#).

Unpunctured bags can be reused several times, amortizing the few dollars they cost over two or three crop seasons. They do not require sanitizing between uses; holes can be patched.

An [app matches up bag buyers with sellers \[bit.ly/2MkxFEO\]](#). PICS bags and other products like them are now manufactured in several African countries. While they can be successfully repaired to extend their lifespan, their success has, in fact, created a new problem: how to dispose of them when they're worn out.

Hermetic bags come in 50kg and 100kg sizes. These aren't intended for small withdrawals as needed. Untying and retying three bags is a chore and compromises the oxygen-free interior,



A farmer shows off her ten full 100kg PICS bags, more than a ton of cowpeas - Photo: IITA/Flick

so they are best-suited for long-term use. Metal silos [Tool 60], by contrast, have a spigot for withdrawing grain while the top remains sealed, letting in very little air.

Hermetic sealed bags are not rodent-proof. However, there are reports of rodents puncturing the outer two bags without making it to the contents. No smell is detectable through the triple bag, decreasing rodent attraction.



ACDI/VOCA Hermetic Storage Summary: SAVE MONEY, SAFE FOOD [\[bit.ly/2p77GmZ\]](#)



PICS Project Guide [\[bit.ly/2xcMUqD\]](#)



[Grainpro.com](#) tools and storage products



PICS Bags Demonstration in Uganda [\[bit.ly/2NawHw0\]](#)



Members of a Cambodian agriculture cooperative in Krabao village use a rice dryer to dry and store rice using a hermetic sealed bag and bin - Photo: ©IFAD/Phan Chansey

Hermetic Sealing Free-Standing Dried Grain Containers

Hermetic storage containers that can be opened and easily resealed protect their contents while allowing stored dried foods to be removed as needed.



59 For safely hermetic storing of food that will be removed in small quantities as needed, free-standing containers allowing access through removable tops or an outlet-and-cap are ideal. Stored grain, of course, must first be sufficiently dry. Low-cost moisture detection is featured in Tool 45.

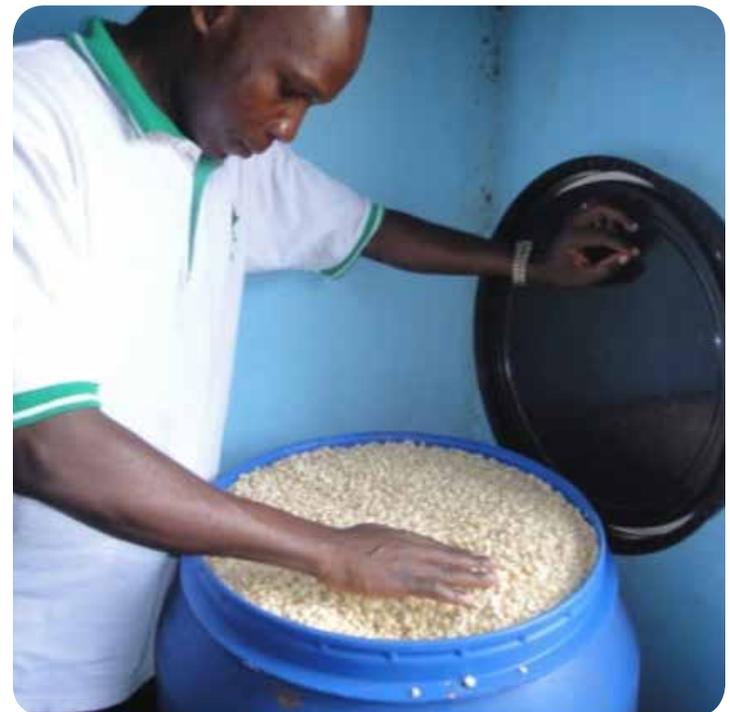
Storage solutions designed for frequent withdrawal of contents come in a wide variety of styles, materials, and sizes:

- Repurposed empty heavy plastic bottles or jerry cans [Tool 57] can be used for smaller quantities
- Plastic bins designed for grain storage, if locally available, get the job done
- Food-grade plastic buckets in 2k and 5k sizes—these can be sanitized reused buckets—are useful when used with Gamma seal™ tops, a two-piece mechanism that transforms a pail into an air and moisture-proof storage container. An outer threaded rim fits around the top of the pail and the top screws into it, easily opened as needed and reclosed.
- Metal silos [Tool 60] are fabricated locally

Glass containers are air and moisture tight but are heavy, breakable, and if clear, don't protect contents from light; they

are unsuitable for storing large quantities. If it's necessary to use jars for storage, amber or other dark colored jars obstruct light.

Large bins can serve as micro-silos for households or stores. Farmers can use them to safely store their harvest, trusting the grain—when properly dried—can reliably be preserved



Safe storage for dried commodities in Uganda - Photo: Leony Halos-Kim

Storage technology adoption had a positive impact on farmers' livelihoods.

Similar to previous studies in Central America, storage technology adopters in Uganda reported a significant improvement in income, food security, and socio-economic well-being. . . . As households begin to consume more of the food they harvest and store, reduced food expenses enable financial flexibility to address other needs. . . . It was not surprising to observe improvement in areas such as children's education, as grains are often a suitable form of tuition payment, and women's workload, as storage technology reduces daily efforts to gather grains for consumption that are typically undertaken by women.

—**CITE Postharvest Technology Evaluation**
[\[bit.ly/2P6qVj6\]](http://bit.ly/2P6qVj6)



Plastic grain storage in Agago, Uganda; the heavy black tank can also be used for water storage - Photo © 2015 Mark Brennan, MIT CITE, Courtesy of Photoshare

long-term. The family can sell surplus when income is needed; the later they wait (before the next harvest, or course) the higher the prices are.

Sasakawa Africa Association promotes the use of plastic storage bins to achieve economic security: after one season, the storage tanks (about \$25) pay for themselves, and each subsequent year generate benefits with no additional outlay.

“Bazanya Rozius of Keto Village, in Sekanyonyi sub-county, Uganda kept 200 kg of beans in a plastic tank for more than 3 months before selling it at 2800 Ugandan shillings/kg. Those in the area who did not use a tank were forced to sell their beans earlier at around 1,200/kg shillings.”

—**Sasakawa Africa Association**
[\[bit.ly/2KQh4nx\]](http://bit.ly/2KQh4nx), Chris Dowsell



A Kenyan farmer adds maize to her large, prized metal silo - Photo: CIMMYT

Hermetic Sealing Metal Silos and Cans

Metal silos offer hermetically sealed safe food storage for dried commodities. They are well-accepted; families save their metal silos as heirlooms due to their long life and positive impact.



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Locally fabricated from household sheet-metal, metal silos for storing dried grains, beans, and legumes hermetically protect from air, moisture, and pest damage. Introduced in Central America by SDC, The Swiss Agency for Development and Cooperation, in the 1980s, silos are a very popular innovation, though the costliest of hermetic storage options. They add back at least the 10-15% of the stored yield that farm families formerly lost. At present, NGOs are introducing metal silos to Eastern and Southern Africa where crop loss is estimated to be higher, 16- 23%, so their potential benefit is even greater.

Safe storage adds opportunities for income generating from year-round value-added activities. Women can prepare processed foods as time permits, not just during the harvest season bounty.

A household metal silo with a capacity of 1000kg can conserve the grain needed to feed a family of five for one year. Farmers [dry the grain to 14% moisture \[bit.ly/2MqitWE\]](https://bit.ly/2MqitWE) or less (according to type of grain) before placing it in the silo, which is essential to prevent any mold or insect pest growth. According to Kenyan tinsmith Benjamin Njue Ngari, once filled with grain, a small space is left at the top where a burning candle is placed just before it is sealed shut. The candle consumes

oxygen remaining in the silo, preventing any pests present in the grain from maturing.

Metal silos

- Reduce losses to nearly zero
- Helped to increase food security by 30-35 days per year in Central America
- Save money by eliminating the purchase and use of insecticides
- Require a tight cover and outlet cap, crucial for preventing moisture, insects or fungus from entering the silo
- Must be placed on strong wooden pallet platforms to prevent contact with ground moisture corroding the metal
- Should be kept sealed up for as long as possible (at least 2 months) before removing grain so any insect pests will die, and any hatched eggs will have suffocated
- Are successfully adopted by local farmers; they sell themselves. Silo numbers kept on increasing after the

Central American program ended. Local artisans continued to find a strong market for their silos.

- Are valued by their owners. The first silos from the 1980s are now considered family heirlooms in Central America. They are perceived as more aesthetically pleasing than cheaper plastic options.
- Come in a variety of sizes. Farmers can start with an entry level household size and invest in additional silos when income and yield expand. Note three different sizes are pictured.

Damaged silos can be repaired, lasting for a decade but often much longer.

- Rust is a common problem, solved by sanding and painting.
- A hole either punched or rusted can be patched, though the silo must be empty.

[The Technical Manual for the Construction of Small Metal Silos \[fao.org/3/a-au178e.pdf\]](#) is based on the SDC Swiss Agency for Development and Cooperation's successful introduction and promotion of the silos' spread and adaption in Central America.

Metalsmiths in Africa are farmers earning additional money in the quiet season. In venues where it would be difficult to move a large silo, workers fabricate them on site. Once tinsmiths learn to make them, through training using available templates, they keep the patterns so they can be replicated.

Recently, again supported by the SDC in partnership with CIMMYT, experienced Central American tin smiths were brought to Eastern and Southern Africa, where the technology is being transferred. Local tin smiths learn the tricks of the trade and are setting up shop providing locally fabricated silos.

[Adopters are enthusiastic \[bit.ly/2UQ2rpk\]](#):

“Six mouths are a lot to feed so Pamela Akoth, a 39-year-old Kenyan farmer and mother to half a dozen children, doesn't want any weevils or borers—two of the most common post-harvest pests—nibbling at her grain supply. Akoth grows maize on 0.7 hectares in Homa Bay, western Kenya. In the past, she stored her grain in a traditional granary: a structure

built with mud, branches, and cow dung that allows free entry to the maize weevil and the larger grain borer, the two most damaging pests of stored maize in Africa. Infestation starts in the field and continues after harvest when grain is stored. Losses of 10-20% are reported three months after storage, and this goes up to more than 50% after six months.

With help from a subsidy program—the Agriculture and Environment Program (AEP) of the Diocese of Homa Bay helps needy farmers to acquire metal silos by providing interest-free loans—Akoth purchased a metal silo able to store 20 bags (1,800 kilograms) of maize; roughly what her land yields. Made of galvanized metal, the silo is airtight, so it keeps out insects and suffocates any that might have snuck in with the stored grain. “I am happy that since I started using the silo, I don't experience any loss of grain,” Akoth says. “I have enough to feed my family and even some left over that I can save and later sell, when there is a shortage in the market.”

—CIMMYT



A farmer from Mbeere, Kenya, stands by her two giant-size metal silos - Photo: W. Ojanji/CIMMYT



CIMMYT representative demonstrating a small silo metálico in El Salvador - Photo: CIMMYT

CIMMYT also reports on other agro-professionals benefiting from metal silo storage. Poultry farmer Rose Owanda acquired six 2.7-ton capacity metal silos. “I intend to be buying grains from the market during times of glut. This will not only ensure that I buy the grains at the lowest prices, I am assured of enough grain for making the feeds for the birds throughout the year.”

Traditionally, women in the household are responsible for maize storage. In some venues, they have added locks and keys to the spigots to prevent family members’ unauthorized withdrawals. Metal silos are a form of savings. Grain is removed and sold to cover health or school expenses, or to invest in income generating opportunities.



FAO Household Metal Silos [\[bit.ly/2pajvc1\]](https://bit.ly/2pajvc1)



POSTCOSECHA's Guide to Making Metal Silos [\[bit.ly/2NOheRM\]](https://bit.ly/2NOheRM)



FAO Technical Manual for the Construction of Small Metal Silos [\[bit.ly/2xecThi\]](https://bit.ly/2xecThi)



Metal Silo Project in Tanzania [\[bit.ly/2xdjIPu\]](https://bit.ly/2xdjIPu)



Designer Gilberto Tethere, a farmer in Mozambique, next to his innovative clay silo - Photo: Helvetas Mozambique, permission requested

Natural Material Hermetic Sealing: Mud and Earth Clay Silos

Combining indigenous silo construction methods using mud bricks with new techniques to make them completely air tight can provide trustworthy, locally fabricated hermetic storage for dried grain crops.



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Hermetic sealing is required to eliminate the vulnerability of a silo's contents. With this design goal, traditional mud silos can be improved upon to become reliable storage made from locally available materials using culturally familiar techniques.

Mud silos are permanent. While they lack the portability of empty metal or plastic silos, with proper maintenance they last 10-50 years, a worthwhile investment. They provide local work opportunities, an added benefit.

Mozambique and Ghana have strong mud silo storage traditions. One barrier for sharing their effective strategies is tribes' unwillingness, or at least wariness, in adopting traditions of tribes with whom they lack connections. Numerous training programs have worked to overcome this cultural resistance.

One method is to build the silo out of trapezoid shaped sun-baked bricks, set to create a free-standing cylindrical structure.

- In Mozambique, the FAO has developed local capacity for constructing cylindrical earthen storage structures known as Gorongosa silos, named for their home region. [Fabricated from traditional mud and clay \[bit.ly/2OyquGr\]](https://bit.ly/2OyquGr), they are augmented with modern structural materials like cement and metal rods. They feature a cement base as well as a cement cover under a thatched canopy.
- A second method is to create an armature out of a large woven bamboo basket and then plaster both

sides with clay to seal it. Mozambican farmer Gilberto Tethere designed this method, calling it the ZEFRA, Zero Emission Fridge for Rural Africa, akin to the ZECC—Zero Energy Cold Chamber [Tool 71]. Its design with an inlet in the top and a capped outlet at the bottom is modeled on metal silos. They are placed under a thatched canopy sunshade to decrease heat exposure. Insect traps are added. They are far less costly than metal silos to construct.

Like all hermetic storage, mud silos help in eliminating the hunger season.

The Gorongosa silo plays an important role in the life of Antonio Mazane. It provides safe storage, which in the long term affords him greater food security and optimal selling prices. “It is cheap and it is mainly built from local materials”, says Antonio. The results are remarkable. “The silo has made it possible for me to store my grain and sell it on the market for a better price” (250 meticaais [US\$ 7] instead of 200 [US\$ 5] per 50 kg bag). Before the silo, Antonio was forced to sell immediately after harvest. “This year I was able to store 20 bags of maize - a ton in total”.

—World Food Programme



Nadia Elkordy spreading clay inside an air-tight grain storage structure in Chitambala Village, Zambia - Photo: Bianca Anderson/USAid



Mud silos under construction in Ghana - Photographer: Pertina Nyamukondiwa/USAid



GGT stands for “Granary Gorongosa Type”—see full [pdf](https://bit.ly/2OyquGr) [bit.ly/2OyquGr] for more information; a written summary is [here](https://bit.ly/2MIB39y) [bit.ly/2MIB39y].



FAO Appropriate Improved Storage Structures [\[bit.ly/2p7yUtG\]](https://bit.ly/2p7yUtG)



DPA Sofala (Mozambique) Extension Services: The Gorongosa Mud Silo Design Project [\[bit.ly/2QvdUK0\]](https://bit.ly/2QvdUK0)



ZEFRA—Zero Emission Fridge for Rural Africa [\[bit.ly/2OngQXs\]](https://bit.ly/2OngQXs)



An oxygen absorber, with its post-use oxidized contents - Photo: Wikimedia

Oxygen Absorbers and Dry Ice

Food stored in containers for extended stretches of time benefit from the elimination of oxygen. Oxygen absorbers sachets prevent insect infestation, bacterial, and mold growth.



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Commodities stored for lengths of time, unless they are hermetically sealed, will be at risk for insect infestation and mold growth. Eliminating as much oxygen from the storage container as possible prevents insect larvae from maturing and hatching, eliminating them as a threat without the use of toxic pesticides, providing some of the same benefits as hermetic sealing [Tool 57].

Dry ice [bit.ly/2McYJqv], which is frozen CO₂, can displace oxygen and lower the concentration to below the level required for insects' eggs to hatch and develop. Carbon dioxide in the storage container will kill many kinds of insects within 7 days.

Oxygen absorbers are considered safe. Used sachets can be discarded without any further treatment.

Oxygen absorbers, also known as scavengers, are an effective and inexpensive technology developed in Japan. Each packet, made of food-safe porous material, contains iron powder and salt. When the packets are removed from their airtight container and come in contact with oxygen, the powder oxidizes, transforming into iron oxide—rust—via chemical reaction. The packaging process needs to be as efficient as possible to minimize the oxygen absorbers' exposure to air before being packed into commodities and sealed.

After the activated oxygen absorber is added to a container of food, the container is sealed tight and no additional oxygen can enter. When the oxygen absorber removes oxygen inside the container, a low oxygen/nitrogen rich atmosphere is created, inhibiting growth of insects, bacteria, and molds.

Oxygen absorbers are packaged and shipped in sealed

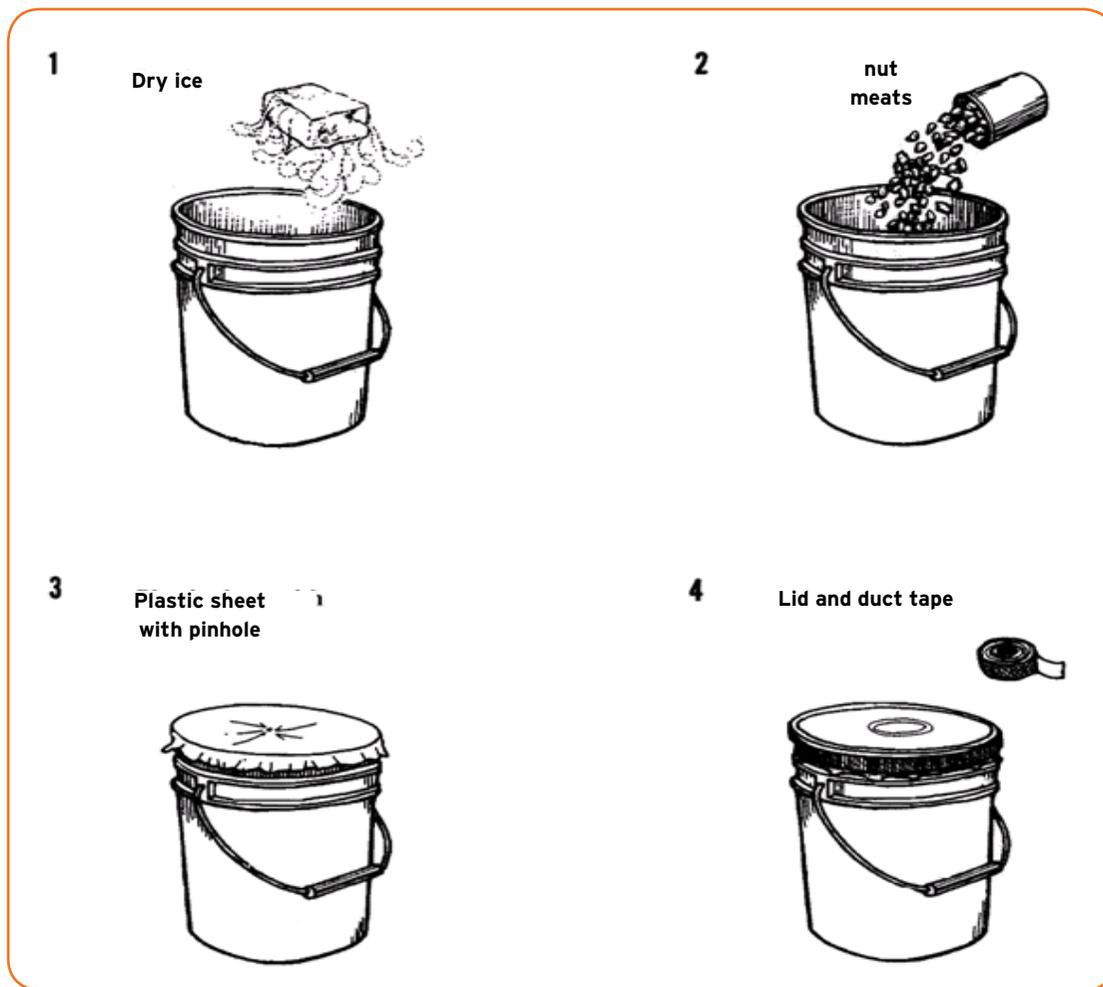
containers. Once the container seal is broken, packets need to be used within a few hours or they are no longer effective, since they will have already reacted to the ambient air and their contents will prematurely become iron oxide. After being removed from their original packaging, they must be kept in a reliably airtight container. Plastic ziplock bags are unsuited to this; they are moisture-proof but—surprisingly—not airtight.

Oxygen absorption is suitable for dried or dehydrated foods intended for long term storage, such as military food storage or those who stockpile food for religious reasons. It is also used for storage of commodities that will be sold at a later time to take advantage of higher prices. For such a market-timing strategy to be effective, though, the food must be stored safely so it doesn't degrade in quality or succumb to pest invasion. Typical foods suitable for long-term storage are dried mushrooms, jerky, beans, nuts, dried vegetables, flour, and small grains.

Oxygen scavenging technology can quickly reduce oxygen levels in sealed containers to below 0.01%.

Oxygen absorbers are considered safe for organic foods. The contents, while non-toxic, should not be ingested. They are eco-friendly since they eliminate the use of pesticides during storage.

The Postharvest Education Foundation recommends an added precautionary technique: packing **many** small packages into a 5-gallon bucket, adding oxygen absorbers, and sealing it tightly.



A simple mechanism of utilizing dry ice to generate CO₂ for insect control in stored grains, dried fruit and nuts is illustrated here (Source: WFLO 2010)



Oxygen absorbers and Long-Term Food Storage [\[bit.ly/2p4Z00x\]](https://bit.ly/2p4Z00x)



Postharvest Innovations Plan Series #15: Guide for Small Container Storage [\[bit.ly/2NdLjuL\]](https://bit.ly/2NdLjuL)



The neem tree's seeds, pressed into oil, along with the neem's leaves, are effective natural treatments for food preservation - Photo: Jimmy Tikhak/WikiMedia

Green Pesticides: Natural Treatments for Food Storage

Treating stored foods with essential plant oils can protect against a wide variety of insect invaders and pathogens. Eco-friendly natural treatments expand opportunities for farmers who grow them.



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While natural biopesticides, derived from plants in the form of essential oils, are proven to protect stored food from insect attack, they compete against a robust international pesticide industry. There are many benefits to using “green” treatments, and many risks—as well as high costs—involved with using chemical treatments. It is useful for actors in the value chain to be aware of green alternatives.

Chemical treatments are not permitted for organic [Tool 89] agricultural commodities, an increasing and lucrative share of the global market. Using natural remedies more widely and reducing chemical inputs offers harm reduction for eco-systems, workers along the value chain, and for consumers, so it is beneficial to expand their use for conventional (non-organic) commodities as well.

Many effective biopesticides are documented but not commonly utilized. **[“Due to the introduction of chemicals, many traditional storage treatments are often forgotten \[bit.ly/2vJLvXI\].”](https://bit.ly/2vJLvXI)** Essential oils, the most common biopesticide, are distilled from a variety of plant materials—they are the essence of the aromas and flavors of the plant. Oils are usually cold pressed from seeds. Users can purchase them in vials.

How oil coatings prevent infestation is not completely understood, but the oil layer prevents insect eggs from boring into the seed, so they cannot hatch.

Oils should not be used on seeds that will be planted, since they can inhibit germination.

Numerous vegetable oils can be used as a protective additive. An advantage is that they are easy to apply. These plant oils have been used successfully:

- Peanut (*Arachis hypogea*)
- Coconut (*Cocos nucifera*)
- Safflower (*Arthamus tinctorius*)
- Mustard (*Brassica* or *Sinapis* spp)
- Castor bean (*Ricinus communis*)
- Cotton seed (*Gossypium* spp)
- Soybean (*Glycine max*)
- Neem (*Azadirachta indica*)
- Cucurbit (*Cucumis sativus*)
- Maize (*Zea mays*)

All “natural pesticide” must be shown to be safe for humans before being approved by regulatory authorities.

Use only small amounts of oil (for instance: 2-4 ml per kg of threshed beans) and mix the oil and the product thoroughly. This is best done in a big pot or something similar, in small batches. After treatment the product can be stored in sacks. Oil can be used preventively as well as curatively.

- Neem oil [bit.ly/2vGCJcX] is a naturally occurring pesticide found in seeds and leaves from the neem tree. It is yellow to brown, has a bitter taste, and a garlic/sulfur smell. It has been used for hundreds of years to control pests and diseases and is found in many products, from toothpastes to soaps and bio-pesticides. Neem oil made of many components but Azadirachtin is the most active. Studies have shown that it reduces insect feeding and acts as a repellent. It also interferes with insect hormone systems, making it harder for insects to grow and lay eggs.

Most essential oils are distilled from plant materials. They are used in very tiny amounts, usually mixed with inexpensive carrier oil like coconut, olive, or soy. They are either steam distilled or water-and-steam distilled. Other plant material can be used effectively:

- Cassava leaves are known to protect harvested cassava roots from pests when used as packing material in boxes or bags during transport and short-term storage. The leaves are believed to release cyanogens, which are toxic to insects. —Aiyer 1978, in Kitinoja and Kader (2015).

Recent studies have confirmed that cassava leaf extracts can be employed as biopesticides for protection of grain against the rice weevil (Thambi and Cherian 2015).

- The ashes of the leaves of *Lantana spp.* and *Ochroma logopur* have been found to be very effective when used as a dust against aphids attacking stored potatoes (CIP

1982 in Kitinoja and Kader 2015). Recent studies in Ethiopia have shown application of *Eucalyptus* spp, Pyrethrum flowers and *Lantana camara* leaf powder at the rate of 50 g per 650 potato tubers can be used as a component of integrated pest management by farmers to tackle the problem of potato tuber moth (Ibrahim and Sisay 2011).

- Fenugreek is used in Freshpaper [bit.ly/2vKgzGQ], a simple tool made of thick paper embedded with essential oils and herbs used to keep fresh produce fresh. Cloves and garlic are also used for at-home food protection.
- Typically, essential oil is purchased from a manufacturer, but it is possible to make essential oils using a distillation kit [bit.ly/2OBRnxJ]. It is important to start with healthy, clean, pesticide free plant materials. In ancient times, essential oils were distilled using copper vessels, but modern kits include a set of metal pots or glass flasks and some type of separator.
- Researchers at Oregon State University have developed a simple glass distillation kit to use in a microwave. Their website provides instructions and videos on how to distill essential oils from a variety of plants materials, including citrus peels, leaves, flowers, roots and more.

[Oilextech.com's kit](https://www.oilextech.com) is placed in the microwave for 6-8 minutes; it uses ice to condense the steam/oil vapors created from the plant material. Each time you use your extractor you can yield up to 3.5 grams of oil depending on the plant material and 7-9 oz of hydrosol. One run uses 50-100 g (1/8-1/4 lbs) of plant material.



National Pesticide Information Center/Oregon State University Neem Fact Sheet [\[bit.ly/2Oq1PVb\]](https://bit.ly/2Oq1PVb)



National Pesticide Information Center/Oregon State University Pyrethrins (Marigold Fact Sheet)
[\[bit.ly/2NepXxh\]](https://bit.ly/2NepXxh)



Academic Paper: Green Pesticides: Essential Oils as Biopesticides in Insect-pest Management
[\[bit.ly/2MqYJyh\]](https://bit.ly/2MqYJyh)



SAWBO-Animation: Making Natural Insecticide from Neem Seed [\[bit.ly/2NLVs1q\]](https://bit.ly/2NLVs1q)



Properties and Potential Natural Pesticides from the Neem Tree, Azadirachta indica by H. Schmutter
[\[bit.ly/2UqKDG6\]](https://bit.ly/2UqKDG6)



Moving fruit drinks via plastic pallet at Blue Skies, in Accra, Ghana - Photo © Dominic Chavez/World Bank

Pallets: Benefits and Best Practices

Pallets support food containers both in stationary storage and in transit. Pallets stabilize containers and raise them, preventing them from moisture and jostling.



64 Pallets improve logistics. The four-way pallet innovation, allowing a pallet jack [Tool 37] to lift and smoothly move a pallet and its load from any side, was developed during World War II. Pallets are made of cheap wood or heavy reusable plastic in a variety of sizes. Using a pallet/jack system reduces the number of times commodities are moved and/or dropped, decreasing damages.

When warehouses only utilize their pallets internally, they reuse them every season. Some pallets that travel with commodities can be “pooled”, reused as part of a complex rental system similar to

reusable plastic crates. Others are discarded after one-way journeys due to the expense of shipping empty pallets over long distances. Reusable pallets are sometimes equipped with RFID trackers, a trend which will surely accelerate as these systems drop in price.

Creative designs reusing trashed pallets are a popular genre at [Pinterest \[bit.ly/2KViWeY\]](https://www.pinterest.com/2KViWeY/), [Instructables \[bit.ly/2MJgrxP\]](https://www.instructables.com/2MJgrxP/), and other DIY sites.

Pallets lift loads off the ground, adding ventilation and decreasing moisture contact. This also provides higher effectiveness of any fumigation treatments during storage. A pallet improves



Pallet stacked with cartons of fresh vegetables - Photo: Lisa Kitinoja



Corner reinforcements on a pallet of bananas at the St. Bernard's Parish Community Center, New Orleans, LA - Photo: CC of St. Bernards



Once a pallet, now a vertical garden - Photo: Ellin Beltz/Wikimedia



Pallets and their shrink-wrapped loads of cartons hoisted on board a ship - Photo: Naval Service Warriors/Jason Noble

sanitation as well; the empty space beneath it can be accessed. This is important even for a very small storage room or cool room.

Often cartons are shrink-wrapped and strapped to pallets, adding stability. The whole unit can be picked up together. Palletization speeds the job of loading and off-loading produce for transport; that in turn reduces the loads' exposure to heat, beneficial for maintaining quality and reducing losses.

Using uniform boxes maximizes storage efficiency. Unbalanced carton stacks can collapse, ruining much or all of their contents. Boxes should not overhang a pallet's edges.

Pallet/carton optimization visualizations look like a cellphone game, but they are important for efficiently utilizing storage space and resources. Cooling or heating consumes energy; maximizing the numbers of cartons a storage space can accommodate can lower per carton costs, though care must be taken not to overstock the warehouse [Tool 66].

Strapping tape and heavy shrink-wrap create mountains of trash. Reusable plastic pallet [wraps \[palletwrapz.com\]](http://palletwrapz.com), RPPWs, are an innovative solution. The challenge is creating an economical infrastructure for moving them to their next job,

similar to reusable plastic crates and the pallets themselves.

Corner braces for pallet stacks can be used to reinforce their integrity; see the photo of banana crates.

For temperature control, "[a wide range of reusable pallet covers are available](http://qasupplies.com) [at qasupplies.com] for covering cooled product during handling and transportation." Polyethylene covers are inexpensive and lightweight, and protect pallet loads from dust, moisture and some loss of cold. Lightweight insulated covers can protect the load from heat gain for several hours (for example, during a delay in loading). Heavyweight covers are sometimes used to protect tropical products from the cold when shipped during winter." —Kitinoja and Kader (2015) p. 202A

When stacking containers, be sure to align them properly (most of the strength of a corrugated box is in the corners). A one-inch overhang will decrease stacking strength by 15 to 34%.
—Kitinoja and Kader, (2015) p. 203



Pallet builders in Senegal - Photo: FAO Forestry



Why Palletize? [\[bit.ly/2Mx3bLH\]](https://bit.ly/2Mx3bLH)



Demo of StackBuilder, Open-Source Packing/Palletization/Loading Software [\[bit.ly/2pa8FTm\]](https://bit.ly/2pa8FTm)

Improved Storage Structure Design

Implementing established design features in storage structures to minimize heat build-up and maximize air flow extends shelf life for stored commodities, thereby reducing losses. Screens reduce pest access.



Improved storage structure with shade, cement pad, and a good quality, well-sealed door in Guatemala - Photo: Steve Sargent, [IFAS](#)

65

Building an improved storage structure would generally be the province of farmer groups [Tool 87] or underwritten by NGOs or other sponsors, but the cost per co-owner or user will be affordable. Whether retrofitting an existing storage structure or constructing a new one, there are many well-established design features that reduce the amount of heat build-up in the storage area. Reducing heat increases the length of time stored food retains quality. The rule of thumb: reducing temperature by 10°C (18°F) (within the safe limits of the produce) will double or triple potential storage life.



Ventilated onion storage structure, showing rat guards [Tool 75] and shade cover, designed by Mekbib Heilegebrile Seife - PEF Graduate, Ethiopia, 2012 - Photo: Lisa Kitinoja

Even if each design component provides modest reductions in heat accumulation, their cumulative impact is much greater. Structural features to reduce heat include:

- Recessing the lower portion of the structure below ground level, to take advantage of the cooling properties of soil - Kitinoja and Kader (2015) p. 160
- Repairing any cracks in the foundations and walls at the end of each season, to guard against moisture and air leakage (and deter pests, an added benefit)
- Ensuring proper air circulation within the structure, by providing air inlets at the bottom and outlet vents up high near the roof. Since hot air rises, convection moves warmed air out.
- Installing fans [Tool 67] to increase the airflow.
- Making sure the structure's vents open easily, allowing cooler night-time air to flow through the structure. Vents should be closed at sunrise and remain closed during the heat of day. This is a tried-and-true, effective, low-tech method for decreasing temperatures.
- Building a square structure. Rectangular buildings have more wall area per square foot of storage space, so more heat is conducted across the walls, making them more expensive to cool.

- Painting the roof and exterior walls white or silver to deflect sunlight and reduce heat absorption.
- Adding roof overhangs of at least one meter to provide deep shade for walls and doors.
- Adding awnings (if overhangs are not feasible).
- Erecting a [sun screen \[bit.ly/2P58Vih\]](https://bit.ly/2P58Vih) over the entire structure to further reduce sun exposure.
- Attaching a rubber seal on the door.
- If artificial light is needed, using LEDs; due to their high efficiency they do not give off heat. Or considering natural solar bottle lights such as [Liters of Light \[bit.ly/2P7BNXu\]](https://bit.ly/2P7BNXu), bottles filled with disinfected water embedded in the roof and providing daytime light equivalent to 60-watt bulbs with no energy consumption.
- Maximizing insulation of roof and walls to help maintain lower temperatures in the storage structure.
- Building with ferrocement, the recommendation of the United Nations' Food and Agriculture Organization (FAO.) In tropical regions, thick walls—thermal mass—provide better insulation.
- Installing a cement floor [Tool 65].

Additional benefits accrue from:

- Screening all vents and windows to reduce vulnerability to pests and insects [Tool 75].
- Installing rat guards [Tool 75].

The Peace Corps in Guatemala pioneered building [school buildings out of bottle bricks \[bit.ly/2oo8unc\]](https://bit.ly/2oo8unc), 2-liter bottles manually filled with compacted inorganic waste, primarily plastic. The bricks are attached vertically to a chicken-wire armature and gaps are filled with more waste plastic. The whole structure is then covered with cement. Bottle bricks are excellent insulators, so would lend themselves to a storage structure. The technique is labor-intensive, but cheaper than other construction (it displaces cinderblocks) and takes advantage of ubiquitous local “resources”—trashed bottles and plastic litter.



BC Open Textbooks: Fruit and vegetables storage plan [\[bit.ly/2AipkKR\]](https://bit.ly/2AipkKR)



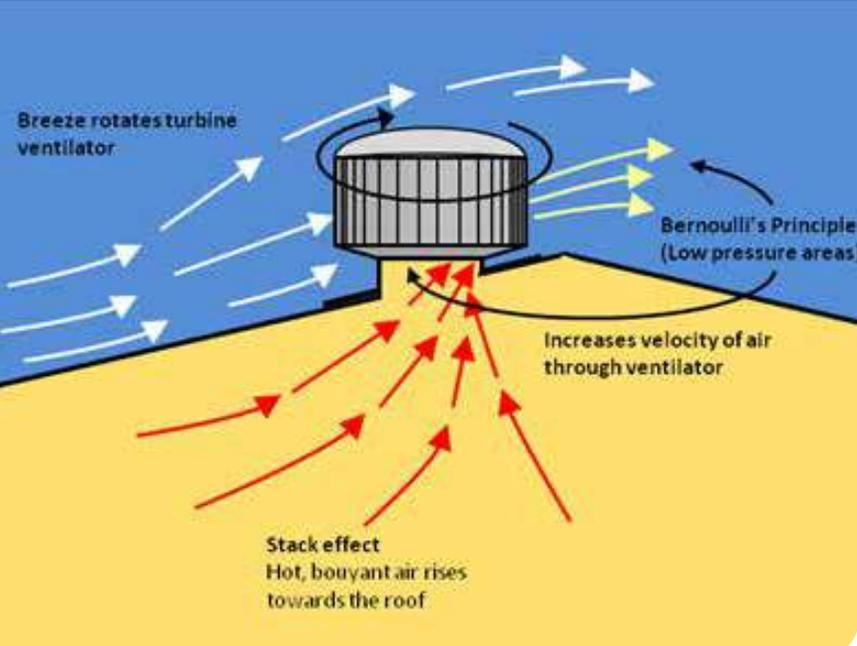
Kerala Agriculture Data on Ventilated Onion Storage Structure [\[bit.ly/2D9gfVW\]](https://bit.ly/2D9gfVW)



Academic Paper on Improved Yam Storage Structures (with data and plans) [\[bit.ly/2xiq3t1\]](https://bit.ly/2xiq3t1)



Cold Storage for Small Farms [\[bit.ly/2QwPtvo\]](https://bit.ly/2QwPtvo), [\[bit.ly/2Mr29RD\]](https://bit.ly/2Mr29RD), and [\[bit.ly/2QtVFoh\]](https://bit.ly/2QtVFoh)



How a roof turbine works [bit.ly/2vERBca]

Improved Storage Area Ventilation Systems: Fans and Turbines

Mechanical wind spinner turbines atop a storage structure's roof pull out the hot air resulting from the natural flow of hotter air rising inside the structure, without any fossil fuel consumption.



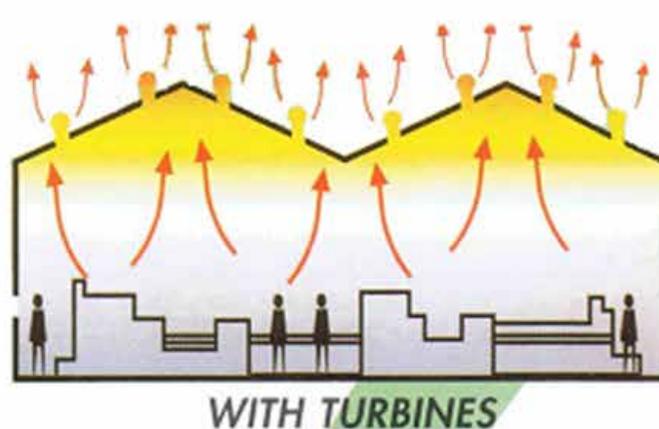
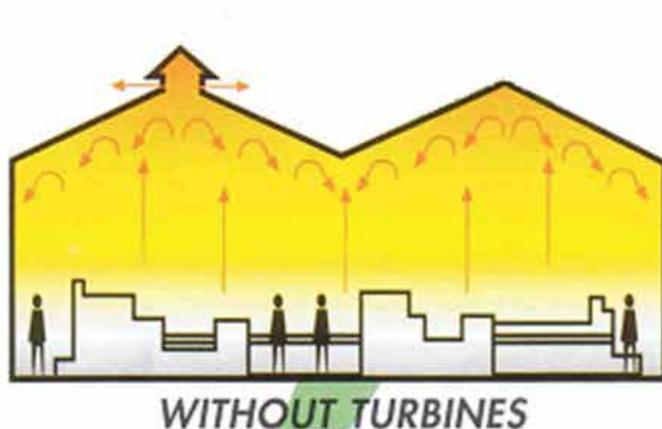
67 Utilizing convection to create airflow facilitates moving warm air through a storage structure up and out. Inlet vents at the bottom of the structure and outlet vents at the top will facilitate the flow of air, since warm air rises, but adding a turbine and/or fan speeds the process.

A balance ventilator, also known as a turbine, spinner, or whirlybird, has a dome that turns on high-quality ball bearings. Hot air rising out from the storage structure will make it spin. If the wind is blowing and catches the fins, then the turbines act like giant vacuum pumps, sucking hundreds of cubic feet of hot air out per minute. The faster the wind speed, the faster the turbine rotates. They can be purchased for around \$75 and since there is no motor, once installed they work well without any expense and require little maintenance, except keeping the ball bearings oiled.

Night air ventilation is an additional effective practice, simply opening the inlet vents at night to let in more cool air, pushing the warmer air up and out naturally. This is why storage structures should be very well-insulated.

The turbine should be placed at the highest point, the peak of the storage structure's roof.

Global South agricultural product storage structures are typically located in areas with unreliable and constrained energy sources. Any well-designed, reliable solar technology used to power an appliance has a built-in power source, since sun is so plentiful in these locales. Solar technology has the economic advantage of being free to operate unless a battery needs replacing. Typically, they pay for themselves within a season or two, and for the remainder of their working life, they perform their job without consuming energy.



An additional feature of using a solar powered exhaust fan to remove hot air is that it works when it is needed most, when the sun is out and heating up the storage area. Solar doesn't work at night (unless it has battery storage)—but at night the temperature is naturally lower and there is less need for the fan; the vents can be opened to take advantage of cooler temperatures (see above).

A similar solar powered vent fan can be used in a greenhouse or indirect solar dehydrator [Tool 15] to pull out hot air. Some readers will recognize that this mechanism is comparable to a domestic attic or garage fan.

Turbines are able to move a lot of hot air from attics. Even a small foot-long turbine can remove over 300 cubic feet of hot air in each minute, and one only a couple of inches larger can remove over 1,000 cubic feet. Even if there is no wind speed to drive the turbine, they still allow hot air to rise through the open flaps of the turbine.

—<https://www.doityourself.com/stry/advantages-of-turbine-roof-vents>

[bit.ly/2NiciFp]



Hoop House (a low tunnel like in Tool 2) with Solar Powered Fan Ventilation [bit.ly/2p99Xyb]



AVRDC World Vegetable Center Solar Dryer with Turbine [bit.ly/2RY24Zz]



Roof Turbine Installation [bit.ly/2Ncf5jz]



Science Lesson on Heat Rising and Rotating a Paper Spiral [bit.ly/2D2ok18]



Fruit and vegetable collage - rageforst æsthir/Flickr

Compatibility and Temperature Management for Fruit and Vegetable Storage

It is important not to store incompatible fruits and vegetables together. Plants that emit ethylene speed ripening in adjacent ethylene-sensitive plants. Optimal storage temperatures vary by commodity.

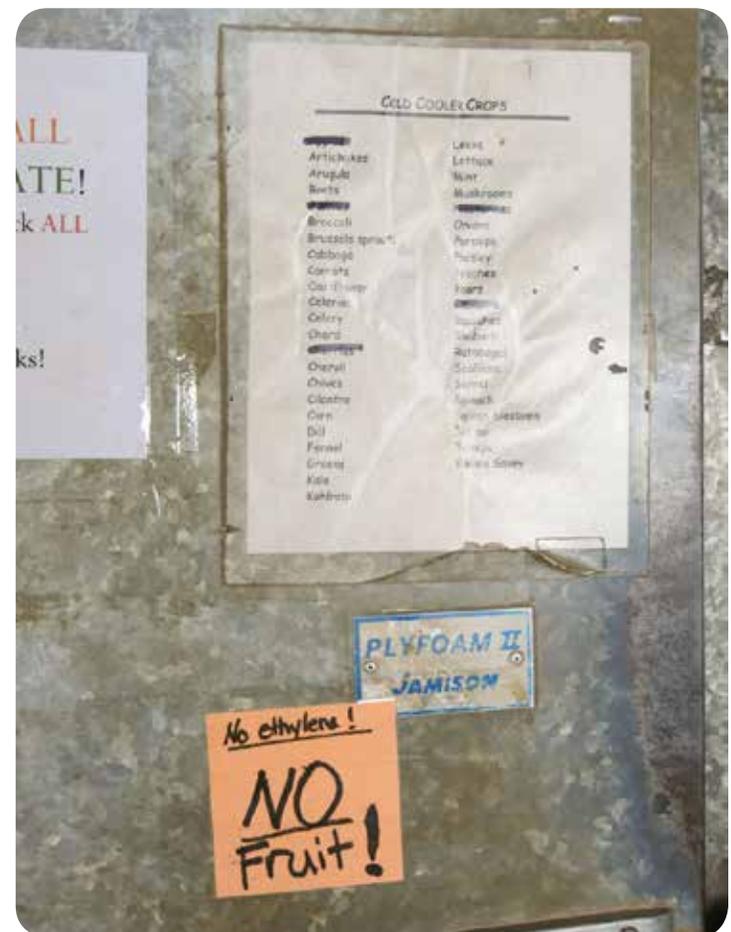


68

Storage of fruits and vegetables is complex. Different commodities' ideal storage temperatures vary. Additionally, some combinations have undesired side effects. If ethylene emitters (such as damaged produce or ripening fruits) are stored with ethylene sensitive plants, they can speed ripening. While sometimes this is intentional, generally it is something to be avoided.

Temporary storage temperatures for locally produced crops: When produce is held at a destination for a short time before marketing, to maintain quality and reduce losses the commodities should be held at their most suitable temperature. However, most commodities can be handled and stored according to these three temperature-based groups if they meet these three conditions:

- The storage period is **seven days or less**
- Relative humidity (RH) is maintained between **85% and 95%**
- The **ethylene level is kept below 1 ppm** by ventilating or using a scrubber or absorber



Adhering to compatibility protocols - Photo: Tatianna Dupont/Penn State Extension

Cold Storage for Fresh Fruits and Vegetables—from Postharvest Education Foundation, 2016

| 32-36°F, 0-2°C | | 45-50°F, 7-10°C | | 55-65°F, 13-18°C | |
|------------------------------|-------------------|-----------------|----------------------------|----------------------------|--|
| Vegetables and Melons | | | | | |
| anise | collards* | parsnip | basil | casaba melon | |
| artichoke | cut vegetables | radish | bell peppers | Crenshaw melon | |
| arugula* | daikon radish* | rutabaga | cucumber* | dry onions | |
| asparagus* | endive* | rhubarb | eggplant* | ginger | |
| beet | esacrole* | salsify | fresh beans; snap, green | honeydew melon | |
| bok choy | garlic | shallot | haricot vert, French, etc. | potato | |
| broccoli* | green onion* | spinach* | okra* | Persian melon | |
| brussels | herbs (not basil) | snow pea* | pepper; hot, chili | pumpkin | |
| sprouts* | horseradish | sweet corn | squash; summer, soft rind* | squash; winter, hard, rind | |
| cabbage* | kale | sweet pea* | watermelon* | sweet potato* | |
| cantaloupe | kohlrabi | Swiss chard | | tomato; ripe | |
| carrot* | leek* | turnip | | mature green | |
| cauliflower* | lettuce* | turnip greens* | | | |
| celeriac | mint | water-chestnut | | | |
| celery* | mushroom | watercress | | | |
| chard* | mustard | | | | |
| chicory* | greens* | | | | |
| | parsley* | | | | |

| 32-36°F, 0-2°C | | 45-50°F, 7-10°C | | 55-65°F, 13-18°C | |
|----------------|------------|-----------------|---------------|------------------|---------|
| Fruits | | | | | |
| apricots | cut fruits | cranberry | passion fruit | grapefruit* | pomelo |
| raspberry | gooseberry | kumquat | pomegrante | lemon* | sapote |
| strawberry | grape | mandarin | tangelo | lime* | soursop |
| blackberry | nectarine | olives | tangerine | | |
| blueberry | peach | orange | | | |
| cherry | plum | | | | |
| currant | prunes | | | | |

* Products marked with an asterisk are sensitive to ethylene damage.

Modified by PEF from original source: Thompson, J.F., Kader, A.A. and Sylva, K. 1995



EcoFrost.In: Storage Temperature and Humidity App [\[bit.ly/2xIroJO\]](https://bit.ly/2xIroJO)



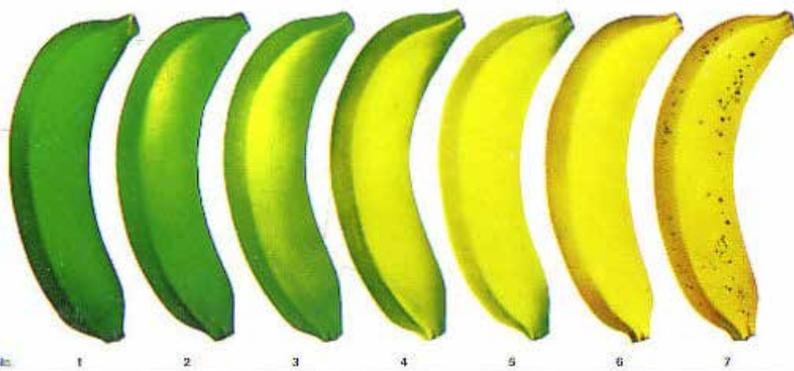
UC Agriculture and Natural Resources' Compatibility Chart for Fruits and Vegetables in Short-term Transport or Storage [\[bit.ly/2FZTnvM\]](https://bit.ly/2FZTnvM)



Smart Home Storage and Ripening [\[bit.ly/2qOFsen\]](https://bit.ly/2qOFsen)

Pulp Temperatures °F

| Day Schedule | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| 4 Day Schedule | 64° | 64° | 62° | 60° | | | | |
| 5 Day Schedule | 62° | 62° | 62° | 62° | 60° | | | |
| 6 Day Schedule | 62° | 62° | 60° | 60° | 60° | 58° | | |
| 7 Day Schedule | 60° | 60° | 60° | 60° | 60° | 58° | 58° | |
| 8 Day Schedule | 58° | 58° | 58° | 58° | 58° | 58° | 58° | 58° |



This banana ripening chart shows that by controlling variables, suppliers can ripen bananas in anywhere from four to eight days, allowing adjustments for weaker or stronger demand - [\[bit.ly/2pvgOC3\]](https://bit.ly/2pvgOC3)

Ethylene Management

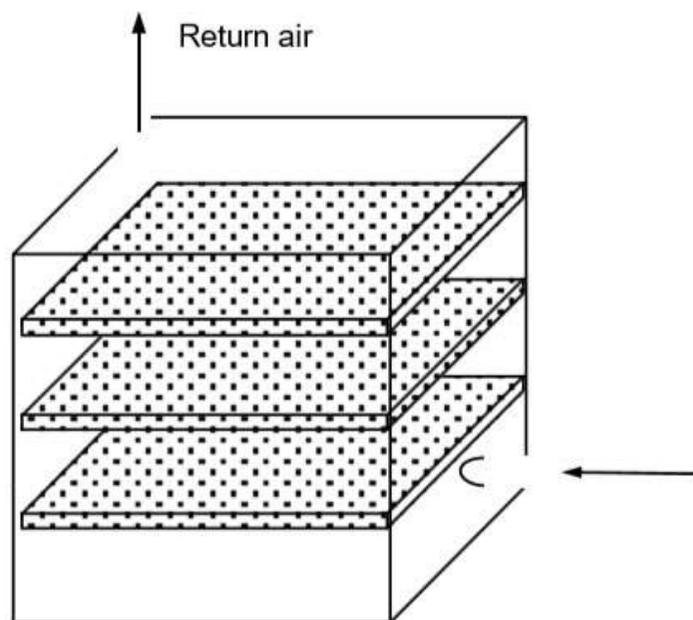
Controlling ethylene, a naturally occurring gas emitted by ripening plants, allows ethylene-sensitive fruits to ripen more slowly (or quickly) in response to market demand, decreasing wasted food.



69 Ethylene scavengers in individual containers or cartons of fruit help retard the ripening process of climacteric fruits by absorbing ethylene, a gas naturally emitted by fruits that acts as a ripening stimulant. In general, climacteric fruits can ripen even after separating them from the tree, like mangoes, avocados, and apples. Non-climacteric fruits that can only complete their ripening process when attached to parent plant include citrus fruits, strawberries, and grapes. Ethylene scavengers can also slow down ethylene related aging in non-climacteric fruits.

Commercially ethylene ripening rooms are used to induce uniform ripening in crops such as:

- Bananas
- Tomatoes
- Avocados
- Pears
- Mangoes
- Citrus fruits - degreening for uniform peel (rind) color



ETHYLENE SCRUBBER: place Purafil® pellets ($KMnO_4$) in shallow layers on screen trays sealed inside a solid wooden box. Air must flow through 3 or 4 trays of pellets for successful removal of ethylene gas.

Do it Yourself Ethylene Scrubber box; the box walls are made of solid wood, but this rendering shows the configuration of the interior shelves - Photo: Kitinoja and Kader (2015), p. 183



Difference in ripening of banana fruit exposed to different concentrations of ethylene gas - Photo: Vijay Yadav Tokala, Curtin University.

The ripening schedule is adjusted to demand. Less ethylene means slower ripening; increasing ethylene speeds ripening. This avoids flooding the market with too much fruit, leading to overripe fruit spoiling and going to waste. Marketers can respond to the consumer trend, a preference for “ripe ‘n ready” fruit rather than purchasing fruits ahead and letting them ripen naturally at home.

Circulating ethylene gas in the closed storage rooms promotes even ripening; ventilation and air circulation systems facilitate this. A controlled atmosphere chamber is closed and the air inlet to the room is controlled.

For preventing the buildup of ethylene [slowing ripening], a [commercial filter \[bit.ly/2nB8CiN\]](https://bit.ly/2nB8CiN) can be added to the existing air flow system, or a simple “scrubber” can be constructed and added to the air supply line. As air passes through, ethylene is absorbed or neutralized. Specifications for an ethylene removal system depend on both the product’s requirements and the storage environment’s characteristics.

To decrease ethylene:

- **Potassium permanganate (KMnO₄):** available in pellets
- **Activated charcoal:** Obtained by heating granulated charcoal and has high absorbent capacity.
- **Catalytic oxidation:** Oxidation of ethylene to ethylene oxide in presence of catalyst such as platinum, an electric-powered reaction produced by a small generator.

–Kitinoja and Kader (2015), p. 183 (image on preceding page)



Ethylene and Tomato Ripening [\[bit.ly/2MuovSh\]](https://bit.ly/2MuovSh)



Virginia Wango explains an evaporative charcoal cooler for storing green beans - Photo: [YouTube/Green Shots \[bit.ly/2MeJRaXj\]](https://www.youtube.com/watch?v=2MeJRaXjMitja) Mitja Mithans

Evaporative Cooling Structures: Charcoal Coolers

Evaporative cooling results when warm air moving through a saturated porous surface causes its water to evaporate and pull heat with it. A small chamber with charcoal-lined walls cools products effectively.



70

Evaporative coolers, also called swamp or desert coolers, consume no fossil fuel energy but are able to maintain a humid space that is 5° to 10° C (9° to 18° F) lower than the ambient temperature. This helps fruit and vegetables retain moisture and can keep them fresh and saleable for several additional days, avoiding losses.

Evaporative cooling structures based on locally available, cheap, porous charcoal are effective. A wooden skeleton holds walls made of two sheets of mesh mounted about 6 inches (150 mm) apart. Charcoal chunks are placed in the empty space between the mesh surfaces; it is important not to use ground charcoal, a pollution and health hazard. A non-porous roof protects the structure from direct light and water. The **floor is ideally brick or cement** [\[bit.ly/2vC50BF\]](https://bit.ly/2vC50BF). Space is left between the walls and roof for ventilation.

Vegetables and fruits are placed inside the evaporative storage structure in stacked reusable plastic crates [Tool 12]. Pallets [Tool 64] should be used to lift the stored crates off the floor, allowing cool air to circulate under the load.

Evaporative cooling is more labor intensive than refrigeration, since a watering system must be implemented and maintained, but it can be built with local materials for relatively little cost. In regions that are dry, hot, and windy it affords an excellent low-tech cooling option. The air near the walls is the coolest, making it the priority storage spot.

An evaporative cooler relies on wind to push the hot air through the wet surfaces, so should be sited where there is

natural wind. If a fan [Tool 67] can be powered, it could provide the pull. A convenient water source is necessary as well; if people need to carry, purchase or pump water there is an added cost for operation.

The **Bidii Farmers Group** [\[bit.ly/2MI9zAW\]](https://bit.ly/2MI9zAW) women's cooperative based in Kambi Sheikh Village in Isiolo County, Isiolo—a dry, hot region of Kenya—has a wholesale contract [Tool 97] for green beans, a good income producer. With help from Action Aid, they constructed a walk-in charcoal cooling structure. Its roof holds a water tank and through gravity-fed irrigation, it drips water into the charcoal.

With temperatures in the area rising to over 30°C (86°F), their French beans would rot before getting to the market due to the bad weather.

But gone are the days when they would be stranded with tonnes of rotten French beans.

The beans can stay in the fridge for as long as one week, explains Catherine Wanja, a group member.

—**Pauline Kairu, for Daily Nation**
[\[bit.ly/2BajVbz\]](https://bit.ly/2BajVbz)

Charcoal evaporative chambers give farmers a more flexible window to respond to market fluctuations or weather obstacles.

Keeping a temperature log of outdoor and in-the-cooler temperatures will provide useful data for future farming operations [Tool 1].



Mary Gatumitha, a member of the Bindii Farmers Group, stores their contract French green beans in their evaporative charcoal cooler, Biolo, Kenya - Photo: Pauline Kairu, permission requested



Produce cooled in a 30 square meter charcoal cooler in Tanzania [bit.ly/2P7KqBp]; solar panels run a water pump to moisten the walls and the water dripping through is collected in gutters under the walls to be recirculated - Photo: © Marc van der Sterren



Charcoal Cool Room Review and Construction Guide [bit.ly/2MFqBio]



Bidii Women's Cooperative's Charcoal Cooler [bit.ly/2Nv9Ydx]



Women constructing a ZECC in Bundelkhand, India - Photo: Anita Yadav

Evaporative Cooling: ZECC, Zero Energy Cool Chambers

Zero Energy Cool Chambers, ZECCs, are constructed from local materials. To maintain the evaporation that lowers interior temperature and preserves the contents, they are watered regularly.



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Evaporative cooling properties can be deployed in many different types of structures.

- In packinghouses, saturated mats are used with a fan to remove field heat [Tool 38].
- A walk-in charcoal evaporative structure [Tool 70] can hold up to a few tons of produce.
- A ZECC is generally best suited for smallholder farmers storing produce for market.
- The Evaptainer [Tool 74] is a new, more sophisticated evaporative cooling innovation.
- A [Zeer pot-in-pot \[bit.ly/2MlcQJu\]](https://bit.ly/2MlcQJu), a large ceramic pot with another that fits inside it separated by a layer of wet sand, is best-suited for domestic use and for small market quantities.

A ZECC is easy to build and relatively simple, though laborious, to operate and maintain. It can be fabricated with

local materials. Fruits and vegetables stored in the ZECC maintain quality several additional days due in its lower temperature environment. It creates higher relative humidity; since fruits and vegetables are sold by weight, this allows them to retain moisture, providing economic benefit. Storing produce instead of selling ASAP means farmers can hold out for the better prices. More food makes it to market instead of withering or rotting.

ZECCs perform best in hot, dry climates. In coastal, humid climates air is already more saturated and not much evaporation takes place.

Siting the ZECC near an available source of water facilitates saturating it several times a day. They are waist-high rectangular structures; if you mistook one for a mausoleum, it would not be surprising.

Constructing a ZECC does not require precise measurements or construction experience. The recipe is about 800 bricks, two loads of sand, shovels, a rake, six reusable plastic crates, and a lot of water. It takes 2-3 people about three hours to put together a ZECC, with some added time to create a sunshade canopy [\[bit.ly/2P58Vih\]](https://bit.ly/2P58Vih) and woven mat cover.

1. Wet the bricks thoroughly. They must have flat sides; chipped or irregular bricks will be unstable.
 2. Rake a flat, debris-free expanse. Lay out three stacks of two crates, measuring four-finger width between them.
 3. Lay a rectangular border of bricks four-finger width away from the crate stacks. Work from the corners to the center of each side of bricks. If there is a gap too small for a brick, cut a brick to size. The smaller custom brick should be in the center of the side to aid stability.
 4. Measure a four-finger distance and lay a second parallel rectangle of bricks outside the first.
 5. Fill in the gap between the walls with sand and wet thoroughly. There is no mortar in this brick-laying.
 6. Repeat interlocking nine layers of bricks, adding and compacting wet sand into the gap between the brick walls. Add a tenth layer to the inside only.
 7. Cover the opening with a palm-frond woven top reinforced with poles.
 8. Set extra bricks around the bottom of the ZECC to provide secure footing.
 9. When cooling fruits and vegetables, lay a plastic sheet the size of the opening over them, to protect them from dust and water.
 10. Build a sunshade canopy over the structure.
 11. After three years, the bricks should be replaced. The pores get encrusted with mineral deposits, slowing the water movement through the bricks. No worries, though—these deposits actually make the used bricks stronger and more suitable for reuse in other construction projects.
- “The first time I placed my hand inside the chamber, it was quite a surprising feeling. It was indeed cool, even though it was very hot outside.”
- Ghanaian farmer [Nafisa Alhassan](#) [bit.ly/2B8XSSn], FarmRadio



Raising the roof at the Zero Energy Cool Chamber training in Tanzania - Photo: Lisa Kitinoja/Postharvest Education Foundation

| | Immediate sale, vegetables packed in sacks or baskets | Temporary cool storage in ZECC, packed in plastic crates |
|--|---|---|
| COSTS | | |
| Zero energy cool chamber small model (100kg size ZECC) | | \$100 |
| Containers (5 sacks) | \$2.50 | |
| Reusable Plastic crates (6) | | \$ 60 |
| Relative cost | \$2.50 | \$160 |
| EXPECTED BENEFITS | | |
| % losses | 30% | 10% |
| Amount for sale | 70 kg | 90 kg |
| Value/kg | \$1.00 | \$1.20 |
| Total market value of one load | \$70 | \$108 |
| Market value – recurring costs | $\$70 - \$2.50 = 67.50$ | \$108 |
| Relative profit | | + \$40.50 |
| Time required to repay the investment in the ZECC | | $\$160 / \$40.50 = 4$ The investment pays for itself in about 4 weeks (4 uses) if used at full capacity. |
| Return on Investment (ROI) | | Each subsequent 100kg load provides a \$40.50 premium compared to the traditional practice. |

ZECC construction pays for itself in four weeks and then generates a \$40 premium for subsequent uses – Chart: Postharvest Innovations LLC, PI Plans Series #6.



PowerPoint Presentation by ZECC Inventor Dr. S. K. Roy [\[bit.ly/2OICs6x\]](https://bit.ly/2OICs6x)



MIT D-Lab's Overview of Evaporative Cooling [\[bit.ly/2p7ZuDc\]](https://bit.ly/2p7ZuDc)



Postharvest Innovation Series #6: Zero Energy Cool Chamber [\[bit.ly/2MALhYF\]](https://bit.ly/2MALhYF)



World Vegetable Center: Build your own ZECC [\[bit.ly/2pb6saD\]](https://bit.ly/2pb6saD)



Photo: CoolHubs

Solar Cold Micro-Room Subcontracting

Solar powered cold rooms significantly extend product shelf life. Farmers pay for this cooling by the crate; expenses are more than offset by expanded market opportunities and decreased losses.



72 Solar-powered cool rooms maintain a temperature of between 8°C (46°F) and 16°C (61°F), warmer than conventional refrigeration (0°C–4°C) (32°F–39°F) but cool enough to keep produce fresh and hydrated for anywhere from days to weeks. The walk-in cool room is highly insulated and cooled by an electric-powered refrigeration system, charged by roof top solar panels connected to batteries and an inverter. Enough energy is stored in its battery for 36 hours of back-up.

Several maturing technologies are integrated to make this a viable for-profit social business in non-electrified areas. Solar panels are continually dropping in price while increasing in

efficiency, generating more output per panel at ever lower costs. Battery storage is improving. Integrated digital payments are popular with customers with access to mobile money [Tool 96].

Siting solar cold rooms at a large farm or market allows growers to hold back their harvest while waiting for the best prices. Without cool storage, smallholder farmers are often forced to sell their fruits and vegetables as quickly as possible to avoid being stuck with rotting wares. A commodity held and sold at the end of the product's season brings higher prices, if it has maintained quality.

Nnaemeka Ikegwuonu, founder of CoolHubs, a chain of Nigerian solar cold rooms, came up with a business model for affordable cold micro-storage after interviewing a vendor who had driven a truckload of cabbage to market and was now stuck with unsold product. Since it wasn't worth investing petrol and labor to bring the cabbage back home, as it would further wilt and spoil in transit, he just abandoned it at the market. Ikegwuonu realized affordable temporary cool storage at the market would have provided a way for this vendor's produce to remain fresh, saleable, and secure, and he could have stuck around until he sold it all instead of taking that huge hit. On-site cooling will significantly reduce "strategic" waste of this type.

Farmers pay about 30 cents per day for each crate stored. The CoolHub needs just two employees, one managing the cool



Users set EcoFrost's app to the desired commodity and it optimizes temperature and humidity - Photo: EcoFrost

room and the other handling customer recruitment and payments. Cool micro-storage

- Provides security from theft
- Cools fruits and vegetables, preserving them for future sales
- Avoids product-damaging round trips
- Avoids labor and energy expenditures for loading and toting the vegetables a second time

Cool room managers need expertise in storage compatibility [Tool 68] and an understanding of ethylene management [Tool 69]. Dr. Lisa Kitinoja observes it's not just a matter of cold rooms. "Successfully storing fresh produce requires a lot of attention. It must be visually inspected, and removed if ripe, or the ethylene generated will ripen the other crates of fruit. Fruits shouldn't be mixed with vegetables."

A similar enterprise in India, EcoFrost.in, offers sophisticated technology to set the optimal temperature and humidity for specific commodities. It advises its clients on market pricing and helps them determine the best timing and prices for maximizing returns. Its mobile app is easily understood and users have remote access to data. Its company, EcoZen solutions, was a [2018 Ashden Award](#) winner for green business empowerment [\[bit.ly/2D0pGIU\]](http://bit.ly/2D0pGIU).



Preparing vegetables for storage in the CoolHub, utilizing Reusable Plastic Crates, Tool 12 - Photo: CoolHubs



ColdInnov's Solar Cold Technology Products (including a solar-powered "FrigoMobile") [\[bit.ly/2MF3GU6\]](http://bit.ly/2MF3GU6)



Case Study: Solar Small Cold Storage System in India [\[bit.ly/2OrDz4N\]](http://bit.ly/2OrDz4N)



ColdHubs' Elevator Pitch [\[bit.ly/2QAb9HI\]](http://bit.ly/2QAb9HI)



A recessed trash can serves as an entry level root cellar for keeping produce cool and moist - Photo: [Micah Gallant/YouTube \[bit.ly/2MfWize\]](https://www.youtube.com/channel/UCMfWize)

Natural Underground Cooling

Caves and hand-dug underground root cellars provide natural cooling, protecting fruits and vegetables for short term storage until market prices rise. They provide multi-month, longer term storage.



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Underground storage exploits the cooling properties of soil, essentially using geothermal principles. Soil maintains a fairly stable temperature year-round, making it cooler than above ground air in summer. In a colder climate, this is also a way to provide no-cost heating during winter temperatures. Caves provide the same conditions, if one happens to be accessible. This is ancient technology which consumes no energy. Digging is hard work, but a root cellar can last decades, offering substantial return on the investment.

A smaller storage option is recessing a barrel or garbage can in the ground by digging a hole larger than its volume, adding insulation, inserting, and covering it.

When building a larger root cellar, below or partially below ground, the optimal siting is on a slope to provide easier access. It should not be near any trees, to avoid the cellar being entangled by growing roots. It should also not be near any water source, since that could cause water-logging or flooding.

Humidity is generally naturally high in underground storage, a benefit to keep fruits and vegetables from losing moisture. To prevent moisture from condensing and accumulating, drainage is necessary.

- The walls must be reinforced to prevent collapse.
- Doors should face north to avoid excess sun exposure.

- Root cellars should have a screened vent, or two vents (inlet and outlet), allowing air to circulate but preventing pest entry [Tool 75].
- Floors are ideally porous. Gravel on dirt takes advantage of the soil's cool temperature and humidity.
- Light should only be used when visiting the root cellar; darkness inhibits plant activity (respiration, ethylene production, greening, sprouting).

While underground cool storage is highly effective for roots (as the name root cellar suggests), allowing them to last many months, it can also provide shorter term “parking” for produce awaiting better market conditions. When a crop is harvested, local markets are generally deluged with an oversupply of nearly identical product. By holding onto crops in cool storage, farmers can wait until that glut is absorbed, introducing their commodities when supplies dwindle and prices are rising. This offers economic advantage and also avoids excess crops spoiling and going to waste.

If farmers want to engage in value addition activity, the availability of cool storage allows them to postpone the food processing until sufficient labor is available. During harvest times, all hands are generally on deck. Storage gives them the option to make products in demand at a later date, when they

have more time available. Hence, cool storage gives flexibility for strategic decision making about how to deploy resources.

If the root cellar is being used for short term storage, it is important to make sure not to store incompatible produce

together [Tool 68]. Ethylene emitting produce speed up ripening and this can accelerate anticipated maturing of ethylene-sensitive storage companions.



Build a Root Cellar [\[bit.ly/2NSNfsg\]](https://bit.ly/2NSNfsg)



Mother Earth News: Fundamentals of Root Cellaring [\[bit.ly/2MEJu53\]](https://bit.ly/2MEJu53)



55 Gallon Drum Root Cellar [\[bit.ly/2xnhVr9\]](https://bit.ly/2xnhVr9)



Evaptainer's new Yuma 60L 2018 model evaporative cooler (renamed Fenik www.fenik.io) collapses for easy transport - Photo: Evaptainer

Vegetable and Fruit Storage Innovations: Evaptainers and Wakati Storage Chambers

Innovative coolers include the collapsible, portable Evaptainer using only a quart of water daily and Wakati storage tents featuring humidifying technology powered by a 3V solar panel to maintain quality.



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Humanitarian engineering pairs contemporary know-how with appropriate, affordable solutions to meet low resource regions' needs. A typical design approach is to adapt known technologies, co-create with end users, devise prototypes, and keep testing and refining them. Iterate, iterate, iterate!

Designers compete for grant money and other sponsorships in the design phase; winners test and improve their designs. Then comes a challenging stage of ramping up for production; lower prices are achieved through mass production,



requiring substantial advance investment and a sales and distribution infrastructure.

Two promising fruit and vegetable storage designs are moving forward.

“Evaptainer emerged from a research project at the Massachusetts Institute of Technology (MIT) that challenged students to create something that could help improve the lives of 1 billion people. The students' technology was the EV-8, a 60-liter cooling container that activates a 15-20°C (20 to 30°F) cooling effect when the user fills the internal reservoir with water.” — GlobalKnowledgeInitiative.org [bit.ly/2yVyXz6]

Evaptainers were inspired by the Zeer pot-in-pot [Tool 71], an interior ceramic pot fitting inside a second pot, separated by a layer of wet sand. While cheap and effective, they are both breakable and heavy, limiting them to a stationary location. Evaptainers use the same technique but are lightweight, portable, and collapsible.

Evaptainers can be used at farms, in packinghouses, during transport, and by end users. In the postharvest storage stage, they significantly extend viability of fruits and vegetables, providing farmers or vendors more time to sell their wares. This decreases pre-sale spoilage as well as maximizing income through both

added volume and market timing. Households can use them to store food for longer stretches, allowing them to make fewer trips to the market. Evaptainers are expected to cost around \$30.

Wakati storage (“time” in Swahili) works by elevating humidity, substantially lengthening the viability of fruits and vegetables. “Wakati is a stand-alone storage unit that consists of three pieces: a tent, a small solar panel, and a ‘climate unit’ that requires 1 liter of water per week. Together these elements create a microclimate inside the tent that can be used to store 200-1000 kg of fresh fruits and vegetables. While it does not cool the produce, it does help to reduce spoilage rates by maintaining humidity, controlling the release of ripening hormones like ethylene, and sterilizing mold growth. Wakati has recently made their technology open-source to expand the reach of PHL-reducing on-farm storage solutions.”—GlobalKnowledgeInitiative.org [bit.ly/2yVyXz6]

Wakati’s “climate unit” is fabricated using a 3-D printer. It includes a small reservoir of water and fan that adds moisture **into** the tent and maintains a humid micro-climate that extends produce viability by many days. To compensate for creating a microbe-friendly space, it discharges ozone, reducing mold growth as well as retarding ethylene emissions. They report that similar high relative humidity storage conditions could possibly be achieved with just a simple spray closed watering system that would be drastically cheaper, but more studies are needed.

Wakati’s research has shown that not only does reducing losses increase sales income for Wakati users, but their produce fetches higher prices due to higher quality when compared to produce stored in ambient conditions.



www.wakati.co



AVRDC’s Evaptainer Testing [bit.ly/2D2Yr13]



[S. Mohan's Two-in-One Trap](#) - Photo: Sarma Mohan / www.mohantrap.com

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Since the dawn of agriculture, growing food has always meant competing with fellow creatures, flying and four-legged, for the fruits of farmers' labor. Pesticides and rodenticides that kill undesired insects and rodents are costly, pose many risks, and result in unintended consequences. Their toxicity can wreak havoc with eco-systems, poison humans, and speed the development of pesticide-resistant species. Prevention, trapping—and cats!—are all wise alternatives.

Hermetic storage [Tool 57] deprives insects of oxygen and has proven very effective at pesticide-free interior insect control. Triple bagging is not resistant to insects per se, nor does it protect against rodent damage. However, studies have shown that the rate of penetration through all three bags by insects and animals is low. The fact that they are hard to invade means there is next to no spilled grain littering structures where they



[Pitfall trap](#) designed by S. Mohan - Photo: Sarma Mohan / mohantrap.com

Pest Traps: Insects and Rodents

Using DIY tools for the never-ending battles with insects and animal invaders can reduce postharvest losses of fruits and vegetables as well as grains and pulses.



are stored, so pests are not drawn to the spaces like they are when contents of conventional porous storage bags are penetrated or in response to spills.

[Dr. Sarma Mohan \[www.mohantrap.com/\]](#), professor at Tamil Nadu Agricultural University (TNAU), in India observes that if there is a granary, there will be insects. They travel in larvae form along with grain; the best eradication strategy is timely detection. He has devised [a wide variety of non-chemical mechanical gadgets \[www.mohantrap.com/video-reel\]](#) for killing crop-destroying insects, many of which can be constructed by end-users. His inventions for insect monitoring and trapping are freely shared. In a monitored evaluation, “nearly 74% of the insect trap users agreed that the insect trap has been able to save grains to the tune of 3 to 5 kgs during last four months. Nearly 88% of the respondents agree



Rat guards made of metal or plastic for small grain storage - Photo: [SAWBO Scientific Animations \[bit.ly/T09kYw\]](#)

that the trap has been able to reduce the drudgery for women.”
—Dr. Sarma Mohan

Educating farmers and householders that it is possible to trap insects in the storage phase is the first step toward adoption and reducing losses:

In the village of Tarkulva, the insect trap was demonstrated to a group of farmers at the local grocery shop that also doubled as the hang-out of farmers. The grocery shop owner provided a sack full of grain where the Insect Trap could be placed. The assembled farmers were very eager to see the trap in action since they had witnessed the results on the Insect Trap video. The enthusiastic farmers took out the trap in less than three minutes to find close to 10 insects trapped.

—Dr. Sarma Mohan

Plastic bins [Tool 59] used for hermetic storage effectively kill larvae but are not rodent-proof. Metal silos [Tool 60], another hermetic storage option, are not penetrable by rodents.

Storage structures should have room around their perimeter for insect and rodent traps. Screened vents and concrete floors help block rodent entry [Tool 65].

Rodents not only eat stored foods but they damage equipment and leave contaminating messes that attract yet more pests. It is easier to prevent than to treat rodent activity. The FAO recommends keeping the area surrounding storage structures free of weeds and plants to deprive rodents of shelter; vigilance in removing trash reduces rodents' attraction to the venue. Any accumulating water should be removed so as not to provide essential drinking water for pests.

The storage structure itself should be inspected frequently and any spilled grain must be removed immediately. Interiors should allow for perimeter space for animal traps and they must be maintained. Doors and openings should be in good repair, creating barriers to rodent entry.

Smaller field storage structures should be raised, and the supporting poles should have plastic or metal rat guards; they can be locally fabricated using empty cans or used plastic containers.



Dr. Sarma Mohan's Website www.mohantrap.com



TNAU (Tamil Nadu Agricultural University) Summary of Mohan Traps [\[bit.ly/2NksPJ9\]](http://bit.ly/2NksPJ9)



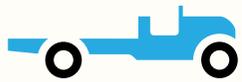
Improved Granary with Rat Guards and Deterrents [\[bit.ly/2QuIAw9\]](http://bit.ly/2QuIAw9)



IRRI Post Production Course [\[bit.ly/2UHKsFA\]](http://bit.ly/2UHKsFA) and [\[bit.ly/2G6j38I\]](http://bit.ly/2G6j38I)



SAWBO Animation: Transporting and Storing Grain (including rodent and insect deterrence)
[\[bit.ly/2NifYa7\]](http://bit.ly/2NifYa7)



Section 5

TRANSPORTATION

76. Optimizing Packing and Palletizing for Transport

77. Bicycles, Tricycles, and Wagons

78. Cushioning Loads and Avoiding Overloading

79. Improved Loading Techniques

80. Insulated Packages and Insulating Blankets

81. Cool Packs: Phase Change Materials for Lowering Temperatures



Contents of truck loads will vary - Photo: ©IFAD/G.M.B. Akash

TRANSPORTATION: INTRODUCTION



Reusable Plastic Crates of produce en route to the Vimruli Floating Market, Bangladesh - Photo: Khokarahman, Wikimedia Commons

Each time a load of fresh produce and stable crops is moved, they are vulnerable to damage from

- The jostling of transport
- A closed, unrefrigerated unit's internal heat
- Sun, rain, and wind's impact on open conveyances
- Pests and pathogens traveling along for the ride
- Birds attacking open shipments

These can all seriously damage or ruin foods during transport.

The four postharvest **supertools** each contribute to reduced losses during transit. Naturally, deploying

as many as best practices as possible multiplies post-harvest loss reductions.



Gentle Handling. Bruising decreases value and increases vulnerability to pathogens that cause quick spoilage. Spoilage impacts not only the individual fruit or vegetable, but it can spread through the whole load.

Transport begins at the farm. It is efficacious to integrate packinghouse functions directly at the farm, minimizing transport logistics and potential damage of multiple moves. Improved packaging [Tool 32], both for individual units and carton loads, decreases damage.

Cushioning the whole load is vital, as is avoiding overloading [Tool 78].



Temperature Management. The Global South value chain generally focuses on keeping commodities cool, due to the hot climates in which agricultural infrastructure must function.

Transporting in early daylight or after dark takes advantage of lower temperatures, less direct sunlight, and less traffic. For heat sensitive produce requiring cold storage, temperatures need to be carefully managed.

Providing ventilation in transport helps reduce heat build-up. Innovative packaging can help maintain the cooler temperatures achieved before transport.



Sanitation. Maintaining clean vehicles helps prevent the spread of damaging pests and pathogens. Preventative measures are always more effective than treatment.

Trucks should be kept clean and care should be taken to sweep and wash surfaces between trips.



ICT. The new frontier of digital information can help reduce postharvest losses. With more information, optimized choices can be made at each step of a commodity's trip from field to fork.

That might be utilizing GPS systems to cut driving time, reducing exposure to extreme heat. Perhaps it will be tapping into the **shared economy** by bike sharing or farmers summoning pick-up trucks on demand, providing livelihoods to drivers while adding time back to farmers' days. At present a great deal of food spoils waiting for transport.

Cutting-edge technology using solar panels to generate the energy for cooling could radically upgrade temperature management. A portable cooling unit with a solar panel atop could travel from storage to destination; the challenge is in part figuring out security and how to return the unit. Technology already exists [to monitor panels remotely \[bit.ly/2PJ3ohx\]](https://bit.ly/2PJ3ohx); if they are tampered with or stolen (or if they are leased and the user misses a payment), function can be locked. Perhaps in time there will be a RFID system to track micro-cold storage pods and transport them to where they are needed next, similar to Reusable Plastic Crate [Tool 12] systems and established pallet reuse [Tool 64].

Alternatively, a solar panel could be mounted on the roof of the truck, charging during transit, and connected to a portable cool storage unit.

Be it a tricycle, pick-up truck, canoe, boat, ship, or plane—paying close attention to best transport practices reduces losses.

Optimizing Packaging and Palletizing for Transport

Cushioning containers, using RPCs [Tool 12] or strong cartons [Tool 32], and pallets [Tool 64] reduce postharvest losses every time a load is moved.



Colombian dragon fruit farmers preparing the fruit for transport - Photo: Fruandes/Simón Valencia, Leader of the Organic Dragon Fruit Farmers Association

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The postharvest journey of fruits and vegetables is perilous. Jostling fruit and vegetables against sharp edges of leaves, boxes, or branches while being tossed around on bumpy roads can result in a load of damaged product.

Bruises and wounds increase plants' vulnerability to pathogen attack. Injury to a small portion of a load's contents can result in a much larger amount of loss if the invasion spreads from an infected fruit or vegetable to adjacent plants. Commodities injured in transit become more vulnerable to this spreading damage.

Improved packaging does a better job of cushioning crated fruits and vegetables from these threats, especially in regions where there are rarely dedicated, appropriately outfitted trucks available for transport.

RPCs, reusable plastic crates [Tool 12], provide an extremely economical, eco-friendly, and sturdy solution. Featured in the Farming section but reappearing here, they play a vital role all along the food value chain.

RPCs provide secure stacking, aiding in the loading process. Generally, they are used for loose produce but are also well-suited for pre-packaged items, like fruits in clam-shell containers. Because of their open-structure, RPCs are easily bundled in vertical stacks using reusable bungee cords or simple cord to secure the crates; they can also be lashed together horizontally. Their handles make them easier to move, as well.

If the RPCs are used to transport produce from farm or packing house to market, farms or cooperatives can purchase them. They can be reused 150 times or more and are easy to clean between uses, making them a great investment. They cost

far less per trip than single-use cartons. If they will be shipped to a storage venue, it generally requires a rental per-use infrastructure. These types of initiatives are developing—markets are a venue where they can be collected and redeployed. ICT can aid the logistics of moving RPCs to where they are needed, such as the banana system used by [IFCO \[bit.ly/2PJ72Ia\]](https://bit.ly/2PJ72Ia).

Fiberboard cartons [Tool 32], a common option for storing and shipping produce, must balance a number of characteristics to perform the job well:

- **Large vs. small** – right-sized containers reduce losses. If they're too large, they are easily dropped or can crush other cartons. If they're too small, they're harder to manage and unstable in stacking.
- **Stable vs. lightweight** – Cartons that are too light for the job often collapse, a flaw magnified by transport. If they are too heavy, they add unnecessary weight and expense.
- **Affordable vs. reliable** – Well-designed packaging usually costs more, though it enhances efficiency and reduces labor. Cheap, poorly made packaging can backfire, causing food losses.
- **Durable vs. permeable** – storage containers need to withstand open truck transport (it could be raining!) and humid storage without falling apart and imperiling their contents. However, products need venting to protect produce from overheating.

If wooden crates are used, they should be sanded to ensure a smooth interior, and/or lined [Tool 34] to protect their contents.

Pallets [Tool 64] help stabilize loads and are useful in truck transport. They cushion the contents and absorb vibration, especially important when driving on rutted roads in vehicles lacking effective shock absorption.



Loading flats of clamshell containers of strawberries in Kashmir, India; the cushioning from individual packages inside well-designed containers can offset the downsides of a trip in a vehicle not designed for the task - Photo: Mike Prince/Flickr



The Postharvest Education Foundation's White Paper on the RPC Value Chain [\[bit.ly/2Q8giWV\]](https://bit.ly/2Q8giWV)



Banana Case Study from IFCO [\[bit.ly/2PJ72Ia\]](https://bit.ly/2PJ72Ia)



Collapsible Reusable Plastic Crates [\[bit.ly/2NNbh7T\]](https://bit.ly/2NNbh7T)



Motorized tricycle delivery vehicle with a mini-sunshade in Silay City, Philippines; such a canopy could be extended to cover the load as well as the driver - Photo: Brian Evans/Flickr

Bicycles, Tricycles, and Wagons

For local transport, a wide variety of pedaled vehicles are deployed for farm-to-market runs. Tricycles, side cars, or trailers feature expanded storage capacity and stability.



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Bicycles, tricycles, motorized bikes, and wagons offer infinite variety for sturdy, lower-cost, eco-friendly transport in low resource regions where ownership of a car or truck is prohibitive. For short runs, whether moving produce around the farm or hauling it to a market within walking or pedaling distance, cycling gets the job done. Utilizing either human pedal power or small motors, cycles are inexpensive to operate. They save time, cover more distance, and handle heavier loads than their alternative: walking with crates, baskets, or sacks. For women who often head-carry, a physically demanding balancing act, a bike is an especially huge upgrade.

Pedaled vehicles are easily shared. As the **sharing economy** expands worldwide, cycle transport can be subcontracted, networked by digital apps, providing work and income for the cycle-entrepreneur and a reliable method of moving produce to market in a timely way. This will reduce loss from product that spoils awaiting transport.

General postharvest loss reductions principles apply, but since bike runs are local and short, less time elapses for produce to be damaged by heat, wind, pests, jostling, and all the other perils of transport. Short trips don't require as much investment in careful packaging, as typically the load is headed straight to a retail market.

The most applicable postharvest super tools for short-haul cycling are **gentle handling** and **temperature control**.

Entry level cycle transport is a simple two-wheeler bike, without any modifications. Bikes are designed for transporting a few items in a front basket or rear panniers. Tying bulky, heavy loads to the bike is an art; quite often the person involved walks the bike, essentially using it as a wagon. (Of course, once



A farmer in Bangladesh transporting produce to the market via bicycle cart (that would benefit from a sunshade) - Photo: International Food Policy Research Institute



Three-wheeled vehicle for farm use in Ghana - Photo: International Institute of Tropical Agriculture



While a bike aids the movement of produce, this man pushing a bicycle loaded with large bags of potato leaves as he heads to market in Kilobelobe, near Lubumbashi, Katanga province, Democratic Republic of Congo, is performing back-breaking labor - ©FAO/Olivier Asselin

the load is dropped off, it can be ridden home, an enormous time saver.)

This type of loading is hard on produce, since there is no cushioning. Overloaded bikes are extremely hard to balance. Their cargo is at risk for toppling over and bruising or crushing fruits and vegetables. Workers are at risk as well, trying to ride, or guide, an overloaded bike.

Modifications fabricated by local welders provide trailers designed for transporting cargo. Some tricycles, a more stable vehicle in general, feature an attached platform in front or a flat-bed in back. Side-storage adds space as well. These investments allow for more stable, cushioned loads and decrease losses.

Open produce on a bike or tricycle is vulnerable to heat, moisture, rain, wind, and pests. Simple additions like a protective tarp can minimize weather-damage and overheating. Sunshades are an upgrade added to heavier bikes and tricycles that transform into micro-kiosks at markets [Tool 82]. The shade benefits both the produce and the vendor.

Cargo bicycles, like those designed by PortalBikes in Nepal, are versatile, sturdy bikes meant to be loaded up for local delivery. They could serve well for farm-market runs.

Motorized three-wheeled vehicles are effectively small trucks. The picture shows a type used in Ghana for agricultural produce.



Sacramento, CA, Veggie Trike [\[bit.ly/2xIUJtn\]](https://bit.ly/2xIUJtn)



Fruiti-Cycle Prototype: Pedaled, Electrical Assist Fruit Truck with Evaporative Cooling [\[bit.ly/2NLoNJa\]](https://bit.ly/2NLoNJa)



Brooklyn, NY, Upcycles: Urban Delivery Pedal Trucks (with Electrical Assist) [\[bit.ly/2pdafnP\]](https://bit.ly/2pdafnP)



Cushioning inside a carton for protecting papayas in Ghana - Photo: Lisa Kitinoja

Cushioning Loads and Avoiding Overloading

Cushioning the conveyance reduces damage from vibration and jostling. Avoiding the temptation to overload decreases losses.



78 Taking trouble and care to cushion fruits and vegetables within each carton and optimizing the cartons and/or crates used to pack the commodities both contribute to minimizing damage and losses. That is not the end of the process, though. It is equally important to cushion the containers within vehicles or on small wagons or cycles. The suspension on these conveyances is typically unreliable or missing, pretty much guaranteeing bumpy rides that subject the load to vibration, jostling, bouncing, shaking, and pitching.

It's important not just to cushion the load, but also not to overload the vehicle. Loading more than a vehicle can handle invites breakdowns that halt delivery, leading to spoiled cargo. Piling produce over the truck's height leaves produce unsupported and vulnerable to wind and roll-overs. Overloading causes overheating, and possibly compression damage to the produce at the bottom of the stack. Many more protocols to optimize loading trucks are listed in Tool 76.

When cushioning the load with natural materials, care

needs to be taken that they are insect and pest free. Otherwise, it is inviting trouble into the truck. Leaves and straw are abundant and low-cost or free. This type of natural cushioning is used domestically; it is not suitable for shipping long distances or international export.

After the trip, natural cushioning materials can be composted.



Banana bunches cushioned using banana leaves on the bottom and sides of the load in India - Photo: Lisa Kitinoja



USDA Manual: Transporting Perishable Foods by Truck (100 pages) [\[bit.ly/2peAFVW\]](https://bit.ly/2peAFVW)



Truck Loading Principles for Hauling Perishable Commodities (in refrigerated trailers) [\[bit.ly/2D2aThB\]](https://bit.ly/2D2aThB)



Workers unload bags of grain in Nimla village, from a truck covered with a magenta tarp - ©IFAD/Susan Beccio

Improved Loading Techniques

Farmers in remote areas seldom have access to state-of-the-art trucks. Doing the best job possible loading the available transport vehicles significantly reduces the amount of food lost en route.



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Ensuring that a load is stable and ventilated is essential. Overloading is tempting, since it reduces the cost of shipping per unit, but it can end up devaluing the whole load.

Sanitation should be managed. Before packing a truck, it must be cleaned of debris from former loads. Before loading, mechanical problems should be addressed. A vehicle breakdown can result in big losses due to sitting by the side of a road while the contents spoil.

When transporting bags of grain, care must be taken that there are no sharp edges on the truck's surfaces that could snag bags and spill contents. Any surface holes or cracks should be patched.

Open trucks have both advantages and disadvantages. They are easier to access and have natural wind ventilation. But of course they are open to the elements and birds that can attack the load, or leave their own loads. Open cargo needs to be protected with a tarp. Adding a windcatcher to the load's front funnels night-time air down into the load to help keep it cooler.

[SAWBO's animation on transporting grain sacks in open trucks \[bit.ly/2B8HMbh\]](#) stresses that the tarp should be stretched over arched cross-pieces made of metal, bamboo, or wood spanning the width of the truck. This keeps rain and moisture away from the load. The tarp, which obviously should be free of holes or rips, must cover the load plus one third of the sides of the open truck. It should be tied tightly to the arched strips or side-grips with ties or straps. During the

trip, the driver should stop to check if the tarp is still secure and adjust it accordingly.

For transporting a bulk, unbagged load, the same principles apply, but as emphasized in SAWBO's [animation outlining the transport of loose grain in a truck bed \[bit.ly/2MJneHP\]](#), a tarp must be folded as an in-set liner, covering the bottom and sides of the truck and clamped to the truck's walls.

Closed, unrefrigerated trucks can protect their contents from the elements, but require ventilation management so the interior doesn't overheat and "cook" the contents.

Following basic truck loading protocols reduces losses:

- **Crates or boxes should not be stacked too high;** leave about 8 inches (20 cm) between the top container and the ceiling
- **Containers should not be packed too tightly.** It is important to allow some space (6 inches or so away from the wall) for ventilation within and around the load. However, loads do need to be secured to prevent excess jostling.
- **Place heaviest containers at the bottom,** if the load is not uniform.
- **Align containers** to take advantage of corner strength. Overhanging boxes decreases their integrity.

- **Ventilate** to provide a way for air to pass under, within, and above the load, keeping produce from overheating. Pallets [Tool 64] provide air circulation space.
- **Brace the load** to assure the stacking is secure. Falling containers damage their contents and other cartons of food as well.
- **Brace the load's rear end** near the opening, to prevent contents moving in transit and/or falling out when the truck is opened. Falling boxes not only damage food, they can injure workers unloading the contents.
- **Avoiding overloading** reduces losses. While it is tempting to pack a truck as high as possible, it increases the load's vulnerability and can result in greater losses than the benefits yielded by lower per unit expenses.

It is important, when transporting a mixed load, to make sure that the combination is safe [Tool 68]. Some combinations of fruits and vegetables are incompatible, such as ethylene-emitting commodities traveling with ethylene-sensitive plants. Check Tool 68 for a compatibility list.



Safe Transport of Leafy Vegetables [\[bit.ly/2xIUGxu\]](https://bit.ly/2xIUGxu)



SAWBO Animations: Best Practices for Transporting Grain Bags by Truck [\[bit.ly/2D6qVqS\]](https://bit.ly/2D6qVqS)



SAWBO Animations: Best Practices for Transporting Loose Grain Bulk Loads [\[bit.ly/2D29tDW\]](https://bit.ly/2D29tDW)

Mobile Cool Chamber

The insulated box was designed such that it could hold 8 plastic crates of size 540x360x295 mm in two layer of four each
Capacity of storage was 100 kg of fruits with 80% filling of each plastic crates
Costs around Rs. 18,000-20,000/-



Low cost unit saves the fruits from exposure to sunlight and preserves the quality.

From SlideShare on [Cold Chain Management \[bit.ly/2B8Znjx\]](https://www.slideshare.net/RamabhauPatil/Cold-Chain-Management) by Ramabhau Patil, Bhopal, India: merging a bike [Tool 77] with an insulated box.

80

The **Cold Chain** refers to refrigeration temperature management from the time a crop is harvested until it is consumed. For heat sensitive commodities, reliably maintaining lowered temperatures is key to reducing losses. A crate of fruit or vegetable's journey can consist of multiple transports, packing, unpacking, repacking, and storage in a series of locations. It is challenging to

Insulated Packages and Insulating Blankets

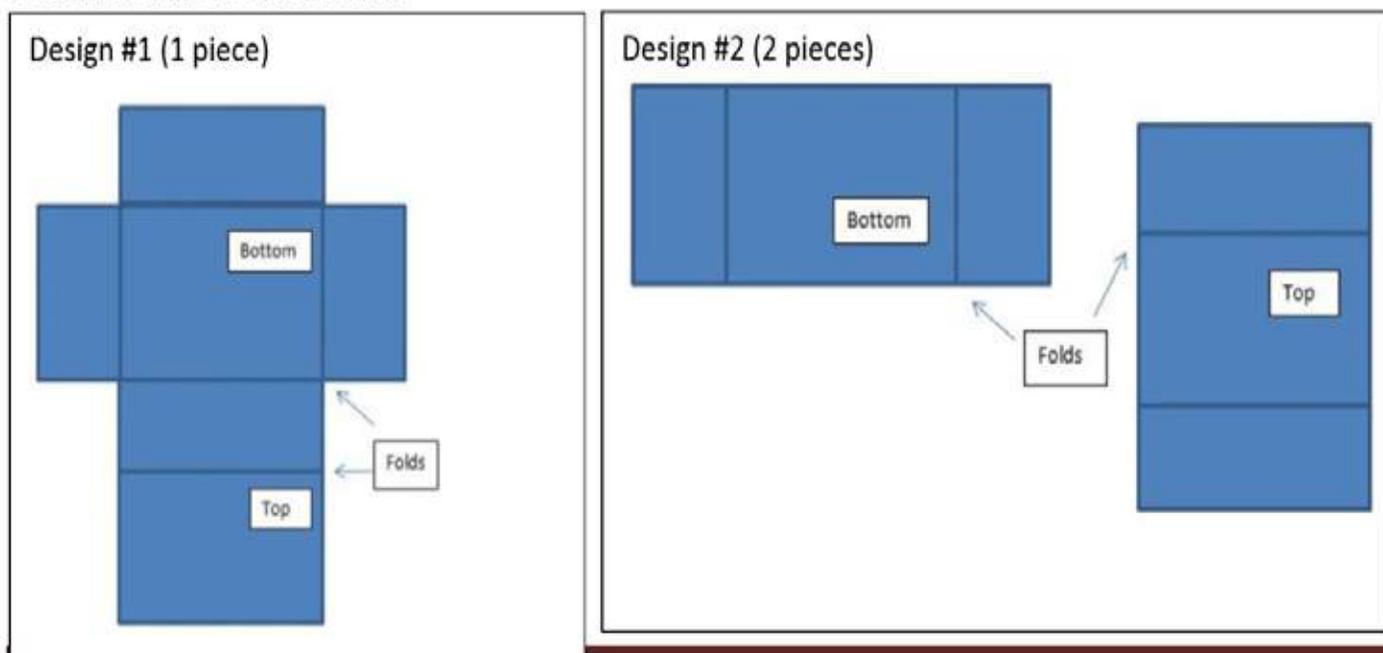
Insulated packages help retain the cold for longer shipping distances, a crucial part of temperature management. Insulating blankets also help retain low temperatures.



manage gentle handling and temperature control throughout these many transitions and changes of venue, especially when refrigeration is not an option.

Lowering the temperature of the fruits and vegetables is generally done at the farm, packinghouse, or in storage. Moving cooled vegetables requires conserving those low temperatures, often without refreezers, as refrigerated trucks are called. A

Patterns for liner construction:



2017© Postharvest Innovations LLC - [\[bit.ly/2ypiOfg\]](https://bit.ly/2ypiOfg)

number of techniques are available for this, which can be combined for added temperature management security. Gelpacks [Tool 81] are commonly used, frozen and included in shipments.

Insulated boxes can be purchased, but they are pricey and the cost of shipping them, empty, to remote locations is a large added expense. It is more economical to purchase rolls of insulating material and create your own insulated containers. Provided the boxes can be returned after their contents have been unpacked, insulated boxes can be reused many times. This amortizes their per use cost and is eco-friendly.

The insulation materials used to line the inner surfaces of the package can be locally identified (such as foam pads or insulated fabrics) or purchased in sheets (thin foam or a metal foil bubble material

such as Reflectix™.) The size of the insulation liner will depend upon the size of the package to be lined. To make a liner, cut the insulation material to a few mm smaller than the inner dimensions of the container. Reflective bubble insulation and foam sheets do not need to be finished after cutting, but fabric-based insulation (a sandwich of fabric and foam) will need to be sewn around all the edges to prevent unraveling.

An insulated package covering made of quilted fabric, a thick blanket or a pallet cover can be used to add even more insulation during long distance journeys

—Postharvest Innovations [Series Number 16 \[bit.ly/2BFerDl\]](https://bit.ly/2BFerDl)

The payback is quick, and if they are reused, they reduce losses and raise the value of shipments. Postharvest Innovations LLC lays out the value of this relatively simple investment:

| Crop (1000 kg) | Typical package or container shipped under ambient conditions | Insulated package liners for containers shipped under ambient conditions | Potential increase in profits |
|-------------------|---|---|--|
| Guava fruits | Market price \$1.50 per kg 83 cartons @ \$1.00 (holds 12kg) 15% weight loss + discards due to shrivel Market value = 850 kg x \$1.50 = \$1275 \$1275 - \$83 = \$1192 | Market price \$1.75 per kg 100 cartons @ \$1.00 (holds 10 kg) 100 reusable liners @ \$4.00 2% weight loss, no shrivel Market value = 980 kg x \$1.75 = \$1715 \$1715 - \$100 = \$1615 | \$1615- 1192 = \$423 The first use of the insulated liners will repay the total cost of \$400 plus provide an added profit of \$23. Use with each subsequent load of 1000 kg will result in an increased profit of \$423 |
| Chili peppers | Market price \$3.00 per kg 166 cartons @ \$1.00 (holds 6kg) 15% weight loss, discards due to shrivel Market value = 850 kg x \$3.00 = \$2550 \$2550 - \$166 = \$2384 | Market price \$3.50 per kg 200 cartons @ \$1.00 (holds 5 kg) 200 reusable liners @ \$4.00 2% weight loss, no shrivel Market value = 980 kg x \$3.50 = \$3430 \$3430 - \$200 = \$3230 | \$3230- 2384 = \$1046 The first use of the insulated liners will repay the total cost of \$800 plus provide an added profit of \$246. Use with each subsequent load of 1000 kg will result in an increased profit of \$1046 |
| Mangoes | \$2.00 | \$1700 | \$1900 |

Insulated boxes and blankets are used to retain cold temperatures but they are effective cushioning material as well. Hence they provided added protection for shipments.

Postharvest Innovations Plan Series Number 14, a Cold Box directly on a truck bed, is too costly for most smallholder contexts, but the pictured cold box on a bike is a clever hack.



Global Cold Chain Solutions: Hard Shell Cases with Insulated Liners [\[bit.ly/2MCKcj1\]](https://bit.ly/2MCKcj1)



RefrigiWear: Soft-sided Insulated Bags, with Gel Pack Pockets [\[bit.ly/2DayKLU\]](https://bit.ly/2DayKLU)



Uline.com's Insulated Reflective Bubble Foil Box Liners [\[bit.ly/2NP42wb\]](https://bit.ly/2NP42wb)



Typical freezer ice packs, a common change phase cooling solution - Santeri Viinamäki/Wikimedia

Cool Packs: Phase Change Materials for Lowering Temperatures

Cold packs made of Phase Change Material help maintain a cool environment for heat sensitive produce. They are reusable, decreasing their cost per use.



81

Until the introduction of Phase Change Materials capable of retaining temperatures (high or low) for long periods, the main options for cooling without electric refrigeration were ice or dry ice. That is still the case where PCM packs are not available.

Phase Change Materials, PCMs, maintain cold temperatures for longer periods than ice. PCMs can convert from solid to liquid, or liquid to solid, inside sealed pouches. Once frozen, they maintain low temperatures longer than conventional ice. Eventually they turn back to liquid and can be refrozen. They may be familiar to readers as Blue Ice for coolers, packs for icing sore limbs, and the packing inside shipments of medicines or foods requiring cold temperatures.

Since heat rises, placing gel packs on the top of a carton is the most important. But the optimal approach is using gel packs on all six sides of a container.

Dry ice, the solid form of carbon dioxide, is costly and not readily available. Creating it is energy intensive and it sublimates, the technical term for turning into gas. It is a short-term, expensive, single use cooling solution. It requires extra safety precautions since CO₂ gas is deadly in high concentrations, another reason why it is not a first choice cooling material.

Gel packs are sealed heavyweight polyethylene containers; their contents are non-toxic, foodsafe liquid/gel. They are intended to be frozen at the packinghouse and added to shipments for retaining cold temperatures. They are sealed; unless they are punctured, they do not leak any of their contents.

They can be reused, though like RPCs and pallets, if they are used for one-way trips, returning them is a problem. In time a secondary market may develop; at present they are primarily used in closed loop systems.

There are many varieties of gel-packs, lasting from 5-14 times longer than ice-to-water. Some come in flat sheets with a grid of pouches. Others are solid plastic blocks. Used together with insulated containers, they keep produce at a reliably cold temperature for a predictable number of hours. Packing choices will depend on how long the trip is expected to last. Using too many will waste energy and consume space that could be used for shipping for more produce.

What volume can be transported? This will always depend on the inner dimensions of the container and how much volume of the phase change material is included.

Example: A typical outer dimension sized container of 16x16x15 inches will have a liner of insulating material that makes the interior dimensions 12x12x12 inches. This is approximately 20L. If 6 gel packs of 500g each are included in the package, this would take up approximately ¼ of the volume inside, leaving 15L for the product.

Holdover time is highly dependent on the external temperature encountered during the shipment.

- If the external temperature is equal to the target temperature range, holdover time is infinitely long.
- If the external temperature is 10° to 15°C higher than the target temperature range, most insulated containers will “hold the cold” for several days.
- If the external temperature is more than 30°C higher than the target temperature range, then most insulated containers can only “hold the cold” less than 24 hours.

To minimize need for using gel packs, and to maximize holdover time during any shipment:

- Insulated containers can be pre-cooled along with the product to be shipped, products can be wrapped in insulation inside the container, and then after being sealed, the whole package can be covered with an insulating blanket to keep the bundle cold for as long as possible.

- Planning to open the container only once upon arrival will help to maintain the cold for the longest period of time.
- Keeping the container out of direct sun during shipment will increase holdover time.
- A light-colored container (white, silver or light beige) will reflect sunlight and stay cool longer than a black or dark colored container. A dark container can be covered in a light-colored blanket or cloth sheet to reduce the external heat load.

Cost for insulated containers and gel packs depends upon their size, quality and the number purchased (volume discounts are beneficial).

Retail price for a 25L insulated container is about \$30 to \$35 each.

Retail price for a 500g gel pack is about \$1 each.

Phase Change Materials are also used to provide warmth retention. **Embrace Infant Warmers** [embraceinnovations.com] are designed to keep premature babies warm enough to survive in areas lacking electricity for incubators. A PCM pad is heated using boiling water and inserted into the “papoose”, helping save premies’ lives by maintaining a constant temperature for four hours with no added energy.



ThermoSafe Catalog [bit.ly/2NRLZ4f]



Global Cold Chain Solutions (gel bricks that change phase without becoming soft) [bit.ly/2OtDopM]



Sonocare ThermoSafe (Polar Pack® refrigerants and Utek® phase change materials system) [bit.ly/2NMwSgz]



Section 6

MARKETS: LOCAL TO GLOBAL

- 82. Raised Display Stalls with Sunshades
- 83. Portable Stores: Bikes, Trikes, Wagons, Carts, and Cars
- 84. Scales: Weights and Measures
- 85. Sorting/Repacking/Trimming and On-Demand Ripening
- 86. Misting or Sprinkling with Cool, Clean Water
- 87. Market Access: Agricultural Co-ops and Self-Help Groups
- 88. Branding
- 89. Value-Added Certifications: Organic and Fairtrade



A roadside produce vendor in Anuradhapura district, Sri Lanka, utilizing best practices such as raised, multi-tiered surfaces [Tool 82], a sunshade, and ready-to-go suspended racks of bagged products at eye-level, attracting customer attention - Photo: ©IFAD/G.M.B. Akash

MARKETS: INTRODUCTION



A Bangkok vendor offers beautifully prepped fruits protected by glass, but allowing buyers full view - Photo: Twentyfour Students/Flickr

The job of farmers, first and foremost, is growing food. Harvest yields are the bounty by which a farmer supports herself and feeds her family—first by directly consuming the food, or secondly by selling any surplus. Transacting fair sales between producers and purchasers in a timely manner is far from guaranteed, yet a farming family's security depends on the outcome.

Farmers with surplus to sell must access a market. Usually this is a physical collection of temporary stalls, but sometimes the farmer sells to intermediaries, accessing the larger market of buyers and sellers

ranging from regional to international. Connecting with markets beyond a farm's immediate vicinity expands opportunities for sales, though many steps need to align to make that possible.

Selling locally is the typical approach, but reliance on local buyers is limiting. If the farmer is near an urban population center, a larger number and wider range of customers expands opportunities. Selling direct eliminates any go-between, increasing farmers' net. However, there are many challenges to running a physical market stall. This section features numerous upgrades

Direct marketing is a complex skill. Many tweaks and techniques can help vendors add value to their fruits and vegetables. Sanitation measures observed at temporary venues such as maintaining clean surfaces, as well as appropriate packaging, attractive presentation, and TLC (tender loving care) for the fruits and vegetables all improve the bottom line.

Adding value at the retail market stage has three advantages:

- Increasing sales volume
- Raising the price of offerings, growing net profits
- Speeding sales, minimizing losses by moving produce along before it deteriorates

Smallholder farmers also have the option of selling to a middleman/woman. Purchases are sometimes contracted [Tool 97] before the growing season, but more often this takes place at the farm gate during harvest season. In any given area, most farmers' produce matures for harvesting at about the same time. Growers sell in lock-step, causing prices to fall. Higher yields can, ironically, result in price-lowering gluts in local markets. If farmers lack storage capacity, their hard work can result in forced sales at disappointing prices.

Wholesale buyers can take advantage of the asymmetry of information and power between themselves and farmers—who frequently lack literacy skills—in a variety of ways. A classic ploy is misrepresenting weights and measures [Tool 84]. Another is assessing the crop in a negative light to devalue it.

Weather events or long waits for slow-to-arrive purchasing agents can result in crop damage and depreciation. Farmers rarely have price guarantees and have little choice, once their harvests are in, about the selling price. These are some of the many challenges that result in postharvest waste.

Farmer cooperatives address many of these problems. Organized groups of growers have more leverage and better access to information and opportunities. This allows them to better meet market demands and diversify their commodities to reduce risks. They can jointly finance and share upgraded facilities for processing and storage, cutting their crop losses and improving their bottom lines. Cooperatives can negotiate contracts with growers for specific commodities, covered in Tool 97.

Expanding market access means more opportunity for reducing postharvest losses while growing incomes and improving food security: a triple win.



Kumasi, Ghana fruit vendor raises his wares up, protects them from direct sun, and arranges them artistically - Photo: Adel A. Kader

Raised Display Stalls with Sunshades

Raised tables and overhead sunshades decrease damages to fruits and vegetables from infestation and extreme heat. They add visual appeal, speeding sales, and the shade protects the vendor, too.



82

From time immemorial, people have gathered at outdoor markets for buying and selling. Farmers bring their bounty; news and gossip is exchanged, too. Direct retail markets can eliminate middlemen along the value chain, allowing farmers to sell food straight to customers at fair prices.



Vendors chat at a market in Ubud, Bali - Photo: © Michal Osmenda/ Flickr.com

From a makeshift roadside stand with fruits or vegetables direct from the field to a permanent stall rented in a full-service market with ongoing infrastructure, quick product turnover is the goal. In an exercise of pure market economics, vendors seek to maximize prices while selling everything they have transported; buyers want the lowest prices possible. Lively bargaining ensues.

Sellers generally lower the price towards the end of the day, to avoid carrying their harvest home; unsold produce is not only burdensome, but a day outside in a hot market increases the likelihood of spoilage. CoolHubs, [Tool 72] innovative at-market cold storage, seeks to address this market gap.

Transporting products to market is a logistical challenge for any farmer, but even more so for those without access to mechanized transport. Carrying a cloth to the local marketplace, spreading it out on the ground, and arranging offerings on it is common the world over. However, this practice should be avoided. Just as people gather at the market place, so do a wide variety of pests, attracted by the same foods the shoppers are seeking. Raised racks and tables protect the products from contaminants, dirt, insect pests, and rodents.

- Raised racks have the additional benefit of bringing the offerings closer to customers. Creative solutions abound for raising the height of displays to grab eye-level attention.

- Inverted crates, plastic or wood, can be used to support a flat table as well as for vendor seating.
 - A slanted table with a bottom ledge provides passersby a better look at the products displayed. It holds a bed of ice to conserve perishables, with the melt water running off.
 - Multi-tiered levels increase visibility and attractiveness. Inverted cartons or crates create platforms for upper-level arrangements. Colorful cloths covering the crates add visual appeal.
 - Trestle tables, flat surface supported by free-standing supports, or a simple folding table work well.
- Adding a sunshade [\[bit.ly/2P58Vih\]](https://bit.ly/2P58Vih) slows down water loss and can be used to suspend items, expanding the booth and catching customers' attention. In windy venues, a side-screen can help reduce moisture loss.
 - To avoid damaging the bottom level of produce, it is important not to pile too many layers of perishable fruits and vegetables on top of each other.
 - Artful presentation of fruits, vegetables, grains, and spices help attract customers. Complex arrangements are not only eye-catching, but cut down on customer handling, which damages produce.



Farmers Market Guide [\[bit.ly/2QD5MqP\]](https://bit.ly/2QD5MqP)



Doing Market Research While Selling Direct [\[bit.ly/2D4EgQq\]](https://bit.ly/2D4EgQq)



University of Illinois Extension Webinar: Marketing and Merchandising for Farmers Markets
[\[bit.ly/2OwLLkv\]](https://bit.ly/2OwLLkv)



A gaily painted wheeled wagon stands out from endless others just like it across India, utilizing a basic marketing technique: create eye-catching, memorable presentations, along with adding tiers to the sales platform - Photo: Carlos Penalba

Portable Stores: Bikes, Trikes, Wagons, Carts, and Cars

Rolling one's wares on a wagon, cart, bike, or truck that transforms into a shop saves a vendor time, expense, and labor. Eliminating one transfer decreases product stress. Customized upgrades can be added.



83

Fruit and vegetable vending microenterprises benefit from wheels. From an entry-level wheelbarrow to a fully equipped truck, conveyances that transform from haulers to a sales venue provide portable business set-ups. They eliminate the overhead expense of maintaining a market stall. By minimizing extra unpacking and setting up for sales, they reduce stress on their produce as well as saving the vendor labor.

Vendors tinker and adapt their wheeled vehicles, adding devices to allow for more vertical capacity like wire siding on round bamboo platforms, Kathmandu style. They can hang a scale from a handlebar or awning. Sunshades protect both vendor and wares, plus adding visual appeal and character. In a crowded marketplace, artistic touches can help differentiate one micro-business from another.

Rolling shops can also be used for mobile door-to-door sales, providing fresh produce directly to customers' homes. This is a service which buyers appreciate. If a vendor establishes a regular route and becomes familiar with customers' tastes and preferences, she can tailor her inventory. Finding a route without competition that yields sufficient income is challenging, but so is hawking wares at a crowded market. While a traditional marketplace has more customers, there is also more duplication of offerings. Creating a differentiated market niche is, in a basic way, branding [Tool 88].

Portable kiosks raise inventory up off the ground, protecting it from contamination.

Pushcart peddlers can also sell value-added street food intended for on-the-spot consumption. Be they hot potatoes, sliced fruits, sandwiches, or roasted nuts, there will be eager buyers. I still remember a street vendor's hot popcorn, reliably available outside a Jerusalem movie house 45 years ago.

Handcarts are well-suited for peri-urban neighborhoods with narrow, winding, unpaved streets. Old sections of established cities are also popular venues for street vending from carts, wagons, and bikes, since they are too tight for most motorized vehicles to maneuver.

Rolling stores are rent-free; stationed in public places, they create lively street life, often unlicensed and unregulated. Countless people world-wide make their livings selling farm-fresh fruits, vegetables, and prepared food direct to the public, in what is known as the informal economy. Most vendors are not farmers—these sellers tend to purchase their produce wholesale at an early morning open-air market the same day as their sales.

These images speak to the creativity and ingenuity of sellers short on capital but rich in entrepreneurial flair.



Creative use of wheelbarrows on the streets of Coyoacan Borough, Mexico City - Photo: Ted McGrath



Rolling cart laden with fruits protected under a sunshade, with a hanging scale [Tool 84], in a public square in Cusco, Peru - Photo: Betsy Teutsch



A Kathmandu, Nepal vendor's bike doubles as his fruit shop, complete with a vertical storage cage and sun canopy - Photo: Toni Sagristà Sellés



Vegetable truck vendor utilizing vertical space, reusable plastic crates [Tool 12], and stacking open cartons [Tool 32] in Petra, Jordan - Photo: Betsy Teutsch



Farmer selling tomatoes at dusk from reusable stacking wooden crates [Tool 32], straight from the field to a Petra, Jordan street - Photo: Betsy Teutsch



A picturesque Cairo citrus wagon vendor; note the handmade palm rib crates (PEF highly recommends using liners in these) - Photo: Marie M./Doozzle - Flickr



Caracas, Venezuela fruit truck with its white surfaces suggesting high sanitation standards, sporting a shingled sunroof - Photo: Kayla Sawyer/Flickr



2-Wheel Market Pushcart Wagon [\[bit.ly/2Nj8RhD\]](https://bit.ly/2Nj8RhD)



A Bogota Tricycle Food Cart with Snazzy Upgrades [\[bit.ly/2xqDlnr\]](https://bit.ly/2xqDlnr)



A widow weighing carrots with a mechanical balance and weight in modern India - Photo: Deborah Espinosa/SameSkyPhoto.com

Scales: Weights and Measures

Accurate weighing allows farmers to document their yields, leading to fair, transparent transactions and better planning. Transparency in weighing produce protects both sellers and buyers.



84

Human beings “measure what we treasure.” This is the mantra of the evidence-based data-gathering revolution, analyzing the effectiveness of interventions and innovations. Scales are an essential tool for gathering accurate data. When farmers can quantify their yields, they can improve their planning for their next crops [Tool 1].

Scales for weighing are an ancient technology. If sellers don’t know the weight of their product, scales are notoriously easy to rig in the buyers’ favor. The Bible includes many verses

calling out these common injustices. “Do not use dishonest standards when measuring length, weight or quantity. Use honest scales and honest weights.”—Lev 19:35-36

Weighing is important all along the value chain. Farmers who weigh their own yields have more leverage in the selling process. Packinghouse workers weigh produce when compensating farmers and during packaging. Food processing relies heavily on accurate weights. Direct markets feature scales for weighing the produce for each sale.



Ana Almanza, a member of the Colombian APPROACA cooperative, weighs the cocoa crop in Isla de la Amargura, Caceres, Antioquia - Photo: Thomas Cristofolletti, USAID



Organic cocoa collecting station in Monte Forte, 30 km from the capital, Sao Tome, an island off the West Coast of Africa; cocoa beans are weighed and stored before being sent to France for processing - Photo: ©IFAD/Susan Beccio



Pat Brown demonstrates weighing a crate with a digital, handheld luggage scale and bungee cord - Photo: Lizanne Wheeler



Lilian Nafula, from Khaoya in the Bungoma South district of Kenya, happily weighing her sorghum after a good harvest - Photo: Kelvin Owino, OneAcreFund

Farmers in remote locations are dependent on local wholesale farm-gate purchasers. This is the stage when information asymmetry reduces farmers' bargaining power, lowering their payments. Postharvest processing and temporary storage options can provide smallholder farmers with opportunities besides selling all their yields as quickly as possible, under pressure. This can reduce losses and raise family income.

Weight is the generally agreed upon pricing method for commodity markets, but weight does not necessarily correlate with quality. Hence, weight is best used in conjunction with grading [Tool 29]. A study of Senegalese rural onion growers highlights this problem. When pricing went strictly by weight, farmers used urea fertilizer, water-logging the onions. This added weight but lowered quality. (Another ploy a farmer might use to increase weight is including rejects and debris along with quality produce, putting the whole lot at risk.)

When the Senegalese farmers in the study were briefed on the grading standards that would be used for the market, and given their own scales, they grew better onions. Growing higher quality, cleaned, and graded produce increases farmer income and reduces waste. When farmers are incentivized to grow higher quality produce, they need the tools to self-assess their progress. This needs to be in the context of transparent, stable markets.

“Using data from each batch of onions that went through the weighing and quality certification system, we find that bags originating from villages where information had been provided were sixteen percentage points more likely to be of higher quality than those from control villages. . . . The experimental introduction of scales and labeling where they were not yet present has allowed us to show that they create large gains for farmers.”

—[Expected Product Market Reforms and Technology Adoption by Senegalese Onion Producers \[bit.ly/2nBaSGN\]](#)

Mechanical balance scales, depicted as the scales of justice, are still common but are giving way to digital technology.

For large bags of produce, platform scales are popular but hand-held luggage scales—inexpensive, portable, and accurate—are a popular alternative.

In open marketplaces, customers value accurate measures. They are more willing to make a purchase if they are confident they are not being cheated—the vendor can weigh the package in their presence and they can see weight and price/kg, rather than just being quoted the price without any reference to the weight. Though some buyers prefer bargaining.

Phone apps are available for weighing tiny quantities that can sit on the smartphone's screen.

Knowing the weight of their produce (how it diminishes if left in the sun or if damaged) can teach vendors how to take better care of their wares. A vendor I met in Kolkatta, India, told me that he knew that someone was stealing from him each day—he weighed his produce on arrival, weighed his sales, and then weighed his remainder and found a big gap of 10%.

I told him it was the gods who were stealing from him—the missing weight was the high rate of water loss from neglecting to use shade and cooling.

—Lisa Kitinoja



Scale Designs and Styles [\[bit.ly/2OztqDr\]](https://bit.ly/2OztqDr)



Weighing Dragon Fruits with a Hanging Scale (Caveat: using a plastic crate, not a bag, is best practice) [\[bit.ly/2PECVRM\]](https://bit.ly/2PECVRM)



Using a Balance Scale to Weigh Produce in China [\[bit.ly/2PDoSvy\]](https://bit.ly/2PDoSvy)



Strawberries in this vendor's prepared cups with jaunty-looking forks undoubtedly are more expensive, per berry, than the adjacent ones in plastic tubs at the Tel Aviv Carmel Shuk, but they fly out of his stall - Photo: Betsy Teutsch

Sorting/Repacking/ Trimming and On-Demand Ripening

Sorting, trimming, bunching, and prepping for retail markets create niche products with higher value. Controlled ripening smooths supply. Selling pre-packaged products streamlines sales.



85 Sorting and repacking larger crates of fruits and vegetables into a variety of differently sized portions reduces losses and adds value. Targeting produce to customer preferences results in higher buyer satisfaction and more sales.

Washing and trimming at the wholesale or retail market level adds value. High-end customers, or people short on time but with disposable income, appreciate the aesthetics and labor-saving of trimmed fruits, beans, sliced peppers, and more, ready for cooking or immediate eating.

When I lived in New York City in the 1980s there was an influx of Korean immigrants. Beautiful vegetable markets sprung up featuring washed, trimmed, seeded, sliced products artistically arranged on trays and wrapped with transparent film. These presentations quickly displaced the conventional open-bin markets offering produce in its natural, unwashed state. Fruit and vegetable vendors worked very long hours growing this new market and eventually dominated the whole sector, prospering by offering customers visual appeal, quality, and convenience.

There is also a market for cheaper, lower grade fruit and vegetables. My urban Philadelphia neighborhood is home to a corner market featuring just such inexpensive produce. The owners purchase lower grade (that is, smaller) produce at the wholesale vegetable market and their staff repacks it. Priced by the bag, it streamlines sales and lowers their labor costs. They

have created a destination for shoppers appreciating cheaper, fully ripe (as in, if they don't sell within a day or two, they will be over-ripe and not saleable) smaller grade produce.

This business model is a winner all over the world. Cafeterias, schools, restaurants, soup kitchens, and other institutional food preparers purchase lower grade produce for soups, stews, sauces, and salads. Aesthetics are not an issue if the fruits and vegetables are sliced and/or cooked. Such buyers purchase large quantities at wholesale prices; they and vendors who provide their daily orders both benefit from this win-win strategy.

Beautiful fruit practically sells itself; making it available for on-the-spot eating is a smart approach. In strawberry season in Tel Aviv's Shuk HaCarmel Market, the vendor pictured undoubtedly makes more profit on his individually packaged strawberries in cups with forks than on the adjacent larger quantities he also sells. Note that he does not trim the strawberries for the ready-to-go cups. He likely knows from experience that customers are content to pull off the hulls themselves and he can skip investing in a time-intensive detail that does not increase sales. (And perhaps he knows that removal of the strawberry hulls will expose the most vulnerable area of the fruit and lead to enhanced respiration, water loss, and susceptibility to pathological invasion.)

Vending often involves a fair amount of tedium, sitting around waiting for customers. Using some of that time

in value-addition trimming or more, even creating beautiful carved fruits—hello, pineapple! —can both help pass the time and increase income. It can even attract potential customers watching the performance, a competitive advantage where most vendors sell similar offerings.

Ripe fruits fetch higher prices. To control ripening, vendors have an effective trick up their sleeves. Whereas earlier in the value chain the emphasis is on slowing ripening [Tool 35], vendors often want to speed ripening to meet demand. Several methods are well-established:

- Ripening fruits under a tarp where it is warm and humid, pairing them with ripe, high ethylene-producing fruits like bananas, apples, avocados or mangoes.
- Using ethephon, a ripening agent available in powdered form sprayed on the mature produce just before or immediately after harvesting, considered food-safe.
- Using Ethylene gas directly as demonstrated in this [video \[bit.ly/2vGSoZY\]](https://bit.ly/2vGSoZY).

Staggering ripening according to demand helps smooth the supply; experienced vendors know which days to expect heavier demand, like weekends, Christmas, festivals, and the month of Ramadan, and plan accordingly.

Speeding the ripening process means quicker sales of ripened fruit with less fruit wasted.



Vendor/artist carving pineapple at the Palengke (Market), Lucena, Philippines - Photo: Philip Brookes/Flickr



On-site Ethylene Generation [\[bit.ly/2xf0euA1\]](https://bit.ly/2xf0euA1)



TNAU Ripening Mangoes with Ethylene Spray at the Farm [\[bit.ly/2pdZbXt\]](https://bit.ly/2pdZbXt)



Mango Ripening with Ethylene [\[bit.ly/2PHkyM8\]](https://bit.ly/2PHkyM8)



DIY Laotian Spiral Pineapple Carving Tutorial [\[bit.ly/2NQfqYv\]](https://bit.ly/2NQfqYv)



“The farmer, who was very proud of his harvest of green onions, cauliflower and cilantro, waters down his load to keep the veggies fresh as he transports them via a bicycle cart [Tool 77] along the busy roads to buyers in New Delhi” - Caption and Photo: Joan Conrow

Misting or Sprinkling with Cool, Clean Water

Fruits and vegetables are sold by weight; their value declines as they wilt. Misting plants to avoid shriveling keeps them fresh longer, decreasing the quantity of deteriorated produce and reducing losses.



86 Produce sold in outdoor markets is subject to intense heat and wind. This causes plants’ water content to evaporate, eventually leaving them wilted and unappealing to buyers. Vegetables lose water much faster than fruits which are typically well protected with thick peels and natural surface wax.

Using a sunshade [\[bit.ly/2P58Vih\]](http://bit.ly/2P58Vih) is an important protection from water loss. Added side screens can shield produce from wind.

Supermarkets feature elaborate overhead misting of their greens, in particular. This high-tech system can be approximated with a home-made outdoor market version. A pipe can be perforated with tiny holes or a soaker irrigation hose can be used, if available, and connected to a hose, provided the venue has potable water. A bike pump can be used to provide extra pressure. Suspended over the vegetables for sale, this do-it-yourself watering system supplies uniform and consistent moisturizing.

Water needs to be potable and sanitary, of course, and the cooler the better. Well water is cooler than water at ambient temperature.

A less complicated moisturizing method is attaching a spray nozzle to a bottle of water or reusing an empty cleaning product container with a spray top, and frequently moistening the products. Of course, any product bottle needs to be thoroughly cleaned before reusing.

“Misting commodities that can tolerate surface water

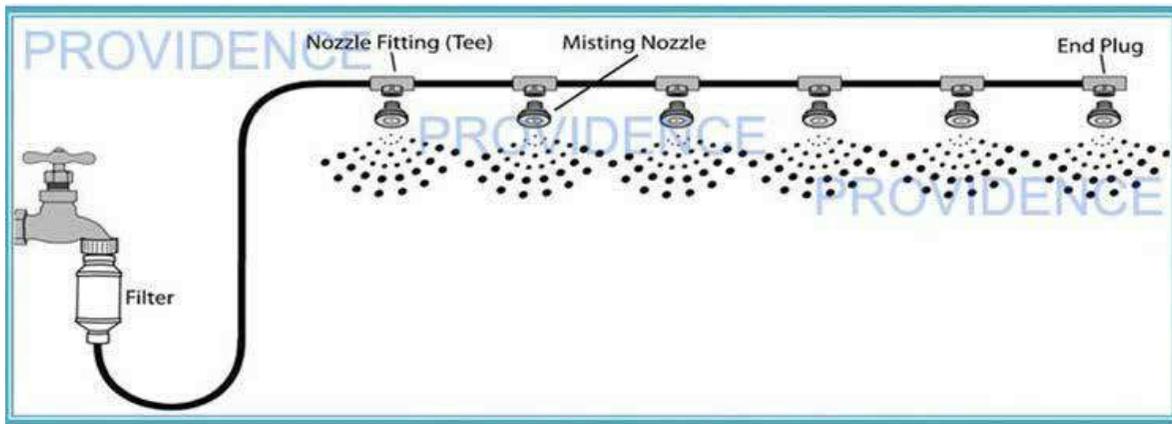
(lettuce, broccoli, green onions) with cool clean water can help maintain a high relative humidity around the product.” —Kitinoja and Kader (2015), p. 221



A spray nozzle attached to a bottle of cool, clean water also does the job - Photo: Upupu4me/Flickr



Utilizing an early prototype of Evaptainer [Tool 74], a portable evaporative cooler, at the market to keep produce moist and cool during transit and sale - Photo: Quang D. Truong



Installation Steps:

1. Connect the filter to the water tap, and then connect the misting system assembly to the filter.
2. Turn on the water tap to wash the system for 1 minute to purge the system and remove any impurities.
3. Screw the misting nozzles to the Tee fittings, except the last one on the end plug.
4. Turn on the water tap to wash the system for 2 minutes to insure that the system is fully purged.
5. Turn the water off and install the last nozzle into the fitting with the end plug.
6. Fix the misting line by the saddle clamps provided..
7. Turn on the tap slightly until jets are working, enjoy the cooling misting system .
8. Periodically remove the misting nozzles, and follow steps 2-5 to clean out the misting system.
9. Replace the filter as necessary.

Illustration via Alibaba.com

Vegetables that benefit from misting (note missing mainstays like regular onions and garlic):

| | | | |
|-----------------|----------------|------------------|---------------|
| Artichoke | Celery | Onions (green) | Sprouts |
| Beans (snap) | Collards | Parsley | Summer squash |
| Beets | Corn | Parsnips | Swiss chard |
| Broccoli | Eggplant | Peas | Turnips |
| Brussel sprouts | Endive | Peppers | Watercress |
| Cabbage | Kale | Radishes | Zucchini |
| Carrots | Lettuce | Rhubarb | |
| Cauliflower | Mustard greens | Shallots (green) | |

Kitinoja and Kader (2015), p 239



Penn State Extension: Best Practices for Keeping Produce Fresh [\[bit.ly/2OzbN6n\]](https://bit.ly/2OzbN6n)



Misting system in a supermarket [\[bit.ly/2AjHWuk\]](https://bit.ly/2AjHWuk)



This lentil separator or “dal mill” separates lentils from pebbles and debris; it processes as many lentils in five minutes as would normally take a woman all day - Photo: IFAD/Susan Beccio

Market Access: Agricultural Co-ops and Women's Self-Help Groups

Farmer groups provide training to improve both yields and postharvest handling. Pooling resources facilitates machinery purchases and storage structure construction as well as providing access to regional, national, and international markets.



87 Smallholder farmers work hard, too often for returns that barely feed their families. Banding together in cooperatives, associations, and women’s self-help groups provides many benefits. Farmers can collectively improve their knowledge base, planning [Tool 1], harvest yields, post-harvest processing, and market access. This decreases crop losses and increases incomes.

By organizing as groups, farmers can share their expertise and create leadership opportunities for members talented at educating, organizing, negotiating, and managing. Women’s groups take the job of training members for community roles very seriously; women in patriarchal societies rarely speak publicly. Women’s groups provide a forum for members to master this skill and develop their leadership potential.

Organized groups of growers have more leverage and better access to information and opportunities. They can jointly finance and share improved facilities for processing and storage, growing their incomes. Developing relationships with local, regional, or export customers can generate a contract [Tool 87] for growers. Knowing what a customer commits to purchasing takes the guess work out farmers’ lives, reducing risk and losses

resulting from a wrong hunch. Farmers groups with a contract plan, prioritize, and process their yields jointly according to the needs and requirements of their buyer.



Kweigbein Farmers Association members meet after a nine-month savings cycle to jubilantly divide the shares of the savings and loan group in Bensonville, Liberia - Photo: USAID Food and Enterprise Development Program for Liberia (FED) / Nico Parkinson



Seed systems:

- Strategic partnerships to increase the availability of improved seeds developed
- The actors in these partnerships include NARS, commercial seed companies, input suppliers and farmer associations
- Farmers and extension agents are trained in seed production
- Farmer cooperatives, local seed enterprises and input stockists were established and /or strengthened



Developing a robust pigeonpea value chain includes farmer cooperatives - Photo: Pigeonpeas in ESA - A Story of Two Decades, Said Salim: ICRISAT PowerPoint, Slide 13

In Western Kenya, Bidii Farmers Group's contract for growing French Beans [Tool 70] has provided security and a platform for improving their lives. Members have invested in a charcoal cool storage room to keep their product safe while awaiting pick-up, decreasing their losses and increasing their sales.

Collectively owned processing tools speed work formerly requiring arduous, time-consuming manual labor. This frees members up to devote labor to value addition, an income generating activity. Running even a small food processing initiative takes more hands and a larger volume of raw ingredients than an individual farmer could supply.

In Nimla village, a farmer's cooperative [pictured above] has set up a farm implementation bank and training center. Farmers can borrow equipment to save on labor and improve crop output. The lentil separator or "dal mill" which separates lentils from pebbles and debris can process as many lentils in five minutes as would normally take a woman all day.

—IFAD

Gaining sophistication in marketing, packaging, and distributing both raw yields and value-added products can expand a co-op's earnings, benefiting all its members. A virtuous cycle ensues, whereby a co-op can reinvest a portion of its increased profits on shared facilities. Improved storage facilities [Tool 65] can accommodate members' yields and improve their market timing. If they have surplus storage space, it can be rented to non-members. These added initiatives require skilled managers. A successful co-op can invest in member training, helping members advance in skill and responsibility.

Co-ops have the additional advantage of expanding access to credit [Tool 95]. Working as a group rather than individual farmers, risk is spread over the whole cooperative. Village savings and loans require no outside capital, well-suited for farmer groups in remote locations. The elated women featured are distributing cash loans to themselves and fellow members for land and tools to boost their incomes.

Farmer cooperatives often bring in health care providers, improving access. For example, some coffee cooperatives provide cervical cancer screening [bit.ly/2MpQZ3B] for their members.



Fintrac: Market Systems Approach in the Smallholder Agricultural Sector [\[bit.ly/2xpoM3u\]](https://bit.ly/2xpoM3u)



Feed the Future Innovation Lab for Assets and Market Access [\[bit.ly/2A1cKdY\]](https://bit.ly/2A1cKdY)



Agriculture for Impact: Farmer Cooperatives Summary [\[bit.ly/2xn5aN6\]](https://bit.ly/2xn5aN6)



CASA India: Women's Self-Help Group in Maharashtra [\[bit.ly/2NhrjCG\]](https://bit.ly/2NhrjCG)



John Rimui and his daughter Nancy Wambui Rimui show off their newly bottled tomato sauce near Leshau, Nyandarua County, Kenya.

"We learned that we had to register our tomato sauce with the Kenya Bureau of Standards. We needed to get certification. The first time we failed. Right now, we can sell locally and to our friends but we cannot sell to supermarkets. We are trying to bring the standard up so that we can be certified, then we can sell to a larger market"- Photo: IFAD/Susan Beccio

Branding

Branding—creating a distinctive product—requires consistent management from beginning to end. A successful brand creates a following, providing secure demand for farmer suppliers and expanded income for the business.



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Cooperatives [Tool 87] are good platforms for creating a brand. Building a business that produces a desirable product takes a great deal of effort. Informal market observation and research at local venues provide a sense of what people are seeking in a value-added product and how much they will pay for it.

Growing a brand requires business training and investment in equipment and supplies, something hard for an individual smallholder family to accomplish. But a group working together

can pool time, resources, capital, experience, and ideas. Value-added food processing increases incomes, so it is well-worth the work in establishing a branded product. It decreases postharvest losses by absorbing the large, lower-priced quantities available at harvest-time and processing them for later consumption. If a business expands and adds storage capacity, workers can continue producing their product for a longer season or even year-round. A growing enterprise can recruit farmers and contract with them to grow what the company requires.



KB Krusha's branding, label, and color scheme are distinctive, consistent, and eye-catching - Photo: KB Krusha/Facebook



These two nearly identical produce wagons, photographed on an overcast day in Kathmandu, Nepal, exemplify a basic market challenge: differentiation. How could branding and value-addition activities to better utilize the vendors' time attract customers? - Photo: Dina Tanners

Jams, jellies, dried fruits, spreads, sauces, condiments, and fruit drinks are popular items to brand. Generally, the marketplace already has such products; finding a niche is challenging. A co-op member may have a recipe she knows is popular—her lifetime experience is a form of market research. Food production must be routinized so each batch of product is reliably the same. Once the brand grows, its demand for produce expands. This is beneficial for farmers and reduces losses compared to farmers guessing, incorrectly, what buyers will want.

When product and packaging design is consistent, the brand stands out from others on a market shelf. Food processors must meet established regulations, sanitation standards, and labeling requirements. As many countries in Africa and around the world ban single use plastic packaging, food processors need to be designing alternative, more sustainable types of packaging.

A successful brand must manage its inventory, guaranteeing it can fill orders, and its cash flow so it can pay its suppliers and workers. It must preserve quality control. It must contain costs so the prices it charges customers covers expenses and nets

a profit. A successful brand plans for growth; often this requires a loan based on a business plan. Word of mouth is a great start for advertising, but eventually an expanding enterprise requires marketing materials and a sales department.

Quality brands can sell locally, regionally, nationally, or internationally. Each market has its own requirements and protocols, requiring specific knowledge.

The KBKrusha.com cooperative has created one of the most popular brands in post-war Kosovo. Their village, Krusha e Madhe, was the site of a 1999 massacre killing all the men in the village. When their widows returned, they needed to support themselves and their children. Led by one of their own, Fahrije Hoti, they created a small cooperative preparing traditional ajvar, pepper spread, and pickled foods. The women's foods became renowned; they sell within Kosovo and export out-of-country, now employing over 50 workers. KB Krusha sources agricultural produce locally. "With the collection and processing of vegetables we try to strengthen local production by helping the farmers to have a better and more reliable market."
—kbkrusha.com



How to reach the high-end market (every country has one) [\[bit.ly/2Ozn0rZ\]](http://bit.ly/2Ozn0rZ)



NPR: Pepper Co-Op Helps Kosovo's War Widows Reclaim Their Lives [\[n.pr/2NOIFLo\]](http://n.pr/2NOIFLo)



Brand Name or Generic? [\[bit.ly/2ph0Vi\]](http://bit.ly/2ph0Vi)



Value-Added Certifications: Organic and Fairtrade

Farmers participating in networks that train growers to meet specific standards add value from the beginning of the supply chain through the end by producing higher quality, more valuable crops.



There are **2.7 million** organic producers worldwide.

Top 3 Countries:

835,000 210,352 210,000

FiBL

The World of Organic Agriculture 2018.
FiBL & IFOAM - Organics International

In 2018, India, Uganda, and Mexico have the largest numbers of organic producers in the world, like the tea growers pictured here - Photo: IFOAM

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To participate in niche global market such as organic agriculture or the fairtrade movement, smallholder farmers must be trained in those agricultural methods and commercially integrated. This generally happens through farmer groups [Tool 87] working with larger initiatives; it is beyond the capacity of an individual smallholder farmer.

Organic agriculture focuses on high environmental stewardship standards. Fairtrade focuses on creating a transparent value chain guaranteeing farmers fair returns on their labor while accomplishing many other goals. Organic and fairtrade are similar certifications; a product might be both organic and fairtrade, or just one or the other. Recruiting and training farmer partners to achieve these higher standards provides opportunities for smallholder growers to earn more by growing premium products.

Demand for certified produce is not limited to far-off wealthy countries. It also is growing domestically—each country and region, typically in key areas such as a capital city, has high-end supermarkets, hotels, restaurant chefs, and local food enthusiasts (“foodies”) seeking safe, top-quality foods. Showcasing locally grown foods at farm-to-plate restaurants is a global trend.

Organic agriculture is certified at the national level. If the product is shipped abroad, it bears the country of origin’s label, not that of the destination.

While the global percentage of certified organic farmland

is small (around 1%), the number of Global South organic farmers is surprisingly large, due to the fact so many of them are smallholder growers. In 2017, [the top five countries \[bit.ly/2vI4EcO\]](http://bit.ly/2vI4EcO) by number of organic farmers were India, Ethiopia, Mexico, Uganda and the Philippines.

Third party certification is costly for smallholder farmers, with burdensome paperwork. More accessible verification mechanisms are being developed.

Organic principles, [as stated by IFOAM \[bit.ly/2METc86\]](http://bit.ly/2METc86), International Federation of Organic Agriculture Movements, the international organic umbrella, are:

Health—integrating soil, plant, animal, human, and planet wellness, avoiding the use of fertilizers, pesticides, animal drugs, and food additives that may have adverse health effects

Ecology—protecting and benefiting the common environment including landscapes, climate, habitats, biodiversity, air, and water

Care—Preserving indigenous knowledge and preventing significant risks by adopting appropriate technologies and rejecting unpredictable ones, while respecting scientific evidence

Fairness—Employing systems of production, distribution and trade that are open and equitable and account for real environmental and social costs

Fairtrade is a vertical integration system, providing oversight from farm through end-consumer. Working directly with farmer groups, fairtrade guarantees a minimum advance price for commodities. The largest fairtrade crops are cocoa, coffee, and bananas.

Fairtrade principles mandate that a portion of proceeds be returned to the farmers' community to invest as they choose. Farmers receive credit [Tool 95] as needed to provide for their needs until their crops are harvested; they also receive training. Child labor is prohibited and gender equity is championed.

Like organic certification, the fairtrade certifying process is tedious and costly for farmers. Some farmers adopt as many of the principles as they can and sell direct based on trust rather than formal verification; this is termed “ethical sourcing”.

Environmental standards are integrated into fairtrade. In both organic and fairtrade certifications best postharvest practices such as sanitation, grading, temperature management, and quality packaging are baked in. Thus, **organic and fairtrade farmers reduce postharvest losses by definition**, though this is not an explicitly stated intention in their values and promotional campaigns. Perhaps it will be in the future.

Organic/fairtrade protects agricultural workers' health by eliminating their exposure to pesticides. Some communities reinvest their dividends in co-op healthcare services.



Fairtrade Foundation (U.K.) [\[bit.ly/2MMFzDi\]](https://bit.ly/2MMFzDi)



GlobalGAP's International Found Safety Certification [\[bit.ly/2D3yi20\]](https://bit.ly/2D3yi20)



USA Organic Certification (an example) [\[bit.ly/2NOTRrr\]](https://bit.ly/2NOTRrr)



Washington State Dept of Agriculture: USDA's Steps to Organic Certification [\[bit.ly/2xekkVV\]](https://bit.ly/2xekkVV)

THE JOURNEY OF AN EQUAL EXCHANGE

BANANA

◀ HOW THE COUNTRY'S FAVORITE FRUIT GETS FROM FARM TO KITCHEN



GROWN ON SMALL FARMS IN
ECUADOR AND PERU



Available at stores and food co-ops across the U.S.

4 WEEKS AFTER HARVEST, **YELLOW BANANAS** are **READY TO GO HOME WITH YOU!**

ALL 1,000 CASES OF BANANAS ARE LOADED INTO A **RIPENING ROOM**



ECUADOR EL GUABO CO-OP

EXPORTED BY **FARMER COOPERATIVE**



PERU CEPIBO CO-OP

DELIVERED BY TRUCK to the **WAREHOUSE**

CONTAINERS LOADED WEEKLY with **1,000 CASES OF BANANAS**

TWO WEEK JOURNEY

EXPORT PORTS
Guayaquil, Ecuador
Paíta, Peru

IMPORT PORT
Philadelphia, PA
U.S.



CONTAINERS UNDERGO CUSTOMS AND AGRICULTURAL **EXAMS** AT THE PORT



LEARN MORE AT beyondthepeel.com

Equal Exchange's fairtrade banana value chain; more info at beyondthepeel.com - Photo: EqualExchange.com



Section 7

ICT

90. Extension Agents

91. Radio

92. Video/TV

93. Cellphone/texts and apps

94. Internet



Ruby Mehla and her husband Vinod Kumar receive regular updates on weather and climate smart practices through voice messages on their registered mobile phone in the Climate Smart Village of Anjanthalli, India - Photo: CCAFS/2014/ Prashanth Vishwanathan

INFORMATION AND COMMUNICATION TECHNOLOGY: INTRODUCTION



ICT, a Postharvest Loss Reduction Super Tool, stars throughout the postharvest value chain. From helping farmers determine the optimal time to harvest, accessing prices, checking best practices for food processing, ordering storage bags, managing transport, to getting paid, digital communications provide quick, cheap, and efficient information and services.

Smallholder farmers in sparsely populated, remote location, far beyond “**the last mile**”, are caught in multiple poverty traps. Goods and services do not flow to far-flung, low-income regions lacking roads, electricity, and a concentration of well-heeled customers. Along with low literacy, communities are cut off from

information and markets. The digital revolution is penetrating at varying speeds. In some places its arrival is very, very slow. Bringing rural people into the digital information age is imperative.

Ahead of ICT, agricultural extension agents [Tool 90] routinely visit these isolated locations, sharing important information and demonstrating improved techniques. Building and maintaining relationships with farmer groups and individual farmers, extensionists build a trusted network for disseminating information and introducing new ideas and tools. They teach farmers who can teach other farmers, expanding their reach.

Radio [Tool 91], old-fashioned and trustworthy ICT, reaches the remote rural areas lacking electricity and cellphone coverage. Hyper-localized programming in indigenous languages transcends limited literacy. Providing entertainment, useful public service messaging, and agricultural education helps farmers expand their yield and reduce their postharvest losses. Smallholder farmer families are frequently malnourished. Improving postharvest techniques not only puts money in farmers' pockets, it keeps food on their tables, addressing food insecurity with calories that would have disappeared as waste.

Moving up the ICT technology ladder, digitization paired with affordable mobile phones [Tool 93]—even the simplest kind—revolutionizes farming life. Texting, ordering supplies, comparing prices, and sending and receiving payments [Tool 96] are just some of the ways in which smallholder farmers armed with mobile phones can save time and make more informed choices. Not only do they allow for quick communication, they equalize some of the asymmetry that characterizes negotiations between farmers and middlemen that disadvantages growers.

Mobile phones are getting smarter. Phones that run apps or directly access the internet are increasingly common, even in low-resource regions. The prices of these features are dropping, and the technology itself is evolving, adding better methods of accomplishing digital tasks without internet connection. Mobile phones are effectively becoming handheld computers, performing tasks in seconds that previously took hours or even days. Networked farmers share information via WhatsApp [Tool 93] or social media like Facebook, bringing the world's information straight to the palms of their hands. For example, Cipotato.org runs a WhatsApp [bit.ly/2wcfBTq] group for marketing orange flesh sweet potatoes in Tanzania; anyone with an internet connection can also follow the sweet potato discussion using #OFSP, their hashtag on Twitter and Instagram.

ICT researchers analyze large data sets generated by those who never before had access to digital communications, to better design solutions and delivery

of services to the base of the pyramid. Of course, data can be used for harm, as well; safeguards are needed.

The line between radio, mobile phones, videos and TV is blurring. Once users decouple watching a live TV broadcast from seeing it on any screen at any time, everybody with inexpensive devices has access to an astonishing array of programming. Instructional videos [Tool 92] as well as edutainment productions can engage audiences while changing farmer behaviors and demonstrating skills for reducing losses. People listen to radio on cellphones and make “phone” calls through their computers. It's dizzying. A new generation of digitally literate natives will no doubt transform smallholder farming.

The planet's wisdom is now available on the worldwide internet [Tool 94] to anyone with a computer and Wi-Fi access. This entire book was researched without consulting a single printed book; all necessary resources were available digitally, through countless PDFs and pictures.

Students from all over the world can participate in free online classes in Postharvest Loss Reduction offered by The [Postharvest Education Foundation](http://PostharvestEducationFoundation.org) [bit.ly/2BlcEpj], [ADMI](http://ADMI.org) [bit.ly/200IZXr], and the [FAO](http://FAO.org) [bit.ly/2PIFWG3], accessing world-class instruction without leaving their villages.

The web is a source of content created by professionals as well as user-posted. I was able to better understand and describe some of the tools in this book by watching videos posted by farmers themselves demonstrating their techniques.

There is an enormous digital divide between Global North and Global South, but smallholder farmers are already reaping benefits from even limited ICT access. There is also a gender divide; men are the Global South gatekeepers of technology, and mobile phones and computers are no exception.

We are just at the early stages of harnessing ICT tools to reduce postharvest losses. They will enhance food security, raise farmers' incomes, expand available food, and help combat climate change.



Extension agents can educate farmers all along the value chain. Postharvest Specialist Agricultural Extension Agent Odette Ngulu demonstrates cooking with QPM, high-protein fortified maize [Tool 55] in the Morogoro, Tanzania, region - Photo: Courtesy of Odette Ngulu - PEF Graduate, Tanzania, 2012

Agricultural Extension Agents

Millions of Agricultural Extension Agents train farmers in improved methods, helping growers increase yields and income. Training agents in postharvest technologies expands these impacts further.



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Agricultural Extension Agents (also known as development agents, rural advisors, or farm advisors) are a vital link in information dissemination, connecting farmers to educational resources and techniques. Extensionists generally serve large areas with limited budgets and resources. Not all smallholder farmers have equal access to their services. Distance and gender are two limiting factors; expanding agents' reach via ICT multiplies their impact, as do the farmers they train who then teach other farmers.

Most Agricultural Extension Agents are employed by national governments, typically based at agricultural ministries or universities. The extension or rural advisory services of many countries is based on the model provided by the USA Land Grant system of research and extension, with resources shared by federal, state and local extension offices. Extensionists at the local level travel directly to farmers, connecting research to practice. They both share and gather knowledge. In developing countries, donor NGOs or intergovernmental organizations often fund a portion of these budgets, as national level support for these services has—unfortunately—declined over the past few decades.

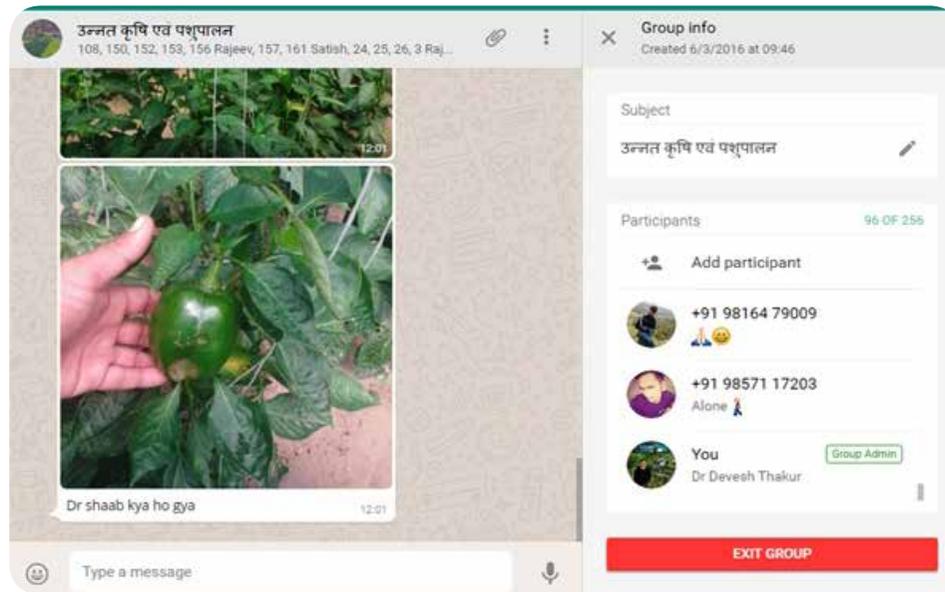
Agricultural agents are responsible for large swaths of rural areas with few roads. Only a portion of their clients have mobile phones and while some read, many are illiterate. But most have radios [Tool 91], a resource to deploy.

“One extension officer visits a community once in every fortnight, every two weeks, and the visit cannot last the whole day. So, in a community of over 200 farmers, how can one man visit them at once, all their fields?”

—Alhassan Dramani, extension officer for the Ministry of Food and Agriculture (MoFA) in the Savelugu district of Ghana's Northern Region

Partnering with Farm Radio International, Alhassan is a regular visitor on [a weekly show \[bit.ly/2KQxdcO\]](http://bit.ly/2KQxdcO) broadcast by MIGHT FM to six districts, hugely multiplying his impact beyond his single assigned district. His explanations about cowpea cultivation and marketing are loud and clear, reaching listeners. Reaching them just when it is time to implement his instructions, he teaches them for a fraction of the cost of agents making personal visits.

WhatsApp, a popular worldwide cross-platform (web and mobile) service, offers free texting and photo sharing. WhatsApp groups are a cheap, effective tool for local farmers. As part of his doctoral dissertation research, Dr. Devesh Thakur researched WhatsApp Farmer Groups by creating a group [\[bit.ly/20A1m2ij\]](http://bit.ly/20A1m2ij) in Himachal Pradesh, India. Its mountainous high altitude makes it difficult for extension agents to reach.



Screenshot of Dr. Devesh Thakur's WhatsApp Farmer Group in Himachal Pradesh, India - Photo: Dr. Devesh Thakur

Farmers participated enthusiastically, bridging their isolation. Experts answer an array of questions. Thakur concludes:

WhatsApp ([Telegram.org](https://www.telegram.org) is a similar service) is an easy and cost-effective way to establish and maintain linkages with smartphone farmer clientele.... As an extensionist, it helps build trust and credibility among the farmers. Overall, it is a wonderful tool to promote and support networking, encouragement and enthusiasm among the farmers. Extension-based organizations should encourage and support this innovative outreach tool.

Postharvest.org observed that agricultural agents generally lack training in postharvest skills. To fill that gap, in 2012 they launched an [online](https://bit.ly/2P7OIlV) training program [bit.ly/2P7OIlV] and a free training manual for extensionists working at the national, state or district level, providing postharvest information, tools, training resources, networks, and mentoring. About half of their 160 graduates are women, spanning 30 countries, and offering “training the trainer” postharvest extension programs in their home countries. They are reaching deeply into farming communities, marketplaces, and village level processing operations. Sharing ideas and demonstrating cost effective methods for improving food handling, preservation, storage and marketing, their impact is vital.

Extensionists sharing postharvest expertise are one of the most powerful “tools” that exists for reducing postharvest losses!



G-FRAS.org Global Forum on Rural and Advisory Services [\[bit.ly/2GeL5wV\]](https://bit.ly/2GeL5wV)



GFRAS Training Directory [\[bit.ly/2lhQhUv\]](https://bit.ly/2lhQhUv)



US Land Grant System (links to USA extension services in every state) [\[bit.ly/2CWttGS\]](https://bit.ly/2CWttGS)



PlantWise PowerPoint: Promising Innovative Extension Approaches for Climate-Smart Agriculture [\[bit.ly/2PKGkOT\]](https://bit.ly/2PKGkOT)



Women gather to listen to the radio in Andarapa, Andahuaylas, Peru - ©IFAD/Pablo Corral Vega

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Information access in remote regions is hampered by low literacy, scarce electricity, and a lack of connection to communication networks. Radio has helped bridge that gap for several generations. Shortwave radio can reach listeners in hyper-local settings, in their local language. Entertainment, news, sports, and music provide company on long, dark nights.

While digital communications, especially via mobile phones [Tool 93], now link formerly isolated farmers to the larger world, there are still many communities lacking cellphone reception. Residents of the high altitudes of Peru's Altiplano rely on radio to communicate, as is also true in many other regions. If a local radio station has internet connectivity, it can access programming from all over the world. Much is not suited for local audiences due to language barriers, but access to this vast quantity of programming raises production quality. As popular as text messages (SMS) are, non-readers cannot decipher them; radio speaks to them directly.

Radios come in a wide variety of forms. Farming families and friends still gather round the large radios like the one pictured above. Increasingly mobile phones include radios, and radio shows can be accessed from the internet. [LifeLine Energy](http://bit.ly/2nAjOXZ) [bit.ly/2nAjOXZ] distributes battery-operated multi-function radios designed for large-group listening.

Canadian-based [Farm Radio International](http://farmradio.fm) [farmradio.fm] produces programming for hundreds of African affiliates by providing them with scripts. These are translated into the area's spoken language and the local staff inserts examples their

Radio

Radio beams programming to the earth's most remote regions, far beyond mobile phone reception. It informs, entertains, and educates farmers. Now integrated with digital ICT, its impact has grown.



listeners will understand. One script highlighted the [ZECC, zero energy cool chambers](#) [Tool 71], describing how to construct them and the benefits they provide. They publish farm news stories, including many about postharvest tools, weekly in [BarzaWire](http://wire.farmradio.fm/en) [wire.farmradio.fm/en]. Their materials are available electronically to broadcasters and to rural development organizations in Africa, Asia, and Latin America.

In traditional patriarchal rural communities, women are often socially isolated, with little access to information beyond their home or village. Programming aimed at female farmers fills this gap; these programs are scheduled at times when women are more likely to be available. Programming targeted to women's groups [Tool 87] turn dissemination of information into a gendered social activity.

Male and female listeners both find soap operas engaging. "Edutainment" delivers useful facts as well as modeling behavioral change while people laugh and cry at the story line. Millions of listeners follow the same series, sharing their opinions and absorbing new ideas, multiplying their impact.

'[Beans, a family affair](http://bit.ly/2MIGlwk)' [bit.ly/2MIGlwk] is a new five-part radio drama covering gender equity issues in common bean production. It has been written in an effort to bring women's issues to light while providing farmers with valuable information for growing and marketing various legumes, including common beans.

—[Farm Radio International](http://bit.ly/2KPrqEk) [bit.ly/2KPrqEk]

Digitally-enabled audiences are a new frontier for local radio, engaging listeners in interactive programming. Participants can vote by text, call in and ask questions, and share information. Creative hosts can structure and moderate lively discussions.

Radio Marketplace, one of FRI's regular programs, teaches farmers about value chains for their yields. That's how orange-flesh sweet potato (OFSP) farmer [Linet Nalugo Musana](https://www.linkedin.com/in/linet-nalugo-musana) [bit.ly/2KSwFTD] found a higher-paying, regular customer for her crops—she learned about the buyer listening to the show, followed up with him, and cut a deal.



Listening to a Freeplay Encore solar-powered radio in Tanzania - Photo: Simon Scott/Farm Radio International



G-FRAS: Using Radio in Agricultural Extension - [bit.ly/2luMwu2]



AgriLinks: The Role of Radio in Agricultural Extension and Advisory Services - Experiences and Lessons from Farm Radio Programming in Malawi [bit.ly/2NnFzyH]



USAID Toolkit: Interactive Radio for Agricultural Development Projects [bit.ly/2P2XQ1J]



Kenyan celebrities Tony Njuguna and Naomi Kamau hosting a Shamba Shape-Up episode on a mango and livestock farm in Ukambani, Kenya - Photo: Susan MacMillan/International Livestock Research Institute

Video/TV for Agricultural Education

From high production TV to amateur videos, images moving on a screen tell a story compelling to all. Delivering information and entertainment together—infotainment—packs a punch.



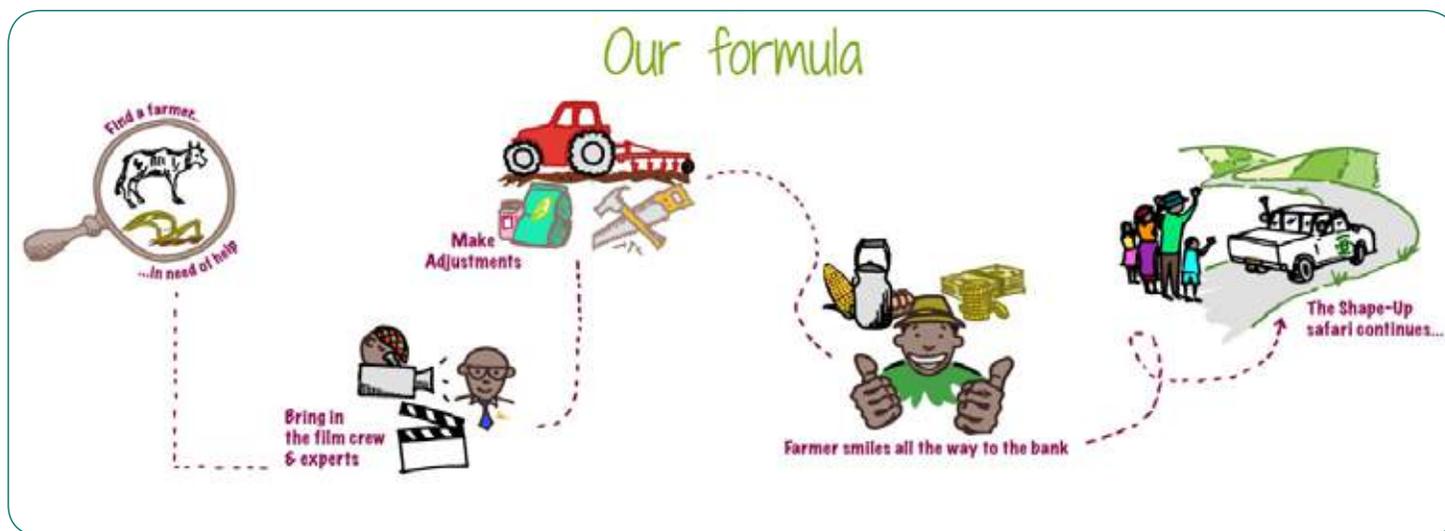
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Video has merged with television; in most cases live television shows can be viewed later with a Wi-Fi or internet connection. Engaging farmer and stakeholder viewers from across the value chain can introduce innovations and best practices. Until recently, smallholder farmers did not see themselves portrayed in typical TV shows, nor did they have much access to TV due to a lack of electricity and reception limitations. This is changing.

TV has long been aspirational for rural smallholders. A restaurant or bar with a TV connection can count on it to draw

patrons. Distributed solar pay-as-you-go streaming TV services like Kenya's Azuri's [bit.ly/2P3GO3j] are increasingly affordable and do not require grid access. Likewise, anyone with a smartphone or tablet can watch videos. If a user has intermittent access to the internet, videos can be downloaded for future use.

[Shamba Shape-Up](http://shambashapeup.com) [shambashapeup.com], a popular East African TV show, provides entertaining makeovers for smallholder farmers. Visiting working farms, the hosts learn about the farmers' challenges and invite experts along to provide solutions. Produced in Kenya and funded by the Rockefeller



Shamba Shape-Up's formula for programming - Photo: www.shambashapeup.com

Storing Potatoes

The market price of potatoes changes over the year. Do not sell when the market is bad. Store your potatoes well and wait for the market to get better. You will get more money for the same potatoes.

Form a group with your neighbours to sell to large potato buyers. It is easier to sell 1000 bags than 100 bags. You will get a bigger profit.

Store potatoes in a Charcoal Store

Build a big charcoal store with your neighbours. Store your potato crop for up to 3-4 months.



The open walls are made of mesh wire packed with charcoal.



The charcoal is always kept wet by water from a tank. Water evaporates from the charcoal which takes heat from inside the store. The store is therefore kept very cold.



Inside the store is cold and dark – perfect for potatoes! Make sure the bags do not touch the walls.

Benefits of charcoal stores

- No electricity needed, just water.
- Can be used to store many different fruits and vegetables.
- They stop fruits and vegetables from drying out.
- Easy to build.
- If many farmers join together to build the store, it is not expensive.
- Cheap to maintain.

Shamba Shape-Up's free leaflet on an evaporative cooling charcoal potato store from Season 6, Episode 12

Foundation, a variety of NGOs, and private sector sponsors, the program's high production quality lands it squarely in mainstream programming. But make no mistake, agricultural education modules are artfully woven into the scripts. Viewers are invited to text questions or request free leaflets summarizing an episode's content. Data gathered from eight seasons demonstrate its positive impact.

Season Six, Episode 12 features a charcoal chamber [Tool 70] for storing potatoes on Avraham and Priscilla's farm. Host Tonny Njuguna makes a great show of freezing in the cold, dark

structure while interviewing Beatah Nzove from Technoserve. She explains the benefits of farmers forming a co-op [Tool 87] and aggregating their potato storage: selling in larger quantity means members can become "Price makers, not price takers."

YouTube, Vimeo, and UC Davis/ANR's video library website [bit.ly/20w9iS6] are rich agricultural educational resources for extensionists [Tool 90] and farmer groups [Tool 87], as well as individuals with the technology and skills to access them.

[SAWBO - Scientific Animations Without Borders](#)

produces content specifically for smallholder farmers; many tools in this book link to their clear, easily understood videos. The narration can be downloaded in numerous languages, greatly expanding their usefulness. For example, its video [\[bit.ly/2w6BdR7\]](https://bit.ly/2w6BdR7) on forming a microfinance savings club [Tool 95] is available in Chinese, Amharic (Ethiopia), Chinese, Bengali (India), Dangme (Ghana), English, French (DR Congo), Lingale (DR Congo), Lomwe (Mozambique) and Yoruba (Nigeria). Animations can be downloaded from a variety of SAWBO channels and used on computers, tablets, cell phones, TVs, and overhead projection systems.

Creating do-it-yourself videos requires more skill than one might imagine. However, how-to-do-it videos can be very effective teachers. Using local scenes and featuring familiar people engages watchers. Once a video is posted online, it becomes available to anyone in the world via search engines. It can be posted on social media like Instagram, Facebook, and Twitter as well, multiplying its reach. (This author is appreciative of the many practitioners who did just that, teaching me so much about the mechanics of reducing postharvest losses.)

Postharvest.org has a [white paper with links to 75 videos \[bit.ly/2nBdR1X\]](https://bit.ly/2nBdR1X).



USAID's Guide [\[bit.ly/2YW4Vpv\]](https://bit.ly/2YW4Vpv) - Photo: USAID



USAID Toolkit: Low-Cost Video for Agricultural Development Projects [\[bit.ly/2YW4Vpv\]](https://bit.ly/2YW4Vpv)



SAWBO-Animations: Scientific Animations without Borders www.sawbo-animations.org



Shamba Shape-Up: Postharvest Loss Prevention Episode [\[bit.ly/2ByZANk\]](https://bit.ly/2ByZANk)



SAWBO Jerry Can Bean Storage song [\[bit.ly/2LcV9fU\]](https://bit.ly/2LcV9fU)



Mobile Phones/Apps

Mobile phones have leapfrogged smallholder farmer families into the digital world. Affordable, fun, easy to use, and continually expanding in utility, cellphones have quickly become indispensable.



Dwomoh Kwasi Christopher receives a [Mergdata](http://mergdata.com) [mergdata.com] call at his cocoa farm in Kyekyewere, Assin South District, Ghana, to help him make decisions on the best time to harvest or dry his cocoa - Photo: King Baudouin African Development Prize

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The Global South base of the pyramid mobile phone revolution took many by surprise. The mobile sector is strictly commercial, with no stated humanitarian goal of connecting hundreds of millions of off-grid customers who had never before had landline phones. Several factors merged to create this phenomenon, once low-income populations' collective buying power was unleashed.

Entry level phones, also called feature phones (as opposed to internet-connected smartphones), use very little electricity, critical for customers with energy constraints. By definition, cellular phone transmission is wireless, making it instantly available to people for whom accessing the wired telephone grid was beyond imagination. Mobiles feature a built-in flashlight, hugely compelling for those using kerosene lamps and battery-powered torches for evening light.

Vendors have created a system whereby customers buy pre-loaded cards, as opposed to the monthly contracts common in wealthy countries. Selling minutes rather than monthly contracts make mobiles affordable to very low-income users. As

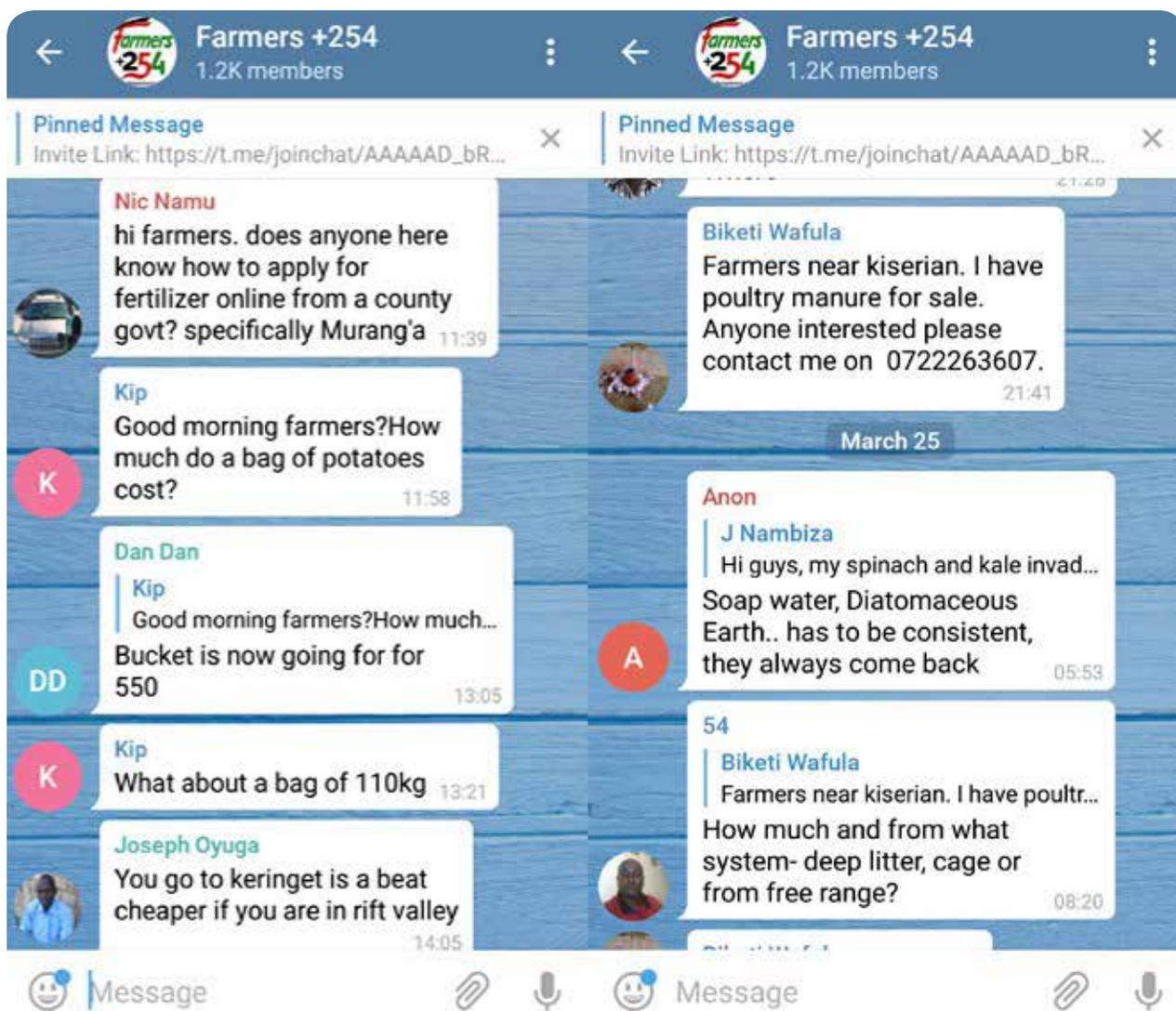
G-FRAS reports: Mobile telephony is a technology that has developed significantly in the past few years, and the subscription rate in developing countries has gone up from 22 per 100 inhabitants in 2005 to 91.8 per 100 inhabitants in 2015.

demand surges, prices drop further due to scale, technological advances, business innovation, and competition.

Mobile phones' attractive, user-friendly design has driven a quest for the literacy and numeracy required to send and receive SMS text messages, utilize the calculator function, make phone calls, and—let's be honest—playing games and following sports. A wide variety of streaming video is available, even for simpler phones, including SAWBO's [Tool 92] [educational videos](http://bit.ly/2MpkMa) [bit.ly/2MpkMa]. For non-electrified householders, mobile



An added benefit of co-op membership: mobiles belonging to members of the Basotho Poultry Farmers Association in Keramelle village charge at the new hatchery; the women from the association do not have electricity in their homes - ©IFAD/ Guy Stubbs 2013



Screenshot of a Farmer+254 Telegram Chatgroup in Kenya - Photo: FarmersTrend.co.ke

phone ownership has unleashed relentless demand for electricity, launching an entire industry of micro-enterprises to provide mobile charging. The desire for at-home charging is a driver for distributed solar-power.

Mobile money [Tool 96], sending and receiving money by text, can be accomplished via a basic feature phone, greatly expanding financial inclusion. Ag info texting services that provide weather advisories and more have been well-established for over a decade. Mobile communication is two-way, providing farmers with real-time prices. Armed with this vital information, growers can sell their harvests for the highest price, completing the transaction via mobile.

In addition to two-way communication, a host of apps facilitating group discussions provide a free platform for extensionists [Tool 90] to share information with large numbers of farmers simultaneously, and also for farmers to communicate directly with one another. Problem-solving, information exchange, and deal-making are now woven into mobile phone use.

Entry level feature phones remain very popular in the Global South. Energy-sipping and flexible, many of them include radios, increasing their utility. Newer phones have larger screens, often used for reading books. Cameras and video capability are increasingly wide-spread. The point when a phone morphs into a hand-held computer is hard to pin-point.

Mobile phones are an exciting tool in reducing postharvest losses. They speed the process of **connecting buyers and sellers** [bit.ly/2PnEB2v]. GPS could potentially cut crop-spoiling transit times. Apps that assist along the value chain can do everything from collecting sweet potato stats to locating the nearest PICS bag dealer. The data they generate allows researchers to identify macro-trends, expanding the knowledge base about smallholder farmers.

“If you don’t have a phone as a farmer, go sell a goat and buy yourself one,”

–Farmer participating at a World Bank Hack4Ag Hackathon, Uganda, 2016



G-FRAS: Mobile Phones for Agricultural Advisory Services [bit.ly/2v4lhyA]



GMED Project India Evaluation (phones for linking farmers to markets) [bit.ly/2NmaNWE]



M-Pesa Documentary [bit.ly/2xqdonP]



86-year-old Ki Surtpto, a traditional maker of gamelans, accesses the internet using a mobile phone with the help of his grandchildren in Sumogawe Village, Semarang district in Java, Indonesia - Photo: © 2013 Aji Styawan, Courtesy of Photoshare

Computers and the Internet

Computers' capacities—continually expanding even as costs decline—provide vital tools for extensionists, farmer associations, and agribusinesses. Internet connection accesses the worldwide web's wealth of resources.



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Computers' computational power combined with the myriad tasks they perform via software programs—word processing, spread sheets, data bases, design, and more—are so integrated into 21st Century life that we can lose track of how transformative they are.

Sacred Valley Health, an NGO based in Machu Picchu's foothills in Ollantaytambo, Peru, recently promoted Bertha, a field worker, to a bigger job at their city office. On her first day at her new job she was issued her own computer. Bertha burst into tears. It was beyond her wildest dreams that she, an indigenous Quechan woman from a remote Altiplano village, would ever have a computer.

There are many factors that limit access to computing; they correlate to the circumstances of rural people and include:

Literacy—Using a computer requires the ability to read instructions and type commands, numbers, and words.

Expense—Computer costs, including tablets and smartphones, have plummeted but remain beyond the buying power of smallholder households. Computers are typically available at an NGO, or in cities at internet cafés.

Energy Access—Desktop computers require plug-in power, though laptops can be charged off-site. Students' pre-loaded Readers are solar-charged at school.

Age/Technical Skill—Worldwide, a huge gap exists between elders and “digital natives”. Computers are challenging for older people to master, even those with high literacy skills.

Gender—Globally, women have far less opportunity to acquire computer skills than men. The gap is even larger in the Global South where women's literacy lags behind men's.

Language—Speakers of languages not among the top ten or so most web-prominent have less content on which to draw. Digital translation services help but are typically awkward and not up to the task of complex communication, plus they require high-speed access, lacking in rural locations.

Geography—In remote locations, there are unlikely to be computers for sale, or anyone who knows how to service them. In the NGO world, it's not uncommon to see abandoned computers donated with good intentions, unused and collecting dust due to these limitations.

Consequently, an older, female, off-grid, impoverished speaker of a minority language is very unlikely to have access to computing. That describes a huge number of the world's smallholder farmers, unfortunately.

For the rising generation of farmers, food processors, and other actors along the value chain, computing will become increasingly central to market activity. For those able to get online, many free services open up tremendous potential. As mobile phones morph into handheld tablets/computers, casual users will be able to leapfrog over dedicated desktops and laptops. This is already happening in India.

Cloud Storage allows data to be shared and stored safely; computers then require less storage, lowering their price. Social media provides entrée to the world economy, research, and discussion. I communicated with many farming and food processing initiatives included in this book directly through their Facebook pages.

Skype, Google Hangout, Zoom, and other services provide real-time face-to-face experience facilitating not just social contact but instruction. Postharvest.org features online training via internet and a free [training manual \[bit.ly/2OQoppM\]](http://bit.ly/2OQoppM). To attend class, participants sit at their computers around the world and interact via LinkedIn discussion groups.

Helping smallholder farmers cross the digital divide will unlock enormous potential, reducing postharvest losses, improving food security, and moving farmers up out of extreme poverty.



In Gaibanda, Bangladesh, Info Lady Mahfuza answers farmer Nojrul Islam's question about using fertilizer on his crops by showing him a video on her laptop - © 2013 GMB Akash, Courtesy of Photoshare



UC Davis Postharvest Library (in PDF format) [\[bit.ly/2pfGdzD\]](http://bit.ly/2pfGdzD)



FAO Postharvest Digital Compendium [\[bit.ly/2NRMyzh\]](http://bit.ly/2NRMyzh)



The Postharvest Education Foundation Digital Resources [\[bit.ly/2NNmOEh\]](http://bit.ly/2NNmOEh)



Section 8

FINANCIAL AND LEGAL

95. Credit/Lending/Saving

96. Mobile Money

97. Contract Farming

98. Land Titling

99. Border Crossing



Smallholder farmers attend a training event featuring equipment like this hand-cranked maize sheller, along with microcredit opportunities for purchasing, in Nyando, Kenya - Photo: V. Atakos (CCAFS)

FINANCIAL AND LEGAL TOOLS: INTRODUCTION



Speeding the crossing at the Kenya-Uganda border reduces crop losses - Photo: BorderlessWA/Facebook

This book is full of tools proven to reduce postharvest losses. Doing so adds income to farmers' pockets and continues producing returns all along the value chain. This virtuous cycle spins off many other benefits, too—improved food security, better health and quality of life, less waste of water and energy, and diminished global carbon loads. But systemic failures block the tools' implementation. While financial and legal interventions are not mechanical tools, when done right, they are important facilitators and catalysts in realizing the gains that can be achieved through reducing losses.

An old adage, “a stitch in time saves nine” is apt for postharvest loss reduction. Inexpensive interventions pay for themselves. A postharvest stitch can be anything from a locally fabricated harvest bag (literally stitched...) to a state-of-the-art storage facility. In some cases, tools can be made by anyone following instructions from readily available free or inexpensive materials. But most require at least modest outlays.

In many cases the implementation barrier is a lack of information; smallholder farmers or other actors in the value chain need knowledge and training about optimal postharvest practices. This book, and others

it draws from, especially Kitinoja and Kader's manual (2015 is the latest edition) serve to disseminate these tried-and-true procedures.

Access is an added challenge. Products that reduce postharvest losses must be available where and when they are needed. Investments in agricultural extension and local for-profit providers stocking such tools [Tool 100] will benefit everyone along the value chain. Both these businesses and their customers need capital to close the loop.

The lack of credit for launching initiatives is a major bottleneck. Farmers, especially hardscrabble smallholders, typically borrow at the beginning of the season for purchasing seeds and inputs. They are reluctant to add more debt to buy tools at harvest time. They are most flush after selling their harvest, but by then they have missed the opportunity to plan for and add processing or storage that would have generated larger profits. Devising credit schemes that address this risk aversion and timing challenge will speed adoption.

As demonstrated by data as well as by experiences, many small postharvest tool purchases pay for themselves as quickly as after a single use. Once paid

off, reusing the tools season after season adds value straight to the bottom line. Working backwards to ensure the money is available for that initial modest investment will vastly expand implementation. Few investments can match the [high returns of postharvest investments \[bit.ly/2xwYyMy\]](https://bit.ly/2xwYyMy).

Well-conceived infusions of government, non-profit, and private capital can unleash enormous value.

Legal policies can have the unintended consequence of exacerbating postharvest losses. Lack of property titles for smallholder farmers, discrimination against women in acquiring land titles, and red tape at borders all add to losses and can be remedied.

When farmers' groups negotiate a fair contract, everyone benefits. The buyer is assured a steady supply of product, and the growers can better plan how to allot their time and resources.

Aligned finance and laws can facilitate huge returns on investment in the postharvest sector. Slashing harvest losses can feed our hungry world, help smallholder farmers pull themselves up out of extreme poverty, and help mitigate climate change. It is an opportunity to triple our impacts in addressing these global challenges.



Village Savings and Lending (VSL) group members in Gwanda, Zimbabwe, collect monthly contributions to their groups. All deposits are made in public and recorded in the group's ledger book - © 2012 David Snyder, Courtesy of Photoshare

Capital: Savings, Credit, and Loans

Effectively providing capital to farmers and actors along the value chain speeds the adoption of loss reduction tools. Expanded microfinance offers smallholders comprehensive microfinancial services.



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Farmer cash flow is, by definition, irregular. It is a rare smallholder farmer with enough stashed aside for purchasing seed and inputs at planting season; few households have the resources to avoid immediate selling after harvest. Agricultural loans come from a variety of sources, but rarely from mainstream banks. Smallholder farmers generally lack credit histories (though this is changing in some places) or collateral. Credit is sometimes extended directly from seed sellers, although often at very high rates, sometimes up to 35%, or through farmer co-ops or credit unions.

Village Savings and Loans or informal savings circles are a significant source of lending in remote rural areas. Smallholder groups, typically women—who are additionally marginalized in accessing loans but good at saving—gather weekly. Each member contributes to the shared funds. They are disbursed to members with a modest interest charge which they pay back along with the principle. Over time this grows their assets.

Microfinance Institutions have been working with the unbanked poor for decades, but their focus on microenterprises is not tailored for farmers' needs.

- Farmers require financial products that offer flexibility. Due to the seasonal nature of farming, smallholder farmers experience irregular cash flow, and their investments provide a slower and less predictable return than other businesses.

- “The front-end effort required for delivering flexible repayment products is outweighed by the huge market opportunity of serving smallholder farmers. If lenders adjust the way they manage credit risk, portfolio quality, and liquidity risk and deploy proper IT and staff development, they can realize significant ROI and significant impact.” —[One Acre Fund \[bit.ly/2RABogP\]](#)

NGOs, IGOs (intergovernmental organizations), governments, foundations, private sector businesses, and social enterprises partner in a variety of ways to expand farmer and SME access to capital. Loan guarantees can leverage more money on the ground. Individuals can loan farmers money, too; Kiva raises funds at no interest that are re-lent to MFIs which in turn offer credit at a lower interest rate to their agricultural clients.

SMEs, small to medium enterprises, generally require larger loans than individual smallholders. Often a microentrepreneur succeeds in growing a business with a succession of ever larger microloans and can then leverage that record to secure more conventional sources of capital.

Most businesses offer credit to established customers, essentially a short-term loan, with little or no interest for the first few weeks. This float helps their clients manage cash flow.

A PICS hermetic bags [Tool 58] sales superstar is succeeding in just this way.

In 2015 [Georgina Pius Mbawala \[bit.ly/2Plk1jv-p. 4\]](http://bit.ly/2Plk1jv-p.4) was so impressed by her first two PICS bags that she used savings to purchase 200. She worked very hard demonstrating this new tool to skeptical fellow-farmers, managing to sell all her merchandise. Next year, she and her husband used the proceeds from their crops plus savings to purchase 2000 bags from PPTL, the Tanzanian PICS manufacturer. She sold those all, too, plus an additional 3600. PPTL could see she got results and helped finance her next purchase of 5000, also paying for radio advertising. She sold a total of 24,000 bags that year. This year she has obtained financing to purchase a 10,000 lot—bulk discounts are an entrepreneur’s best friend. Her goal was to sell 40,000 PICS bags in 2018.

Storing grains, when reliable postharvest storage is available, is another form of saving. Instead of selling harvests for cash when the harvest time prices are low, storing and releasing

product later raises crop value. **Warrantage [inventory credit \[bit.ly/2w5OHfQ\]](http://bit.ly/2w5OHfQ)**—is a system of lending through smallholder farmer associations [Tool 87] using members’ stored grains as collateral. Selling later in the season improves farmer income and decreases postharvest losses. After deducting the cost of the storage and interest, farmers still come out ahead and receive an infusion of capital to finance value addition or other income generating activities while their crops are in storage.

Blockchain technology, a burgeoning financial technology, offers opportunities for smart contracts (agreed upon terms that are embedded directly into digital code), and tracing money and goods as they change hands. An innovative pilot is using blockchain with agricultural co-ops to record their contract payments. Blockchain’s ability to generate reliable records that can become members’ credit histories could replace a co-op’s internal financial record keeping, often recorded in unverifiable paper notebooks.



Kiva: Direct Microloans for Farmers and Agricultural Coops [\[bit.ly/2xmreaT\]](http://bit.ly/2xmreaT)



Guide for Smallholder Farmers: Saving, Accessing Credit, and Effectively Managing Money for Improved Livelihoods [\[bit.ly/2Mllywv\]](http://bit.ly/2Mllywv)



GrameenFoundation.org



Rockefeller Foundation Initiative: Reducing Global Food Waste and Spoilage (includes information about expanding credit access) [\[bit.ly/2xIFckh\]](http://bit.ly/2xIFckh)



SAWBO Animations: Microfinance 1 - Starting a Savings Group [\[bit.ly/2xnIPjm\]](http://bit.ly/2xnIPjm)



Kenya's M-Pesa pioneered mobile money; over 20 million Kenyans use this service.

Mobile Money

Mobile Money makes banking accessible to anyone with a cellphone, decoupling geography from financial services. It brings previously unbanked smallholders into the formal financial sector.



96 Mobile money, sending and receiving digital payments via mobile phone, has transformed life for the world's poor who live in regions where it is available. Base of the pyramid populations typically operate in an informal cash economy. Reaching the unbanked facilitates financial inclusion.

Though its success in reaching the poor is being widely researched and new development programs are continually being deployed, mobile money is strictly a for-profit enterprise. Digital money can be sent cheaply, in any quantity. Once mobile phones [Tool 93] became available to low-income populations, mobile money enabled them to become customers. It is possible to send money via SMS/text on a feature phone, though more sophisticated apps are proliferating as users upgrade to smartphones.

Mobile money has not taken off as quickly in the industrialized world where older systems for payments are well-established, though some readers may be familiar with sending money to family and friends via Paypal and Venmo. Europe is moving more quickly towards digital money transfer, while the USA has been slow to adopt digital payment systems. Kenya's MPesa has been the global pioneer in mobile money.

MPesa financial transactions are accomplished by the sender texting an instruction, amount, and the recipient's account number. The receiver keeps the money in her digital savings account or withdraws it as cash from the nearest mobile money kiosk, of which there are thousands. The servicer and kiosk vendor each charge small fees. A mobile money account effectively combines a checking account with a savings account. Options for interest bearing savings accounts are also available.

Mobile money provides secure transactions, in contrast to carrying around vulnerable cash. It saves immense amounts of time. With barely existent transportation, no viable mail service, and few rural banks, simply making a deposit, sending cash, or paying fees or bills is a major undertaking for smallholder farmers and other value chain actors. Pressing a few buttons to send or receive payments means that time saved can now be redeployed for more productive pursuits. Women carrying cash are at extra risk, which is eliminated by mobile deposits and withdrawals.

Mobile money facilitates savings. For those who saved informally and were subject to the constant demands and temptations of daily life, including friends and family needing money, their nest-egg is safely stashed off-site. It is more corruption-proof, as well. Payments go where designated, and there are transaction records.

Mobile money account holders establish a [formal ID \[bit.ly/2nS7BTS\]](https://bit.ly/2nS7BTS) and a credit history, requirements for securing conventional loans. Sending digital payments lowers transaction costs for loan payments. Microfinance institutions, many of which are evolving into providers of full-service microfinancial product offerings for the poor, pass on some of those savings in lowered interest rates.

The mobile industry is highly competitive. Customers can take advantage of specials and premiums, customer loyalty rewards for purchasing cellphone minutes. One common benefit is insurance—life, health, disability, and maternity. The more cellphone minutes a customer purchases from the same carrier,

the more insurance they receive. These help people recover from financial shocks that destabilize low-income households.

Developing postharvest crop insurance for stored harvests (which is not currently available anywhere that we have heard of) would help build trust in long-term storage investments.

Mobile money payment is now integrated **with utility providers** [bit.ly/2N1lbz1], a model spreading throughout the Global South. Customers pay a small amount per week for a rooftop solar panel system to generate electricity. Each payment pays for part of the overall cost, and within a year or two, they own the system outright. These installment plans are a form of credit.

Electrifying smallholder farms will speed uptake of post-harvest tools such as ventilation fans, grain dryers, processing equipment, and the Holy Grail: cold chain technologies. As solar access expands, so will the manufacture of equipment that can be powered by these systems. Keeping their functions very simple and not adding any unnecessary gizmos, a trend called frugal engineering, will increase energy efficiency, expand energy access, and promote uptake.



Feature phones still get the job done—M-Pesa is the pioneer of the mobile money sector



GSMA: Accelerating the Mobile Money Ecosystem for the Underserved [bit.ly/2xrPjgp]



M-Pesa's 10th Anniversary Success Story - cnn.it/2xwDIlw



MTN Rwanda [bit.ly/2xtCSAS]



Brookings Institution: Mobile Money in Developing Economics [bit.ly/2D9bb6f]



Contract farmers show off a bumper crop of chilies in Gabbur, Raichur district, Karnataka, India (though they ought to swap out those baskets for Reusable Plastic Crates...) - Photo: Asian Development Bank

Contract Farming

Well-defined, mutually-beneficial contracts between buyers and farmers reduce postharvest losses by eliminating bad guesses about what to grow and improving postharvest handling methods.



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Contract farming (also known as an outgrower schemes) has been growing over several decades. When contracts clearly spell out each side's obligations it offers benefits to both buyers and farmers. Building trust, based on fair, reasonable, mutually respectful terms, allows the contractor/farmer or contractor/farmer association [Tool 87] relationship to deepen over time. This results in greater marketable yields, increasing profits and supply for the buyer, and more income for farmers. Decreasing postharvest losses effectively expands those benefits further.

Each contract is different, making it difficult to generalize. Contracts tend to be for high value commodities produced for exports or crops used for food processing.

Smallholder farmers typically decide what to grow based on past experience and personal preference. If they guess wrong, they can end up with too much of one crop and not enough of another, lowering their income. They are disinclined to experiment much, given the potential risk. Contracting to sell a specific product to a buyer for an agreed upon price allows farmers to access global markets, reduce risk, and focus their energies on maximizing production. They don't need to gamble about what to grow, nor do they need to negotiate harvest time sales, a high-stakes stresser for smallholders.

Contractors provide private extension [Tool 90] services for farmer education. While they focus on the contracted crop,

company representatives do introduce farmers to improved techniques that decrease waste. They demonstrate planning tools, ICT, and record keeping, skills that can also expand marketable yields in the farmers' individual plots where they grow their own food.

Buyers can underwrite the construction of packinghouses or purchase of machinery if needed. They research and supply or recommend optimal packaging [Tool 32]. This reduces waste, as well.

One common cause of postharvest losses is, paradoxically, a bountiful harvest. When farmers in the same region bring their crops to market simultaneously, the oversupply causes prices to drop. The surplus of the now less valuable crop can go to waste. An agreed upon price means when contract farmers produce crops that suffer local market price drops, they will still receive the agreed upon price. While contracts usually have a cap in volume, a good contract allows the farmer to keep or sell overage.

The buyer arranges transportation; it is specified in the contract. Harvests are moved as quickly as possible from the farm, using appropriate conveyances, directly to appropriate packinghouses, storage facilities or processors. Quick transport, planned in advance, reduces losses.

There are concerns about contract farming, including unfair contracts and corruption. Farmers have been known to

use the inputs purchased with buyer credit for other crops. But there are many examples of long-term, win-win contract farming relationships.

Monocropping is harmful for eco-systems and exposes farmers to greater risk from crop failure if they haven't diversified their planting. Cash contract crops can be intercropped with staples, adding diversity as well as providing food supply for the farmer and her family.

Organic and fairtrade certified buyers [Tool 89], contractors by definition, integrate social benefits and eco-standards into their value chain. Conventional buyers sometimes offer incentives and bonuses for timely loan repayment, and other

benefits like providing insurance to their contract farmers or paying growers' children's school fees up front. Deducted from final net, these are functionally loans.

Gender dynamics are sensitive in contract farming. Patriarchal norms dictate that men are the signers of contracts, but often it is the women growing the deliverables. When women sign contracts, it is empowering, but that can destabilize communities if it is not well-managed. Including men in any informational events and training workshops offered for women can help to reduce the stress on the family. Inviting a few key men in the village to witness that nothing objectionable is going on helps keep communal peace.



FAO Contract Farming Resource Center [\[bit.ly/2QFIW1N\]](https://bit.ly/2QFIW1N)



GIZ Denmark's Contract Farming Handbook (116 pages) [\[bit.ly/2BUKfVr\]](https://bit.ly/2BUKfVr)



Next Billion: Outgrower Schemes - A Pathway to Sustainable Agriculture [\[bit.ly/2D76I9A\]](https://bit.ly/2D76I9A)



Alberta Agriculture and Forestry Animated Guide for Farmers: What About Contracts?
[\[bit.ly/2UXRLpt\]](https://bit.ly/2UXRLpt)



Tesfar Kasin and her husband Mulgeta Amas show their land certificate for their 0.75 ha [1.85 acres] landholding. Tesfar's name on the certificate acknowledges her as joint owner with inheritance rights for their plot in the Lake Tana, Ethiopia, region - ©IFAD/Wairimu Mburathi

Land Titling, Certificates, Deeds, and Tenure

The global movement to secure land certification for smallholder farmers boosts their investments in their farmlands. Deeds are required for credit, facilitating improvements.



98

Hundreds of millions of smallholder farmers lack proof of ownership for their land. The journey from agrarian, tribally run, pre-literate communities to contemporary land-titling via aerial mapping and digital records has left many with undocumented holdings. Without a deed, title, or certificate or proof of tenure to their lands, smallholders are vulnerable to land grabs and disputes. Women in patriarchal societies subject to tribal rules are further marginalized by a lack of inheritance rights.

The global focus by governments, NGOs, and intergovernmental organizations to help indigenous peoples and general smallholders gain title to their land generates many benefits. While reducing postharvest losses is not the goal of these initiatives, secure land rights set the stage for a variety of smallholder investments and improvements that contribute to crop loss reductions and food security.

Smallholders without land title struggle to access credit or loans [Tool 95]. With land titles, they can use their property as collateral for loans. These may be for seeds and inputs, but also for financing home or storage improvements and purchasing productive assets like livestock.

Without land tenure, low-income farmers are unwilling to risk time or capital (which would be hard to access, without a deed) on long-term improvements. Why keep careful records for future planning [Tool 1] without assurance of being allowed

to plant the next season? Who would build a proper onion storage shed [Tool 65] knowing she may be thrown off her property? What sense would an investment in reusable plastic crates [Tool 12] make if a farmer doesn't have confidence in being able to farm his plot in future seasons?

Hence, a deed not only paves the way for loans and credit, but also for thinking, planning, and working for the future. Many of the tools in this book require sweat equity plus inexpensive, readily available local materials. In many cases they pay



Yenithe Amare, an administrator for the Ethiopian Environmental Protection and Land Administration Bureau, at his desk holding the land registry for Dangila Este District. Working with Kebele (village) land committees, he is able to refine data in the lands registry and resolve disputes over land transfer and inheritance - ©IFAD/Wairimu Mburathi

off in one season, generating free benefits moving forward, but these are not sensible for untitled farmers. They miss out on these opportunities to improve their lives.

Nothing requires a faith-in-the-future mindset more than planting orchards. In a much-loved folktale, Honi the Circlemaker, an old man, is mocked by his village for planting slow-growing carob tree seedlings. “Honi, how foolish! You will never eat their fruits, Old Man.” His reply, “Just as my ancestors planted for me, so I plant for my children”, captures the wisdom of thinking of the long game.

Trees have multiple benefits, but one doesn’t harvest them for many seasons. Once planted, a tree grows on its own, yielding more fruit every year. Missing out on a food and income source that doesn’t require annual loans for seeds and inputs and reduces soil erosion is a serious disadvantage remedied by a land title.

Other benefits, including greater access to government services such as agricultural extensionists [Tool 90], become available to titled landowners.



FAO: Land Tenure and Rural Development [\[bit.ly/2PniOC0\]](https://bit.ly/2PniOC0)



Landesa Rural Development Institute - www.Landesa.org



FAO Gender and Land Rights Portal [\[bit.ly/2NTJZg1\]](https://bit.ly/2NTJZg1)



USAID's Mobile Application to Secure Tenure (MAST) [\[bit.ly/2xsJdws\]](https://bit.ly/2xsJdws)



Waiting at a border crossing back-up takes patience - Photo: Asian Development Bank

Border Crossings

Back-ups at border crossings due to inefficiencies, red tape, corruption, and non-tariff barriers impede the flow of goods. Streamlining crossings decreases postharvest losses resulting from delays.



99

Africa is home to 1.2 billion people living in 55 countries, each with its own regulations and systems. African highway infrastructure is inadequate and the continent has very few railroads. The flow of goods is slowed by these transportation limitations, and further impeded by border crossing hassles.

Once a truckload of export produce is on its way, time is of the essence. Haulers' loads of fruits and vegetables degrade or spoil while stuck waiting in the hot sun at border crossings. These losses hurt everyone along the value chain as well as diminishing the global supply of high-quality food.

A variety of [non-tariff barriers \[bit.ly/2vWIBQR\]](https://bit.ly/2vWIBQR) slow the flow of goods, such as regulatory paperwork, licenses, inspections, and quotas. Countries create free-trade alliances to synchronize their regulations, encouraging and easing trade and benefiting all partners.

The African Free Trade Zone, a solution to these problems, is in the process of forming, eliminating tariffs. Ghana and Kenya are the first countries to ratify the treaty which 44 countries have agreed to; it will go into effect after 22 countries ratify the treaty. The vision is a Pan-African union where import-export is streamlined. Among the many social and economic benefits will be a reduction in postharvest losses. As African countries' standards of living increase, the African market will be increasingly robust. Intra-African trading benefits both the exporting and importing country.

Similar networks are being developed in Asia to expedite trade. Eleven countries have joined to create [CAREC \[carecprogram.org\]](https://carecprogram.org), the Central Asia Regional Economic Cooperation Program. Their motto— “Good Neighbors, Good Partners, Good Prospects”—sums up the win-win of streamlining BCPs, border crossing points.

While bribes and corruption are extremely difficult to eradicate, and [informal cross-border female vegetable traders \[bit.ly/2zJ29Zs\]](https://bit.ly/2zJ29Zs) are subject to additional abuse and harassment, there are new on-the-ground initiatives addressing border crossing delays. Anything that reduces delays also reduces losses.

[CHEETAH \[cheetah.ujuizi.com\]](https://cheetah.ujuizi.com), an acronym for Chains of Human Intelligence; towards Efficiency and Equity in Agro-Food Trade along the trans-Africa Highway, aggregates information shared by fed-up Ghanaians. Drivers report road-blocks, estimated times, and even the types of bribes expected. ([I Paid a Bribe \[ipaidabribe.com\]](https://ipaidabribe.com) is a different initiative.)

Ironically, it is common for exporters to air-freight produce rather than utilizing trucks to deliver to neighboring countries. While costlier on the face of it, safe arrival by air is more secure.



Screenshot of CHEETAH founder Valentijn Venus explaining its use - Photo: [CHEETAH.com/University of Twente](https://CHEETAH.com/University%20of%20Twente), vimeo.com/92588868

Says founder Valentijn Venus, “The overriding objective is to assess whether CHEETAH can inform effective postharvest management decisions and policies by crowd-sourcing postharvest intelligence in the form of spatially explicit human interactions and infrastructural status.” Data collected on the app will document postharvest losses to improve value chain efficiency.

BorderlessWA.com, in partnership with USAID, runs six West African country [Border Information Centers \[bit.ly/2PpiUPY\]](https://Border%20Information%20Centers%20BICs) to cut through red tape. BICs have reduced clearance times at borders where they operate by 27%, resulting in reduced postharvest losses.



Borderless Alliance WA/West Africa [\[bit.ly/2NQQiRy\]](https://bit.ly/2NQQiRy)



CHEETAH's Crowd-Sourced App for Reducing Road Delays [\[bit.ly/2NSTVX1\]](https://bit.ly/2NSTVX1)



How CHEETAH Works - vimeo.com/92588868



Tool 100

POSTHARVEST RESOURCE CENTERS: BRINGING IT ALL TOGETHER

We feature 99+ effective tools to reduce postharvest losses. Demonstrating and marketing these tools together at the local level greatly boosts their impact, expanding income and food supply.



100

Many of the 99 tools presented in this volume include data proving their effectiveness at reducing losses and raising income. But what if farmers, processors, and marketers utilize multiple tools? Quantifying the impacts of several variables is difficult, but the synergy created by multiple tools has greater impact than the quantity of products saved through each individual loss reduction tool. **The whole of postharvest loss reductions is greater than the sum of its parts.**

One of the biggest challenges of the postharvest loss reduction sector is deploying the tools where and when they are needed. Demand for the tools must be matched by supply; Amazon doesn't offer next day delivery to the middle of the actual Amazon.

Some of the tools can be fashioned by users, such as building trellises [Tool 3], making sizing rings [Tool 30], or transforming used grain storage bags into sunshades [bit.ly/2P58Vih]. Others are behavioral, like presorting crops or upgrading sanitation procedures. Many, however, are hand-held, manufactured tools that save time and/or add value to the harvest along the value chain. How can these be made readily available to potential users?

Dozens of Postharvest Resource Centers—part training venue, part “hardware” store, and part skill-sharing hub—are

already up and running. Larger, non-portable tools like the ZECC [Tool 71] are built on-site for direct observation and learning. Nothing is as effective as seeing and touching the genuine article. Most of these centers have been designed and/or



Farmers inspect a demo ZECC [Tool 71], zero energy cold chamber, at the Postharvest Training and Services Center in Arusha, Tanzania - photo: ARVDC

A Sampling of the 25 Postharvest Resource Centers Open as of 2018:

Arusha, Tanzania (World Vegetable Center)

Njiro, Tanzania (**Selian Agricultural Research Center** [bit.ly/2L8LNMS] -SARI)

Lushoto, Tanzania (Ministry of Agriculture and Food Security)

Njombe, Tanzania (Tanzania Horticulture Association–TAHA has three centers in Morogoro, Njombe, and Bajamojo, near Dar es Salaam.)

Zanzibar, Tanzania (**TAHA**, [bit.ly/2N3cgx2] Finnish Gardening Association)

Mulindi, Kigali, **Rwanda** [bit.ly/2PsFRSi] (National Agricultural Exports Board - NAEB)

Bushogo, Rwanda (University of Rwanda)

Dhaka, Bangladesh (Agro Tech Park, Bangladesh Agricultural Research Institute - BARI)

Karurumo, Kenya (Smallholder Horticulture **Aggregation and Processing Centre** [bit.ly/2L8X5R7], University of Nairobi)

Jimma, Ethiopia (Postharvest Technology Department, University of Jimma)

Tuskegee, Alabama, USA (University of Tuskegee, TU **Global Center** [bit.ly/2BsRoxY] for Postharvest Training and Research)

launched by PEF e-learning [graduates](http://bit.ly/2nS8nAc) [bit.ly/2nS8nAc] professionalizing this new sub-sector. They are known as master postharvest trainers or postharvest specialists.

The [model](http://bit.ly/2Mswl3J) [bit.ly/2Mswl3J] of the Horticulture Innovation Lab housed at the AVRDC World Vegetable Center in Arusha, Tanzania, the pilot project for a Postharvest Training and Services Center, combines a number of functions. Including both education in improved postharvest practices and on-site equipment sales, it also offers services, generating income to support these enterprises. “The site is now becoming a gathering place for local farmers, extension workers, and postharvest researchers, just as we intended,” reports Lisa Kitinoja, a visionary leader of this project, and head of the Postharvest.org which trains postharvest specialists. Graduates of their program have visited the Postharvest Resource Center in Tanzania and are working to replicate it in their home countries.

Stocked merchandise includes PICS bags, PH testing strips, sizing rings, DryCards, glass jars for canning and more, greatly

speeding their adoption. Rental products could be housed in the center, as well. Reusable plastic crates could be leased, stored, and returned to the Center. Locally made harvest bags and sunshades might be marketed there. Pairing an entrepreneur with a postharvest extensionist is an exciting model for ramping up a whole new type of marketplace.

A Wish List might include:

- A commercial food processing kitchen for value addition training (how about juice making and bottling?) and for rental use, since kitchens can be shared
- A walk-in Charcoal Cooler for temperature control where farmers could rent short-term space, like Kenya’s Center

- Sample onion and maize storage, like Ethiopia's Center.
- An array of solar dehydrators, available for use for a fee
- A café serving locally prepared foods and demonstrating value addition options
- A sewing workshop creating postharvest tools
- A microfinance service office with a mobile money kiosk
- Advice on packaging, branding, and contracting
- A best-practices fruit and vegetable market, demonstrating packaging, display, value addition, and marketing techniques
- A legal center for attaining land tenure and deeds

Postharvest Resource Centers are innovation platforms that create value by averting losses. When center staff share strategies, and procure and sell equipment at fair prices, they lower costs and expand opportunities for smallholders. The economic, nutritional, environmental, and social returns from investments in Postharvest Resource Centers are all interconnected—and immense.

“In a true-life situation, for an inter-connected sector such as agriculture to yield development outcomes, technological, institutional and infrastructural issues must be addressed in a coordinated manner (Adekunle, 2006; Adekunle and Fatunbi, 2010; Hounkonnou et al., 2012)”
–Integrated Agricultural Research for Development–IAR4D



Launch celebration at the PTSC in Arusha (2012); note the retail supply shop in the right rear - Photo: Lizanne Wheeler



PEF's Postharvest Service and Training Centers (PTSCs) [\[bit.ly/2ph0sv5\]](https://bit.ly/2ph0sv5)



Launch of the Regional Postharvest Center in Tanzania [\[bit.ly/2PKMi2g\]](https://bit.ly/2PKMi2g)



PTSC Success Story [\[bit.ly/2OzE5hk\]](https://bit.ly/2OzE5hk)



World Vegetable Center PTSC PowerPoint, Ngoni Nenguwo (AVRDC) and Pendo Bigamo (PEF Graduate, 2015 (MAFSC)) [\[bit.ly/2Qeacb6\]](https://bit.ly/2Qeacb6)



Postharvest Management: From Lab to Land [\[bit.ly/2HUIst5\]](https://bit.ly/2HUIst5)

AFTERWORDS: ESSAYS

1. Shared Tools: Leveraging Collective Power
2. The Global Effort to Reduce Food Loss and Waste
3. Combating Global Warming by Reducing Food Loss and Waste
4. Plastic: Challenges and Opportunities
5. Female Agricultural Workers: Gender Equity and Postharvest Loss Reduction
6. Looking Ahead: Promising Tools



Longan packing shed in Thailand: note sun screen, tarp, and reusable plastic crates both as collection bins and stools - Photo: Lab Postharvest Chiang Mai

Tools for reducing postharvest losses cut across many sectors. These Afterword Essays provide a closer look at ways this book's tools integrate with poverty alleviation, economic development, the campaign to reduce Food Loss and Waste (FLW), hunger alleviation,

global warming mediation, plastic pollution, women's empowerment, and humanitarian engineering. Each of these sectors is enormously complex. It is always important for practitioners in one sector to better understand how their work fits into the bigger picture.



1. Shared Tools: Leveraging Collective Power

This book focuses on the \$100 price point. Symbolically, \$100 is the upper level of what a smallholder farmer or value chain actor in a low resource region is able to pay, through savings or loans, for upgrades. As outlined in Tool 95—Savings and Credit—it is typical for a tool featured in our book to pay for itself in just a single use or season, but without upfront capital, farmers are stuck with the low productivity/high postharvest loss status quo. This lack of financing is a poverty trap, keeping everyone poorer and hungrier.

What about tools or equipment in the \$100 — \$2500 range? Such upgrades are beyond the cost a solo smallholder farming household can finance, and also offer more capacity than one family can absorb. Two logical solutions to this conundrum are cooperative purchases or growing SMEs.

1. Farmers pooling their resources in a women's self-help group, agricultural cooperative, or other grower organization [Tool 87] makes a larger investment possible.

All members gain access to the equipment, each saving an enormous amount of time and labor. Processing equipment that saves women from gender-assigned tedious manual tasks like threshing grain or sorting lentils frees up their labor for redeployment at more productive pursuits.

An additional benefit is specialization. A few co-op members can develop skill and familiarity running and managing the new equipment or improved storage facility. Once the member-owners actualize increased income, this assignment can become a paid job. If the group has excess capacity beyond what its members need, it can rent or charge others to use their equipment or storage space.

2. A local entrepreneur can seek a loan to open an SME, a small to medium enterprise, to offer postharvest services. A business adds additional functions to its core

products, such as outreach, training, and marketing. The profits go to the business owners, not the community, but if they provide fair prices for improved services, everyone benefits—just not equally. If the entrepreneurs succeed, they can franchise or expand to other locales. This is the model of CoolHubs [Tool 72], solar-powered cold chain storage.

An excellent example of a great candidate for pooled funding is a [Coolbot™](#) equipped cold room, providing dedicated cooling at a fraction of the cost of an industrial walk-in refrigerator. This makes cooling affordable for smallholder farmers to share or for a food processing company to own. Coolbots have proven functionality and have become quite popular both for small farmers in affluent countries as well as in the resource-poor areas where the cost of mainstream commercial refrigeration would be prohibitive as well as impractical due to electricity constraints.

Its inventors, upstate New York farmers Kate and Ron Khosla, fashioned a walk-in cooler using an off-the-shelf air conditioner rather than conventional refrigeration tech. The Coolbot has a controller to manage the AC unit – “Today’s [CoolBot](#) now utilizes a micro-controller brain with multiple sensors attached to it and can work efficiently with many brands of air conditioners.” The controller “tricks” the AC to lower the temperature to 2°C (35°F), far below its intended range.

A Coolbot requires a free-standing shed with as much insulation as possible, an AC unit, and the sensor/controller unit. It runs on grid power but connecting it to solar panels allows off-grid installation. Over time, once the solar panels have paid for themselves, this lowers overhead. Costs vary depending on how much of the work is done with available owner labor versus contracting it to professionals.

Coolbot equipped cold rooms are a significant investment; while cheaper than industrial refrigeration systems they still cost between \$2000 and \$3000. Women’s groups and farmer

associations often have 25 to 50 members, so it is reasonable to believe they could save or borrow enough money as a group to make this type of investment.

Their investment is recouped in both reduced losses and the higher prices that market timing strategies fetch. A co-op can share space, expanding as profits accrue. Another model

would be a business that rents cooling space to paying clients. For perishable crops, the Coolbot investment is typically paid back after four uses; each use is for a few weeks to a few months.

Managing a shared tool requires both technical and managerial expertise, especially for ensuring compatibility when storing fresh fruits and vegetables [Tool 68].



2. The Global Effort to Reduce Food Loss and Waste

Global, national, and local campaigns to reduce food waste are raising awareness and promoting solutions. [Sustainable Development Goal 12.3 \[bit.ly/2Q9M1uk\]](#) calls for cutting world **FLW, food loss and waste in half**, by 2030, the last year of the current SDGs.

[Champions12.3 \[champions123.org\]](#) is a coalition of executives from governments, businesses, international organizations, research institutions, farmer groups, and civil society. Its 40 members, along with the “Friends of Champions 12.3” (including The Postharvest Education Foundation), collaborate to set goals, standardize methodology to measure waste and loss, and assess annual progress in meeting the targets.

It is important to understand the distinction between the two main categories of disappeared food: **food loss** and **food waste (FLW)**

- **Food loss** is endemic in infrastructure-poor, low resource regions described in this book. The absence of reliable sanitation, appropriate containers, cold chains, effective storage, well-designed packaging, and efficient transportation systems each contribute to the estimated cumulative 30-40% of postharvest product that spoils before sale.
- **Food waste** is primarily a problem in high-resource, affluent countries with complex infrastructures. Product is discarded all along the value chain as a result of inefficiencies, misaligned policies, quality standards

based on appearance or size rather than nutritional value, and market and consumer indifference to discarding edible food.

Compelling moral, economic, and ecological imperatives for reducing food loss AND food waste include:

1. Misalignment of food production and human nourishment results in hundreds of millions of people suffering from food insecurity and malnourishment, while 40% of the global food supply is lost or trashed.
2. Food loss reflects missing revenue for farmers, packers, processors, and marketers and wasted money at the end user household level. Smallholder farmers and businesses along the value chain can generate economic benefits by reducing losses. Families can add money back to their pockets by better postharvest management.
3. Food waste and loss squanders valuable resources and directly pollutes the environment. Project [Draw-Down \[bit.ly/2BRHupP\]](#), an analysis of the 100 top strategies to reduce carbon emission, lists Decreasing Food Loss and Waste as the third most effective global warming mitigation strategy. Food production requires inputs and energy, all of which are wasted when harvests rot. The emissions from rotting food itself contribute to greenhouse gas accumulation, as well.

Regardless of whether food is lost or tossed, the results are the same. This book is a compilation of 100 tools for reducing postharvest **food losses** for smallholder farmers in low-resources regions. Since we have local, regional, national, and global food systems, solutions also need to be local, regional, national, and global. Champions123.org serves as a global portal tracking successful approaches to reducing food waste and loss.

Many of the strategies laid out in this book are applicable for both high-resource settings and low-resource venues. Small farms anywhere can utilize them, as can food companies and households. In the United States, there is a renaissance of **small farms** [bit.ly/2wH99Um]; American smallholder farmers invented the CoolBot, an innovation spreading around the world.

Food Loss in Low Resource Regions

Food in low-resource regions is generally lost before it could be purchased and consumed by an end user, the status quo this book aims to remedy. Hungry people rarely waste food. Most poor people cannot afford to buy food in sufficient quantities to accumulate surpluses that spoil.

Without refrigerators or freezers, families are accustomed to making due with a ZEER pot-in-pot cooler [Tool 72] or simply consuming food directly after preparation. Stored grains are often lost to infestation over time, bringing a Hunger Season for households, when their stockpile is depleted before the next crop is mature.

Food Waste throughout the Value Chain in Wealthy Regions and Countries



At **farms** in high-resource regions, causes for food waste include:

- Migrant labor shortages, resulting in food rotting in fields.
- Over-production [bit.ly/2NsBOE9] of contracted crops with no easily accessed or economically satisfactory market. It simply may not be worth selling surplus crops.
- Crops that fail industrial standards and are not harvested, sometimes up to 55% of the crops.
- Commodities whose prices have fallen too steeply to make harvesting worthwhile.



During **packing and processing**, food loss results from

- Edible, nutritious foods being discarded because of failure to meet cosmetic, color, size, shape, or weight standards.
- The absence of infrastructure or incentives for capturing, redistributing, and utilizing edible trimming, rejects, or other discards.



Restaurants, cafeterias, markets, and prepared food venues routinely trash leftover foods due to a multitude of factors, including

- Oversized portions
- All-you-can-eat buffets
- Rules barring the reuse or donation of leftover prepared foods
- Legal liability concerns
- Lack of systems for permissible distribution of unconsumed prepared foods
- Diseconomies of saving food—when labor costs are high, it is not worthwhile for businesses to invest time in food-conservation or donation
- Caution in observing health and sanitation regulations
- Concern about brand reputation



End-consumers waste edible food for complex reasons, such as

- “Eat by” date label misunderstandings. Concern for food safety—even when vague or intentionally misleading—**encourages food waste** [on.nrdc.org/2CYVWw7]. Studies show that up to 10% of food waste is due to consumers’ misunderstanding of label terminology.

- End-user indifference to tossing edible food; high earners short on time do not want to spend it saving leftovers.
- Over-purchasing due to declining food costs relative to salaries, bulk purchasing availability, and expansive buying in response to marketing.
- Expanding home size, providing ample storage, along with automobile use, further encouraging buying more than a household actually can consume. This combines with the rise of discount warehouse shopping, and the resulting competition from grocery stores and online vendors also selling large quantities, to facilitate household food accumulation that can result in wasted products.
- Food's abundance—some might say *overabundance*—in affluent regions or entire countries decreases people's perception of its value. People can afford food waste, and with no direct experience of food shortages in their households or their communities, wasting food is normative. Households are short on domestic labor; frugal habits are time-consuming and require tight, time-bound planning. Eating leftovers also requires close attention and focus, hard to come by in busy households. Food tossing is a quick fix, perceived as “victimless” since there is no hungry person at hand to receive the discards.

As the world becomes more prosperous and the number of well-fed people in the Global South expands, food waste will no longer be just a rich world problem. Those residing in emerging economies will also increasingly become food wasters. Strategies to combat this waste need to be deployed globally.

Solutions for Reducing FLW (Food Loss and Waste)

Solutions applicable for both food loss and food waste include public campaigns to promote consuming “ugly fruits and vegetables”, the irregulars now discarded [Tool 14]. Creating a market for them facilitates their entry into the food supply where they provide affordable, high-quality nutrition. A Bay Area, California, company called UglyJuice [drinkuglyjuice.com] features this model. Drinks are an ideal product for imperfect specimens.

Developing systems to capture culled discards and trimmings include numerous win-win approaches:

- Donating them or selling them at bargain prices to
 - Food banks and soup kitchens
 - School lunch programs
 - Other institutional food preparers
 - Retailers who market “ugly fruit” and “ugly vegetables” [Tool 29]
 - Food processors who capture discards and create new products
- Installing biodigesters at food processing facilities, capturing the waste and using it to generate natural gas to power their equipment
- Designing systems to distribute them back to farmers to use for animal feed
- Composting wasted products and using the resulting compost as fertilizer

Food capture initiatives that collect and temporarily store unsold fruits, vegetables, and prepared foods and then redistribute them prevent the “farm to landfill” path of much wasted food. Systems for pick-up are already facilitated by **digital IT apps** [bit.ly/2Pncpfd] in both the Global North and Global South.

As globalized import/export grows, standardizing and simplifying product labeling with the intent to reduce waste instead of selling more products can help, too. Labeling is done by the importing country; a commitment to transparency and consistent standards will contribute to reducing unnecessary product destruction at all points on the value chain, including end users.

SDG 12.3: By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including postharvest losses.



3. Combating Global Warming by Reducing Food Loss and Waste (FLW)

Food waste and loss (**FLW**) produces so much carbon emission that reducing it is #3 in Project [DrawDown.org](https://drawdown.org)'s comprehensive list of the top hundred strategies to reduce global carbon. Postharvest loss reduction's contribution to combating global warming is an important element of the global [Champions12.3](https://champions12.3.org) [bit.ly/2DzIz7y] initiative.

A simple science lesson about plants and the carbon cycle teaches that plants absorb carbon from the atmosphere and turn it into energy.

1. When trapped and buried over hundreds of millions of years, decomposed plants become fossil fuel. This concentrated energy is extracted as natural gas, coal, and crude oil. When burned, it releases formerly stored carbon—more so than do renewable, non-concentrated fuels like burning wood—into the atmosphere as carbon dioxide. It is the accumulation of this carbon dioxide in the atmosphere that has trapped solar radiation (the greenhouse effect) and caused atmospheric temperatures to climb since the Industrial Revolution.

2. When plants die and decompose undisturbed on the earth's surface, they emit carbon dioxide at a gradual, steady rate. If new plants grow and absorb these natural emissions, the global eco-system's carbon dioxide concentration stays balanced.

Human activity, both burning plant material and consuming fossil fuels, is gradually heating our planet. The balance is tipping; less carbon is being absorbed than is being released.

Humans utilize plants as a direct fuel source. For example, three billion people still cook over open fires. The emissions from burning wood or charcoal releases soot or black carbon into the atmosphere. While not long-lasting, this too is a significant

contributor to global warming. The burning of trees, such as forest fires or slash-and-burn agriculture, releases vast amounts of black carbon as well.

Plant waste, when it decomposes without the presence of oxygen, produces methane. Methane, also known as natural gas, is a clean burning fuel. Biodigesters are an eco-friendly energy technology designed to produce just this effect. When plant waste is landfilled, however, it likewise produces methane, but with landfill technology the methane often leaks into the atmosphere where it is a potent greenhouse gas, emitting 84 times as much as the primary greenhouse gas, carbon dioxide.

When fossil fuels are burned, they release carbon dioxide into the atmosphere. Over the last two centuries of carbon consumption, since the beginning of the Industrial Revolution, so much carbon dioxide has been released that it has raised the temperature of the entire planet.

Decreasing the burning of fossil fuel, with the goal of eventually eliminating fossil fuel consumption altogether, will reduce the rate of global warming. Burning fossil fuels is the major cause of global warming, but not the only contributor.

Food loss and waste is estimated to cause about **8% of human-generated greenhouse gas emissions** [bit.ly/2BVM1aP].

Reducing food loss and waste has a significant role to play in decreasing fossil fuel carbon emissions.

Resources consumed to produce a wasted product generate emissions. One third of the world's food production—due to food loss and waste—does not provide any nutrition. The resources consumed in producing that missing third (energy, water, inputs, packaging, transportation, etc) nevertheless still add to the planet's warming, **without producing any benefit**.

Reducing food waste increases efficiency; more **consumed** calories are produced per unit of fossil fuel consumed. Measuring the carbon footprint of food throughout the whole

value chain would yield a “**calories per gallon**” or “**calories per liter**” figure analogous to automobile fuel efficiency numbers, miles per gallon/MPG or kilometers per liter/KPL. Decreasing food loss and waste increases the “**CPG**”, producing the same amount of consumed food using less fuel.

Measuring the ratio of fossil fuel per calorie would help set achievable goals to lower that number. Just as getting more mileage per gallon or liter of fuel when driving is an obvious, smart carbon reduction strategy, extracting more edible calories per gallon or liter of fossil fuel lowers global carbon loads.

Food Miles is a popular concept describing how far foods travel and tallying the carbon consumed to transport them. “**CPG**” would be a more holistic measure, adding up all the fossil fuel inputs from planting to eating, of which food miles is just one factor.

Growing food is resource intensive. Many inputs are required and each of those inputs—seeds, fertilizer, and pesticides—must be processed, packaged, and delivered. Their production and transport are fuel intensive. While labor in the developing world is generally performed manually, any mechanized equipment consumes fuel. Once the food is harvested, it is transported again, processed and packaged. All the fuel consumed in the process of growing, processing, packaging, storing, and distributing is wasted when the food is lost or tossed. Tightening up all these systems to reduce losses would mean each calorie eaten will be produced with less fossil fuel, a higher CPG, than when losses are greater, a lower CPG number.

When unharvested or surplus food sits around in fields or dumps, rotting, it is emitting carbon dioxide. Even worse is landfilled food, as it produces methane which often flares or leaks, producing hyper-toxic emissions. Reducing direct food loss of this type decreases carbon emissions.

All postharvest loss reduction tools, techniques, or activities directly reduce the carbon imbalance driving climate change.

One way to unlock more financing for postharvest loss reduction tools is to compute their carbon-emission reduction benefits into the calculations. When the global financial system starts directly accounting for the externalities of climate damage, postharvest loss reduction’s positive ecological contribution can be monetized and included in business plans.

DFID and USAID have partnered to offer prizes for the best off-grid refrigerators and cooling systems for reducing food losses via the GlobalLEAP.org innovation competition. Leading impact investors Acumen and Shell Foundation are partnering with Global LEAP to accelerate the off-grid appliance market. Fans, refrigerators, and pre-coolers designed for the developing world will help efforts to catalyze and validate new technology and business models suitable for off-grid, low-income value chain actors.

There are many climate friendly technologies to support the postharvest loss reduction sector. Expanding supplies of solar and wind power, especially in areas which have been denied the opportunity to benefit from industrialized fossil-fuel dependence, will help build a healthier, flexible, renewable energy infrastructure moving forward. As the cost of renewables plummets, many countries are finding it cheaper to bring them online instead of investing in dirty coal-fired plants. Decentralized renewable energy is well-suited for remote locations, especially given their high solarization and dearth of power plant and grid infrastructures.

Farmers in low resource regions rely on physical labor to perform tasks which are motorized in richer realms. Industrial machinery relies on fossil fuels. Innovations for the developing world need to be hyper energy efficient. If they get the job done using less in-put energy, there is potential for them to spread to small farms in industrialized settings, helping to reduce their emissions too. “Frugal engineering”, a design concept popular in the Global South, is a movement to increase efficiency by eliminating excess energy-consuming features while providing equipment that works well. Removing bells and whistles (added to sell products) can lower cost as well as energy consumption. Equipment that can run on solar or wind-generated power will be especially useful.

There is a growing renaissance of small farmers in high income countries. In the [United States \[bit.ly/2MCMcN3\]](http://United States [bit.ly/2MCMcN3]), the USDA estimates that 90% of farms are small farms, operating on nearly half of all farmland. Many of the solutions in this book are applicable for just such enterprises; indeed, some of our photos are from these farms.

Meat consumption is rising worldwide, due to population expansion and rising incomes. Creating appealing plant-based alternatives [Tool 54] to eco-resource intensive farmed animals (big producers of intensely polluting methane) will be another path to combat global warming.



Throughout the book we have identified tools with bonus eco-friendly features. Eco-friendliness generally coincides with frugal resource management, saving money for producers and processors and expanding consumable calories. But it bears repeating: **EVERY TOOL THAT REDUCES POSTHARVEST LOSSES REDUCES GLOBAL CARBON LOADS**. This is the vaunted triple bottom line that sustainable business values: people, profits, and planet.



4. Plastic: Challenges and Opportunities

Plastic, as described in Tool 33, is a wildly popular, universally adopted agricultural, packing, transport, marketing, and consumer tool. Plastic is prized for its

- Light weight
- Low cost
- Flexibility (the word plastic means “easily shaped or molded”)
- Strength—from ultra-thin to rigid and heavy
- Transparency, translucency, or opacity as desired
- Water-resistance, meaning it doesn’t disintegrate when moistened, providing reliable, long-term packaging

Available in a wide variety of weights, plastic can be fabricated as a heavy material suitable for long-term use, light-weight for disposable packaging, or any weight in between. Plastic is easily colored, and is well-suited for direct color printing, a marketing advantage.

Plastic is beneficial all through the agricultural value chain.

Heavy reusable plastic has become an important postharvest loss reducer when molded into Reusable Plastic Crates, RPCs [Tool 12]. These are superior to the natural materials previously used.

Due to its traits mentioned above, light-weight single-use plastic performs three vital roles in postharvest loss reduction:

- Cushioning fruits and vegetables, providing **gentle handling** to reduce bruising
- Extending shelf life (through shrink wraps, films, bags, clamshell enclosures, and other sealed containers), by **preventing water loss**
- Protecting produce from pathogens, promoting **sanitation**

Any plastic substitutes need to perform these functions.

Plastic has two major downsides.

- It is sourced from fossil fuels such as petroleum or natural gas. As the world works to reduce fossil fuel consumption, the driver of global warming, many countries are attempting to reduce dependency on petroleum-based single-use plastic.
- Since plastic takes centuries to biodegrade, it is causing a global pollution crisis. It creates endless unsightly, unsanitary litter and damages avian and land-based life; in our oceans it strangles marine life. Plastic does not biodegrade into its constituent molecules,

but rather breaks up over time into ever smaller pieces known as microplastics. These plastic bits are consumed by aquatic life, bioaccumulating up the food chain, endangering many forms of life on earth. Humans who consume seafood contaminated by plastic are at risk, as well.

Substituting sturdy plastic for wood or metal when manufacturing permanent items is non-controversial, but single-use, light-weight plastic packaging is increasingly being identified as a global hazard. Plastic waste accumulations pollute and endanger ecosystems and human communities.

Many cities as well as whole countries have banned or taxed “disposable” plastic bags on the grounds that disposability is a myth—single-use plastics persist in the environment and cause long-term damage. Other newly banned single-use items include plastic straws, eating utensils, and Styrofoam packaging, cups, and plates.

Taxes or bans on single-use plastic utensils and bags are primarily relevant for retail food venues, but the move away from plastic is unmistakable. It has obvious impact on the value addition food processing sector. Adopting eco-friendly packaging can give some products a competitive edge, but until sustainable packaging is comparable in price and performance to conventional plastic, standard plastic packaging will continue to dominate.

Packaging choices [Tool 31] balance many variables. Plastic is a sturdy, inexpensive, lighter weight replacement for glass jars and bottles. Optimally plastic bottles would be recycled or even reused, but that is almost never the case. Phasing out plastic and returning to glass containers would decrease carbon in the package itself but by adding weight, glass requires much more fuel to transport. Such a switch would likely add rather than subtract to the product’s carbon footprint.

Single-use cushioning, padding, lining, and shrink-wrapping are not covered by bans and wind up in the trash, moving on to landfills or the [great open dumps \[bit.ly/2PVdWL4\]](https://bit.ly/2PVdWL4) of the Global South.

Reused packing materials must be sanitized. While heavy plastic can easily be cleaned, lightweight plastic packing material’s reuse potential is limited by it being impractical and/or diseconomic to clean, given how cheap it is.

Any substitute material needs to provide sanitary cushioning and water retention.

Eliminating disposable plastic is both a challenge and an opportunity. Standard environmentally friendly recommendations are to Reduce, Reuse, and Recycle. In the case of plastics, we can add “Replace”.

- **Reducing** = using less product at the beginning
- **Reusing** = a closed loop system whereby the product is continually used until it wears out. This works for heavier plastics that can be sanitized. **Upcycling** is a subset of reusing materials, repurposing them into a product of higher value than the original
- **Recycling** = capturing the value of waste by degrading it and reformatting it into a new, reusable material of lesser value
- **Replacing** is returning to older pre-plastic packaging options or creating eco-sustainable plastic alternatives such as plant starch-based bio-films

Reducing Plastic Packaging

Efforts to reduce plastic packaging by using only the weight needed to perform the intended function have resulted in innovations like lighter water bottles and yogurt cups with thin aluminum seals. Going too thin/light has risks—containers can split or leak. Ultra-thin single-use plastic bags and dry-cleaner type wrapping can cause suffocation. Reducing plastic weight must be balanced by safety and function.

Reducing redundancy decreases plastic packaging. Some products have both inner and outer bags, not essential for keeping their contents fresh. Plastic wrapping can be overused, such as shrink-wrapping plastic single-use utensils and cups with film or packaging them in sealed bags.

Trapping air for cushioning is light-weight and effective. Bubble wraps have been popular since they were invented in the 1950s. Air pillows cushion products without adding significant weight, provided they don’t deflate. Bubble paper can replace styrene pellets or sheets, which are impossible to recycle and disperse through the environment.

Packaging designs that do not fuse different types of plastic facilitate separating plastic by type, useful in regions with recycling capacity.

At some markets, customers bring their own containers and purchase their commodities from bulk containers. In Arusha, Tanzania, the local jam making co-op gives a discount to customers who return with their original jam jar [Tool 50]. Such practices, the norm in bygone days, can be revived.

Facilitating Reuse

There are two types of reuse. One is to create durable plastic products intended for long-term use, like Reusable Plastic Crates [Tool 12], that can be used 150 times or more. The other is to upcycle, collecting waste material and utilizing it for a higher quality purpose.

Heavier plastics are readily reusable. Informal systems for collecting, cleaning, and renting reusable plastic crates have developed around the world. Likewise, in wealthy countries, pallets [Tool 64] are tracked and reused. Prices for equipping products with tracking microchips are declining. Cheap digital tracking systems would help in building a viable reuse economy.

At my food co-op in Philadelphia, members are lobbying our suppliers [to switch to reusable pallet wraps \[bit.ly/2otAOo5\]](https://bit.ly/2otAOo5) to eliminate heavy-weight shrink-wrapping that cannot be recycled. This innovation could be introduced anywhere in the world. If an infrastructure for sending reusable pallet wraps to where they are next needed is created, reusable pallet wraps will lower per-use costs and if widely implemented, would lower food costs.

Middle-weight cushioning pads or wrap could be cleaned and rented or resold. The challenge is to establish the return/reuse practice, or a system of moving to heavier wraps will just waste yet more materials. Using ziplocks or other resealing bags can also help facilitate reuse, as they don't need to be ripped open, making them easier to reuse.

PICS Bags [Tool 58] are an example of a product that can be reused several times before replacement is needed. Creating reuses for worn-out PICS bags is becoming a significant challenge, though PICS bag holes can be patched with tape.

Corrugated plastic cartons [Tool 32] can be reused many more times than comparable corrugated cardboard. If more systems were in place to collect, clean, and resell or rent used

corrugated cartons, they would ultimately reduce emissions and lower costs. Standardizing designs would aid in implementing this system.

Hermetic storage is an effective creative reuse strategy. A clean jerry can or detergent bottle [Tool 57] can be used to store beans or grain, extending their shelf life significantly. The containers provide more value as storage for food than when they stored the original product, often water or oil. A smart product manufacturer might take this type of reuse into consideration when designing their packaging.

Part of the task moving forward is to educate customers and create a reuse economy. Higher taxes on virgin materials and tax breaks for utilizing reused materials could help support and incentivize these new endeavors; entrepreneurs can create jobs and livelihoods while reducing plastic pollution.

Upcycling: Creating Products of Greater Value out of Waste

Upcycling approaches for using single-use plastic waste to create greater value is environmentally preferable to incineration or landfill (or, as is also common, sea-dumping), the usual methods of discarding of plastic. Experiments in compacting plastic waste to create building materials are promising. Plastic waste then becomes a raw material with value, justifying collection. Upcycled plastic building blocks have a much lower carbon footprint than the virgin materials they displace, an added eco-benefit. They are earthquake resistant, an additional feature.

[ByFusion.com](https://www.bymfusion.com) is developing a mobile machine to fabricate building blocks from plastic waste; their video has been widely viewed on social media. Manually fabricated [bottle](https://www.bymfusion.com)



ByFusion's prototype compressed plastic waste building blocks - Photo: [ByFusion/Vimeo \[bit.ly/2wx4kOX\]](https://www.bymfusion.com)



Building a bottle brick (“ecoladrillo”) structure in Chipila, Guatemala; bottles filled with inert waste are affixed to a mesh backing and covered with a cement veneer - Photo: HugItForward.org



Why not manufacture bottles intended for reuse as a building material? Photo: Gaviotas



Bag made of upcycled pop-tops by Mexican artisans - Photo: [ImagineArte](https://www.imaginearte.com) [bit.ly/2NevHX8]



Tote bag made of upcycled rice bags in Cambodia - Photo: [NomiNetwork](https://www.nominetwork.org) [bit.ly/2R7Pmq1]

[bricks](https://bit.ly/2oo8unc) [bit.ly/2oo8unc], plastic bottles filled with local inorganic trash (primarily plastic), are popular throughout the developing world, used to build retaining walls, playgrounds, and even schools. Why not storage structures?

Eco-bricks and blocks are great insulators [Tool 65], an essential component of improved storage structures. They displace concrete or cinderblock, both of which consume a great deal of energy to manufacture and transport. Filling bottles

with trash is very labor intensive but the whole community can be engaged in the project, resulting in a significant contribution to improved food storage that benefits the community. Agricultural extension postharvest educator (and 2016 PEF graduate) Hadija Nantami Ssekyondwa of EcoLife Foods is utilizing [bottle brick insulation](https://bit.ly/2NCmOP7) [bit.ly/2NCmOP7] in her cold room pilot project in Uganda, another way to upcycle waste plastic.

Gaviotas, a utopian sustainable community in the llanas of Colombia, pioneered a rectangular water bottle design. Their interlocking bottle “blocks” were intended for children to use as construction toys. Bottle manufacturers could run with this idea. If bottles are used as bricks, this interlocking shape saves time on gap filling and reduces the cement consumed.

Upcycled waste plastic is being utilized for [paving roads](#). Asphalt is made of crude oil, so using substitute paving not only consumes waste plastic but reduces the road’s carbon footprint. In regions with a paucity of well-paved roads and exploding quantities of plastic waste, this solution is a win-win boon to productivity and eco-system health. Inventors claim that plastic roads last longer than conventional paving, an additional advantage.

Various consumer products can be fashioned from discarded material. An American company, [Terracycle](#) [Terracycle.com], uses this as its business model. Many fairtrade cooperatives create attractive bags out of pop-tops, labels, or used grain or rice bags.

Fabricators, as 3D printers are nicknamed, utilize plastic filament. It can be made from recycled plastic to meet the growing demand for fabricating material. The Wakati [Tool 74] utilizes 3-D printing; in time this will make it accessible anywhere 3-D printers are available.

Incinerating plastic to generate electricity is a common solution around the world. However, it requires a power plant as well as an infrastructure to collect and haul the plastic to the generation site. Unfortunately, this makes it a non-starter in most low resource regions. In many locales, plastic is simply burned to get rid of it, without utilizing the released energy. This obviously produces air pollution and emits carbon, making it a doubly detrimental practice.

Recycling: Recovering Plastic’s Value

Waste plastic can be recycled, but this requires an elaborate recycling infrastructure loop extending from collection point to recycling plant and back to remanufacturing. Sufficient demand for recycled materials is necessary for the system to function effectively.

Additional challenges are the small percentage of eligible materials that actually wind up in the recycling infrastructure and that state-of-the-art recycling is only suitable for a small percentage of all plastic. At best, therefore, recycling captures only a tiny percentage of discarded plastics. Recycling tends to be a Global North endeavor, though recycled plastics are frequently

shipped to the Global South for reformatting. As of this writing (2018), China has stopped accepting recycled materials from abroad, causing a global glut of recyclables.

Recycling systems in most of the Global South are in their infancy. Vast amounts of plastics, as well as other retrievable materials, are hauled to open dumps in Global South cities and peri-urban communities. Impoverished residents eke out a living manually separating and collecting reusable materials. In some Latin American municipalities, *recicladores* are recognized workers. This is a modest solution and provides jobs, but most plastic still becomes waste.

Replacements for Fossil-fuel Based Plastics

Plastic’s ubiquity is a modern phenomenon. Older materials are getting a second look. Cellophane, for example, is over a century old. Sourced from natural, renewable cellulose, it is transparent and stiff, thin and attractive for packaging, and repels moisture. It doesn’t provide cushioning like plastic, but does provide moisture retention and pathogen protection, important for food loss reduction. It is far less flexible a material than plastic, but for many functions it is a viable alternative. While cellophane requires polluting chemicals in its manufacture, it is entirely biodegradable and can be composted. Drawbacks include its shelf life limitations (also a virtue, in that it does biodegrade), unreliability at lower temperatures, and higher cost compared to the polypropylene that has typically replaced it.

Sustainable, eco-friendly packaging is a growing sector. Bioplastics, biodegradable materials with plastic-like properties, address many of the problems of single-use plastic. They are sourced from plants, sometimes even [organic waste](#) [bit.ly/2PWEhbj]. They provide a market for farmers’ produce and create jobs. But they are not a panacea. Claims of compostability are more theoretical than practical; products requiring expensive industrial composters are ill-suited for settings without access to them. Companies that succeed in creating affordable, reliable, biodegradable bioplastics will create a global stampede for their products.

Packaging needs to last long enough to get the job done; obviously quick biodegradability doesn’t work for products designed for long-term storage.

Carbon life cycle analysis of materials yields important data. Greenwashing and other claims made by those promoting innovative materials which solve the plastic problem must be carefully evaluated. If they result in food losses, they increase rather decrease carbon.



5. Female Agricultural Workers: Gender Equity and Postharvest Loss Reduction

Throughout our featured 100 tools, we have included an icon, where appropriate, for “female friendly”. Nearly one quarter of the entries provide features that are particularly helpful or relevant for women, like tools that leverage strength, decreasing women’s disadvantages, as well as time-saving devices to free up more of their time. Some center on microenterprises well-suited for women’s co-ops. A complete listing is included at the end of this essay.

Women comprise nearly half of the world’s smallholder farmers. They work throughout the value chain, but as profits go up, women’s presence decreases. Women’s lack of access to capital and entrée to higher profit activities inhibits their earning potential and contribution to reducing postharvest losses. Promoting gender equity in postharvest loss reduction investments provides many opportunities. Engaging women in this growing sector provides them a pathway for improving their own personal status and expanding food supply for all.

Addressing gender equity in agriculture requires [holistic intervention \[bit.ly/2R1JHB\]](#). Female farmers often do not perceive farming to be their primary job or professional identity. They, and their families, often think of the male head-of-house as “the farmer”, and the female as merely helping. Female agricultural efforts are typically focused on growing lower-cost staples for the family to eat rather than cash crops. Women and girls have less education, less access to capital and training than male farmers, and if married, they lack agency over household and agricultural decisions.

Since female farm labor is frequently uncompensated, it is invisible and undervalued. Women’s contributions are unrecognized—often even by themselves. They are responsible for domestic duties and childrearing; raising food is just another task of their busy lives. Living in rural, traditional, patriarchal societies means female farmers have numerous constraints on their activities. Investments that would improve female productivity are a low priority or even met with opposition, despite the

fact that improving women’s productivity benefits the whole family and community.

Girls and women are typically marginalized from technology. The innovation women could contribute by tinkering and inventing better tools for themselves is unrealized when gender segregation persists. Male engineers often design without input from women, resulting in solutions that are inappropriate or unappealing for women to use. Development engineer [Dr. Camille George](#) reports that efforts to design machines that reduce women’s manual labor suffer particularly from a lack of funding. Because women’s labor is so undervalued, introducing technologies like the manual shea butter processor her team has been testing is difficult. Women love the idea of avoiding hard, manual labor and accomplishing tasks in a fraction of the time it takes to do by hand but they lack the agency to embrace and adopt mechanized innovations.

Many efforts initiated by governments, NGOs, and IGOs (intergovernmental organizations) aim to expand women’s agricultural empowerment. Helping female farmers develop agency and higher status expands yields; this makes postharvest technologies even more impactful. Unleashing female creativity will help women contribute effective improvements in postharvest loss reduction.

Better jobs with larger incomes can be generated with the upgrades featured in this book. Bringing women into paying work in food processing and value addition, capitalizing on their familiarity with food preparation and cooking, utilizes their skills. Women have a natural network for market research: their life experience. With business training, affordable tools, encouragement, and credit [Tool 95], women can turn wasteful postharvest gluts into remunerative, job-creating, nutritious products.

Women’s cooperatives [Tool 87] play an important role in educating female farmers and can serve as launching pads for farming women to develop professional identities. Women’s co-ops often create packing, marketing, and value addition

enterprises. Gendered co-ops provide women with a forum to grow their skills and confidence. When they realize how vital their labor is, they can work to gain more control over how they are compensated. Introducing them directly to improved tools and techniques bypasses sexist systems resistant to change. Co-ops have greater access to extensionist services and capital, helping break the bottlenecks of low productivity resulting from a lack of technical knowledge and the inability to purchase equipment up front.

With a mechanically operated paddy thresher [Tool 19] or lentil separator [Tool 87], not requiring electricity, a cooperative can save each member countless hours. A task that took a day now takes just minutes. That liberates a great deal of girls' and women's labor to be reallocated for school, training, or income generating activities.

When women are perceived as partners, through shared title to land [Tool 98], and facilitated training for communities, they have more say in how the family allocates its resources. One of the benefits of metal silos [Tool 60] is, by tradition, women control the contents. In some communities, women have added locks to the silo spouts to prevent their husbands' unapproved withdrawals. Mobile money [Tool 96] and micro-financial services [Tool 95] provide women a simple method of safeguarding money from spouses or other family members, increasing their capacity to self-finance upgrades and conduct business independently.

Grading crops at the farm [Tool 14] culls nutritious rejects. Expanding the farming household's diet with these culls (eaten fresh or processed for later consumption) is a direct benefit of reducing postharvest losses. Increasingly women farm in their rural homes while men migrate to cities for work. Farming families are often malnourished, so anything that improves their food security is a benefit for vulnerable women and children. Improved health is a boon for female farmers' productivity. They are healthier and if their families are also healthier, less of their time is drained by caretaking.

Processing equipment saves women time, especially

important given how undervalued that time is. A simple as maize sheller [Tool 20], costing a dollar or two, liberates women's labor. This empowers women to redeploy their time elsewhere.

Improved storage allows farmers to store foods safely and release them into the market when prices are high. PICS bags [Tool 58] allow a female-grown crop—cowpeas—to be safely stored instead of eaten at home or sold immediately at harvest time. Their stored crop accrues value over the season, giving women a toehold in larger markets and growing their income when their cowpeas are later released to the market.

Obviously female farmers are, on average, not as tall or strong as men. Tools that overcome those differences increase women's farm labor capacity. Telescoping poles [Tool 11] to pick fruits and wheeled conveyances [Tool 13] to push instead of carry produce on one's head are examples of equipment that compensates for gender differences and reduces strain on women's bodies.

Women typically have less access to ICT. Female-targeted radio shows [Tool 91] have proven effective for reaching women and educating them on improved postharvest techniques on their farms. Female extensionists [Tool 90] are no longer a novelty; they help change perceptions of who has agricultural expertise. They are more successful at reaching female farmers, as they can assemble women directly; in many patriarchal systems women are prohibited from meeting with men.

Girls are gaining increased access to education. Family planning has helped reduce the births per woman. These trends may result in female labor shortages on family farms. One could hope this would lead to women's agricultural contributions achieving higher status, and more investments being made in postharvest tools.

“The production of food crops is largely undertaken by women, who of course also have heavy responsibilities for child-care, cooking and other household chores. Farming may provide them with an independent source of income—but only if they can produce surplus output for cash sale.” [Sasakawa Africa Association \[bit.ly/2KQh4nx\]](#), Chris Dowsell, p. 59



Tools featuring the Female Friendly Icon

Tool 1–Calendar and Advance Planning

Tool 5–Cutting Tools

Tool 8–Harvest Bags

Tool 11–Pole Pickers

Tool 13–Harvest Handcarts

Tool 20–Maize Sheller

Tool 38–Pallets and Handcarts

Tool 41–Grates, Slicers, and Choppers

Tool 43–Power Pedaled Processing

Tool 46–Direct Solar Dehydrator

Tool 47–Indirect Solar Dehydrator

Tool 50–Canning and Bottling

Tool 53–Fermenting

Tool 57–DIY Hermetic Home Storage

Tool 58–Triple Bag Hermetic Sealing

Tool 60–Metal Silos

Tool 87–Women’s Agricultural Co-ops

Tool 88–Organic and Fairtrade Certification

Tool 90–Extensionists

Tool 91–Radio

Tool 95–Capital: Credit, Lending and Saving

Tool 96–Mobile Money

Tool 98–Land Titles

Tool 99–Border Crossings



6. Looking Ahead: Promising Tools

Postharvest technology, like all development sectors, promotes innovations. Some new approaches are tweaks and refinements on earlier designs; others are disrupters. Paradigm shifters transform processes altogether.

Poly greenhouses [Tool 2] take an old technology and utilize polyethylene sheets to replace heavy, breakable glass to bring the costs down. Likewise, evaporative cooling is a traditional temperature control method, but improved versions of this old tech like the ZECC [Tool 71], Zeer pot, and Evaptainer [Tool 74] have popularized and expanded its deployment.

In contrast, reusable plastic containers (RPCs) displace jute bags and woven baskets by offering better support and actively reducing losses. Their versatility and the utility of their

stacking designs mean older forms of non-rigid containers are gradually falling out of use, a classic pattern of disruption.

ICT has introduced a whole new world, with useful applications all through the value chain. Cellphones provide information about pricing to which farmers never had access, and also create entirely new platforms for farmers to communicate with each other. ICT is gradually transforming the whole value chain and linking small farmers to diverse markets, a paradigm shift.

One challenge in compiling the top 100 affordable ideas (since some entries have multiple approaches, the book actually includes **more** than 100 tools) is how do we treat The Next Best Thing in postharvest loss reduction? In order to raise capital and

reach scale, enterprises marketing postharvest tools need to draw attention to their product. Anecdotal evidence can convince supporters of the product's value, but the data may not support its self-reported impact.

Generally, teams piloting innovations compete for prize money to capitalize their business plans or otherwise gain traction. Prototypes need to be tested, data needs to be gathered. That is costly. What works in one region may not transfer to another. A multitude of great ideas is gradually winnowed to a few, and even the winners don't necessarily succeed.

Tools introduced with great fanfare ("solutions hype") that ultimately fail are money wasters and sow distrust for future innovations. It is important to get it right.

Here are a few examples of how we have treated innovations:

1. While researching and writing of **100 Under \$100: Tools for Reducing Postharvest Losses**, Dr. Lisa Kitinoja added an innovation to Tool 45. DryCards, relative humidity (RH%) testers, were too new to give them a starring role with their own solo entry, but their status as a viable, affordable loss reduction tool has been confirmed. Proving a whole load of groundnuts is free of mold can save farmers huge sums. If the produce is wet or moldy, the whole container can be rejected; testing can confirm its status. A distribution system is being developed in East Africa. The production cost will be around \$0.10 each.

"On March 31 [2017] in Nairobi, the DryCard had won the grand prize for the top emerging technology [grand prize at the All Africa Postharvest Technologies and Innovation Challenge](#)."

Time will tell if DryCards are widely adopted. If so, it will bring their cost down more, aiding further dissemination. As is typical for a new product, they are available for purchase only in a few test locations. It takes time—and capital—to develop a manufacturing infrastructure and distribution network.

2. **Apeel**, another prize-winning innovation, is a natural food waste-based product applied to extend fruit and vegetable shelf life for non-refrigerated produce. The coating is biodegradable, replacing plastic shrink-wrapping, an eco-benefit, and adds shelf appeal. It prevents water loss and attack from microorganisms. Applied by rinsing or dipping, it saves labor over individual wrapping. It [extends shelf life](#) by days, or even weeks.

Apeel extends product life so significantly, it changes harvesting strategy. When used as claimed, farmers can wait until a fruit is ripe. Harvesting, coating, and shipping can commence without worrying about the produce going bad. This reduces losses, since too-early harvesting can result in a crop spoiling. One wonders if Apeel might work so well it will frustrate purchasers accustomed to normal ripening times. It is not intended to be rinsed or scrubbed off the fruits and vegetables.

Apeel has not made its data public. It is a California company, but the Bill and Melinda Gates Foundation as well as the Rockefeller Foundation have invested in it with the intention of deploying it to reduce Global South food losses. We will be watching their development and report updates in our social media.

3. Tanzania's **Cheetah Development** works on postharvest income generation, helping farmers realize more income for their hard-earned yields. They have developed a tweak on solar dehydrating, mentioned in Tool 47, building a \$300 direct solar dehydrator that balances on a pivot. In the first half of the day, it can face east to catch the most sun. Midday, a worker can rotate it west, to maximize the afternoon's sun arc. This works on the same principle as a solar panel tracker which rotates panels towards the sun as it moves through the sky, increasing output. Additionally, the angle improves air flow, as hot air rises—similar to indirect solar dehydrators.

Data will be important in making the case for this innovation. Does it indeed dry produce faster, and/or in larger quantities, than stationary solar dehydrators? If so, is the speedier process meaningful for the

bottom line? Perhaps speeding up the process means less food is wasted while waiting for dehydrator space. Maybe its volume is bigger, decreasing labor costs.

If their unique design, costlier than conventional solar dehydrators, proves to be a worthwhile improvement, will it be open source or will they manufacture and distribute the solar dehydrator? This is a good example of a promising innovation that needs more testing and data.

4. Excitement about a DIY eco-cooler circulated widely on the internet in 2016. This system of inserting empty PET bottles horizontally on a board to create a zero-energy cooling system became a sensation: “Create air conditioning without electricity!” That nothing further has been posted is a strong hint of its lack of replicable, verifiable benefits. Needless to say, it is not included in this book.

While sometimes inexpensive DIY solutions don’t go viral because there is no one to push them or profit from them—[SODIS](#), solar water disinfection, for example—in the case of

the plastic bottle cooler, the claims didn’t hold up to scrutiny. In time several scientists explained its faulty design and practitioners who tried it posted their failures. Mercifully, the most harm this unsuccessful innovation did is for people to mount discarded plastic bottles on boards.

Facts will verify (or disprove) a useful innovation. Readers will notice how frequently data tables are included in this book. These numbers show how, and over what time interval, a postharvest loss reduction investment pays for itself. Anecdotal information is insufficient to recommend a tool’s adoption.

Readers with suggestions of tools—with verification! — are invited to contact The Postharvest Education Foundation through email — postharvest@postharvest.org or Twitter — @Postharvest Org.

Here’s to a future volume, chock full of *another* 100 tools to help reduce postharvest losses.

We at The Postharvest Education Foundation hope these 100+ tools will fill many a pocket and expand the global pantry, wasting less and distributing more of the planet’s food supply.

Let all who are hungry come and eat.

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GLOSSARY

Aflatoxin — any of a class of toxic compounds that are produced by certain molds found in food. They can cause liver damage and cancer, a problem particularly in undeveloped and developing countries. Aflatoxin is a naturally occurring mycotoxin produced by two types of mold: *Aspergillus flavus* and *Aspergillus parasiticus*.

Agricultural Extension — the application of scientific research and new knowledge to agricultural practices through farmer education; this knowledge is disseminated in person or through media tools by agricultural extension agents working directly with farmers.

Alum — short for aluminum potassium sulfate, used as a preservative for vegetables since it can block microbial growth.

Baffle — a plate or mechanical device designed to restrain or regulate the flow of a fluid.

Degrees Brix (symbol °Bx) — the sugar content of an aqueous solution; 1° (degree) Brix is 1 gram of sucrose in 100 grams of solution and represents the strength of the solution as percentage by mass.

Climacteric fruits — those fruits that can ripen after being picked.

Cold Chain — a temperature-controlled series of storage and distribution activities which maintain optimum low temperatures for commodities.

Culling — pre-sorting harvested produce, usually done to eliminate injured, decayed, or otherwise defective produce (culls) before cooling or additional handling.

Curing: (Bulb Crops) — For bulb crops like onions and garlic, drying the neck and a few layers of peelings in order to protect the crop from water loss and decay during handling, storage and marketing.

Curing: (Roots and Tubers) — practice that promotes hardening of the skin in preparation for a long storage period or rough handling, accomplished by putting the crop, after harvest, in a warm, moist environment to help wounds and surface damages to heal.

DAH = Days after Harvest

De-Greening — practice of warming and treating fruits with ethylene to decrease surface green color (used for citrus fruits, mangoes).

FBO — Farmer Based Organization

F and V = Fruits and vegetables

Farm to fork — the value chain from where food is grown to where it is ultimately eaten.

Food Crop — commodities raised for smallholder family consumption, not for sale.

Food loss — the decrease in edible food mass at production, postharvest, processing, and distribution in value chains directed to human consumption.

Food waste — Food fit for human consumption being discarded at the retail or consumer level

FLW = Food Loss and Waste

Horticulture — fruit and vegetable production, the branch of agriculture that deals with the art, science, technology, and business of growing plants. It also is the study of plants. It includes the cultivation of medicinal plants, fruits, vegetables, nuts, seeds, herbs, sprouts, mushrooms, algae, flowers, seaweed and non-food crops such as grass and ornamental trees and plants.

Last Mile—Borrowed from the ICT world, the logistics challenge of delivering goods, services, and information to customers in remote, low-resource locations.

MAP — Modified atmosphere packaging, used in conjunction with refrigeration, encapsulates and seals produce in plastic. It reduces moisture loss. Creating an airtight seal results in the plant respiring carbon dioxide which is then trapped, reducing oxygen. This richer carbon dioxide atmosphere preserves quality.

MC — Moisture content

MT — Metric Ton. 1000 Kilograms — 2,205 lbs

Non-climacteric fruit — fruit that stops ripening once removed from the plant.

Oxygen Absorber/Scavenger — sachets added to enclosed packaging to help remove or decrease the level of **oxygen** in the package to help maintain product safety and extend shelf life.

Phase Change Material (PCM) — a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy.

PHL — Postharvest Loss

Polyhouse, Polytunnel — types of greenhouses and protective crop structures made of polyethylene

Poverty Trap — Economic circumstances that perpetuate poverty.

Pre-sorting: see Culls

Pulses — grain legumes. The United Nations Food and Agriculture Organization (FAO) recognizes 11 types of pulses: dry beans, dry broad beans, dry peas, chickpeas, cowpeas, pigeon peas, lentils, Bambara beans, vetches, lupins and pulses not elsewhere specified—minor pulses that don't fall into one of the other categories).

Returnable Plastic Crates — RPCs — used throughout the supply chain: harvest, packing, transport, storage, and at market to reduce postharvest losses.

Sanitation — simple things like sweeping or cleaning with water — more generic than sanitizing.

Sanitizing — using a chemical like detergent or a chlorine solution to disinfect.

Secateurs — pruning shears designed to be used one-handed.

Sharing Economy — collaborative consumption or peer economy facilitated by internet connection, such as private drivers offering taxi services, people buying and selling merchandise directly, or homeowners renting rooms, via an app.

SME — Small and Medium Enterprises

SO2 Pads — sulphur dioxide, used for fumigating grapes when packing. SO₂ pads are used to control Botrytis cinerea (common fungus on table grapes) from forming on the grapes as well as keep the stems green.

Tarpaulin—also, **tarp**—a heavy-duty waterproof cloth, originally of tarred canvas. Now frequently plastic

Thresher/Threshing — the process of loosening the edible part of cereal grain (or other crop) from the scaly, inedible chaff that surrounds it.

Triple Bottom Line — measuring social, economic, and environmental benefits. (People, profits, planet)

Upcycling — creating a product of higher value out of waste materials.

Value Chain — the coordinated sequence of goods and services that move an agricultural product from farm to the final customer or consumer.

Warrantage — Loans against inventory of stored grains.

ZECC — Zero Energy Cooling Chamber — a large, porous brick double-walled evaporative cooler with a wet sand filling.



BETSY TEUTSCH focuses on the intersection of low-tech solutions, women's empowerment, and eco-sustainability. Her book, *100 Under \$100: Tools for Empowering Global Women*, included Postharvest Loss Reduction. This volume zooms in on this vital sector, featuring 100 tools under \$100 for reducing postharvest losses. Teutsch lives in Philadelphia, Pennsylvania.

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 Facebook Page, <https://www.facebook.com/100PostharvestTools>



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