POSTHARVEST TECHNOLOGY FOR FRUIT & VEGETABLE PRODUCE MARKETERS:

Economic Opportunities, Quality & Food Safety

LISA KITINOJA AND JAMES GORNY
Department of Pomology, University of California, Davis

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Dr. Lisa Kitinoja
Training in Postharvest Technology
P.O. Box 3130
Quartzsite, Arizona 85346 USA

James R. Gorny, Ph.D.
Davis Postharvest Consulting
P.O. Box 72711
Davis, California 95617
email: davispc@jps.net
PREFACE

This book is the result of many years of fieldwork as consultants in postharvest horticultural handling and processing technology, and has been written to answer the many questions we have been asked as we visited small-scale growers, produce packers, handlers, shippers and marketers throughout the US and in a wide range of developing countries. Between us we have worked in many states of the US and in more than 20 countries in Africa, the Caribbean, Latin America, Asia and Europe. During our assignments we have assisted produce marketers and processors to identify causes and sources of losses and have developed programs and training materials for teaching local handlers to use practices that will reduce postharvest losses, maintain quality and ensure food safety.

An earlier manual produced as part of the Postharvest Horticultural Series, Small-scale Postharvest Handling Practices: A Manual for Horticultural Crops (Kitinoja and Kader, 1995) introduces many of the topics that we cover in more detail in this book. We have included information gathered from hundreds of published books, university and governmental reports, horticultural magazines, trade publications and unpublished sources. Our intention is to provide specific recommendations for harvesting, handling, storing, processing and marketing a wide variety of crops currently being handled under a variety of conditions in small-scale horticultural operations in India, California, other U.S. states and other countries. While the U.S. is known for its large commercial farms, the 1990 USDA Yearbook of Agriculture reports that nearly 65% of U.S. farms are classified as "rural residence" or part-time farms, with less than $25,000 in annual sales. Another 21% are classed as "small commercial" farms with annual sales of less than $100,000. In India the average size of land holdings place most producers into the small-scale category, as in most developing countries the vast majority of producers are farming a few acres or even less. Horticulturalists may grow only one commodity or a mix of complementary crops.

Since so many improved postharvest technologies have been developed during the past few decades, we first had to narrow our focus to those practices most likely to result in immediate benefits to small-scale producers and/or marketers. Our criteria for benefits included postharvest loss reduction, quality and value maintenance and protection of food safety at reasonable cost. Most importantly, the examples we cover in Parts I and II were chosen for their potential to enhance the economic value of horticultural produce and improve economic returns to growers and direct marketers. Where necessary due to space limitations, we refer readers to well-known books on individual postharvest handling and processing topics. For example, there have been many excellent books published on the complicated process of produce marketing, and we must refer readers to these for complete details on the various traditional wholesale and retail and the alternative marketing options outlined in this book. Rather than rehash this published information, our focus in Part III is upon the postharvest technologies that must be understood and utilized for small-scale marketers to achieve success in their endeavors using whatever marketing strategies they determine are most suitable for their crops, location and culture.

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L. Kitinoja and J.R. Gorny
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INTRODUCTION TO PART I:
FRESH HANDLING TECHNOLOGIES

Successfully marketing fresh horticultural produce begins with production of a quality product and requires careful attention to the details involved in postharvest handling which protects quality, nutritional value, economic value and assures food safety. As a producer, handler and/or marketer of fruits or vegetables you already have some experience with the many steps of postharvest handling of horticultural crops and the general flow of produce from field to market. Small-scale growers and direct marketers worldwide often express concern over produce losses and quality changes during handling that decrease their return on investment, and have to deal with consumers' concerns about loss of nutritional value and perceptions of problems with food safety. Choosing the most beneficial postharvest practices can be a complex decision, based upon the needs of the commodity, cost of the technology, available market outlets and the desired level of involvement of the marketer. Luckily, there are many simple postharvest handling methods from which to choose which will assist you to protect the value of your produce and immediately improve your return on investment.

Whether you sell to wholesalers or market your produce directly to consumers, the choices you make during production, handling and marketing have an important effect on your own profits as well as upon the quality, nutritional value and safety of the fresh fruits and vegetables you grow and sell. After spending a great deal of time and money on crop production, it makes sense
to spend a little more money to protect its value after harvest. The table below lists some of the
types of postharvest losses, quality deterioration and safety problems encountered during fresh
produce handling and marketing. Losses can be economic (loss of value), physical (weight loss
or decay), cosmetic and/or nutritional. For example, if you sell your produce by weight, any loss
of water will be experienced as a direct loss of income since you will have less produce to sell.
When produce is graded by quality standards before sale, any mechanical damage, shrivel, color
changes or pest problems will put your produce in a lower grade, and lower its value compared
to the highest quality produce.

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<td>Water loss (weight loss)</td>
<td>Shriveling, wilting of fruits and vegetables</td>
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<td>Softening, limpness, loss of crispiness or juiciness</td>
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</tr>
<tr>
<td>Losses due to continued growth and development after harvest</td>
<td>Rooting, sprouting, shoot development, elongation and curvature of asparagus, greening of potatoes, fiber development seed germination inside fruits, compositional changes (loss of color, flavor, softening)</td>
</tr>
<tr>
<td>Nutritional losses</td>
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The first part of this book will assist you to identify and utilize scale-appropriate, cost-effective postharvest technologies for handling fresh horticultural produce to:

- Reduce postharvest losses due to water and weight loss, decay and physical damage
- Maintain produce quality (color, flavor, texture, appearance, nutritional value, etc.) and economic value during postharvest handling, storage and transport
- Increase shelf life with proper temperature and relative humidity management
- Assure food safety during fresh handling
- Increase income by adopting those postharvest technologies that are most profitable for your small-scale operation.

**RETURN ON INVESTMENT**

There is a tendency to worry that putting time and money into new postharvest technology will be a waste of resources, since buyers will not appreciate (and be willing to pay for) the investment required to improve quality. In fact, any improvements you can make is likely to increase the value of your produce to the point where you will eventually be able to charge lower prices and still have more profit than you make now! Dr. W.E. Deming described the theory of total quality management (TQM) many years ago for industrial production, and his ideas, illustrated here, can help horticultural producers and marketers understand how focusing on produce quality can lead to decreased unit costs and ultimately to increased return on investment.

The table which follows lists some of the common practices that contribute to postharvest problems from pre-harvest factors and harvesting methods through packing, storage and shipping to fresh marketing. In
general, rough handling (mechanical damage) and poor temperature management (inadequate cooling) are the cause of the most postharvest problems. Direct marketers such as truck farmers, market gardeners and farmer's marketers have the most opportunity to reduce losses and quality problems, since they are responsible for fresh produce throughout production, during harvest, and are involved in all the steps of packing, storage and transport as well as destination handling during marketing to retailers or consumers.

COMMON HANDLING PRACTICES AND CONDITIONS AFFECTING POSTHARVEST LOSSES, QUALITY AND FOOD SAFETY.

Pre-Harvest:
Inadequate planning regarding planting and harvesting dates, or growing cultivars that mature when market prices are lowest.
Production of cultivars with high yields but short postharvest life or susceptibility to postharvest pests and diseases.
Use of poor quality planting materials.
Over-fertilization of vegetables with nitrogen.
Lack of use of calcium sprays for pome fruits.
Inappropriate irrigation practices (too close to harvest date).
Poor orchard and field sanitation leading to latent infections and insect damage.
Lack of pruning and/or thinning fruits leading to small sized fruits with non-uniform maturation.
Lack of pest management (lack of spraying for insect or fungal control, bagging or using mesh nets to cover produce susceptible to insect or bird damage).

Harvest:
Harvesting at improper maturity leading to increased severity of storage disorders, lower eating quality (poor flavor and/or texture), failure to ripen or excessive softening.
Use of rough and/or unsanitary field containers.
Soil contamination of produce.
Harvesting during the hot hours of the day.
Rough handling, dropping or throwing produce, fingernail punctures.
Leaving long or sharp stems on harvested produce.
Over-packing of field containers.
Exposure to direct sun after harvesting.

Curing:
Lack of curing or improper curing of root and tuber crops that are destined for storage.
Improper drying of bulb crops before postharvest handling, packing and storage.

Packinghouse Operations:
Lack of proper sorting.
Lack of cleaning, washing or sanitation.
Rough handling.
Severe drops and lack of pads on conveyors/grading equipment.
Improper or excessive trimming.
Misuse of postharvest treatments (over-waxing, inadequate chlorine in wash water, misuse of hot water dips for pest management).
Use of inappropriate chemicals or misuse of registered compounds.
Long delays without cooling.
Lack of accepted and/or implemented and enforced quality grades or standards for commodities.

**Packing and Packaging Materials:**
Use of flimsy or rough packing containers.
Lack of liners in rough baskets or wooden crates.
Containers designed without adequate ventilation.
Over-use of packing materials intended to cushion produce (interference with ventilation).
Over-loading containers.
Use of containers that are too large to provide adequate product protection.
Misuse of films for M.A. packaging, over-reliance on MAP versus appropriate temperature management.

**Cooling and Humidity Control:**
In developing countries and farmer's markets, general lack of the use of any methods of cooling during packing, transport, storage or marketing of fruits or vegetables.
In developed countries, use of inappropriate cooling methods, misuse of cooling methods, over-cooling (chilling injury, freezing).
Lack of efforts to maintain high relative humidity (RH) during cooling and storage.
Inadequate monitoring of temperature and chlorine levels in hydrocooler water.

**Storage:**
In developing countries, general lack of storage facilities on-farm or at wholesale or retail markets, lack of ventilation and cooling in existing on-farm facilities.
Poor sanitation and inadequate management of temperature and RH in larger scale storages.
Over-loading of cold stores (too much produce for cooling system specifications).
Placing warm produce into the cold room.
Stacking produce too high (beyond container strength).
Mixing lots of produce with different temperature/RH requirements.
Lack of regular inspections for pest problems, temperature/RH management.

**Transportation:**
Over-loading vehicles.
Stacking heavy produce on top of delicate produce.
Loading refrigerated vehicles without pre-cooling (both the vehicle and the produce).
Use of bulk transport or poor quality packages leading to compression damage.
Lack of adequate ventilation during transport.
Lack of air suspensions on transport vehicles.
Rough handling during loading.
Lack of cooling and heat gain during delays (turning off the refrigeration unit, or leaving produce exposed to the sun).
Ethylene damage and/or chilling injury resulting from transporting mixed loads.

"India wastes more fruit and vegetables than are consumed in the whole of the U.K." Cumulative waste is estimated at about 40% of the total production value. Much of the produce becomes inedible within a day or two of harvesting.

Source: FoodTalk (March 1998)
Destination Handling:
Rough handling during unloading.
Lack of sorting, poor sanitation, improper disposal of culls.
Improper de-greening of citrus crops and misuse of ripening practices.
Lack of cooling and humidity control during temporary storage.
Handling mixed lots of produce leading to ethylene damage and/or chilling injury.
Lack of protection from direct sun during direct marketing.
In LDCs and farmers' markets, open markets exposed to sun, wind, dust, rain.
Over-cooling in supermarket displays of chilling-injury susceptible produce.

There are many affordable, simple to use postharvest technologies available to assist small-scale growers, handlers, shippers and direct marketers to avoid many of the problems and conditions listed above. The first part of the book provides detailed explanations of specific technologies for handling fresh produce such as curing, field packing, forced-air cooling, and on-farm storage practices. You can try these for yourself on a small scale, work out your actual costs and benefits for the crop(s) you produce and sell, and make the right decisions for your own operation. Using the worksheets provided at the end of each part of the book, you can calculate your expected return on investment and adopt only those practices that will increase your profits. And if you like to "do-it-yourself" you can construct many of these technologies using simple tools, readily available parts and inexpensive building materials.

Chapters 2 through 9 focus upon the specific postharvest technologies useful at each step of the postharvest chain that are recommended for producing, handling and marketing high quality fresh fruits and vegetables. Many of these practices are simple to adopt and require little investment.

Each chapter begins with a brief introduction of generally recommended practices, and a list of DOs and DON'Ts for achieving high quality. The chapters also contain detailed information on more complex technologies that have been shown to be useful in reducing postharvest horticultural losses. We recommend that you begin by carefully reviewing your operation using the Commodity Systems Assessment Methodology questions included in Appendix A. Answering these questions for a specific commodity and
filling out the CSAM worksheets will help you pinpoint areas where you may be able to improve quality, reduce losses and increase your profits. If your loss assessment leads you to one specific area where you have significant problems with physical losses, quality maintenance or food safety, you can refer directly to the chapter that covers that component.

Each chapter concludes with a discussion of the expected costs and benefits of the related small-scale postharvest technologies, along with a simplified example of how to calculate return on investment. You should use your actual costs and the market prices you expect to receive for your produce to compare your own costs and benefits with the examples given. In many cases you may have lower costs due to lower local labor costs or because you can build a piece of postharvest technology, modify an existing building, or buy a used model rather than purchasing new equipment.

Chapter 10 discusses food safety issues and outlines the recommended steps of a HACCP (Hazard Analysis Critical Control Points) program for preventing food-borne illness when handling fresh produce. We have included this topic because we believe that as consumers and governmental agencies become more concerned with outbreaks of food-borne diseases such as those that have been found in fresh produce (Salmonella and virulent E.Coli strains), produce handlers will increasingly be required to show evidence of the actions they have taken to prevent food safety problems.

WORKSHEETS

Worksheets that are designed to help you determine whether your adoption of the discussed postharvest technology will be something that result in profits for your operation are included at the end of Part I. The specifics will depend upon the crop you grow and sell, the cost of making changes and the expected outcomes (yields, grades and the associated market prices). Profits may be enhanced due to higher produce quality (higher grades, larger sized produce, better flavor, etc).
CHAPTER 1: INTRODUCTION TO PART I

WORKSHEETS

1. Basic Information
2. Total Costs
3. Expected Benefits
4. Recovery of Invested Capital

higher volume of sales (lower losses due to less water loss or reduced decay problems) or higher economic value related to improved food safety, higher nutritional value or to marketing an early crop or otherwise extending the season.

Worksheet 1 focuses on collecting basic information needed for producing and marketing crops of any kind (overhead, expected yields, estimated postharvest losses, anticipated market prices). Worksheet 2 requires that you calculate and list the actual direct costs incurred when you grow, handle, store and/or market a horticultural crop. Much of this you should know from your day-to-day recordkeeping for running your business. Worksheet 3 outlines expected benefits in terms of produce quality grades, sales and profit, and Worksheet 4 helps you to determine the return on investment (leading you through the calculation of how long it will take to recover invested capital). If you are not sure of the market prices you may receive, you can do the calculations for a worst case (lowest price) and best case (highest price) scenario and determine whether your investments will be worthwhile within that range of possible outcomes.

REFERENCES


PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE


High quality horticultural produce is appealing in color, flavor, texture, and aroma. Consumers expect that the produce they buy is safe to eat and has good nutritional value. Certain produce of any type of commodity may be more highly valued due to consumer preferences for size (very small, or extra large), shape (highly uniform or novel in some way), flavor (sweetness or intensity) or availability (earlier or later than during the usual season). In the U.S., market prices for organic produce are often much higher than the prices for conventionally grown produce, leading some growers to avoid the use of agricultural chemicals and choose cultural practices that may be more labor intensive. Since even the best postharvest handling practices cannot improve produce quality after harvest, it is very important for producers to use pre-harvest practices that will enhance initial quality and assure food safety while ensuring a profit.

This chapter presents information on selecting cultivars, using cultural practices during production that promote high postharvest quality (field sanitation, intercropping, trellising, pruning and thinning, certain fertilization and irrigation practices), pre-harvest practices that can extend the harvesting period (choice of commodities for early or late planting, protecting plants from excessive cold, heat and pests) and practices that add value (blanching vegetable crops, deflowering herbs, using sprouting inhibitors on bulb crops).
GENERAL DOs AND DON'Ts FOR PRODUCING HIGH QUALITY FRUITS AND VEGETABLES

When choosing cultivars, consider yields but also consider postharvest characteristics and susceptibility to postharvest pests and diseases.

Plan planting/harvest dates, select cultivars that mature when market prices are high and demand for the product is high (avoid periods of glut).

For perennial crops such as tree fruits, plant a variety of cultivars to extend the harvest and marketing period.

Select cultivars with unusual characteristics (heirloom varieties, different colors or shape variations, produce for ethnic cuisines) to take advantage of market niches.

Use clean, healthy, high quality planting materials.

Avoid over-fertilization with nitrogen (reduces quality, increases susceptibility to decays, insect damage and storage disorders).

Take care with animal manures and incompletely composted materials used as fertilizers (prevent contact with produce). Make sure a minimum safe interval of time has passed between application and harvest.

Test soils for possible contaminants if you suspect that animals have had access to the field, the field has ever been used as a feedlot, land fill or waste site.

Avoid wetting the leaves and fruits of plants when irrigating to minimize the spread of disease.

Avoid over-irrigation during the weeks before harvest (decreases produce firmness, increases storage problems).

Practice orchard and field sanitation to prevent latent fungal infections and insect damage. (Remove mummies from fruit trees, remove diseased produce left in the field or on the orchard floor, do not leave culls in the field, and clean field bins that have been in contact with soil contaminated with inoculum).
Do's and Don'ts continued:

Use appropriate pest management practices (spray for insect or fungal control, bag produce susceptible to insect or bird damage, rodent or insect traps, etc.).

Use fine-mesh nets (about 10 threads/cm or 20-30 threads per inch nylon mesh) to protect against bird damage.

Enhance quality by using appropriate cultural practices (calcium sprays to prevent bitter pit in pome fruits; pruning and/or thinning to increase fruit size for stone fruits; blanching asparagus, celery, cauliflower, leeks and endives; use of ethephon spray to spur uniform ripening in tomatoes).

Extend the season by using appropriate technologies to plant earlier and/or harvest later (hot-caps, row covers or plastic tunnels, shade cloth, mulches, etc.).

Consider the pre-harvest application of ethephon \(\{(2\text{-chloroethyl)}\text{ phosphoric acid}\}\) to promote uniform ripening of tomatoes grown for processing.

**SELECTION OF CULTIVARS**

Virtually all postharvest quality characteristics of horticultural crops are genetically programmed and will vary naturally by cultivar. As a small-scale grower, you can choose to produce cultivars that have those specific quality attributes that are most highly valued by your customers. You can plant a variety of cultivars of the same commodity to extend the harvest period—for example, 'Sierra Crest' peaches begin to mature in California during early May, 'June Lady' and 'Rich Lady' mature in June, while July brings 'Faye Elberta', August 'O'Henry' and 'Ryan Sun'. The last peaches to mature in September are 'September Sun', giving you nearly five months of harvest.

The following are just a few of the many varieties of horticultural produce available. Many seed companies can provide you with full color catalogs and detailed descriptions of their products. Check with your local extension agent if you need assistance to ensure you choose cultivars that are well suited to your specific climate, daylength, soils and growing conditions. If you save your own seed, always select seed from your highest quality produce to ensure continuing high quality production.
Varieties with superior or unusual flavor, color or texture:

Apricot/Plum crosses (pluots or black apricots)—from Russia, India, North Africa

Berries—thornless cultivars of blackberries, raspberries, boysenberries, excellent for Pick-Your-Own operations. 'Canby' raspberries are thornless, extra large, heavy bearing and have superior color and flavor.

Chard—cultivars are available with green, white, pink, red, orange, or yellow stems.

Cucumbers—lemon, Armenian, "burpless" varieties.

Garlic—purple bulbs and hot varieties (Korean), elephant garlic.

Heirloom varieties—thousands of rare fruits and vegetable seeds with excellent flavor characteristics are available through the Seed Savers Exchange

Peaches—'Peento' varieties from China are flattened, white-fleshed, self-fertile

Salad greens—provide a variety of choices to consumers: arugula, batavia lettuce, beet greens, chervil, chicory, com salad, cress, dandelion, endive, escaroles, fennel, mustard greens, New Zealand spinach, purslane, radicchio, red-leafed lettuce, romaines, sorrel, spinach, turnip greens.

Strawberries—Locally produced varieties with excellent flavor include 'Earliglow', 'Sparkle' and 'Jewel' (Northeast and Midwest US), 'Cardinal' (Southern US), 'Totem' and 'Redcrest' (Northwest) and 'Chandler' (Western US). 'Alpine' varieties are white or yellow with a hint of pineapple flavor.

Sweet corn—'sh2', 'SE/se' varieties are higher in sugar content, must be isolated in time or distance from other cultivars during production.

Tomatoes—'Brandywine' an 1885 Amish heirloom variety has superior flavor and pinkish fruits. 'Sungold' is a heavy-bearing orange-fruited cherry tomato.

Watermelon—Some Japanese varieties have pineapple-colored flesh

Taking advantage of a marketing niche:

Asian vegetables—"ethnic" produce for specialty markets, restaurants and Asian cuisine

Basil—varieties include lemon, cinnamon, spicy, and purple as well as sweet basil

Lettuce—mini iceberg lettuce cultivars make a salad for one person

Plum/Prunes—provide cultivars with lower water content for processing (drying, canning) including 'Italian Prune', 'Valor', and 'Imperial Epinase' (considered the world standard for high quality).
Shallots—gray shallots have a very high value compared to other varieties.

Tomatoes—provide cultivars with meatier flesh, lower water content for processing.
'Super Italian Paste' is very sweet with little juice and few seeds, making it excellent for drying or canning.

Extending the season with early or late harvests:

Blackberries—'Black Butte' and 'Siskiyou' ripen weeks before peak berry season.

Broccoli—'Saga' is productive in warmer weather than other varieties

Cauliflower—Early: 'Kunwari' and 'Early Patna'; Late: 'Dania', 'Snowball-16' and 'Pusa Himjyoti'.

Chard—long season swiss chard can become a perennial in warmer climates

Chinese cabbage—joi choi is slower to bolt, larger and faster growing than other varieties of pac choi or bok choy

Grapes—'Autumn Royal', a seedless purple grape, can be marketed in the US until mid-January.

Green beans—'Venture' and 'Royalty' will produce well in cooler weather.

Lettuce—'Red Sails', 'Mantilla' resist bolting in warm weather.

Onions—produce a pungent cultivar with multiple uses (harvest young shoots, thinnings as green onions, small bulbs as cooking onions, then allow the remainder to mature, cure for storage).

Peas—Early: 'Asauji' and 'Meteor'; Late: 'N.P. 29.'

Peaches—'Spring Baby' and 'Spring Gem' are new early season varieties, while 'Autumn Red' ripens later than usual.

Potatoes—harvest young new potatoes of 'Yellow Finn', golden or red-skinned cultivars (gently lift vines after loosening soil, remove the small potatoes and replant), then allow the plant to grow to full maturity.

Strawberries—'Firecracker' and 'Independence' begin ripening in the US around July 4th and bear fruit up to 3 weeks longer than other cultivars.

Tomatoes—'Oregon Spring', 'Siberian', will produce well in cooler weather.
Optimizing shelf life and storage potential:

Generally, fruits and fruit vegetables that have a shorter production season and mature earlier have a shorter storage life than slower-maturing cultivars.

Apples—cultivars with the storage potential of 5 to 6 months under normal cold storage are 'Delicious', 'Golden Delicious', 'Granny Smith', 'Rome Beauty', 'Spartan' and 'Winesap'.

Beets—'Winterkeeper' can be allowed to grow to enormous size without flavor problems.

Cabbage—late cultivars (harvested in the fall) store well for 5 to 6 months at 0 °C, compared to 3 to 6 weeks for early spring varieties. The longest keeping cultivars belong to the Danish class and include 'Dutch White', 'Hidena' and 'Bartolo' which store up to 10 months.

Garlic—softneck garlics store better than hardneck (woody stem) cultivars.

Lettuce—'Florida Buttercrisp' is a hybrid with more durable leaves, resulting in less damage during handling.

Melons—'St. Nick' melon has deep green striped rind and cream-colored flesh, stores for 2 months after harvest.

Onions—high SSC, pungent cultivars store better and longer than sweet cultivars. Kharif crops do not store well.

—Onions grown from seed store better than onions grown from bulbs.

—'Sweet Sandwich' requires no chemicals to inhibit sprouting (stores 9 months).

Pears—'Anjou', 'El Dorado' and 'Winter Nelis' pears can be kept safely for 6 to 8 months in cold storage (-1 °C).

Potatoes—late, fall harvested cultivars are less susceptible to Fusarium sp. (dry rot) in storage than early cultivars. 'Kufri Chandramukhi' is high yielding and keeps well in storage.

Radishes—Winter cultivars can be stored for 2 to 4 months, compared to spring cultivars with a storage life of 3 to 4 weeks.

Squash—Curcubita maxima (Hubbard) stores well up to one year.

Tomatoes—Extended Shelf Life (ESL) cultivars contain a gene that slows ripening, and must be harvested at the pink stage or later for optimum quality.

Watermelon—'Katagola' has very good keeping quality.

Disease Resistant Crop Varieties (Sources: Hart, 1995 and Choudhury, 1998):

Apples—'Liberty', 'Priscilla', 'Prima'

Asparagus—'Jersey Giant', 'Mary Washington'.

Beans—'Derby', 'Greensleeves', 'Tendercrop' and 'Top Crop' (snap beans); 'Kentucky Wonder' (pole beans); and 'Eastland' (lima beans).
CHAPTER 2: PREHARVEST PRACTICES

Broccoli—'Green Comet', 'Emperor' hybrids
Cucumber—'Early Pride', 'Salad Bush' and 'Sweet Success Amira' hybrids
Eggplant (Brinjal)—'Vittoria' hybrid
Kiwi fruit—'Issai', a hardy kiwi.
Lady's Finger (okra)—'Parbani Kvanti' is resistant to ym virus, 'Pusa Sawani' resists yellow-vein mosaic virus.
Melons—'Ambrosia' hybrid, 'Bush Charleston Gray', 'Ediato', 'Dixie Queen', 'Sweet n Early' hybrid, 'Sweet Dream' hybrid, 'Sweet Favorite'.
Peas—'Green Arrow', 'Maestro', 'Sugar Bon', 'Sugar Snap'.
Peppers—'Golden Summer' and 'Gypsy' hybrids, 'Bell Boy', 'Lemon Bell'.
Potatoes—'Kennebec', 'Up-to-Date'. 'Kufri Kumar' has high resistance to late blight.
Pumpkin—'Baby Bear'.
Raspberry—many varieties.
Spinach—'Melody' hybrids.
Strawberry—'Allstar', 'Earliglow', 'Guardian', 'Surecrop'.
Tomatoes—'Roma', 'Better Boy', 'Parks Whopper', 'Better Bush', 'Celebrity', 'Big Pick'.
Watermelon—'Crimson Sweet'.

MAIL ORDER AND INTERNET SOURCES OF SEEDS AND PLANTING MATERIALS:

Burgess Plant and Seed Co., 905 Four Seasons Road, Bloomington, Illinois 61701
Burpee Co., 300 Park Avenue, Warminster, Pennsylvania 18974
California Rare Fruit Growers, Inc., P.O. Box W, El Cajon, CA 92022
the Cook's Garden, P.O. Box 65054, Londonderry, Vermont 05148 ($1 for catalog)
Garden City Seeds (406) 961-4837
Gurney's Seed and Nursery Co., 110 Capital Street, Yankton, South Dakota 57079
Henry Field's Seed and Nursery Co., Shenandoah, Iowa 51602
Horticultural Network (HortNet) www.hortnet.com
le Jardin du Gourmet, P.O. Box 75, St. Johnsbury Center, Vermont 05863
Johnny's Selected Seeds, 299 Foss Hill Road, Albion, Maine 04910
LeMarche Seeds Int'l., P.O. Box 190, Dixon, California 95620 ($2 for catalog)
Native Seeds/SEARCH 2509 North Campbell Ave., Suite 325, Tucson, Arizona 85719
Oregon Exotics Rare Fruit Nursery, 1065 Messinger Road, Grants Pass, OR 97527 ($2)
Owen Nursery, 2300 East Lincoln Street, Bloomington, Illinois 61701
Park Seed Company, Inc., P.O. Box 46, Highway 254 North, Greenwood, SC 29648
Raintree Nursery, 391 Butts Road, Morton, Washington, 98356
SeedQuest Online www.seedquest.com
Seed Savers Exchange, RR 3, Box 239, Decorah, Iowa 52101 ($1 for brochure)
Shepherd's Garden Seeds, 7389 West Zayante Road, Felton, CA 95018 ($1 for catalog)
Stokes Seed Company, P.O. Box 548, Buffalo, New York 14240
Stokes Seeds Ltd., P.O. Box 10, St. Catherines, Ontario L2R 6R6 Canada
Territorial Seed Company, P.O. Box 157, Cottage Grove, Oregon 97424-0061
The Tomato Seed Company, Inc. P.O. Box 1400, Tyron, NC 28782

COMPARISON OF ESTIMATED COSTS AND EXPECTED BENEFITS RELATED TO DIFFERENCES IN THE PRODUCTION, HANDLING AND MARKETING OF TWO CULTIVARS.

Costs
New planting materials
Land preparation (plowing, planting, etc.)
Delay between planting and first crop
Higher cost for improved seeds

Potential Benefits
Lower production costs for new cultivar
Higher market value for new cultivar
Extended season (earlier or later)
Example
Assumptions:

1) For the purposes of this example, postharvest losses are assumed to be uniform for both varieties of radishes at 10% of expected yields.

2) Most expenses for production and postharvest handling for the two cultivars will be similar, with the exception of increased handling/packaging costs for the new cultivar due to increased yields.

3) Only average retail prices will be used in the calculations. Higher prices obtained for early or late in the season produce will further increase the potential profits.

Current cultivar: Small round red radishes are direct seeded any time of the year during cool weather at a rate of 2 kg/ 0.1 ha and cost Rs 4400/kg. Expected yield in 26 days is 12,000 kg/ha and the average retail selling price is Rs 5/kg.

\[
12,000 \times 0.1 \text{ ha} = 1200 \text{ kg}
\]

\[
1200 \text{ kg} \times \text{Rs 5/kg} = \text{Rs 6000}
\]

If postharvest losses are assumed to be 10%, expected market value is

Rs 6000 - Rs 600 = Rs 5400

Cost of seeds = Rs 8800

Potential profit (for 0.1 ha in about one month) = Rs 5400/month - cost of seeds = Rs (-3400)

Net loss of Rs3400 per month.

New cultivar: Long white (Daikon) bolt resistant radishes are direct seeded during the late autumn through spring at 1/2 kg/ 0.1 ha and cost Rs 2600/kg. Expected yield in 60 days is 30,000 kg/ha and the average retail selling price is Rs 5/kg.

\[
30,000 \text{ kg/ha} \times 0.1 \text{ ha} = 3000 \text{ kg}
\]

\[
3000 \text{ kg} \times \text{Rs 5/kg} = \text{Rs 15,000}
\]

If postharvest losses are assumed to be 10%, expected income before expenses is

Rs 15,000 - Rs 1,500 = Rs 13,500

Cost of seeds = Rs 1300

Potential profit (for 0.1 ha in about 2 months) = Rs 13,500 - cost of seeds = Rs 12,200

Rs 12,200 /mo divided by 2 months = Net profit of Rs 6100 /month
CULTURAL PRACTICES THAT ENHANCE QUALITY, EXTEND THE SEASON AND/OR ADD VALUE

In general, the less perennial the horticultural crop, the more influences the environment and the cultural practices you use will have upon produce quality. But even with perennial crops, there is plenty you can do to protect your crops in the field or orchard and to ensure the production high quality, high value fruits and vegetables.

Field sanitation

Most growers of stone fruits know they must remove mummies from fruit trees to reduce the incidence of brown rot (Monolinia fructicola), and growers of pome fruits try to keep orchards free of fallen fruits to reduce Mucor rot, but there are two other important sources of inoculum for various fungal pathogens and/or hosts for insect pests. These are 1) culls left in the field or on the orchard floor, and 2) field bins that have been in contact with soil contaminated with inoculum.

**BASIC SANITATION PRACTICES INCLUDE:**
- Remove mummies from trees
- Remove mummies and fallen fruit from the orchard floor
- Remove culls from field and orchards
- Keep field bins clean, smooth and in good repair
- Cover areas where bins are kept with sawdust or wood chips or use trailers to hold bins

Extending the season

Quick maturing crops for cool season production include baby carrots, beets, chinese cabbage, leaf lettuce and spinach. Some quick maturing crops for the warm season are bush beans, summer squash, early tomatoes and early sweet corn.

Slow maturing, extended-harvest crops for the cool season include peas, kale, onions and brussels sprouts. Warm season crops that will continue producing over long periods include lima beans, pole beans, cantaloupes, standard sweet corn, cucumbers, eggplants (brinjal), peppers, winter squash, pumpkins and indeterminate tomatoes.
There are a variety of pre-harvest practices that can extend the season by providing a degree of plant protection from excess cold or heat, maximizing sun penetration and ventilation or encouraging early production.

**Mulching**

Mulches can reduce evaporation of water by 10 to 15%, reduce competition from weeds, and protect the roots of plants from extremes in soil temperatures. Mulching vegetables can increase yields, promote early harvest and reduce produce defects (such as fruit rots, soil contamination). Organic mulches include plant residues, compost, nut hulls, peat moss, sawdust, wood bark, old newspapers and composted animal manures (with the exception of chicken manure). Other materials used for mulching include aluminum foil and plastic, which can be removed at the end of the growing season and reused for several years. Plastic sheets should be perforated to allow air and water to reach the soil.

Loose, dry mulches such as straw or wood chips act as insulation and protect against high temperatures. Use a thick layer of straw—at least 20 cm (8 inches), but first make sure the straw is free of seeds. Finer mulches such as sawdust, compost or leaves can be used as a 10 to 15 cm (4 to 6 inch) layer.

White paper and reflective foils can keep soil about 3 to 6 °C (5 to 10 °F) cooler than bare soil. Potatoes, summer squash and cool season crops such as broccoli and brussels sprouts may benefit from the cooler soil temperatures and have increased yields.

Black paper or black and transparent plastic mulches will increase soil temperature by 6 to 8 °C (10 to 15 °F) when compared to bare soil, and will encourage early plant development. Melons, cucumbers, peppers, pumpkins, squash and early crops of tomatoes and sweet corn will benefit from soil-warming mulches, and reward you with earlier harvests. Sheet mulches need to be well anchored to prevent wind damage. A layer of soil around the edges, or a few stakes or heavy rocks will keep the sheets from lifting and flapping in the wind.

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Splitting or cracking of pomegranates in India can affect up to 50% of the crop. Fruits are often harvested prematurely to avoid fruit cracking, but quality is very poor in this case. The trouble can be minimized by improving the water retention capacity of the soil by adding organic materials.

Source: Singh, 1998
Protection from cold
Hots caps, plastic tunnels, cloches, row covers and products such as "wall o' water" are clear plastic products that provide protection from frosts and cold nights by keeping plants warmer than the outside air temperatures. The clear plastic lets the sun's rays penetrate and warm the plants and surrounding soil, then slows heat loss from the soil during the night (by reflecting infra-red radiation back to the plant). Up to two months can be added to each end of the growing season.

Inexpensive hot caps can be constructed for individual plants using empty, clean plastic containers with the bottoms cut out (2 L soda bottles or 1 gallon milk containers). Usually hot caps are placed over plants when a frost is expected, and are then removed during the following day. If you plan to leave the caps in place for several days, poke some holes in the sides of the bottles to provide for ventilation, and remove the caps to let heat escape during the afternoon. On a 15 °C (60 °F) day, temperatures under hot caps have been measured at 38 °C (100 °F).

Plastic tunnels are row covers that can be constructed from 4 to 6 mil polyethylene sheets held in place over metal, PVC or wooden frames. Leaving the ends open will allow for adequate ventilation, but temperatures should be monitored to prevent heat damage. Some growers prefer to silt the plastic toward the top of the tunnel to allow for more self-modulation of temperatures, but you still must pay attention to prevent buildup of heat on warm days. The plastic should be removed when soil temperature reaches 15 °C (60 °F). The same supporting frames can then be used for shade cloth, agricultural fleece or anti-bird netting.
Protection from heat
Shade cloth blocks the sun's rays to keep the plants cooler than outside air temperature and allow you to produce crops that would normally bolt or become infertile during very hot weather. You can choose from fabrics that block up to 80% of the sunlight (tight weaves), down to loose weaves that block 30%.

SHADE CLOTH: cools the soil, extends the season for lettuces, peas, cool season vegetables.

Protection from wind:
Winds can cause high levels of damage to delicate plants, and can be responsible for heavy losses due to fruit drop. The best protection is provided by fully grown trees or a strong 6 foot high porous fence, but few growers have the luxury of waiting years for natural wind-breaks to grow, or have any desire to build long lengths of permanent fencing. Agricultural fleece is a very fine polyethylene netting that can be attached to any sort of post or pole to make an instant wind-break. If you set up the netting perpendicular to the prevailing winds, it will reduce wind speed by about 60%, and protect an area up to ten times the area of the netting. Netting that is 6 feet high and 50 feet in length will protect 2000 to 3000 square feet of the field.

Maximizing sun penetration and ventilation

Pruning and thinning
Limiting the vegetative growth of crops such as tomato, pole beans and berries will encourage the remaining produce to mature faster. Thinning fruitlets in stone fruit crops, removing side shoots on tomatoes, and removing runners of strawberries results in the production of larger, better quality fruits. Severe pruning of blueberries produces less but larger fruit, and encourages more new growth.
"GUAVA is rarely pruned in North India, but light annual pruning after harvesting to promote vegetative growth and flowering is desirable."

Source: Singh, 1998

For grapes, the general recommendation is to leave 5 or 6 canes on the most vigorous, strong vines; about 4 canes on moderately vigorous vines; and only 2 or 3 canes on weaker vines. Studies in California have shown that leaving too many canes on weak vines will reduce produce quality and further weaken the vines over time.

The banana rhizome produces many suckers continuously. These compete with fruiting and should be removed (Singh, 1998).

When pruning and thinning, there is usually a trade-off to be made between total yield and improved quality, but often the better price received for higher grade produce will suggest that maximizing yield will not maximize profits. Thinning stone fruits increases fruit size while somewhat decreasing total yield. A cucumber plant is capable of producing many medium-sized or a few large fruits, while the total weight of cucumbers produced will be about the same. Removing the first and second female flowers from pumpkin vines will increase the weight of the remaining fruit, since all the plant's energy will be directed into this one fruit.

RECOMMENDATIONS FOR THINNING FRUITS:

**Apples:** Thin fruit to an average of 6 inches apart, after natural fruit drop.

**Cherries:** No thinning required.

**Grapes:** Snip off parts of developing bunches to create the classic cluster shape and to improve size and quality of individual grape berries. Gibberillin is a growth regulator used at the 20 to 80% bloom stage by some producers to reduce berry set when grape vines are carrying a larger crop than they can readily support.

**Peaches & Nectarines:** Thin to one fruit per cluster early in the season; spaced about 6 inches apart.

**Pears:** Thin pears to two per cluster, after natural fruit drop.

**Plums:** Thin large-fruited cultivars to 3 to 4 inches apart; thin small-fruited plum cultivars to 2 to 3 inches between fruits.
Trellising

Encouraging plants to grow upward upon trellises will maximize sun penetration into the canopy and provide good ventilation, lowering the relative humidity around the plants and reducing the incidence of disease. Improved light penetration is related to increased soluble solids content (SSC) and color development in berry crops. Cucumbers will nearly double their yield per plant if trellised during production.

Crops that benefit from trellising:
Fruits-- blackberries, raspberries, grapes
Vegetables-- pole beans, tomatoes, cucumbers, squash, sweetpotatoes and melons.

Trellises can be constructed from poles, twine grids, metal cages, nylon netting, old screens, or wire mesh. You can be creative and build supports with whatever spare materials you have lying about on the farm. It is important the trellises are strong enough to support the weight of the plants and sturdy so they will not tip over in the wind. Heavy crops such as melons will require support as they grow, and should be securely tied to the trellis. Some small growers make a sling of cheesecloth for the heavy fruits and tie these to the trellis. Trellised plants may require more irrigation to prevent wilting in the heat of the day.
Fertilization and Irrigation Practices

Nitrogen
For leafy crops, application of nitrogen is very important for stimulating vegetative growth. Too much nitrogen fertilizer can be the source of quality problems in many crops. Excess nitrogen increases susceptibility to brown rot (*Monolinia fructicola*) in peaches and nectarines. Blossoms of under-fertilized trees are the most resistant to infection. Large amounts of nitrogen encourage vegetative production rather than fruit development and results in poor storage quality of vegetables. High nitrogen fertilization is related to increased water loss in storage for sweetpotato, decreased flavor in celery, decreased ascorbic acid content in potatoes and cabbage, and the development of hollow stem in broccoli. High levels of nitrogen fertilizer contribute to bitter pit in apples, increased leaf production in berry crops (with smaller fruit size and increased incidence of disease). In cranberry, strawberry and kiwifruit, excess nitrogen is related to loss of flavor, decreased firmness and the related increased susceptibility to decay.

In addition to knowing the amount of fertilizer recommended for the soil type in which you are producing the commodity, you must know how much nitrogen is already present in the soil at the start of the planting season. It is easy to over-fertilize, since nitrogen may be left over from fertilizers added during the last season, be present in cover crops and other organic matter as they break down in the soil, or added as rainfall and as you irrigate since most water sources contain some nitrogen. In general, light colored soils contain little organic matter and will release little nitrogen, while dark colored soils release about one-half pound of nitrogen per 1000 square feet over the course of a growing season.

The best approach is to begin by doing soil tests for the nutrients required for high quality production of your commodity, then fertilize to bring the soil up to the recommended rates. The cost of a soil test will pay for itself many times if you determine that you have been wasting resources on fertilizers that are not needed.
If you are planning to mulch for the first time, you will want to add some extra nitrogen to the soil. As soil microorganisms decompose the mulching materials, they will use some of the nitrogen you intended for crop production. The most nitrogen is required for breaking down mulches made from sawdust, wood chips, leaves and corn cobs.

**Calcium**

Calcium deficiencies play a part in determining produce quality, and can lead to blossom end rot in tomatoes, blackheart in celery, tipburn in lettuce crops, bitter pit and internal breakdown in apples, and to the production of small, hard, sour strawberries. Excessively high nitrogen fertilization will prevent apple trees from taking up calcium that is present in the soil. Foliar sprays of CaCl$_2$ or Ca(NO$_3$)$_2$ can improve quality and reduce disease symptoms and decay in storage for these crops, especially if applied after a heavy rain or a period of rapid growth. Calcium is also used to enhance firmness in tomato crops that are destined for processing. Recommended rates are provided with the product, so be sure to follow the label instructions on the product you purchase.

**Irrigation and Irrigation Schedules**

Using irrigation methods that spray water on the foliage of horticultural produce can increase the incidence of disease and increase the rate of spread of fungal infections. Sprinklers also tend to waste water since much of the irrigation water winds up on foliage and bare soil and evaporates directly into the atmosphere before the plant can use it for growth and transpiration. Rather than relying on overhead irrigation (sprinklers or sprayers) consider using furrow irrigation methods or installing soaker systems.

Soaker hoses allow water to reach the plants roots more quickly by delivering water only where you desire. These hoses can be purchased at farm supply stores, and are relatively inexpensive.
Irrigation of citrus is especially important in summer. Frequent light irrigation lowers soil temperature and raises humidity in the orchard.

Source: Singh, 1998

Excess water via rain or irrigation contributes to a loss of flavor in many horticultural crops, increased susceptibility to decay in storage, and early sprouting of root and bulb crops. It appears that too little water may often be better than too much, in terms of overall produce quality. Under-irrigated stone fruits have thicker cuticles and increased resistance to postharvest disease.

The scheduling of the last irrigation has an effect on the quality of onions, garlic and potatoes. It is important that irrigation be withheld for a period of 7 to 10 days before harvest, to allow the tops to dry down and the crops to be ready to dig and cure before further handling.

Adding Value

Blanching

Pre-harvest blanching of vegetable crops during the last stages of growth makes the produce lighter in color and milder in flavor. Blanching requires hand labor but adds market value to crops such as asparagus, cauliflower, celery, endive and leeks. According to Singh (1998) using different colors of twine or rubber bands each day makes it easy at the time of harvest to select those plants tied earliest.
BLANCHING:
Asparagus: Hill soil over beds so shoots grow longer. Whitew

Cauliflower: Grow self-blanching types if possible (the topmost leaves naturally grow upward to cover the head). Cover head with a paper bag or tie outer wrapper leaves around the head.

Celery: Hill soil around stalks after wrapping stalks in newspaper to keep out soil.

Endive: Cover head with wrapper leaves 7 to 10 days before harvest.

Leeks: Cover base of plant with newspaper when it is about half-grown, then mound soil about 20-30 cm (8 inches) up the stem.

De-flowering herbs
Keep the buds of flowers pinched off herbs such as basil, chives, marjoram, mint, oregano and tarragon to improve quality. Just prior to flowering leaves are especially high in the essential oils that give herbs their characteristic flavor and aroma.

Sprouting inhibitors
Maleic hydrazide used as a spray a few weeks before harvest adds shelf life to onions. Follow the label for instructions on concentrations and proper usage.

COSTS AND BENEFITS OF ADOPTING NEW PRE-HARVEST PRACTICES
(example: using hot caps, plastic tunnels, pruning, thinning, shading, trellising, mulching, foliar Ca sprays, soaker irrigation systems, blanching).

Costs
Materials
Labor

Potential Benefits
Earlier harvest (higher market value)
Later harvest (higher market value)
Lower physical losses due to pests, disease
Improved quality (higher market value)
Example 1: Using plastic row covers in California to protect a 200 ft long row of hot pepper plants during early planting in cool weather.

Costs:
Materials $15.00 per 100 ft row
Cost for 200 ft row = $30.00
Labor cost for installation of covers: 1 hour for 2 rows ($7/hr) = $7.00
Total cost = $37.00

Benefits:
Earlier harvest of hot peppers (4 weeks early) gains high market prices of
$1.98/lb for the first 500 lbs of peppers harvested.
Total yield 3000 lbs
Compare to typical mid-season market price of $0.89/lb
$1.98-0.89 = $1.09 per lb higher price x 500 lbs = $545

Profit: $545.00 - 37.00 = $508 per year

Example 2: In India, using plastic row covers to protect 65m of cucumber or long melon during early planting in cool weather.

Costs:
Materials Rs 12/m
Cost for 65m row = Rs 800
Labor cost for installation of covers: 1 hour for 2 rows (Rs 80 /day) = Rs 10
Total cost = Rs 810

Benefits:
Earlier harvest of cucumbers (4 weeks early) gains high market prices of
Rs 30/kg for the first 250 kg of produce harvested.
Compare to typical peak mid-season market price of Rs 5/kg
Rs 30- Rs5 = Rs 25 per kg higher price x 250 kg = Rs 6200

Profit: Rs 6200 - 810 = Rs 5440 per year
SOURCES OF PRE-HARVEST EQUIPMENT AND SUPPLIES

Bird/pest control
- reflective tape
- terror-eyes balloons

Burpee
Johnny's Selected Seeds
Peaceful Valley

Cloches, greenhouse film
and clips for plastic tunnels

Mellinger's
Peaceful Valley
Territorial Seed

Floating row covers

Gardener's Supply
Johnny's Selected Seeds
Mellinger's
Peaceful Valley

Irrigation supplies (drip and soaker systems)

A.M. Leonard
Gardener's Supply
Mellinger's
Natural Gardening Company
Territorial Seed

Mulch, paper and plastic

The Cook's Garden
Gardener's Supply
Johnny's Selected Seeds
Pinetree

Pruners, hand tools

A.M. Leonard

Shade cloth

A.M. Leonard
Peaceful Valley
Territorial Seed

Trellises, bean towers

Plants of the Southwest
Gardener's Supply
Mellinger's

Wall-o-water hot caps

Henry Field's

For addresses of suppliers please refer to Appendix D
REFERENCES


PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
CHAPTER 3

HARVESTING AND PREPARATION FOR MARKET

Now that you have successfully produced a high quality crop, it's time to harvest the fresh produce and prepare it for market. The goals of a harvesting system are 1) to gather the commodity from the field at the proper stage of maturity (which will vary depending upon the commodity, the distance from market and its intended use), 2) with a minimum amount of damage and losses, 3) at the rate required for optimum handling (sorting, postharvest treatments, packing, cooling, transport, marketing operations, etc.) 4) in a cost-effective way.

Small-scale producers can gain an edge over large-scale operations using mechanical harvesting since you, as a small grower, can harvest earlier, when vegetables are more delicate; harvest later, when fruits are at a riper, more flavorful stage; or harvest more often (taking advantage of multiple harvests to gather produce at its optimum stage of maturity). All these options can lead to higher profits due to the higher value of the produce you have to offer for sale.

One of the most common mistakes growers make is to harvest fruit crops too early, when they are underripe and have not yet developed their full flavor. Farm advisors in California warn that many of the organic apples grown for fresh market are harvested immature, when they are of inferior eating quality, and therefore have been poorly accepted by consumers. With many horticultural...
PROPER MATURITY AT HARVEST IS ONE OF THE KEYS TO HIGH QUALITY!

crops, if you harvest all at once you are sure to have many items that are either undermature or overmature.

You can extend the harvesting season by selecting cultivars that are of high quality when picked small and when large, and sell those vegetables and herbs that are removed when thinning during the growing season. Perhaps there is a speciality market for highly valued "baby vegetables" such as tiny beets, carrots, collards, turnips, head and leaf lettuces, onion and garlic greens, summer squash, green tomatoes, new potatoes and baby corn. Others crops such as leaf lettuce, spinach, collards, chives and swiss chard can be picked and marketed multiple times over the growing season. Crops such as Lady’s Fingers (okra), green beans, cucumbers and indeterminate tomatoes should be harvested continuously, since if the older fruit is allowed to mature and remain on the plant, yield is dramatically reduced. Once harvesting starts, cucumbers in India are generally picked at 2 to 4 day intervals, depending on the weather. Lady’s fingers (okra) is picked every 2nd or 3rd day, the best time for harvest being 6 to 7 days after the opening of the flowers (Choudhury, 1998). Small scale growers can take advantage of the fact that side shoots of broccoli and cabbages will develop new smaller heads once the central head has been removed, providing another crop about one month later.

Mechanical damage during harvest can become a serious problem, as injuries predispose produce to decay, increased water loss and increased respiratory and ethylene production rates which all will lead to quick deterioration. Bruising, cuts and other mechanical damage will increase the ripening rate of climacteric fruits such as tomatoes, apples, stone fruits and bananas and shorten the marketing period considerably. Potatoes and other underground crops can be easily damaged by careless digging and are often pierced or sliced by tools used while turning the soil to expose the produce. Training field workers in proper harvesting and handling methods will greatly reduce postharvest problems caused by damage during harvest.

Directly following harvest, when produce is prepared for marketing, cooling is essential. Harvested produce should always be protected from the sun, and kept in the shade if there is any delay between harvest and preparation for market. Avoid exposure to the sun as much as possible
after harvest, as produce left out in the sun will gain heat and may become sun-burned. Harvested produce left in direct sun for only one hour will be 13 to 16 °C (25° to 30°F) hotter than the same produce kept in the shade. Field bins should be placed where they will be shaded by trees or temporary shade, or loosely covered (for example with light colored canvas, leafy plant materials, clean straw or an inverted empty container) if delays are expected in removing them from the field. Removing field heat (also known as "pre-cooling") directly after harvest, should be done before any further handling. Any delays in cooling will shorten postharvest life and reduce quality. Produce left at ambient temperatures can lose water at a rate of up to 100 times faster than produce that is cooled immediately to its optimum temperature. Even produce undergoing repeated cooling and warming will deteriorate at a slower rate than produce that has not been cooled.

This chapter provides information that will assist you to identify the proper maturity stage for harvesting a wide variety of horticultural produce, and explain how to measure a variety of maturity and quality attributes (SSC, TA, firmness, etc) commonly used as maturity indices. Next, some of the tools and equipment that can assist in proper harvesting and handling, the equipment recommended for field packing, and several methods for curing root, tuber and bulb crops before removing them from the field are presented and illustrated. Examples of costs and benefits encountered when field packing table grapes and when curing sweetpotatoes are included to assist you in completing the Worksheets at the end of Part I.

“Very high levels of wastage and value loss in India occur when all produce is harvested simultaneously with no consideration for transport distance.”

GENERAL DOs AND DON'T's FOR HARVESTING HIGH QUALITY HORTICULTURAL CROPS

Always consider the needs and requirements of the market for your produce (customer preferences for size and/or stage of maturity).

Regardless of commodity or development stage of produce, all horticultural products require extreme care at harvest.

Containers used for harvesting should be: clean; smooth and free of rough edges; vented; and not too large. Steel buckets make good harvesting containers.

Use stackable plastic crates as field containers during harvest-- while initially expensive, these are durable, reusable and easily cleaned.

Train manual harvesters in the proper way to harvest the crop to minimize damage and waste.

Train harvesters to recognize the proper maturity stage for the produce they are handling (such as size, shape, color, sweetness or firmness).

Round the tips of knives to minimize inadvertant gouges and excess damage to perennial plants, sharpen knives and clippers.

Wearing cotton gloves, trimming fingernails, and removing jewelry such as rings and bracelets can help reduce mechanical damage during harvest.

Train pickers to empty their picking bags and/or baskets with care, never dumping or throwing produce into field containers.

Keep produce clean and free from soil contamination to reduce food safety hazards.

Always provide shade for harvested produce to prevent heat and sun damage.

Night or early morning harvest is sometimes an option for harvesting produce when internal temperatures are relatively low, reducing the energy needed for subsequent cooling. Let dew dry off first if harvesting crops susceptible to fungal diseases.

Cool produce (remove field heat) as soon as possible after harvest.

Grade roads between the field and the packinghouse and keep them free from large ruts, bumps and holes.
Dos and Don'ts continued

Secure field boxes well during transport and, if stacked, do not overfill.

Disinfect all tools and equipment that comes in contact with produce. Prohibit the use of field containers for any other purpose (tools, foods, fuel, etc) than carrying produce.

Consider field packing to reduce the number of times produce is handled between harvest and marketing.

Cure root and tuber crops intended for storage by exposing them to moist, warm conditions that heal wounds and thicken peels.

Cure bulb crops such as onions and garlic (by drying neck tissue and outer skins) before packing, storage or marketing.

IMPORTANT OF MATURITY INDICES

- Physiological maturity is the stage when a fruit is capable of further development or ripening when it is harvested.
- Horticultural maturity refers to the stage of development when vegetables should be harvested to meet consumer needs.

Using Maturity Indices:
- Assists you to ensure sensory quality (flavor, color, aroma, texture) and nutritional quality. Harvesting horticultural produce too early (when under-developed or immature) will result in poor color, flavor and under-developed nutritional characteristics.
- Ensures an adequate postharvest shelf life. Harvesting too late will reduce postharvest life. Over-mature produce can be too ripe and soft to withstand postharvest handling, or be too fibrous, tough or woody (have reduced eating quality).
- Facilitates scheduling of harvest and packing operations. Maturity indices help to predict beginning dates of harvest and the related equipment, materials, facilities and labor needs.
- Facilitates marketing over the phone. Objective maturity standards can enhance communication about quality between wholesale buyers and sellers. This is important when selling to distant buyers, and allows buyers to have a clear idea of the quality they are purchasing without having to do a visual inspection of produce.
- Improves productivity on the farm. Being able to predict maturity and harvest dates can influence overall productivity. You may need to schedule multiple harvest to increase yields of produce at optimal maturity and highest value.

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Which fruits will continue to ripen after harvest?

Ripening is the process by which fruits attain their desirable flavor, color and textural properties. **Climacteric fruits can ripen off the plant** once they have reached physiological maturity.

Climacteric fruits include apples, avocado, banana, blueberries, breadfruit, cherimoya, durian, feijoa, fig, guava, kiwifruit, mango, muskmelon, papaya, passion fruit, pears, persimmon, plantain, quince, sapodilla, sapote, soursop, stone fruits (apricots, nectarines, peaches, plums) and tomato. Some of these fruits if harvested "mature-green", can be ripened after harvest and short term storage (for more information on postharvest ripening technologies see Chapter 17 on Destination Handling). Pears are unusual in that they develop the best flavor and texture characteristics when harvested mature-green and ripened off the tree.

Some climacteric fruits give off high quantities of ethylene during ripening. These include apples, apricots, avocados, cantaloupe, kiwifruit, nectarines, peaches, pears, plums and passion fruit. A small dose of ethylene gas will stimulate other climacteric fruits to begin the ripening process. A few climacteric fruits, such as muskmelons, will not increase in sugar content during ripening, but will soften.

Non-climacteric fruits must ripen on the plant if you want a fully mature fruit, since once they have been harvested, no further ripening will occur. Flavor and texture will be of low quality if fruits are picked before fully ripe.

Some non-climacteric fruits include berries, cherries, citrus fruits (lemons, limes, oranges, grapefruits, mandarins, tangerines), cucumber, dates, brinjal (eggplant), grapes, lychee, lady’s fingers (okra), peas, peppers, pineapple, pomegranates, strawberry, summer squash, tamarillo and watermelon.

Non-climacteric fruits will not respond to attempts to ripen them with ethylene gas. A partially red strawberry, for example, will not develop any more color or sweetness after being picked, and will deteriorate faster if exposed to ethylene. Watermelons develop most of their sweetness during the week before they reach full maturity, making early harvest very undesirable.
Maturity Indices

Harvesting crops at the proper maturity allows handlers to begin their work with the best possible quality produce. Fruits harvested too early may lack flavor and may not ripen properly, while produce harvested too late may be fibrous or overripe. Pickers can be trained in methods of identifying produce that is ready to be harvested for your various markets. For example, tomatoes for local immediate marketing can be harvested red ripe, while those for distant markets should be harvested earlier (pink stage) so they are red ripe by the time they reach the destination market.

Many fruits are harvested when sugar content or sugar/acid ratio indicates ripening has begun, with minimum standards set for each cultivar. Vegetables are harvested over a wide range of physiological stages, depending upon which part of the plant is used as food. High quality flavor and texture is often correlated with smaller, immature sized vegetables. The following table provides recommended maturity indices for harvesting high quality produce for selected commodities (sources: US Standards for grades, CA Food and Agricultural Code and UC Postharvest Outreach Program publications).

**WHEN TO HARVEST**

<table>
<thead>
<tr>
<th>When to harvest?</th>
<th>Maturity indices or characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almonds</td>
<td>splitting of hull, separation of hull from shell, development of abscission zone</td>
</tr>
<tr>
<td><strong>Apples</strong></td>
<td></td>
</tr>
<tr>
<td>'Gala'</td>
<td>ground color change from green to light green or white</td>
</tr>
<tr>
<td>'Fuji'</td>
<td>ground color change to light green or white, 180-90 days from full bloom</td>
</tr>
<tr>
<td>'Golden Delicious'</td>
<td>12% SSC, 18 lb firmness</td>
</tr>
<tr>
<td>'Granny Smith'</td>
<td>average starch score of at least 2.5 on the 6 point CA apple starch scale</td>
</tr>
<tr>
<td>'Red Delicious'</td>
<td>11% SSC, 18 lb firmness</td>
</tr>
<tr>
<td>'Rome'</td>
<td>12.5% SSC, 21 lb firmness</td>
</tr>
<tr>
<td>Artichoke</td>
<td>immature, compact, closed buds (smaller buds are often more tender)</td>
</tr>
<tr>
<td>When to harvest?</td>
<td>Maturity indices or characteristics</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Asian pears</td>
<td>skin color change from green to yellowish green, 180 days from full bloom</td>
</tr>
<tr>
<td>Asparagus</td>
<td>cut when spears are 9&quot; (23 cm) long; width is not a maturity indicator</td>
</tr>
<tr>
<td>Avocado</td>
<td>will not ripen on the tree. Minimum dry weight (17 to 20.5% dry weight, standard set for each cultivar)</td>
</tr>
<tr>
<td>Banana</td>
<td>disappearance of angularity in a cross section of the finger</td>
</tr>
<tr>
<td>Basil</td>
<td>before night temperatures drop to below 50 °F (10 °C)</td>
</tr>
<tr>
<td>Beans (green)</td>
<td>pods are filled but not bulging, seeds are immature</td>
</tr>
<tr>
<td>Beans (haricot vert)</td>
<td>very thin, over-mature if they snap when bent</td>
</tr>
<tr>
<td>Beets</td>
<td>adequate size, highest quality beets are less than 2&quot; (5 cm)</td>
</tr>
<tr>
<td>Blueberries</td>
<td>10 to 15% SSC and pH 3.43 to 3.73</td>
</tr>
<tr>
<td>Broccoli</td>
<td>adequate diameter, compact, all florets should be closed</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>buds that are 2.5 to 5 cm (1&quot; to 2&quot;) in diameter</td>
</tr>
<tr>
<td>Cabbage</td>
<td>firm head</td>
</tr>
<tr>
<td>Cantaloupe</td>
<td>3/4 to full slip (abscission from vine) under slight pressure</td>
</tr>
<tr>
<td>Carrots</td>
<td>immature, when roots have reached adequate size, have uniform taper</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>mature curds at least 6&quot; in diameter, compact</td>
</tr>
<tr>
<td>Celery</td>
<td>90 to 120 days after transplantifying</td>
</tr>
<tr>
<td>Chard (swiss)</td>
<td>adequate size of large, outer leaves (cut and come again)</td>
</tr>
<tr>
<td>Cherry (sweet)</td>
<td>minimum SSC 14-15% (dep. on cv.). SSC 16% for highest quality; minimum light red color for most cvs.; red mahogany stage recommended for 'Brooks', 'Gamet', 'Ruby', 'Tulare', 'King'</td>
</tr>
<tr>
<td>Corn (sweet)</td>
<td>silks dried, kernels immature, &quot;milky&quot; when squeezed, tight, green husk</td>
</tr>
<tr>
<td>Cucumber/gherkin</td>
<td>immature, glossy skin, 55 to 60 days from flowering, before seeds fully mature</td>
</tr>
<tr>
<td>Cucumber (lemon)</td>
<td>color change of fruit to yellow or orange</td>
</tr>
<tr>
<td>Endive/escarole</td>
<td>after 2 to 3 weeks of blanching, discard outer leaves</td>
</tr>
<tr>
<td>When to harvest?</td>
<td>Maturity indices or characteristics</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Eggplant (Brinjal)</td>
<td>immature, glossy skin, 40 days from flowering, before seeds fully mature</td>
</tr>
<tr>
<td>Garlic</td>
<td>well-filled bulbs, tops dry down, undercut bulbs and cure</td>
</tr>
<tr>
<td>Ginger</td>
<td>8 to 9 months after planting for maximum yield; minimum of 4.5 months</td>
</tr>
<tr>
<td>Grapes (table)</td>
<td>minimum SSC % of 14 to 17.5, depending on cultivar, SSC/TA of 20 or higher.</td>
</tr>
<tr>
<td>Guava</td>
<td>about 5 months after flowering, color changes to yellowing green</td>
</tr>
<tr>
<td>Jicama</td>
<td>large roots require up to 8 months; can harvest anytime after 3 months</td>
</tr>
<tr>
<td>Kiwifruit</td>
<td>minimum 6.5% SSC, minimum firmness 14 lbf (8mm tip)</td>
</tr>
<tr>
<td>Leeks</td>
<td>diameter from 3/4&quot; to 2 &quot; (5 cm)</td>
</tr>
<tr>
<td>Lemon</td>
<td>30 % or more juice by volume</td>
</tr>
<tr>
<td>Lettuce (bibb, romaine)</td>
<td>adequate size, 60 to 70 days</td>
</tr>
<tr>
<td>Lettuce (head)</td>
<td>compact head, not too firm</td>
</tr>
<tr>
<td>Lettuce (leaf)</td>
<td>adequate size leaves, 50 to 60 days</td>
</tr>
<tr>
<td>Lychee/litchi</td>
<td>total SS:total acid ratio of 30-40, bright red in color</td>
</tr>
<tr>
<td>Mandarines</td>
<td>minimum 8% SSC, about 9 months after flowering</td>
</tr>
<tr>
<td>Mango</td>
<td>changes in shape (increased fullness of cheeks or bulge of shoulder), flesh color to yellowish-orange</td>
</tr>
<tr>
<td>Melon (honeydew)</td>
<td>ground color change to white with greenish tint, slightly waxy peel</td>
</tr>
<tr>
<td>Mushrooms (button)</td>
<td>caps well rounded, partial veil completely intact</td>
</tr>
<tr>
<td>Okra (Lady's fingers)</td>
<td>4 to 7 days after flower has opened (pods 2 to 4&quot; long), not fibrous, tips of pods pliable</td>
</tr>
<tr>
<td>Olives (green)</td>
<td>pale, even green color, exudes a white juice when squeezed</td>
</tr>
<tr>
<td>Olives (black)</td>
<td>dark color, 3 to 4 months after green stage</td>
</tr>
<tr>
<td>Onion (green)</td>
<td>minimum 6&quot; tall</td>
</tr>
<tr>
<td>Onion (dry bulbs)</td>
<td>when 10-20% of tops fall over (withhold irrigation, undercut and cure)</td>
</tr>
<tr>
<td>When to harvest?</td>
<td>Maturity indices or characteristics</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Oranges</td>
<td>SSC/TA ratio of 8 or higher and orange color (refer to Munsell color chart)</td>
</tr>
<tr>
<td>Papaya</td>
<td>skin shows yellowing</td>
</tr>
<tr>
<td>Peaches</td>
<td>ground color change from green to yellow (varies by cultivar)</td>
</tr>
<tr>
<td>Pears</td>
<td>harvest mature-green, less than 60% starch; minimum firmness (standards set by cultivar); 'Bartlett' 20 lbf max, min SSC 10%; 'Anjou' and 'Bosc' optimum 13 lbf; 'Comice' optimum 11 lbf.</td>
</tr>
<tr>
<td>Peas (edible pod)</td>
<td>5 to 7 days after flowering, pods slim, immature and very small</td>
</tr>
<tr>
<td>Peas (green)</td>
<td>pods well filled but not faded in color</td>
</tr>
<tr>
<td>Peppers</td>
<td>fruit size and color (depends on cultivar and intended market)</td>
</tr>
<tr>
<td>Persimmons</td>
<td>'Hachiya' blossom end is orange or reddish color; for other cultivars change to a yellowish -green color</td>
</tr>
<tr>
<td>Pineapple</td>
<td>minimum 12% SSC, max acidity of 1%, change of shell color to yellow at base</td>
</tr>
<tr>
<td>Pistachios</td>
<td>splitting of hull, separation of hull from shell, development of abscission zone</td>
</tr>
<tr>
<td>Plums</td>
<td>skin color changes (varies, minimum color described by CA standards for 56 cultivars)</td>
</tr>
<tr>
<td>Pomegranate</td>
<td>minimum 1.85 % TA and red juice color</td>
</tr>
<tr>
<td>Potatoes</td>
<td>harvest before vines die completely, cure to heal surface wounds</td>
</tr>
<tr>
<td>Radish (spring)</td>
<td>20 to 30 days after planting</td>
</tr>
<tr>
<td>Radish (winter)</td>
<td>45 to 70 days after planting</td>
</tr>
<tr>
<td>Shallots</td>
<td>when tops dry down</td>
</tr>
<tr>
<td>Spinach</td>
<td>adequate size (35-45 days after planting), young or mid-maturity, or cut outer leaves and come again in 3-4 weeks.</td>
</tr>
<tr>
<td>Squash (summer)</td>
<td>immature, glossy skin, 45-50 days from flowering, before seeds mature</td>
</tr>
<tr>
<td>Squash (winter)</td>
<td>rind hard, before hard frost</td>
</tr>
<tr>
<td>Starfruit (carambola)</td>
<td>fully yellow for best quality, 3/4 yellow for long distance marketing</td>
</tr>
</tbody>
</table>
When to harvest?  Maturity indices or characteristics

<table>
<thead>
<tr>
<th>Straberries</th>
<th>CA minimum stds: 2/3 of berry surface showing pink or red color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweetpotatoes</td>
<td>adequate size of roots, before first frost</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>seeds fully developed, gel formation advanced in at least one locale (seeds not cut when fruit is sliced) minimum MG2 maturity stage, refer to color/ripeness charts (page 3.12)</td>
</tr>
<tr>
<td>Turnips</td>
<td>adequate size, before weather warms</td>
</tr>
<tr>
<td>Walnuts</td>
<td>ease of removal of hull, packing tissue browning</td>
</tr>
<tr>
<td>Watermelon</td>
<td>ground spot change from white to creamy yellow, arils around seed have been absorbed, flesh color is &gt;75% red, 10% SSC in flesh near center</td>
</tr>
</tbody>
</table>

**MEASURING MATURITY AND QUALITY**

Since maturity of horticultural crops is closely correlated with quality, it is important to measure changes associated with maturity to determine when the best time will be to harvest. The results of many of the detailed chemical tests described below can instead be obtained very simply by visually inspecting the internal structures and color of the produce, and by tasting the produce for yourself and judging its crispness, firmness, sweetness and/or tartness.

The quality attributes that you measure will be different for different types of crops, and what to look for will depend upon the standardized maturity indices described for each crop on the previous pages. Always start with a representative random sample and make measurements on several units to compensate for variability. Sources for tools and equipment used for quality/maturity determination are included for your use.

**Size and shape**

Size and shape charts and sizing rings are available for many commodities. Size is a useful index for most fruits and vegetables, and shape is useful for determining maturity of bananas (angularity) and mangos (fullness of cheeks and roundness of shoulder).
If you do not have access to suppliers or do not want to spend the money to buy pre-made charts you can make them by using photos or hand drawings of the commodity. These charts can be carried and used by harvesters to visually compare produce still on the plant to a known standard.

Size charts, calipers and rings can be easily used to compare produce to pre-determined maturity standards before it is harvested. Sizing rings with holes for specific sized produce can be easily fashioned from a thin piece of wood or sturdy plastic.

Color
Color charts or guides are available for many commodities. Harvesters can compare the produce in the field with a known standard, and select only those units that are ready for harvest. Color charts are used for determining the maturity of stone fruits, bananas and tomatoes. You can make color charts using photographs, or provide each harvester with a sample unit of produce of the proper color to use as a comparison while harvesting.

<table>
<thead>
<tr>
<th>TOMATO MATURITY AND RIPENESS CLASSES (FOR RED VARIETIES):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature green 1: Seeds are cut when slicing fruit with a sharp knife, no jellylike material in locules.</td>
</tr>
<tr>
<td>Mature green 2: Seeds not cut when fruit is sliced, 'jelly' in at least one locule, minimum harvest stage.</td>
</tr>
<tr>
<td>Mature green 3: Jellylike material well developed but still completely green.</td>
</tr>
<tr>
<td>Mature green 4: Internal red coloration at blossom end, but no external color change.</td>
</tr>
<tr>
<td>Breaker: First external pink or yellow color at the blossom end.</td>
</tr>
<tr>
<td>Turning: 10 to 30% of surface shows color change from green to yellowish, pink or red.</td>
</tr>
<tr>
<td>Pink: 30 to 60% of the surface is colored.</td>
</tr>
<tr>
<td>Light red: More than 60% is pinkish red, but less than 90% of the surface is red.</td>
</tr>
<tr>
<td>Red: More than 90% of the surface shows red color.</td>
</tr>
</tbody>
</table>
"Vine-ripened" tomatoes are usually harvested at the breaker or turning stage, but flavor is enhanced if ripening is allowed to continue on the plant. Since most tomatoes for the wholesale market are harvested mature-green and held in storage for a few weeks before they are marketed to consumers, it is understandable why "store-bought" tomatoes have a reputation for less than delightful flavor. If you are harvesting for local specialty or direct markets, you may receive a higher price if you are willing to harvest light red or full red fruit, and carefully pack and handle fully ripened tomatoes. Tomatoes grown for processing should be harvested when fully red.

**SSC (soluble solids content)**

Sugars are the major soluble solid in fruit juices and therefore soluble solids can be used as an estimate of sweetness. A hand-held refractometer can be used outdoors to measure % SSC (in equivalent degrees Brix) in a small sample of fruit juice. Temperature will affect the reading (increasing about 0.5% SSC for every 5 °C or 10 °F), so you should adjust the measurement for the ambient temperature.

A garlic press works well to squeeze the juice from fruit samples. For small fruits, use the whole fruit, while for large fruits, take a wedge for the stem end to the blossom end and to the center of the fruit. Remove any pulp by filtering the juice through a small piece of cheesecloth. You must clean and standardize the refractometer between each reading with distilled water (should read 0% SSC at 20 °C or 68 °F).

On the next page are some examples of minimum % SSC for selected commodities. If your reading indicates a higher % SSC, then your produce is better than the minimum standard. Strawberries which are of excellent flavor, for instance, would measure 10% SSC.

**Good mango varieties contain over 20% of total soluble solids (sugars).**

Source: Singh, 1998
MINIMUM %SSC for HIGH QUALITY

<table>
<thead>
<tr>
<th>Fruit</th>
<th>%SSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>apricot</td>
<td>10%</td>
</tr>
<tr>
<td>cherry</td>
<td>14-16</td>
</tr>
<tr>
<td>grape</td>
<td>14-17.5</td>
</tr>
<tr>
<td>kiwifruit</td>
<td>6.5</td>
</tr>
<tr>
<td>muskmelon</td>
<td>10</td>
</tr>
<tr>
<td>nectarine</td>
<td>10</td>
</tr>
<tr>
<td>peach</td>
<td>10</td>
</tr>
<tr>
<td>pear</td>
<td>13</td>
</tr>
<tr>
<td>plum</td>
<td>12</td>
</tr>
<tr>
<td>pomegranate</td>
<td>17</td>
</tr>
<tr>
<td>strawberry</td>
<td>7</td>
</tr>
</tbody>
</table>

Firmness

The degree of softness or crispiness can be estimated by squeezing produce, or by taking a bite. Objective measurements can be made with inexpensive penetrometers. The most common way to measure firmness is resistance to compression or pounds-force (lbf). The Effi-gi fruit penetrometer is a hand-held probe with a gauge for pounds-force.

To measure firmness, use fruit that are uniform in temperature, since warm fruit are usually softer than cold fruit. Use fruits that are uniform in size, since large fruit are usually softer than smaller fruit. Make two puncture tests per fruit on larger fruits, once on opposite cheeks, midway between stem and blossom ends. Remove a disc of skin (larger than the tip to be used) and choose the appropriate plunger tip (see below). Hold the fruit against a stationary, hard surface, and force the tip into to fruit at a uniform speed (take 2 seconds) to the scribed line on the tip. Take the reading to the nearest 0.5 lb-force.

Appropriate Effi-gi plunger tip sizes to use when measuring firmness in selected fruits:

- **1.5mm (1/16 inch)**: Olive
- **3 mm (1/8 inch)**: Cherry, grape, strawberry
- **8 mm (5/16 inch)**: Apricot, avocado, kiwifruit, mango, nectarine, papaya, peach
- **11 mm (7/16 inch)**: Apple
Calibrate firmness testers by holding the tester vertically and placing the tip on the pan of a scale. Press down until the scale registers a given weight, then read the firmness tester. Repeat 3 to 5 times, if you find the instrument reads the same as the scale, it is ready to use. You can adjust the penetrometers by inserting washers in the appropriate locations (follow the instructions that come with the instrument).

**Titratable acidity (% TA)**

The level of acidity in produce affects flavor (tartness or sourness). Most people may vaguely remember learning how to measure acidity in chemistry class, but probably never thought you'd ever have to use it during your daily life. Luckily the process is straightforward and the formula is simple. Titratable acidity can be determined by titrating a known volume of fruit juice with 0.1 N NaOH (sodium hydroxide) to an end point of pH=8.2

In practice, NaOH solution is added to the fruit juice until the pH changes to 8.2 as indicated by phenolphthalein or by using a pH meter. Use 1 to 10 ml of juice, and add about 20 ml bottled water and a few drops of phenolphthalein. (The actual amount of juice you use depends on the expected acidity; if the sample is highly acid, use less to reduce the amount of NaOH required to titrate the solution.) Stir constantly while very slowly adding the NaOH solution from a calibrated container (such as a buret or small graduated cylinder marked in ml), and stop adding NaOH when the water/juice mixture turns pink and stays pink when you stir vigorously. If you are using a pH meter, stop adding NaOH when the meter reaches 8.2

Plug your numbers into the formula below to calculate the % TA of the commodity.

\[
\text{% TA} = \frac{\text{ml NaOH} \times \text{N(NaOH)} \times \text{acid meq. factor} \times 100}{\text{ml juice titrated}}
\]
For berries, citrus fruits and pineapple, use citric acid (acid meq. factor = 0.064)
For apples, pears, peaches and nectarines, use malic acid (acid meq. factor = 0.067)
For grapes, use tartaric acid (acid meq. factor = 0.075)

Example: 10 ml of ‘Perlette’ grape juice in 20 ml water is titrated with 8 ml 0.1N NaOH.

\[
\text{% TA} = \frac{8 \text{ ml NaOH} \times 0.1\text{N(NaOH)} \times 0.075 \times 100}{10 \text{ ml juice titrated}} = 0.6\%
\]

Sugar/Acid ratio
Knowing the sugar content alone is not enough to measure maturity and quality of citrus fruits and grapes. In these cases, the ratio of sugar to acid content is a much better predictor of high quality produce. You need to measure both %SSC and % TA, then divide SSC by TA to calculate the ratio of the two.

Examples of minimum SSC/TA ratio:
grapefruit 6.0
mandarin 8.0
orange 8.0
grape 20.0

Sources of quality/maturity measurement instruments
McCormick Fruit Tech (sizers, sizing rings, refractometers, penetrometers, pH meters)
615-B S. 48th Ave.
Yakima, WA 98908
Phone (509) 966 3999
FAX (509) 966 7635

DeltaTrak (pH meters)
P O Box 398
Pleasanton, CA 94566
Phone (800) 962-6776
FAX (510) 856 1147
Fruit and Vegetable Quality Control, CA Department of Agriculture
(color charts, sizers, Granny Smith Apple Starch Scale)
1220 N Street, Room A-265
Sacramento, CA 95814
Phone (916) 654-0919
FAX (916) 654 0666

International Ripening Corporation (refractometers, temperature probes, calipers, sizer rings, pressure testers, pH meters, chlorine meters)
1185 Pineridge Road
Norfolk, Va 23502
Phone (800) 472 7205

Radiometer America, Inc. (titrators)
811 Sharon Drive
Westlake, Ohio 44145
Phone (800) 0600, Extension 72
FAX (216) 835 8118

VWR (refractometers, titrators, penetrometers)
P O Box 7900
San Francisco, CA 94120
Phone: (415) 330 4017
FAX (415) 330 4122

To request a catalog, contact:

Fisher (unbreakable buret, buret stand and clamp, glassware and magnetic stir bars and stir plates)
Phone: (800) 766 7000   FAX: (800) 926 1166

Sigma Chemical Co. (0.1 N NaOH in pre-measured vials, phenolphthalein pH indicator)
Phone (800) 325 3010   FAX (800) 325 5052
Harvesting Tools and Containers
To protect produce quality and safety, keep your harvesting tools and containers clean. Use a 1 part chlorine bleach :1 part clean water solution to clean tools and plastic or wooden picking containers before use each day. Use containers that are smooth on the inside, or provide clean, disposable liners made from paper or cardboard.

Picking baskets, bags and buckets come in many sizes and shapes. You can reduce some of the drudgery of harvesting and minimize damage to produce by providing containers that can be easily carried and filled by workers. Portable containers that can be opened on the bottom allow harvesters to gently fill larger field containers without ‘dumping’ produce. With a bit of creativity, you can even construct picking containers that allow workers to sort while picking.

Raspberry sorting cups:
(worn as a belt around the waist)

Picking bag: fabric bag with openings on both ends
(worn over the shoulders with an adjustable harness)
Harvesting containers can be made by fitting fabric over the opened bottom of ready-made baskets, fitting readymade canvas bags with adjustable harnesses, or by simply adding some carrying straps to a small basket. All of these will reduce mechanical damage to produce if used properly by harvesters and not over-loaded.

Picking Bags/Baskets (Source: Friend Manufacturing Co., 1993):

Picking poles and catching sacks can be made by hand or purchased from horticultural supply companies. A long pole is attached to a collection bag, allowing the harvester to cut and catch produce growing on a tree without having to climb a ladder. The collection bags can be hand woven from strong cord or sewn from canvas. The hoop used as the collection bag rim and sharp cutting edges can be fashioned from sheet metal, steel tubing or recycled scrap metal.
Harvesting practices should cause as little mechanical damage to produce as possible. Gentle digging, picking and handling will help reduce crop losses. For some crops, a natural break point forms at the junction of the stem and the stalk when produce is mature. Harvesters should grasp the product firmly but gently and pull upward as illustrated below. Wearing cotton gloves, trimming fingernails, and removing jewelry such as rings and bracelets can help reduce mechanical damage during harvest.

- Pick carefully to avoid damaging plants and trees:

Some fruits such as citrus, avocados and mangoes, need to be clipped or cut from the parent plant. Clippers or knives should be kept well sharpened and clean. Penduncles, woody stems or spurs should be trimmed as close as possible to prevent fruit from damaging neighboring fruits during transport.
Pruning shears can be used for harvesting fruits and some vegetables. A variety of styles are available as hand held or pole models, including shears that cut and hold onto the stem of the cut product. This feature allows the picker to harvest without a catching bag and without dropping fruits.

- **Straight bladed hand shears for fruits and flowers.**
- **Thin curved blade for grapes and fruits.**

- **Cut and hold hand shears:**
- **Clipper for citrus fruits:**

- **Pole mounted cut and hold picking shears:**

**Tripod ladders**
A ladder with three legs is very sturdy and more stable than a standard ladder. The single pole of the front leg lets the picker get safely into the canopy of the tree to harvest fruits without damaging branches.
Harvesting Containers
Plastic crates are relatively expensive to purchase, but are very durable, reusable and easy to clean. They have the characteristics you really want-- stacking strength, ventilation holes and long life. You can use them for harvest, storage, cooling procedures, transport and even for display in retail markets.

If you decide to buy plastic crates, look for crates that can be nested when empty to save space in storage or transport. Various brands and styles are manufactured, but all can be stacked securely if they are not over-filled.

Stackable, reusable plastic crates:

Plastic vented crate:

Steel buckets are a good investment since they will last for many years and can easily be cleaned. The inside surfaces are smooth and will not damage delicate crops if the buckets are not overloaded.

Steel bucket:
FIELD PACKING

Selection, sorting, trimming and packing the produce in the field at the time of harvest is known as "field packing", and has great potential to reduce mechanical damage by reducing the number of postharvest handling steps between the field and the consumer. Any practice that reduces the number of times the produce is handled will help reduce postharvest losses. Field packing often also reduces costs since you won't need to build and manage a packinghouse, and can reduce handling problems such as "shaker" problems in melons (where the seed cavity loosens from the pericarp wall), while allowing producers to market produce of the optimum quality and highest value.

When crops are field packed the picker harvests and then immediately packs the produce after minimal handling. Fruits can be harvested at a riper, more flavorful stage, and vegetables can be handled while very young and delicate. Strawberries are generally field packed, since even a small amount of handling will damage these soft fruits. When lettuce is field packed, several wrapper leaves are left on the head to help cushion the produce during transport.

Providing workers with a small cart can help reduce the amount of bending and lifting the picker has to do during harvest. The carts shown here have a single wheel in front, and can be pushed along the row ahead of the picker. Filled cartons should be immediately moved into the shade and then into the cooler as soon as possible.
Small, mobile field packing stations are designed to be moved along with the packers and to provide shade for packing operations. A movable cart should provide a comfortable place for packers to fill boxes and have a wide roof to provide shade. The cart illustrated here was designed to be pushed along the outer edge of the small field where a table grape harvest is taking place.

Carts for field packing can also be designed to be pulled by a small tractor into the field when the crop is harvested. This type of cart can be used for field packing many types of crops. The roof folds down for easy transport, and opens up to provide a wide area of shade for the packers and the commodity. The cart design can be modified as needed to suit various products and different operations.

FIELD PACKING STATION:
- Mobile, shaded,
- Roof extensions
- can be closed
during transport
- via tow vehicle.
COMPARISON OF ESTIMATED COSTS AND EXPECTED BENEFITS RELATED TO TRADITIONAL PACKHOUSE OPERATIONS OR FIELD PACKING FRESH PRODUCE.

Costs:
Equipment (carts, mobile packing stations or wagons equipped with shade)
Trained Labor
Packages suited to field packing, cooling

Benefits:
No packinghouse to maintain
Less damage to produce (no dumping, resorting)
Quick handling (less water loss)

Example 1:
If 1000 lbs of table grapes are harvested and field packed by 4 trained workers (1100 lbs of grapes are picked trimmed, packed 25 lbs per carton, and SO₂ pads inserted) in 2 hours. Losses are calculated to be 10% compared to the typical 20% losses associated with grading, trimming, packing and cooling grapes in a local packinghouse. Workers are paid $1.00 more per hour than usually paid to field laborers who harvest crops to be transported to the packinghouse.

Costs:
Additional labor cost $1.00 x 4 workers x 2 hours = $8.00/day
Equipment -- shaded packing station $150.00 (used for several seasons)
Materials -- same grape lugs and pads used in packinghouse = $ 1.50 per set
Cooling -- same cost as for packinghouse

Benefits:
Packinghouse power, water and ventilation costs savings = $10 /day
Postharvest losses reduced to 10% (4 additional cartons per day from the vineyard).
100 lbs x 0.50 per lb = $50

Return on investment:
(for simplicity, assume 20 days of harvesting are equal to one month of sales)
Difference in costs for field packing = $15 + $8/day for 20 days = $310
Savings compared to current practice = ($10/day - $6/day for extra packages) x 20 days = $4 x 20 = $80
Change in sales using field packing = $50/day x 20 days = $1000

Calculate ROIC in months to pay for investment:
(Difference in costs - savings) / Change in Sales per month = Months to pay for investment.

($310 - $80) / $ 1000 per month = 0.23 Months or 4.6 days
Example 2:
If 1000 lbs of table grapes are harvested and field packed by 4 trained workers in India (500 kg of grapes are picked trimmed, packed into wooden crates) in 2 hours. Losses are calculated to be 10% compared to the typical 20% losses associated with transport, grading, trimming, packing and cooling grapes in a local packinghouse. Workers are paid Rs 20 more per day than usually paid to field laborers who harvest crops to be transported to the packinghouse.

Costs:
Additional labor cost (4 workers x 2 hours) = Rs 20/day
Equipment -- shaded packing station Rs 2200 (used for several seasons)
Materials -- same grape lugs used in packinghouse (Rs 1/ 1 kg produce packed)
Cooling -- same cost as for packinghouse

Benefits:
Packinghouse power, water and ventilation costs savings = Rs 100/day
Postharvest losses reduced to 10% (4 additional cartons per day from the vineyard).
50 kg x Rs 30/ kg = Rs 1500

Return on investment:
(for simplicity, assume 20 days of harvesting are equal to one month of sales)
Difference in costs for field packing = Rs 2200 + Rs 20/day for 20 days = Rs 2600

Savings compared to current practice = Rs 100/day - Rs 50/day for extra packages) x 20 days
=Rs 50 x 20= Rs 1000

Change in sales using field packing = Rs 1500/day x 20 days = Rs 30,000

Calculate ROIC in months to pay for investment:
(Difference in costs - savings) / Change in Sales per month = Months to pay for investment.

(Rs 2600 - Rs 1000) / Rs 30,000 per month = 0.086 Months or 1.7 days
Curing root, tuber and bulb crops
Mechanical damage can be extensive when harvesting root, tuber and bulb crops. Bruises and cuts allow the produce to lose water more rapidly, while wound-induced increases in respiration will lead to increased rates of water loss, decay and physiological deterioration.

Fortunately much of this damage can be corrected if you are willing to take some time and create the proper conditions for these crops to "heal" before they are removed from the field. Curing root and tuber crops such as sweetpotatoes, potatoes, cassava and yams is especially important practice if these crops are to be put into storage for a month or more. The reduction in water loss and decay rates will more than pay for the cost of curing.

Curing practices for root and tuber crops require holding the produce at high temperature and high relative humidity for several days while harvesting wounds heal and a new, protective layer of cells form. The best conditions for curing vary among crops as shown in the following table, but in practice curing is usually done under ambient field conditions. At the time indicated as the minimum, begin to check the produce for signs of proper curing (thicker, toughened peel; healed over cut surfaces) until it is ready for removal from the field for postharvest handling, storage and marketing.

<table>
<thead>
<tr>
<th>RECOMMENDED CURING CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commodity</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Potato</td>
</tr>
<tr>
<td>Sweetpotato</td>
</tr>
<tr>
<td>Yams</td>
</tr>
<tr>
<td>Cassava</td>
</tr>
</tbody>
</table>

Curing onions and garlic refers to the practice of allowing the external layers of skin and neck tissue to dry out directly following harvest, prior to handling and storage. If forced heated air is used for curing onions and other bulbs, one day or less at 35 °C (95 °F) and 60 to 75% relative
humidity is recommended. The dried layers of 'skin' then protect the produce from further water loss during storage.

Field Curing
Root and tuber crops
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. The stack should be left for about four days.

Bulb crops: onions and garlic
Onions and garlic can be cured in the field in regions where harvest coincides with the dry season. If local weather conditions are dry and warm, these crops can be undercut in the field and left there to dry for five to ten days. The crops can be cured either in windrows or after packing into large fiber or net sacks. The dried tops of the plants or a light covering of dry straw can be arranged to cover and shade the bulbs during the curing process, protecting the produce from excess heat and sunburn. The produce can be left in the field for five days, then checked daily until the outer skin and neck tissues are properly dried. Curing may take up to ten days, depending on weather conditions. The best scale color is obtained when onions are cured at 25 to 32 °C (77 to 90 °F).
Curing assisted by shade and ventilation

The curing of bulb crops can be assisted by the use of ventilated sheds in regions where solar radiation and/or relative humidity is high or natural air movement is low. Produce in sacks should be stacked in the shade on canvas tarpaulins under one or more ceiling fans.

Emergency Curing

If conditions such as rain or flooded fields do not permit field curing and curing facilities are not available, a temporary tent can be used for curing onions. In the example illustrated below, the tent is constructed from large tarps. Heated air is forced into a hollow area (known as a plenum) at the center of the bins of produce. Several fans are used to circulate the warm air through the onions while they are curing.
COSTS AND BENEFITS OF CURING ROOT, TUBER AND BULB CROPS

Example 1: Curing sweetpotatoes in California

Costs:
Heaters-- $175.00 used over many seasons
Fans-- $150.00 used for many seasons
Fuel-- $6.00 per 1000 lb lot
Labor-- 1/2 hour at $7.00/hour to load produce into the curing room, set up and monitor the curing process.
Total recurring costs = $6 + $3.50 = $9.50

Benefits:
Reduced water loss (about 2% per month compared to uncured loss of 3% per month)
Reduced losses due to decay (20% after 4 months compared to 60% for uncured)
Longer storage life (4 to 6 months)

1000 lbs of sweetpotatoes are cured for 5 days at 85 F and 90% RH at a cost of $9.50 ($0.01 per lb). Market value is $15.00 per 40 lb carton.

Produce available for marketing after 4 months in storage: 20 cartons = $300
(compared to 9 cartons for uncured = $135)
Profit = ($300-135) - $9.50 = $155.50

Return on investment:
Capital costs for the heaters and fans = $325
The first three loads of sweetpotatoes cured will pay for the fans and heaters, and each additional 1000 lb load that is cured before storage will result in an additional profit of $155.50 compared to uncured sweetpotatoes.

Example 2: Curing sweetpotatoes in India

Costs:
Heaters and fans-- Rs 9000 used over many seasons
Fuel-- Rs 1000 per 1000 kg lot
Labor-- 1/2 hour to load produce into the curing room, set up and monitor the curing process
(very low labor costs).
Total recurring costs = Rs 1000

Benefits:
Reduced water loss (about 2% per month compared to uncured loss of 3% per month)
Reduced losses due to decay (20% after 4 months compared to 60% for uncured)
Longer storage life (4 to 6 months)
1000 lbs of sweetpotatoes are cured for 5 days at 30°C and 90% RH at a cost of Rs 1000 (Rs 1 per kg) and placed into storage for 4 months.

<table>
<thead>
<tr>
<th></th>
<th>Cured</th>
<th>Uncured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>cost of curing</strong></td>
<td>Rs 1000</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Postharvest losses</strong></td>
<td>20% (200 kg)</td>
<td>(600 kg)</td>
</tr>
<tr>
<td><strong>produce available for marketing</strong></td>
<td>800 kg</td>
<td>400 kg</td>
</tr>
<tr>
<td><strong>market value</strong></td>
<td>Rs 6/kg</td>
<td>Rs 5/kg</td>
</tr>
<tr>
<td><strong>potential sales</strong></td>
<td>Rs 4800</td>
<td>Rs 2000</td>
</tr>
</tbody>
</table>

Return on investment:
The first three loads of sweetpotatoes cured will pay for the fans and heaters, and each additional 1000 kg load that is cured before storage will result in an additional profit of Rs 2800 compared to uncured sweetpotatoes.

**SOURCES OF TOOLS, EQUIPMENT AND SUPPLIES FOR HARVESTING AND PREPARATION FOR MARKET**

- **baskets/buckets/crates/barrels**: Adelman-Fisher Packaging, Bradbury Barrel Company, Texas Basket Company
- **buckets/bucket straps**: Duluth Trading Company
- **bucket liners/bucket skirts**: Rod Smith Canvas Co.
- **fruit pickers (long poles with basket)**: Burpee's
- **gloves**: Pacific 4/Ranch Brand Supply Co.
- **harnesses**: Orchard Equipment and Supply Co., Rod Smith Canvas Co.
- **harvesting aids for field packing**: Ramsay Welding and Machine Inc.
- **harvesting equipment/potatoes**: Thomas E. Moore, Inc.
- **harvesting tools**: Farber Bag & Supply Co., Orchard Equipment and Supply Co.
- **ladders**: Orchard Equipment and Supply Co.
nut harvesters, shakers
picking containers
potato separator/cleaner
reusable plastic containers
safety supplies
shade cloth
U-pick containers

N H Savage Equipment Inc.
Buckhorn
Friend Manufacturing Corp.
Glacier Valley Enterprises
Hydro-Gardens, Inc.
Orchard Equipment and Supply Co.
Rod Smith Canvas Co.
Sorting Technology, Inc.
Buckhorn
Pacific 4/Ranch Brand Supply Co.
local hardware and garden supply stores
Rockford Package Supply Inc.

For Addresses/Phones of suppliers, please refer to Appendix D.

REFERENCES


Friend Manufacturing Corporation, Prospect Street, P.O Box 385, Gasport, New York 14067, USA


PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
CHAPTER 4

PACKINGHOUSE OPERATIONS
AND PACKING PRACTICES

Packinghouse operations can be as simple as moving produce from a field lug directly into a shipping container, or may include a variety of postharvest handling practices, from cleaning, waxing, sizing, and quality grading to color sorting or hot water dips. It is important to minimize mechanical damage by avoiding drops, rough handling and bruising during the steps of packinghouse operations. Recent studies have shown that average levels of postharvest cherry damage in California packinghouses is extremely high. About 28% of the fruits were bruised between harvesting and arriving at the packinghouse, and another 23% were damaged during mechanical sorting and packing. Hand-sorting by trained workers greatly reduces the rate of damage.

Make sure your packing operations take place in a shaded area if you don't have a permanent roofed structure. Shade can be created using whatever materials are locally available, such as shadecloth, woven mats, plastic tarps or a canvas sheet hung from temporary poles. Shade alone can reduce air temperatures surrounding the produce by 8 to 17 °C (15 to 30 °F).

This chapter describes the postharvest handling steps that typically take place in a packinghouse, and provides examples of practices and simple equipment that will help you to sort, handle and protect produce quality and food safety during market preparation and packing. For those who
would like to reduce the amount of handling steps involved in packing, 'ranch packing' methods can be adopted for most produce. Completing the worksheets at the end of Part I will assist you in determining whether these practices and postharvest technologies can be economically beneficial for your operation.

**GENERAL DOs AND DON'Ts FOR PACKING HIGH QUALITY FRESH PRODUCE**

Provide shade for harvested produce waiting to be sorted and packed.

Grade the roads and entryways between the field and the packing facility.

Avoid locating the packhouse directly next to an unpaved, dusty road.

Minimize mechanical damage--avoid drops, throwing and rough handling.

Use hand-carts to assist workers in the careful movement of produce.

Pre-sort to remove damaged, diseased, immature or overmature produce.

Keep the packing line as simple as possible and keep it clean.

Provide sanitary facilities (bathrooms and hand washing stations) for workers.

Hand sorting can reduce damage if workers are well-trained and provided with appropriate tools and equipment.

Know the requirements and postharvest handling recommendations for the crops you handle.

Consider the use of a water dump system for handling water-tolerant produce.

Do NOT wash green beans, cabbage, okra, peas, peppers or summer squash before packing.
Do's and Don'ts continued:

Monitor chlorine levels in wash water to ensure adequate levels (100 to 150 ppm)

Provide cushioning on all sharp edges and rough surfaces of packing tables or the washing/sorting/grading/packing line. Clean the tables regularly.

Provide good lighting so that workers can see properly to sort and grade produce.

When trimming produce, do NOT remove more than necessary for high quality.

Dispose of waste materials properly.

Use appropriate postharvest treatments (waxing, hot water dips, SO₂, fungicides, etc.) to reduce the rate of decay or water loss.

Do NOT use any chemical treatments that are not specifically recommended for your commodity.

Pack securely to immobilize produce, but do not overfill or underfill packages.

Use "ranch packing" practices whenever possible to reduce handling damage.

Hand packing allows you to handle delicate vegetables and ready to eat, ripe fruits for specialty markets.

Cool the produce as soon as possible after harvesting.

The Indian Standards Institution has specified four grades for tomatoes:

- Super A
- Super
- Fancy
- Commercial
THE PACKINGHOUSE

When deciding upon where to locate a packinghouse, consider ease of access to both the field and the market point. You will need to provide adequate space for transport vehicles or people carrying produce to enter and leave the packinghouse and consider factors such as the ease of access for laborers and where best to provide parking space for their private vehicles. The size of the packinghouse, volume of produce and the number of employees you have will determine the number of docks, packing stations, restrooms, and other facilities you will need.

In the simplest packinghouse, produce is delivered in picking containers, immediately after harvest, directly to the packers. The packers then sort, grade, size and pack the produce directly into appropriate containers. In this case, each worker must be knowledgeable regarding produce defects, grade and size requirements, and packing methods. If you are packing delicate produce such as tree-ripened fruits and do not want to field pack, this simple 'ranch packing' method is the next best choice, since handling is minimized and high quality, ripe fruits can be packed safely as long as they are handled gently. As the size and complexity of the packinghouse increases, more operations and workers trained in specific tasks might be added.

Any of the following postharvest handling steps may help you to protect the value the produce you produce and market.

PRE-SORTING
WASHING/CLEANING
TRIMMING/TOPPING
WAXING
SIZING/GRADING
BUNCHING/WRAPPING
POSTHARVEST TREATMENTS
PACKING
COOLING
DUMPING
Unless produce is field packed, it must somehow be removed from the field bin or harvesting container and packed into a shipping container. The first step of handling is known as "dumping" the produce from the field container. Dumping must always be done gently, whether you are using water assisted methods or dry dumping.

Wet dumping can decrease bruising and abrasions by using moving, chlorinated (100-150 ppm) water to receive produce. You can dump produce into a water-filled basin or immerse the whole container to float produce out of the field bin and carry delicate produce toward the graders and packers. Wet dumping can reduce mechanical damage, since water is more gentle on produce than a hard surface of a sorting table or a conveyor belt. If the specific density of the produce, such as apples, is lower than that of water, the produce will float naturally. For some produce, such as pears, salts (such as sodium lignin sulfonate, sodium silicate or sodium sulfate) must be added to the water to increase its specific density and make the fruits float.

When using dry dumping, having padded, sloped ramps or moving conveyor belts will decrease injuries to produce. The field container should be emptied slowly and gently onto a tilted ramp with padded edges.

PRE-SORTING
Pre-sorting produce is usually done to eliminate injured, decayed, or otherwise defective produce before cooling or additional handling. These un-marketable units are sometimes called "culls". Pre-sorting will save energy and money because culls will not be handled, cooled, packed or transported. Removing decaying produce items is especially important, since this will limit the spread of infection to other units during handling. When packing organically grown produce, pre-sorting is especially critical since pre-harvest chemical controls and postharvest pesticides are not being used during packing and storage.

CLEANING/WASHING
For some commodities, such as kiwifruits and avocados, dry brushing may be sufficient to clean the produce. Other commodities, however, such as bananas and carrots, require washing. The choice of brushing and/or washing will depend upon both the type of commodity and the type of
contamination. Certain produce should not be washed because washing will remove the natural waxes that protect produce from water loss and disease.

- **Wash before cooling and packing:** tomatoes, cucumbers, leafy greens
- **Wash to remove latex, 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

Sanitation is essential, both to control the spread of disease from one item to another, and to limit spore buildup in wash water or in the packinghouse air. Chlorine treatments (100 to 150 ppm available Cl) can be used in wash water to help control inoculum buildup during packing operations. There is some variation in the strength of chlorine bleach available commercially in different countries, but a rule of thumb is to use 1 to 2 mls of chlorine bleach per liter of clean water (1 to 2 ounces of chlorine bleach per 8 gallons). More chlorine will be required if temperatures are high or water contains a lot of organic matter. Maintain the pH of the wash water between 6.5 and 7.5 for best results.

![Graph showing chlorine as HOCl and OCl⁻ vs. pH.](image)

You can use a variety of methods for washing produce, but a constant flow of clean water is essential. This tank for washing produce is made from galvanized sheet metal. A baffle made of perforated sheet metal is positioned near the drain pipe and helps to circulate water through the produce. Fresh water is added under pressure through a perforated pipe, which helps move
floating produce toward the drain end of the tank for removal after cleaning. Improvements to the
design might include a removable trash screen in front of the baffle, and/or a recirculating system
for the wash water (with the addition of chlorine).

TRIMMING/TOPPING
Certain crops should be trimmed or topped to remove inedible plant material or excess outer leaves before packing. This simple practice also helps to reduce the high rate of water loss which occurs through the leaves of root and tuber crops.

WAXING
Waxing of immature fruit vegetables such as cucumbers and summer squash, mature fruit vegetables such as eggplant, peppers and tomatoes, and fruits such as apples and peaches is a common postharvest practice. Food grade waxes are used to replace some of the natural waxes removed during harvesting and sorting operations, and can help reduce water loss during handling and marketing. If produce is waxed, the wax coating must be allowed to dry thoroughly before further handling.
Waxing cassava roots can greatly extend their usually short postharvest life. While cassava has a typical shelf life of 2 weeks at 2 to 4 °C, waxing can increase shelf life to 1 to 2 months.

The waxing device illustrated here was designed in Tasmania to be used after a series of dry brushes on a small-scale packinghouse conveyor line. Industrial wool felt is used to distribute the liquid wax to the fruits or vegetables from a trough made the same width as the conveyor belt. Evaporation of wax from the felt is reduced by covering the felt with a layer of heavy polyethylene sheeting.

SIZING/GRADING

Sizing produce is usually a part of grading, and you must meet the standards for any produce packed for sale through traditional wholesale markets. Sizing produce is optional for direct marketers, but may be worthwhile if certain size grades receive a higher price than others.

Another reason to desire uniform sized produce is for place-packing produce by count or for accurately filling trays. When using these packing methods, if non-uniform sizes are packed together, some produce is not immobilized within the container while other units may be squashed.
Place-pack:

Under the AGMARK scheme, Indian Bartlett pears are graded into 4 classes:

- Extra large (2 3/4" diameter)
- Large (2 1/2")
- Medium (2 1/4")
- Small (2")

Source: Singh, 1998

In most low-input packinghouses, manual sizing is still commonly practiced. Operators should be trained in selecting the size desired and to either directly pack the items into containers or place the selected produce gently into a bin for packing further down the line. Sizing can be done subjectively (visually) with the use of standard size gauges. Examples of the smallest and largest acceptable sizes for each product can be placed within view of the operator for easy reference. Hand held sizers are used for a variety of products.

Round produce units can be easily graded by using sizing rings. Rings can be fashioned from wood or purchased ready-made in a wide variety of sizes.

Single size hand held sizing ring:

Multiple size rings:

Source: FAO. 1989
Several types of mechanical sizers are available for small scale operations. One type is composed of a long slanted tray with a series of openings which converge (largest at the top, smallest at the bottom). This type of sizer works best with round commodities.

The citrus sizer illustrated here is composed of a rectangular chute made of plywood, padded with foam to prevent bruising. The fruit is gently dumped into the octagonal platform at the top of the chute, then allowed to roll, one by one, down toward a series of constrictions. Large fruits are caught in the first constriction, medium in the second, and small in the last. Undersized fruit passes out the end of the chute directly into a container. Workers must manually remove each fruit and place it into the appropriate size container before the next fruit can pass through the chute. The sizing is fastest when five workers are stationed at the sizer.


The onion sizing table illustrated on the next page is one of three (or more) tables used in a series. Each table is made of plywood, and has been perforated with holes of a specific size. The first table has the largest size holes, and the last table has the smallest holes. A layer of onions is dumped onto the first table and moved by hand toward the holes. Those that do not pass through are classified as "extra-large" in size. Those that pass through fall into a mesh bag and roll into a large padded container. This container of onions is then dumped onto the second sizing table. The onions that do not pass through the holes in that table are classified as "large", and so on.
Reduce potential damage to the produce by minimizing the height of the drop into the container, using a thick layer of padding in the collection container, and making sure sorters dump the onions onto the table as gently as possible.


A wide variety of sizers are designed as conveyors fitted with chain or plastic belts with various sized openings, and are useful for sizing most commodities. Another simple method for mechanical sizing in a small-scale packinghouse is to use a set of diverging bar rollers where the smallest sized produce falls through the rollers first to a sorting belt or bin, and larger sized produce falls between successively more divergent rollers. It is important to minimize the height of drops to prevent bruising produce.
Sorting by maturity can maximize the market value of crops such as stone fruits, mangoes and tomatoes. Mature green fruits can be stored for a short time (one to two months under proper conditions), then ripened when there is market demand.

<table>
<thead>
<tr>
<th>RIPE TOMATOES CAN BE FURTHER SORTED AS FOLLOWS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full ripe, ready to eat → local market, immediate sale or processing to paste or dried forms</td>
</tr>
<tr>
<td>Partially ripe (pink or turning) → transport to regional or distant markets</td>
</tr>
<tr>
<td>Breaker stage (10 days from full red at 18 °C or 64 °F) → short term storage or long distance shipping</td>
</tr>
</tbody>
</table>

**BUNCHING/WRAPPING**

Some commodities are easier to handle and pack if they are bunched and/or wrapped. Wrapping cauliflower in vented polyethylene film can reduce damage to the delicate heads by protecting against abrasions during postharvest handling. Small items such as radishes can be bagged and packed as a unit of 0.5 lb or 1 lb, while green onions, broccoli and asparagus spears are often bunched with a wide rubber band before packing.

**POSTHARVEST TREATMENTS**

There are some chemicals used in the packinghouse that are generally recognized as safe (GRAS) which can help control physiological disorders and a variety of molds and fungi on fruit crops.

Calcium Chloride

A solution of CaCl₂ (2 to 3% in clean water) can be prepared as a dip, and acts to control bitter pit in early harvested, lower maturity apples.
Chemical fungal control:
Sulfur dioxide (SO₂) is used as a fumigant or a water spray (0.5% for 20 minutes for the initial treatment, then 0.2% for 20 minutes at 7 day intervals) on grapes to control Botrytis, Rhizopus and Aspergillus fungi. You need to provide a location such as a gas-sealed room or outdoor tent, where fumigation can be done without the gas leaking into work areas.

Careful calculation of the amount of sulfur dioxide required to treat grapes can greatly reduce the need to vent or scrub the storage air after fumigation to remove excess SO₂. For information on the "total utilization" fumigation technique that has been developed for treating grapes with sulfur dioxide, see Luvisi (1992).

Sulfur is used on bananas as a paste (0.1% active ingredient) to control crown rot fungi.

Sodium or potassium bisulfite:
Bisulfites are used in a sawdust mixture (usually contained within a pad that can be placed inside a carton) to release SO₂ for control of molds on grapes (5 grams for a 24 to 28 lb box).

Chemical Bacterial control:
Bacterial soft rot (Erwinia) of cabbage can be controlled by using lime powder or a 15% solution of alum (aluminum potassium sulfate) in water. After treatment of the butt-end of the cabbage heads, the produce should be allowed to dry for 20 to 30 minutes before packing. Lime powder can be easily applied by pressing the butt-end of the cabbage into a small pile of powder.

Applying alum solution
(spray or brush on):
Heat Treatments

Postharvest heating using hot water or hot forced-air to kill or weaken pathogens can be used as a method for decay control in fresh fruits and vegetables. Fruit should not be handled immediately after heat treatment. Whenever heat is used with fresh produce, cool water showers or forced cold air should be provided to help return the fruits to their optimum temperature as soon as possible after completion of the treatment.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Pathogens</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>Possible injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Gloeosporium sp.</td>
<td>45</td>
<td>10</td>
<td>Reduced storage life</td>
</tr>
<tr>
<td></td>
<td>Penicillium expansum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grapefruit</td>
<td>Phytophthora citrophthora</td>
<td>48</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Green beans</td>
<td>Pythium butleri</td>
<td>52</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sclerotinia sclerotiorum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemon</td>
<td>Penicillium digitatum</td>
<td>52</td>
<td>5-10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phytophthora sp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mango</td>
<td>Collectotrichum gloeosporioides</td>
<td>52</td>
<td>5</td>
<td>No stem rot control</td>
</tr>
<tr>
<td>Melon</td>
<td>Fungi</td>
<td>57-63</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>Diplodia sp.</td>
<td>53</td>
<td>5</td>
<td>Poor degreening</td>
</tr>
<tr>
<td></td>
<td>Phomopsis sp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phytophthora sp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Papaya</td>
<td>Fungi</td>
<td>48</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Peach</td>
<td>Monolinia fructicola</td>
<td>52</td>
<td>2.5</td>
<td>Motile skin</td>
</tr>
<tr>
<td></td>
<td>Rhizopus stolonifer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pepper (bell)</td>
<td>Erwinia sp.</td>
<td>53</td>
<td>1.5</td>
<td>Slight spotting</td>
</tr>
</tbody>
</table>

### HOT FORCED-AIR TREATMENTS:

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Pathogens</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>RH (%)</th>
<th>Possible injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Gloeosporium sp. Penicillium expansum</td>
<td>45</td>
<td>15</td>
<td>100</td>
<td>Deterioration</td>
</tr>
<tr>
<td>Melon</td>
<td>Fungi</td>
<td>30-60</td>
<td>35</td>
<td>low breakdown</td>
<td>Marked</td>
</tr>
<tr>
<td>Peach</td>
<td>Monolinia fructicola Rhizopus stolonifer</td>
<td>54</td>
<td>15</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Strawberry</td>
<td>Alternaria sp. Botrytis sp. Rhizopus sp. Cladosporium sp.</td>
<td>43</td>
<td>30</td>
<td>98</td>
<td></td>
</tr>
</tbody>
</table>


### RANCH PACKING

A single worker can pack produce by removing it directly from the field container, grading by size, color or quality, and hand packing each unit into the appropriate container. For example, if there were three quality grades being packed, the worker would have three open cartons within easy reach, and place each unit into the correct package. This practice avoids the handling steps of dumping, cleaning and other postharvest treatments and greatly reduces the amount of mechanical damage during packing.
The table illustrated here is a combination sorting and packing stand. Incoming produce is placed into the canvas sorting bin, sorted by one worker into the packing bins, and finally packed into cartons by a second worker. If workers must stand to sort produce, a firm rubber pad for the floor can help reduce fatigue.

![Diagram of packing stand]

Source: FAO (1986)

**COMPARISON OF ESTIMATED COSTS AND EXPECTED BENEFITS OF SORTING/SIZING/GRADING/PACKING OPERATIONS**

**Costs:**
- Equipment
- Labor
- Package

**Benefits:**
- Reduced losses due to decay, less spread of infection
- Improved overall quality, less damaged produce
- Higher market price for highest graded produce

**Example 1:**
Unsorted chili peppers packed in 50 lb sacks have a value of $0.20/lb in the wholesale terminal market in the U.S. At a given time, 1000 lbs are packed and marketed to commercial buyers, who must sort the peppers before resale to consumers or for food service use with average postharvest losses due to decay of 15%. Sorted produce will have additional marketing options.
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Costs:
Sorting table $50.00, usable over many seasons.
Labor $7/hour for sorting and packing 20 lb cartons of 3 quality grades
(3 hours for 1000 lbs) = $21.00
48 Packages cost $1.50 each (= $72.00) vs 20 sacks which cost $0.50 each (= $10.00)
Total costs (unsorted) = $10 vs Total costs (sorted/packed) 50 + 21 + 72 = $123
(Total recurring costs for sorting/packing = $21 + $72 = $93)

Benefits:
Unsorted/unpacked market price = $10 /50 lb sack, 20 sacks. Total = $200.00
Sorted/packed market prices: highest grade = $ 0.45 /lb
    medium grade = 0.20 /lb
    lowest grade = 0.15 /lb

If 60% of the produce is of the highest grade (30 cartons) = $270
If 25% is medium grade (12 cartons) = $48
If the remainder are the lowest quality (6 cartons) = $12
Culls (not packed) = 4% (equivalent of 2 packages)
Total = $330

Expected profits from sorting/grading/packing: This example demonstrates an immediate recovery of invested capital. The first 1000 lbs of peppers sorted and packed pays for the capital outlay (the sorting table); after this, each 1000 lbs packed results in a return of an additional $47 ($330 - $93 in costs = $237) in comparison to peppers sold unsorted in sacks ($200- $10 = $190).

Example 2: Unsorted 20 kg sacks of sweet peppers (bell peppers) have a market value of Rs 20/kg in the wholesale mandi in Punjab. 1000 kg are harvested, and 15% postharvest losses are due to water loss during transport to market.

Costs:
Sorting table Rs 3000, usable over many seasons.
Labor for sorting and packing 3 quality grades (one day @ Rs 80/day)

100 fiberboard boxes cost Rs 10 each (= Rs 1000) vs 50 sacks which cost Rs 2 each (= Rs 100)
Total costs (unsorted) = Rs 100 vs
Total costs (sorted/packed) Rs 3000 + Rs 80 + Rs 1000 = Rs 4080
(Total recurring costs for sorting/packing = R80 + Rs 1000 = Rs 1080)

Benefits:
Unsorted/unpacked market price = 50 sacks of 20 kg @ Rs20 /kg. Total = Rs 20,000
Sorted/packed market prices: highest grade = Rs 40 /kg
    medium grade = Rs 25 /kg
    lowest grade = Rs 15 /kg

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
If 50% of the produce is of the highest grade (500 kg) = Rs 20,000
If 30% is medium grade (300 kg) = Rs 7500
Culls (not packed) = 4% (40 kg)
If the remainder are the lowest quality (160 kg) = Rs 3000

Total = Rs 20,000 + 7500 + 3000 = Rs 30,500

Expected profits from sorting/grading/packing: This example demonstrates an immediate recovery of invested capital. The first 1000 kg of produce sorted and packed pays for the capital outlay (the sorting table); after this, each 1000 kg packed results in a return of an additional Rs 9520 (Rs 30,500 - Rs 1080 in costs = Rs 29,420) in comparison to peppers sold unsorted in sacks (Rs 20,000- Rs 100 in costs = Rs 19,900).

**SOURCES OF PACKINGHOUSE EQUIPMENT AND SUPPLIES**

<table>
<thead>
<tr>
<th>Item</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>brusher/washer</td>
<td>Northwest Int'l Equipment Co.</td>
</tr>
<tr>
<td></td>
<td>Orchard Equipment and Supply Co.</td>
</tr>
<tr>
<td>chlorine meters</td>
<td>International Ripening Corp.</td>
</tr>
<tr>
<td>chlorination system</td>
<td>American Machinery</td>
</tr>
<tr>
<td>cleaners</td>
<td>Brogdex Co.</td>
</tr>
<tr>
<td></td>
<td>Orchard Equipment and Supply Co.</td>
</tr>
<tr>
<td>conveyors</td>
<td>Agri-Tech, Inc.</td>
</tr>
<tr>
<td></td>
<td>Michigan Orchard Supply</td>
</tr>
<tr>
<td></td>
<td>Northwest Int'l Equipment Co.</td>
</tr>
<tr>
<td></td>
<td>Sorting Technology, Inc.</td>
</tr>
<tr>
<td>dumpers bin</td>
<td>Agri-Tech, Inc.</td>
</tr>
<tr>
<td></td>
<td>Durand-Wayland, Inc.</td>
</tr>
<tr>
<td></td>
<td>Orchard Equipment and Supply Co</td>
</tr>
<tr>
<td></td>
<td>Northwest Int'l Equipment Co.</td>
</tr>
<tr>
<td>field boxes, crates, buckets or baskets</td>
<td>Durand-Wayland, Inc.</td>
</tr>
<tr>
<td>fruit and vegetable waxes</td>
<td>Brogdex Co.</td>
</tr>
<tr>
<td></td>
<td>Michigan Orchard Supply</td>
</tr>
<tr>
<td></td>
<td>Orchard Equipment and Supply Co</td>
</tr>
<tr>
<td>gloves</td>
<td>Pacific 4/ Ranch Brand Supply Co.</td>
</tr>
<tr>
<td>inspection roller tables</td>
<td>Market Farm Implement</td>
</tr>
<tr>
<td></td>
<td>Orchard Equipment and Supply Co</td>
</tr>
</tbody>
</table>
lifting/handling equipment
  folding mini-dolly
  fork lift attachment for tractor
  pallet jack

packing lines
  Ag-Pak
  American Machinery
  TEW Manufacturing Co.

pH meters
  Fisher
  International Ripening Corp.

rotary tables
  Market Farm Implement
  Michigan Orchard Supply
  Orchard Equipment and Supply Co.

scales
  Orchard Equipment and Supply Co.

sizers
  chain sizers
  expanding rollers
  nut sizers
  onion sizers

sizing rings
  Orchard Equipment and Supply Co.
  International Ripening Corp.

washers and waxers
  Agri-Tech, Inc
  Durand-Wayland, Inc.
  Market Farm Implement
  Michigan Orchard Supply
  Orchard Equipment and Supply Co.

water dump
  Michigan Orchard Supply

water quality analyses equipment
  HACH
  International Ripening Corp.

For addresses and phone/FAX numbers, refer to Appendix D.
REFERENCES


Martin, D. and Miezitia, E.O. 1964. A wipe-on device for the application of materials to fruits. Field Station Record Volume 3 No.1 CSIRO Tasmanian Regional Laboratory, Hobart, Tasmania.


CONTAINERS AND PACKAGING MATERIALS

Produce packed for traditional wholesale terminal markets will require the use of new, standard sized packages and standardized packing counts and/or weights. With increasing concerns for environmental health, reusable or recyclable packages and packaging materials are becoming more widely used in the horticultural industry. Typical packaging materials include fiberboard (cartons, boxes, bins, flats, dividers and partitions), wood (wirebound or nailed crates, baskets, trays, lugs), paper (bags, sleeves, wraps, liners, pads, excelsior), plastic (boxes, trays, mesh bags, solid bags, containers, film wraps, dividers) and polystyrene (foam boxes, trays, lugs, sleeves, liners, pads and dividers). Direct marketers can use any suitable package, and can sometimes reuse disposable packages many times as long as they are kept clean. Depending on the delicacy and handling requirements of various produce, packages can be simple and inexpensive to complex and costly.

This chapter describes a variety of packages, packaging materials and package liners and inserts that can be used to protect produce quality during postharvest handling, storage, transport and marketing. Included is a brief introduction to the principles and practices of Modified Atmosphere Packaging (MAP) for those of you who want to take a quick look at a modern postharvest technology that can be used along with temperature management to greatly increase shelf life for certain horticultural produce. MAP requires the use of flexible packaging films specific to the requirements of each commodity. Since MAP is relatively expensive, this technology may be cost effective only for high value produce such as berries and fresh-cut products.

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
In addition to protection, packaging allows quick handling throughout distribution and marketing and can minimize impacts of rough handling. If produce is packed for ease of handling, heavily waxed cartons, wooden crates or rigid plastic containers are preferred over bags or open baskets, since bags and baskets will provide no protection to the produce if they are stacked. Sometimes locally constructed containers such as sturdy baskets or palm-rib crates can be lined to provide added protection to produce. Wax cartons, wooden crates and plastic containers, while more expensive, are reusable and can be used for hydro-cooling and package icing. Although waxed cartons are not recyclable and some people choose to avoid these packages, they stand up to the high relative humidity found in the storage environment.

Containers should not be filled either too loosely or too tightly for best results. Loose products may vibrate against others and cause bruising, while overpacking results in compression bruising. Shredded newspaper or paper excelsior are inexpensive and lightweight fillers for immobilizing produce in shipping containers.

Throughout the entire handling system, packaging can be both an aid and a hindrance to obtaining maximum storage life and quality. Packages need to be properly vented to allow proper air circulation yet be sturdy enough to prevent collapse. Collapsed packages provide little or no protection, requiring the commodity inside to support all of the weight of the overhead load. Packing is meant to protect the commodity by immobilizing and cushioning it, but temperature management can be made more difficult if packing materials block ventilation holes. When packing materials act as vapor barriers they can help maintain beneficial higher relative humidities within the package.

Simple hand-packing or mechanical packing systems often use the volume-fill method or tight-fill method, in which sorted produce is delivered into boxes, then vibration settled. Most volume-fillers are designed to use weight as an estimate of volume, and final adjustments are done by hand. For most small-scale operations, hand packing will be a major part of the postharvest handling system. While hand packing requires a lot of labor, produce can be hand-packed to create a more attractive pack, often using a fixed count of uniformly sized units (in molded trays or place packed, sometimes individually wrapped). Hand-packing also allows you to package riper fruits and more delicate herbs and vegetables and provide buyers with great tasting, ready-
to-eat produce. If you package ripe produce for specialty shops or create gift-packs or gift-baskets, these consumer packs will generally have to be packed into larger containers which will then provide more suitable protective packaging.

For small-scale handlers interested in constructing their own cartons from corrugated fiberboard, Broustead and New (1986) provide detailed information. Many types of agricultural fibers are suitable for paper making (Hunsigi, 1989), and cooperatives of small growers/handlers/shippers may find it economically sensible to include these operations in their postharvest system.

GENERAL DOs AND DON'Ts FOR PACKAGING HIGH QUALITY PRODUCE

Use sturdy packages, capable of standing up to handling, cooling and storage conditions (high humidity environments).

Line rough packages such as baskets and wooden crates with cardboards inserts.

Reinforce packages used for heavy produce with corner supports or folded dividers.

Don't use very large packages-- the larger the container, the more likely the produce is to suffer damage during handling.

Use shallow packages for delicate produce such as berries, grapes, summer squash and ripe stone fruits (single layer or double layers).

Do NOT overload packages or allow produce to bulge up over the sides.

Packages should be vented, about 5% of the surface area per side.

Don't pack produce either too tightly or too loosely.
Do's and Don’ts continued

Consider using packaging materials such as trays, cups, wraps, liners and pads to help immobilize and protect produce, but don’t overdo it.

Small, rigid plastic containers such as clamshell baskets (consumer sized containers placed into larger boxes) are useful for protecting berries from damage and water loss.

Liners made of perforated plastic films will decrease the rate of water loss from produce such as cherries.

Make sure the packages you use for garlic and onions have plenty of ventilation (mesh bags will provide the lower humidity environment required for proper handling).

Do NOT block the ventilation holes of packages with fillers or liners.

Label containers with your logo or farm name for enhanced marketing (have cartons printed or use inexpensive paper labels or stickers).

Consider the use of modified atmosphere packaging for your speciality products (read the section of this chapter on MAP if you are considering modified atmosphere packaging).

Consider using packages that can be used as to display produce during marketing (printed sides, display materials on flaps).

Pack 'consumer packages' such as gift packs or display trays into larger, more protective outer containers before stacking, transport and marketing.

Consider the use of packages with "hand-holds"-- these cut-outs can reduce damage since they provide an easy way to pick up and carry produce.

Use virgin/food grade materials whenever possible. Avoid wood, nails, staples due to possible food safety problems.
PACKING CONTAINERS

There are many types of packing containers available for horticultural produce, and they come in a huge range of sizes. The three containers styles illustrated here are constructed from corrugated fiberboard. The regular slotted container is fully collapsible and the most economical. Collapsible containers can be flattened and stacked, making transport easy and less expensive, and take much less space to store while empty in the packinghouse.

Half or full-telescopic containers have the highest stacking strength and protect against bulging but are more costly. Your choice of package style will depend on what commodity you pack and how you intend to use the container throughout the postharvest system (during cooling, for long-term storage, as a display).

The container known as a Bliss box has very strong corners, but is not collapsible.
A simple wooden tray with raised corners is stackable and allows plenty of ventilation for fragile crops such as ripe tomatoes.

Smaller consumer sized containers can be packed into a larger container:

PACKAGE INSERTS, FILLERS AND LINERS
Adding a fiberboard divider to a carton will increase stacking strength. The use of simple dividers is common with heavy crops such as melons, and prevent melons from vibrating against one another during handling and transport.

Fiberboard divider:
Wooden inserts, or fiberboard folded into tight triangles and placed in all four corners can be especially useful when a carton needs strengthening.

**Triangular support:** right angled block, anchored into corners of simple cartons to reinforce corners, provide ventilation and increase stacking strength; constructed of wood or heavy-weight folded fibreboard.

Using a polyethylene liner in a fiberboard carton can help protect produce and reduce water loss in commodities such as cherries, nectarines, kiwifruits, bananas and herbs. Water vapor given off by the product is contained within the liner, increasing the RH 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. It is important to keep produce cool to prevent causing damage in cartons lined with polyethylene due to gas composition changes related to increased respiration rates.

Never use unperforated plastic bags to store onions or garlic--the relative humidity (RH) inside the bag is too high for proper handling and storage. Losses due to rooting, sprouting and postharvest decay will increase dramatically.

**Thompson (1996) reported that perforated film bags used for onion storage resulted in the following rates of rooting:**

<table>
<thead>
<tr>
<th>Perforations</th>
<th>RH</th>
<th>Rooted</th>
</tr>
</thead>
<tbody>
<tr>
<td>No perforations</td>
<td>98%</td>
<td>71%</td>
</tr>
<tr>
<td>36 perforations of 1.6mm</td>
<td>88%</td>
<td>59%</td>
</tr>
<tr>
<td>16 perforations of 6.4mm</td>
<td>54%</td>
<td>17%</td>
</tr>
<tr>
<td>32 perforations of 6.4mm</td>
<td>51%</td>
<td>4%</td>
</tr>
</tbody>
</table>
When locally made containers have sharp edges or rough inner surfaces, a simple, inexpensive liner can be used to protect produce from damage during handling.

Cardboard liner for a palm rib crate:

![Cardboard liner for a palm rib crate]

Liner for a wooden crate:

![Liner for a wooden crate]

LABELING
Labeling packages helps handlers to keep track of the produce as it moves through the postharvest system, and assists wholesalers and retailers in using proper practices. Cartons can contain information on maximum stacking heights, recommended temperature range and RH conditions. The label on a container of lettuce might warn against storage with ethylene producing crops.

Labels can be preprinted on fiberboard boxes, or glued, stamped or stenciled on to containers. Brand labeling can aid in advertising for the product's producer, packer and/or shippers. Some shippers also provide informational brochures detailing storage methods or recipes for consumers. Some growers put small stickers (with a colorful representation of the farm name, logo or variety name) on individual units of specialty produce, both to increase consumer awareness of where the produce they are eating comes from and to enhance its perceived value.
Labeling of consumer packages is mandatory under FDA regulations. Labels must contain the name of the product, net weight, and name and address of the producer, packer or distributor.

Shipping labels can contain some or all of the following information:

- Common name of the product, including the variety of the commodity.
- Net weight, count and/or volume.
- Brand name.
- Name and address of producer, packer and/or shipper.
- Country or region of origin.
- Size and grade.
- Recommended storage temperature.
- Special handling instructions.
- Names of approved waxes and/or pesticides used on the product.

Economic Considerations

Packages and packaging materials must be evaluated regarding all the costs associated with adapting the package into your marketing system. According to Mitchell (1992) you should consider packaging costs, packing costs, handling costs, marketing costs and product value costs.

**COSTS ASSOCIATED WITH PRODUCE PACKING AND PACKAGING**

1. Packaging costs: package components, shipping/handling costs associated with purchasing packages, labor and materials for package make-up, liners, pads, trays, wraps, storage costs for empty packages.

2. Packing costs: number of packing steps required, effect on packing operation, labor efficiency.

3. Handling costs: stacking efficiency, costs of pallet strapping, glues, pallet materials.

4. Marketing costs: effect on load density, special labor or equipment needed for handling, adaptability of package as a display unit.

MODIFIED ATMOSPHERE PACKAGING

The basic premise of modified atmosphere packaging (MAP) technology is that once produce is placed in a package and sealed, an environment different from ambient conditions will be established as the produce continues to respire. The key to successful use of MAP technology is knowing what type of environment will be most beneficial to the produce inside the package and then determining which packaging materials should be used to create such an environment. MAP is **ONLY a supplement to proper refrigeration and NOT a replacement for temperature management.** MAP without refrigeration is of little benefit in extending the shelf-life of any perishable, and will actually decrease shelf life if produce is handled at temperatures of 20 °C (68 °F) or above.

<table>
<thead>
<tr>
<th>MAP in combination with cold storage may benefit produce in the following ways:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce moisture loss (reduced weight loss)</td>
</tr>
<tr>
<td>Delay ripening (longer marketing time)</td>
</tr>
<tr>
<td>Control decay (reduced postharvest losses)</td>
</tr>
<tr>
<td>Delay undesirable composition changes (delay loss of fruit acids and sugars)</td>
</tr>
</tbody>
</table>

Environmental conditions important to perishables that MAP can effect are atmospheric oxygen ($O_2$), carbon dioxide ($CO_2$), ethylene ($C_2H_4$) and water vapor (relative humidity) concentrations. Correct use of MAP technology can significantly extend the shelf-life of produce but, if incorrect packaging materials are chosen, atmospheric conditions may be generated which will injure produce and this will result in shorter shelf-life or reduced product quality. This section will explain how MAP extends produce shelf-life, how to choose an appropriate packaging film and what packaging materials are available for fresh produce.

In general, unless you are marketing highly valuable produce, you will probably find that the added cost of MAP is not warranted. Good candidates for the use of MAP are berries, fresh-cut produce and for long-term storage of some fruits.
GENERAL DOs AND DON'Ts
FOR USE OF MODIFIED ATMOSPHERE PACKAGING

Use MAP only in combination with refrigeration.

Do NOT package mushrooms in MAP due to the risk of *Clostridium botulinum*.

Always precool products before packaging.

Use films that will not cause product fermentation (you must know the respiration rate of the produce at the temperature at which it will be handled).

Do NOT use MAP on decayed or injured produce.

Do NOT use MAP on overripe or senescent produce.
One of the greatest benefits derived from use of MAP is maintenance of high relative humidity around the product. Natural barriers to water loss may be removed during harvesting, leaving fresh produce susceptible to dehydration. Flexible film pouches significantly reduce the rate of water loss from fresh produce by creating an environment inside the package that is near 100% relative humidity. However, water condensation on the interior of the package, usually caused by temperature fluctuations, may promote the growth of spoilage microorganisms and obscure consumers' ability to examine the product prior to purchase. Temperature control, appropriate selection of flexible film water vapor transmission rate and incorporation of antifog additives into a flexible film can eliminate these problems.

Active versus Passive MAP
Generation of a low O$_2$ and/or elevated CO$_2$ environment within a MAP extends produce shelf-life by slowing browning reactions at cut surfaces, reducing the rate of product respiration and reducing ethylene biosynthesis and action. When the low O$_2$ and/or elevated CO$_2$ atmosphere within a MAP results from the produce consuming O$_2$ and releasing CO$_2$ within a confined space, this is called a passively modified atmosphere. Flexible packaging films used for produce allow O$_2$ to move into the package from the outside air and CO$_2$ to be released from inside the package. The atmospheric composition within a MAP is determined by the O$_2$ consumption and CO$_2$ evolution rate of the product, film O$_2$ and CO$_2$ permeability, as well as film surface area and product mass.

The rapid establishment of a low O$_2$ and/or elevated CO$_2$ environment is critical for the prevention of cut surface browning on many fresh-cut products and equilibrium gas concentrations within a package can be attained quickly by evacuating the package and flushing it with the predicted O$_2$ and CO$_2$ equilibrium concentrations. This type of modified atmosphere is called an actively modified atmosphere and is necessary for MAP fresh-cut lettuce products which commonly have less than 1% O$_2$ to slow browning reactions and more than 10% CO$_2$. Gas flushing packages does not alter the equilibrium O$_2$ and CO$_2$ concentrations within a produce package but merely reduces the amount of time required to reach equilibrium conditions. Although the use of low O$_2$
and elevated CO₂ MAP is very effective for reducing cut surface browning of lettuce products it does not work well for other commodities such as fresh-cut fruit.

![Graph showing effects of passive and active atmospheric modification on O₂ and CO₂ concentrations within a theoretical MAP. The passive modification takes nearly 8 days to reach the desired concentrations in the MAP, while the active modification the proper mix of gases are introduced to achieve desired levels immediately.]

Reduced O₂ and elevated CO₂ atmospheres within MAP also extend the shelf-life of fresh-cut products by reducing their respiration rates and slowing use of finite energy supplies that are available in living tissue. MAP is not a substitute for temperature management, but merely a supplement to cold storage. Low temperatures have a much greater effect on produce respiration rates. MAP’s are designed to maintain optimal O₂ and CO₂ concentrations within a package and proper functioning is predicated upon storage temperatures being maintained within a specified range. Temperatures throughout distribution and marketing must be carefully controlled because, if produce in MAP is exposed to temperatures above its expected storage temperature range, injuriously low O₂ or injuriously high CO₂ levels will be generated and significant shelf-life reduction will occur. Reduction in shelf-life may be due to induction of fermentation and/or enhanced growth of lactic acid bacteria, both of which cause objectionable off-flavors and odors.
The next illustration shows the effects of storage temperature and MAP on the shelf-life of a theoretical perishable commodity, which has an optimal storage temperature of 0 °C (32 °F). At 0 °C the use of MAP extends shelf-life by 2 days or approximately 20%, compared to produce stored in air. Product held at 10 °C (50 °F) in MAP has a longer shelf-life than product held in air at 10 °C, but a significantly shorter shelf-life than product that is held either in air or MAP at 0 °C. This demonstrates that temperature control is more effective than MAP in extending shelf-life. At 20 °C (68 °F) MAP products may actually have a shorter shelf-life than if they were held in air, since anaerobic condition may be generated inside MAP packages at 20 °C and cause accelerated spoilage.

![Diagram showing effects of temperature and MAP on shelf-life](image)

General effects of temperature and/or MAP on the shelf life of produce.

Low O₂ (<5%) and elevated CO₂ (>5%) will also significantly inhibit the effects of the plant hormone ethylene, which promotes tissue senescence. Wounding plant tissue during harvesting operations by cutting, slicing or bruising will lead to production of ethylene almost immediately and promote tissue breakdown. Rapid establishment of a low O₂ and elevated CO₂ environment within a MAP of produce will reduce the effects of ethylene. Numerous industrial attempts have been made to incorporate ethylene absorbing materials into flexible packaging films with the hope of significantly extending the shelf-life of fruits and vegetables. This strategy is redundant, since low O₂ and elevated CO₂ environments within MAP already significantly diminish the production and effects of ethylene.
Elevated CO$_2$ (>10%CO$_2$) environments within MAP bring an additional benefit of being fungistatic and are commercially used in the strawberry industry to reduce the growth of *Botrytis cinerea*. A properly designed MAP, when used in combination with low temperature storage, delays spoilage of fruits and vegetables by slowing the natural processes that lead to tissue death and decay by food spoilage microorganisms. Reducing the rapid senescence rate of fruit products via the use of MAP is not particularly effective, unless the fruit are harvested before ripening has begun. This is because many of the physiological changes associated with fruit ripening are not effected by reduced O$_2$ and/or elevated CO$_2$ atmospheres, once genetically regulated ripening events have been initiated.

Special food safety precautions must be considered when produce which is not acidic (pH >4.6) is packaged in MAP. In particular products such as mushrooms should never utilize MAP since at a pH of less than 4.6 and in very low O$_2$ environments (<2%) *Clostridium botulinum* may germinate and produce its deadly toxin.

Modified Atmosphere Packaging of Strawberries
A single pallet load of strawberries can be sealed within a shroud of 5 mil polyethylene bag and a plastic sheet on the pallet base using wide tape. A slight vacuum can be introduced and 15% CO$_2$ added to the air introduced via a small hose.
DETERMINATION OF THE MOST BENEFICIAL ATMOSPHERE

The optimum atmosphere for extending the shelf-life of a given commodity is determined by the physiology of that commodity, its maturity, the conditions under which it is grown and the expected storage temperature. Appendix C contains tables listing the optimal storage atmospheres for fresh vegetables, fresh fruits and fresh-cut produce. (Chapter 12 provides detailed information on preparation and postharvest handling of fresh-cut produce.) These tables should be used as a starting point and guide from which to begin design of a MAP for any given product. Information is included only for produce that is known to benefit significantly from the use of MAP.

MAP DESIGN

Once it is determined what atmosphere is appropriate for the commodity you want to package, some simple calculations can help you determine what type of film to use to attain such an atmosphere.

<table>
<thead>
<tr>
<th>The important variables in MAP design are:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Mass (Weight)</td>
</tr>
<tr>
<td>Product Respiration Rate</td>
</tr>
<tr>
<td>Film Area</td>
</tr>
<tr>
<td>Film Thickness</td>
</tr>
<tr>
<td>Desired O₂ and or CO₂ concentrations</td>
</tr>
<tr>
<td>Film Oxygen Transmission Rate (OTR)</td>
</tr>
<tr>
<td>CO₂ Transmission Rate (CO₂TR)</td>
</tr>
</tbody>
</table>

The unknown variable is usually film OTR or CO₂TR. Film OTR and CO₂TR are inherent properties of a flexible film and it will determine what flexible packaging material you need to use to achieve the desired atmosphere. Once film OTR and CO₂TR are determined then an appropriate film may be selected with some confidence in its ability to deliver the desired O₂ and CO₂ concentrations within the package for that commodity. Another important variable to know
is commodity respiration rate. The respiration rates of most commodities at various temperatures can be found in USDA Handbook 66: The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks.

**MAP Example**

You wish to package 2 kg of produce which has a respiration rate of 5 (mL O₂ / kg / h) and you will use a package that is 1 mil thick and has an area or 1800 cm². What film OTR will you select to get an atmosphere of 5% O₂ inside the package?

**Important Variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt (kg)</td>
<td>2</td>
</tr>
<tr>
<td>Respiration Rate</td>
<td>5 (mL O₂/kg/h)</td>
</tr>
<tr>
<td>Film Thickness</td>
<td>1 (mil)</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>1800</td>
</tr>
<tr>
<td>Length (cm) x Width (cm) x Package Sides</td>
<td>30 x 30 x 2</td>
</tr>
</tbody>
</table>

**Desired**

Internal O₂ (%): 0.05 = 5%

External O₂ (%): 0.21 = 21% Air

**OTR (CC/mil/cm²/Hr):**

\[
\text{OTR (CC/mil/cm}^2/\text{Hr}) = \frac{(2 \text{ kg}) \times (5 \text{ mL O}_2/\text{kg/h}) \times (1 \text{ mil})}{(1800 \text{ cm}^2) \times (0.21 - 0.05)}
\]

\[
\text{OTR (CC/mil/cm}^2/\text{Hr)}: 0.03472
\]

Film OTR values may be reported by manufacturers in various units. To convert OTR (CC/mil/cm²/Hr) to OTR (cc/100 in²/day) multiply by 15483.84

\[
\text{OTR (cc/100 in}^2/\text{day)}: = 0.03472 \times 15483.84 = 538
\]

Changing any of the key variables such as the amount of produce you put into the package, film thickness or product respiration rate will effect the equilibrium atmosphere inside the package and it will result in less than optimal MAP conditions. A similar calculation can be done to determine
the CO\textsubscript{2} transmission rate (CO\textsubscript{2}TR) needed to attain the target CO\textsubscript{2} concentration within a package. Once the target OTR and CO\textsubscript{2}TR have been determined, the ratio of CO\textsubscript{2}TR / OTR can be calculated. Most plastic polymeric films have a ratio greater than one, with low density polyethylene (LDPE) having a ratio of 3 while air has a ratio of 0.8. Each packaging film will have a different ratio depending on the resin or resins used to manufacture the film. Once the target ratio has been calculated an appropriate film can be selected based on the physical properties of that film. Ask film manufacturers in your locale regarding what packaging materials are available.

**FILM SELECTION**

There are numerous materials that may be used for produce packaging. It is best to speak with film manufacturers, often called converters, about your specific needs. Film manufacturers should be able to tell you what materials they are currently using and what the OTR and CO\textsubscript{2}TR are for any given film that they currently manufacture.

The OTR and CO\textsubscript{2}TR of a film is regulated by the choice of materials used in film manufacturing and film thickness. Low density polyethylene (LDPE) has been the material of choice for flexible packaging of produce for many years due to its low cost and relatively high OTR. Recently film improvements such as linear low density polyethylene (LLDPE) and ultra low density polyethylene (ULDPE) have appeared. These new materials were designed to give film converters the ability to manufacture films with greater consistency in film density and hence give better control of film OTR. The newest generation of PE resins to come into use in produce packaging are based on metallocene technology. Metallocene films have reduced variation in polymer chain length so that better control of film density and are available from Exxon (under the trade name Exact\textsuperscript{®}) and Dow (Affinity\textsuperscript{®}). Metallocenes OTR are achieved by using these resins. These polymers also have superior clarity and create a high quality seal.

Another innovative approach to handling high respiration rate commodities which demand a high OTR film is to use microperforated films. Microperforated films contain tiny holes which go
straight through the film. The atmosphere inside the package is determined by the total surface area of the holes on the package surface. The difficulty with manufacturing such films is in how to consistently get the right number and diameter of holes per square centimeter into the film. Currently, microperforations are placed in plastic films by mechanical means, sparks or by laser. James River recently introduced a new line of micro perforated films with the trade name P-Plus®. These films allow for the development of an elevated carbon dioxide environment while maintaining moderate oxygen levels. Microperforated films also maintain high relative humidity levels and are very effective in prolonging the shelf life of commodities, such as cherries and plums, which are especially sensitive to water loss and decay. Macroperforated in films are packages with larger holes approximately the size of pin holes. These type of packages are an excellent way to control water loss and not significantly alter O₂ or CO₂ concentrations within a package.

Microporous membranes can also be used in conjunction with flexible films, and the best example of this technology is the FreshHold® patch. The microporous membrane is placed over an oxygen impermeable film with a large hole. All gas exchange in the package then occurs through the microporous membrane. The membrane has very small pores of which are made by incorporating calcium carbonate or silica into the membrane during the manufacturing process. The micropores are not aligned and gases must diffuse into the matrix of the membrane, where they may diffuse quickly across the small pores. The OTR of the membrane patch can be changed by altering its gauge or by altering the size and number of micropores present. Micropore technology is very effective in creating atmospheres elevated in carbon dioxide and moderate in oxygen concentration.

Other important film properties which should be considered are:
- Printability
- Sealability
- Clarity
- Cost
- Strength

The MAP Patch
New and Emerging MAP Technologies
Currently, packaging systems are not responsive to changes in the environment in which a package finds itself. A new type of packaging is on the horizon called active packaging. Active packaging maintains product safety and quality by adjusting to various handling and distribution conditions.

An excellent example of active packaging is a new class of membranes which create modified atmospheres within packages and assure that the product will not use up all the oxygen in the package and become anaerobic, even if temperature is not well maintained. These membranes, developed and patented by Landec Corporation of Menlo Park, CA, are called Intellimers®, or smart films. Commonly used films have a preset OTR, and if a product is temperature abused, then oxygen within the package is consumed faster than it can permeate in. This leads to off flavor and odor development, as well as an increased risk of food borne illness due to toxin production by anaerobic microbes. Landec's Intellimer® can be manufactured with a preset temperature switch which increases gas permeability (OTR) of the membrane by one thousand fold when temperatures rise above the set temperature limit, thus avoiding anaerobiosis.

Another innovative area under active development is incorporation of antimicrobial compounds into films and packaging materials. The idea is to have films or packaging materials that will play an active role in reducing the growth of microbes that cause spoilage and foodborne illness. In Japan, the Mitsubishi Corporation is currently marketing a Zeolite film that has been demonstrated to significantly reduce microbial populations on contact. However, a number of hurdles exist which impede the long-term success of this technology, such as the fact that the film will only be effective where it actually touches the food product. Also, regulatory and food safety issues exist regarding the migration of these antimicrobial compounds into the foodstuff.

Many commodities are physiologically damaged when they are exposed to elevated levels of carbon dioxide or ethylene. Traditionally, ethylene and carbon dioxide absorbers have been incorporated into packaging systems as a sachet. Currently, there is an effort to safely incorporate ethylene and carbon dioxide absorbers directly into boxes, packing trays and films to protect products from physiological disorders during distribution and handling. An example is a product called Peak Fresh® which is a PE film impregnated with mineral particles, with the reported ability
to adsorb ethylene. We must caution you if you are interested in trying these products, since testing by independent laboratories has not yet substantiated these claims.

Addresses of Various MAP Film or Resin Manufacturers

Cryovac, 100 Rogers Bridge Road, Duncan, SC 29334 USA
Dow Chemical Co. (Affinity®), 2020 Dow Center Midland MI 48674 USA
Exxon Chemical Co. (Exact®), Box 3272 Houston TX 77253 USA
Fresh Western Marketing (FreshHold®), Salinas CA 93902 USA
James River Corporation (P-Plus®) 2101 Williams St San Leandro, CA 94577 USA
Landec Corporation, (Intellimers®) 3603 Haven Ave. Menlo Park, CA 92045 USA
Mitsubishi Gas Chem., 5-2 Marunouchi 2 Chome Chiyoda-Kutoyko 100 JAPAN

COMPARISON OF ESTIMATED COSTS AND EXPECTED BENEFITS RELATED TO IMPROVED PACKING AND PACKAGING OF HORTICULTURAL PRODUCE.

Costs and Benefits of using Plastic Crates to handle Horticultural Produce

Costs:
Containers
Materials (liners, trays)
Trained labor

Benefits:
Reduced losses due to less crushing and lower produce damage, water loss and weight loss
Higher value paid for higher quality packaged produce

Example: Plastic reusable containers with disposable cardboard liners are used for transport and display during direct marketing in the western U.S. You have reduced postharvest losses due to lower rate of compression damage (fewer failed packages) compared to typical losses of 10%. If you handle 1000 lbs of produce at an average value of $0.95 per lb, you will have 50 additional lbs of produce to market if the crates reduce postharvest losses to 5%.
Costs:
$15.00 per crate; initial purchase of 40 crates = $600
Liners cost $0.25 each (40 used per 1000 lbs of produce packed 25 lbs/crate) = $10.00
Current cost of inexpensive fiberboard packages ($1.00 each) = $40.00
Labor cost $7.00 per hour; 2 hours to pack 40 crates = $14.00 (same for either packing container)
Total recurring costs for disposable liners = $10

Benefits:
50 lbs x $0.95 = $47.50 in additional produce marketed per load.
Savings of $40 per load in fiberboard cartons.
Total = $87.50

Return on investment:
Benefits - recurring costs = $87.50 - 10 = $77.50 profit per load.
The cost of $600 for plastic crates is recovered with the first 8 loads, after which you will have an additional profit of of $77.50 per load. If you also have the benefit of improved quality due to the investment in improved packaging, profits will be even higher since the market value of the produce will increase.

Example 2: Plastic reusable containers with disposable cardboard liners are used for transport and display during direct marketing of vegetable crops in Punjab. You have reduced postharvest losses due to lower rate of compression damage (fewer failed packages) compared to typical losses of 20%. If you handle 1000 kg of produce at an average value of Rs 25/kg, you will have 100 additional kgs of produce to market if the crates reduce postharvest losses to 10%.

Costs:
Rs 200 per crate; initial purchase of 67 crates = Rs 13,300
Liners cost Rs 10 each (67 used per 1000 lbs of produce packed 15 kg/crate) = Rs 670 per load
Current cost of 67 inexpensive sacks each holding 15 kg (Rs 2 each) = Rs 134
Labor cost Rs 80/day; 4 hours to pack 67 crates = Rs 40 (same for either packing container)
Total recurring costs for disposable liners = Rs 670

Benefits:
100 kg x Rs25 = Rs 2500 in additional produce marketed per load.
Savings of Rs 134 per load in cost of sacks.
Total = Rs 2634

Return on investment: Benefits - recurring costs = Rs 2634 - Rs 670 = Rs 1964 profit per load.
The cost of Rs 13,300 for plastic crates is recovered with the first 7 loads, after which you will have an additional profit of of Rs 1964 per load. Government subsidies on purchased crates may reduce the cost by 50%, making it possible to recover your investment in only 4 loads. If you also have the benefit of improved quality due to the investment in improved packaging, profits will be even higher since the market value of the produce will increase.

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
### SOURCES OF PACKAGING EQUIPMENT AND SUPPLIES

<table>
<thead>
<tr>
<th>Category</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>bagging equipment</td>
<td>Chinook Packaging Equipment</td>
</tr>
<tr>
<td></td>
<td>Thomas E. Moore, Inc.</td>
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<tr>
<td>bag sealers</td>
<td>Seal-o-Matic</td>
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<tr>
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<td>Thomas E. Moore, Inc.</td>
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<tr>
<td>bags, paper</td>
<td>Rockford Package Supply, Inc</td>
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<tr>
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<td>Pacific 4/Ranch Brand Supply Co.</td>
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<tr>
<td>bags, plastic</td>
<td>Adelman-Fisher Packaging</td>
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<td>Rockford Package Supply, Inc</td>
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<tr>
<td>bags, net</td>
<td>Northwest Int'l Equipment Co.</td>
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<tr>
<td></td>
<td>Rockford Package Supply, Inc</td>
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<tr>
<td>boxes--berry boxes</td>
<td>Pacific States Box and Basket</td>
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<tr>
<td>--cardboard/fiberboard</td>
<td>Adelman-Fisher Packaging</td>
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<tr>
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<td>Independence Box Co.</td>
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<td></td>
<td>Inland Container</td>
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<tr>
<td></td>
<td>Rockford Package Supply, Inc</td>
</tr>
<tr>
<td>--cucumbers, tomatoes</td>
<td>Hydro-Gardens, Inc.</td>
</tr>
<tr>
<td>boxes</td>
<td>Dyer Fruit Box Mfg. Co.</td>
</tr>
<tr>
<td>--wirebound</td>
<td>Elberta Crate and Box Co.</td>
</tr>
<tr>
<td></td>
<td>Franklin Crates, Inc.</td>
</tr>
<tr>
<td></td>
<td>Growers Containers Coop, Inc.</td>
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<tr>
<td>brocolli buncher</td>
<td>Market Farm Implement</td>
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<tr>
<td>ethylene absorber sachets</td>
<td>Ethylene Control, Inc.</td>
</tr>
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<td></td>
<td>International Ripening Corp.</td>
</tr>
<tr>
<td>fruit protector trays</td>
<td>Rockford Package Supply, Inc.</td>
</tr>
<tr>
<td>insulated pallet covers</td>
<td>International Ripening Corp.</td>
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<td></td>
<td>ThermaGard Inc.</td>
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<tr>
<td>pads/foam, paper</td>
<td>Rockford Package Supply, Inc.</td>
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<tr>
<td>polyethylene pallet covers</td>
<td>International Ripening Corp.</td>
</tr>
<tr>
<td>reusable plastic containers</td>
<td>Buckhorn</td>
</tr>
<tr>
<td>scales</td>
<td>Orchard Equipment and Supply Co.</td>
</tr>
</tbody>
</table>
shrink wrap equipment

Seal-o-Matic
Rockford Package Supply Co.
Seal-o-Matic
Hydro-Gardens, Inc.

staplers

Market Farm Implement
Rockford Package Supply Co.
Seal-o-Matic

tapes, tape dispensers

Rockford Package Supply Co.
Seal-o-Matic

For addresses and phone/FAX numbers, refer to Appendix D.
REFERENCES


PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Temperature and relative humidity management are sometimes referred to as "Maintaining the Cold Chain" during postharvest handling and marketing. Produce should always be cooled as soon as possible after harvest if you want to protect quality and extend shelf life. Fresh fruits and vegetables are living tissues separated from the parent plant, which supplied them with water via transpiration. Once harvested, produce gains heat through respiration and conduction from the surrounding environment. For the highly perishable commodity strawberries, each one hour delay in cooling results in a 10% increase in decay. Produce exposed to the sun after harvest gains an enormous amount of heat and will have reduced shelf life. Tomatoes left in the sun for one hour after harvest will be at least 15 °C (25 °F) hotter than fruit held in the shade. And produce left at ambient, dry conditions will lose moisture up to 100 times faster than produce that is moved into a cold room (FAO, 1986)

Cooling involves heat transfer from produce to a cooling medium such as a source of refrigeration. Heat transfer processes include conduction, convection, radiation and evaporation. If a ready supply of electricity is available, mechanical refrigeration systems provide the most reliable source of cold. One
A ton of refrigeration capacity requires about 1 horsepower of compressor capacity. Fans use about 33% of the energy required for cooling, so don't install fans that are any larger than necessary.

This chapter describes traditional cooling technologies including room cooling, forced-air cooling, evaporative cooling and hydro-cooling. When electricity is unavailable or too expensive, a variety of simple methods exist for cooling produce. Some examples of alternative cooling systems include night air ventilation, radiant cooling, the use of ice and underground (root cellars, field clamps, caves) or high altitude storage. Control of relative humidity is an important part of temperature management, as the two combine to reduce water loss and protect produce quality. The chapter includes some examples that will help you to determine the costs and benefits associated with temperature and RH management technologies for horticultural produce, and help you decide which cooling method(s) will be most profitable for your operation.
GENERAL DOs AND DON'Ts
for MANAGING TEMPERATURE AND RELATIVE HUMIDITY

Cool produce as soon as possible after harvest.

Cool using appropriate methods for each commodity (consider water tolerance, time required to reach 7/8ths cooling, susceptibility to dessication)

Shade should be provided over harvested produce, packing areas, for buildings used for cooling and storage and for transport vehicles.

Trees are a fine source of shade and can reduce ambient temperatures around packinghouses and storage areas.

Light colors on buildings will reflect light (and heat) and reduce heat load. Design buildings with overhangs on the sunny side to provide shade.

High pressure sodium lights in packing and cooling facilities will produce less heat and use less energy than incandescent bulbs.

The best method to reduce water loss is to increase RH by reducing temperature.

Wet the floor of storage rooms to increase the RH inside the room. (Do NOT do this when storing onions or garlic).

Use proper containers, suited to the method used for cooling (waxed cartons or wooden boxes for hydro-cooling or icing, boxes with aligned side vents for forced air cooling).

Consider using forced-air coolers inside a cold room to speed cooling and decrease water loss and decay rate.

Monitor hydro-cooler water quality, clean and sanitize the cooler each day before use.

Do NOT hydro-cool apricots or fresh herbs, since these crops are easily damaged.

Cool before loading produce into refrigerated trucks (these trailers are designed only to maintain cool temperatures).

Use high quality insulation in coolers, storage rooms and transport vehicles to reduce incoming environmental heat load.
Dos and Don’ts continued:

Mist water-tolerant vegetables during handling, storage and marketing to decrease the rate of water loss.

Be careful when using specialty packaging since these are even more sensitive to temperature abuse:
- SO₂ pads: increased rate of SO₂ release damages table grapes
- MAP can become out of control: faster increase in CO₂ and rapid decrease in O₂ damages produce.

TEMPERATURE MANAGEMENT

During the period between harvest and consumption, temperature control has been found to be the most important factor in maintaining product quality. Keeping fruits cool will slow down the changes associated with ripening, and give you more time to market your produce. Generally, for each hour of delay between harvest and cooling, one day of shelf life is lost (Cantwell, 1998). For highly perishable crops like 'Shasta' strawberries, the percentage of marketable fruit decreases rapidly as the time after harvest at ambient temperature increases. Studies at UC Davis have shown that with a 4 hour delay in cooling from 30 °C (86 °F), about 70% of the strawberry crop is marketable, while with an 8 hour delay in cooling, only 40% of the crop is marketable.

The temperature at which you handle produce will directly affect how long you have to get the produce to market. Asparagus has a five day shelf life when handled at 20 °C (68 °F), compared to almost one month when handled at 3 °C (37 °F). When you delay cooling asparagus, the

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**Effect of temperature on ripening rates of mature-green, breaker, turning and pink tomatoes of standard varieties** (from Suslow and Cantwell, 1997)

<table>
<thead>
<tr>
<th>Maturity Stage</th>
<th>Days to full red color at the indicated temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13 C</td>
</tr>
<tr>
<td></td>
<td>55 F</td>
</tr>
<tr>
<td>Mature green</td>
<td>18</td>
</tr>
<tr>
<td>Breaker</td>
<td>16</td>
</tr>
<tr>
<td>Turning</td>
<td>13</td>
</tr>
<tr>
<td>Pink</td>
<td>10</td>
</tr>
</tbody>
</table>
spears will toughen and quality will decrease. The effect of temperature on tomato ripening rates is described below. Handling fruits at even higher summer temperatures will further speed the rate of ripening.

Temperature also has a direct effect on the rate of decay development. Sommer (1992) described the development of decay symptoms on peaches when they were infected with brown rot (Monilinia fructicola). When peaches were cooled immediately after harvest, 3 days after removal from cold storage decay lesions were less than 2mm wide. Any delay in cooling greatly increased the spread of decay.

| Lesion size 3 days after removal from storage with a 36 hour delay in cooling |
| Lesion size after storage with a 24 hour delay in cooling after harvesting |
| Lesion size after storage with no delay in cooling (barely visible) |

Effect of delays in cooling on the development of Brown Rot symptoms in peaches. Peaches were held at 20 °C for 0, 24 or 36 hours before being stored at 0 °C. (Adapted from Sommer, 1992).

When cooling horticultural produce, various methods are compared to determine how long it will take for produce to reach 7/8th of its final temperature. Each method is suited to specific commodities, based upon their tolerance of direct contact with water and their susceptibility to water loss during cooling. In general, room cooling of packaged produce is the slowest method, while forced-air cooling is much faster since produce comes into direct contact with cold air as it is pulled through packages. For produce that tolerates water contact, hydro-cooling is a good choice, since it is the fastest cooling method, as ice water can carry away more heat than cold air during the same time period of contact with produce.

Once produce is cooled, keeping horticultural products at their lowest safe temperature (0 °C or 32 °F for temperate crops or 10-12 °C or 50-54 °F for chilling sensitive crops) will increase storage life by lowering respiration rate, decreasing sensitivity to ethylene and reducing water loss.
loss. An inexpensive temperature probe can be used to monitor temperature during postharvest handling, storage and marketing. Chapter 7 focuses on storage practices and Appendix B lists specific temperature and RH recommendations for a wide selection of commodities.

COOLING METHODS
Room Cooling
Room cooling is a relatively low cost but very slow method of cooling when electricity for mechanical refrigeration is available. When using room cooling, produce is simply loaded into a cold room, and cold air is allowed to circulate among the cartons, sacks, bins or bulk load. This cooling method is best suited to less perishable commodities such as potatoes, onions, apples and citrus fruits, since highly perishable crops will deteriorate too much before being adequately cooled. Room cooling may be all you need if you handle chilling sensitive crops that need to be cooled from early morning harvest temperatures to storage temperatures of 10 to 13 °C (50-55 °F). The design and operation of cold rooms are fairly simple and no special equipment is required.

It is important to leave adequate space between stacks of boxes inside the refrigerated room in order for produce to cool more quickly. About 1 inch (2.5 cm) is sufficient to allow cold air to circulate around individual boxes. Produce in vented boxes will cool much faster than produce packed in unvented containers. In many small-scale cold rooms, produce has been loaded into the room so tightly that room cooling cannot take place at all, and despite the high cost of running the refrigeration system, the produce temperature never decreases to recommended levels.

Stacks of produce inside the cold room should be narrow, about one pallet width in depth (two or three cartons). Fans should be installed to move the cold air throughout the room. Air circulating through the room passes over surfaces and through any open space, so cooling from the outside to the center of the stacks is mostly by conduction. You'll want to monitor the temperature of the produce within the packages at various locations in the room to determine that the produce is being cool as desired. Rearrange the stacks and measure the rate of cooling until you find the right pattern for your cold room.
Low cost cold rooms can be constructed using concrete for floors and polyurethane foam as insulation materials. Building the storeroom in the shape of a cube will reduce the surface area per unit volume of storage space, also reducing construction and refrigeration costs. All joints should be carefully caulked and the door should have a rubber seal around the edges. While cooling produce, the ventilation system should be set to create an air flow rate of 100 cfm/ton (5 l/sec/ton). Once cooling is completed, air flow rates should be decreased to the lowest speed that will keep produce cool (20 to 40 cfm/ton is usually sufficient, according to Thompson et al. 1998). The greater the refrigerator's evaporator coil area, the less of a temperature difference there will be between the coils and the target room temperature, and the less moisture will be lost from the product as it cools.

For complete plans on constructing small-scale cold rooms, contact the Small Farm Center, University of California, Davis CA 95616, and ask for the publication entitled Small-Scale Cold Rooms for Perishable Commodities by Thompson and Spinoglio (1994).

Times* for 7/8th cooling for selected commodities using room cooling.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Package type</th>
<th>% vents</th>
<th>Average</th>
<th>Slowest time to 7/8th cool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>wooden box, bulk</td>
<td></td>
<td></td>
<td>2-3 days</td>
</tr>
<tr>
<td></td>
<td>wooden box, packed</td>
<td></td>
<td></td>
<td>6-8 days</td>
</tr>
<tr>
<td>Artichoke</td>
<td>corrugated container</td>
<td></td>
<td>24 hours</td>
<td></td>
</tr>
<tr>
<td>Grapes</td>
<td>wooden lug, solid stacked</td>
<td></td>
<td></td>
<td>30 hours</td>
</tr>
<tr>
<td>Pears</td>
<td>24 lb lug</td>
<td></td>
<td>16 hours</td>
<td>20 hours</td>
</tr>
<tr>
<td></td>
<td>24 lb lug, wrapped</td>
<td></td>
<td>30 hours</td>
<td>39 hr s</td>
</tr>
<tr>
<td></td>
<td>telescoping containers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 inch space between, 3.5%</td>
<td></td>
<td>16 hours</td>
<td>23 hours</td>
</tr>
<tr>
<td></td>
<td>no space between, 5%</td>
<td></td>
<td>24 hours</td>
<td>40 hours</td>
</tr>
<tr>
<td>Plums</td>
<td>corrugated container, tight fill, 28 lb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 inch space between, 4%</td>
<td></td>
<td></td>
<td>22 hours</td>
</tr>
<tr>
<td></td>
<td>no space between, no vents</td>
<td></td>
<td></td>
<td>84 hours</td>
</tr>
<tr>
<td>Oranges</td>
<td>24 inch deep bulk bins, no side vents</td>
<td></td>
<td>33 hours</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 inch deep bulk bins, no side vents</td>
<td></td>
<td>45 hours</td>
<td></td>
</tr>
</tbody>
</table>

*Times are approximate and should be used only as guides. Carefully monitor produce temperature to determine actual rate of cooling for your operation, climate, equipment, type and arrangement of containers.

Forced-Air Cooling

Forced-air cooling pulls or pushes air through the vents in storage containers, greatly speeding the cooling rate of any type of produce (taking 1/4 to 1/10 of the time needed for room cooling). Some cold rooms have permanent forced-air cooling units built into a side wall. A variety of portable forced-air coolers have been designed for use by small-scale growers and handlers.

Cooling time depends on the air flow rate, the temperature difference between the produce and the cold air, and produce diameter. Small produce such as berries or cherries (about 1" in diameter) will cool almost 6 times faster than 6" diameter melons. The fan needs to be big enough to provide an airflow of about 1 cfm/lb (1 liter/sec/kg) against a wide range of static pressures. You may have to experiment a bit with fan speed settings and air flow rates, since static pressure will change depending upon the types of containers, width of stacks, air spaces between containers, size and shape of the cold room, and type of packaging materials (liners or wraps) used. Doubling the air flow will speed cooling slightly but cost a lot more because you would need a much larger and costlier fan (with 6 to 7 times more horsepower). Reducing air flow by one-half will increase cooling time by about one hour for most commodities, and would dramatically reduce fan motor size and energy costs.

To reduce cooling time and associated costs, it helps to reduce the initial temperature of the produce by harvesting early in the day (when temperatures are cooler) and by keeping produce shaded during any delays in moving it into the cooler. When stacking boxes against the cooler, stacks one box wide will cool faster than boxes stacked two or three wide.

The produce closest to the cold forced-air will cool faster than produce near the center of the load. Cooling this center-placed produce will take about the same time as it takes for the center of large diameter produce to come to the proper temperature. You can measure the temperature of the produce with an inexpensive temperature probe. Make sure not to stop the cooling process before the warmest produce has reached the desired temperature.
The operation of the forced-air cooler should be stopped as soon as the produce is cooled. Additional high speed air movement through the cold produce will cause serious water loss unless the air is at nearly 100% RH (but very high RH during forced-air cooling can add moisture to packages and reduce their strength and durability). It is better to closely monitor the forced-air cooler and shut it off or remove produce as soon as it is cooled.

**Times* to 7/8th cooling for selected commodities using forced-air cooling.**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Type of package</th>
<th>% vents</th>
<th>Flow rate (cfm/lb)</th>
<th>Average time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artichoke</td>
<td>Corrugated container</td>
<td>9%</td>
<td>1.0</td>
<td>4 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5</td>
<td>3 hours</td>
</tr>
<tr>
<td>Grapes</td>
<td>Full telescoping</td>
<td>5.8%</td>
<td>0.27</td>
<td>6 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td>4 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>2 hours</td>
</tr>
<tr>
<td>Nectarines</td>
<td>Corrugated container</td>
<td>6%</td>
<td>0.5</td>
<td>4 hours</td>
</tr>
<tr>
<td></td>
<td>with plastic trays</td>
<td></td>
<td>0.8</td>
<td>3 hours</td>
</tr>
<tr>
<td></td>
<td>Bliss box, 2 layers</td>
<td>5%</td>
<td>0.5</td>
<td>6 hours</td>
</tr>
<tr>
<td></td>
<td>with top pad</td>
<td></td>
<td>0.8</td>
<td>4 hours</td>
</tr>
<tr>
<td>Pears</td>
<td>Corrugated container</td>
<td>2%</td>
<td>0.3</td>
<td>9 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.2</td>
<td>3 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td>6 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>3 hours</td>
</tr>
<tr>
<td>Oranges</td>
<td>Bulk bins, slotted bottoms</td>
<td>2-3 ft. deep, vertical airflow</td>
<td>0.4</td>
<td>6 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>3 hours</td>
</tr>
<tr>
<td>Strawberries</td>
<td>Open crates on pallets</td>
<td></td>
<td>0.5</td>
<td>4 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.8</td>
<td>3 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.4</td>
<td>2 hours</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>Corrugated container</td>
<td>10%</td>
<td>0.6</td>
<td>6 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.1</td>
<td>4 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.6</td>
<td>3 hours</td>
</tr>
</tbody>
</table>

* Times for forced-air cooling are approximate and should be used only as guides. Carefully monitor produce temperature to determine actual rate of cooling for your operation, climate, equipment, type and arrangement of containers.

**Portable forced-air coolers**

A portable forced-air cooler can be constructed using a canvas or polyethylene sheet. The sheet is rolled over the top and down the back of the boxes to the floor, sealing off the unit and forcing air to be pulled through the vents of the cartons stacked against the cooler. The energy requirements for running the fan will be reduced if the vent area is at least 4% of the surface area of the carton. Most good quality fiberboard containers can be vented up to 5% without significant loss of stacking strength.

This unit is designed to be used inside a refrigerated storage room. Keeping the air inside the cold room humidified will reduce water loss during forced-air cooling. A single width of containers allows produce to cool as quickly as possible in the forced-air cooler. Setting the cooler up with two layers of containers with aligned vents will slow cooling considerably.

These illustrations show a portable tunnel type forced-air cooler equipped with a fan to pull air from a cold room through the boxed produce. The first illustration shows the cooler in its empty state, with the canvas cover extended (it should be rolled up for storage when not in use). The fan is housed inside the box on the base of the cooler. The second illustration shows the cartons of produce set up in a row on each side of the cooler for forced-air cooling.
If you are using two forced-air coolers in the same cold room, it is important to separate them (using a screen or temporary wall) so that the warmer produce in a recently loaded cooler does not slow down cooling in the other cooler.

**VENTED CONTAINER DESIGNED FOR FORCED-AIR COOLING:**
- avoid round vents (they can easily be blocked)
- make vents 1 cm (1/2 inch) wide or larger
- keep vents 4 to 7 cm (2 to 3 inches) from all corners
- vents should be about 5% of the side area
Evaporative Cooling

Evaporative coolers (also known as desert coolers) can be constructed to cool the air in an entire storage structure or just to speed cooling in a few containers of produce. These coolers are only suitable for lower humidity regions of the world or during dry seasons, since the degree of cooling is limited to 1 to 2 °C (2 to 4 °F) above the wet-bulb temperature.

Evaporative coolers contain a cooling pad of wood fiber or straw, moistened with water. Air is pulled through the pad using a fan, and the cooled, moist moves through produce, carrying away the heat it contains.

Room sized unit:
Source: Thompson and Scheuerman, 1993

An evaporative cooler can be combined with a forced air cooler for speeding the cooling of small lots of produce in dry regions of the world. Evaporative-forced-air coolers are especially suitable for cooling produce that is very sensitive to moisture loss. In the example provided here, a small-scale evaporative cooler uses about 4 L (0.5 gallon) of water per minute dripped onto a one square meter (8 square foot) pad, providing enough moist air to cool up to 18 crates of produce in 1 to 2 hours. Water is collected in a tray at the base of the unit and recirculated.

Evaporative forced-air cooler
The low cost cooling chambers illustrated below are constructed from bricks. The cavity between the walls is filled with sand and the bricks and sand are kept saturated with water. Fruits and vegetables are loaded into plastic crates and put inside for storage. During the hot summer months in India, this chamber is reported to maintain an inside temperature between 15 and 18°C (59 and 65°F) and a relative humidity of about 95%. PAU has a working model of this cooler at the Department of Agricultural Structures.

Improved zero-energy cool chamber: the entire rectangular chamber is covered with a rush mat, which is also kept moist.


Larger round storage structure: The same methods were used to construct this larger evaporative-cooled storage structure. Since a relatively large amount of materials are required to construct this structure, it may be economically feasible only when handling high value products.
Hydro-Cooling

Even faster than forced-air cooling is hydro-cooling, where water-tolerant produce is either immersed or showered with icy cold water. Several designs for hydro-coolers are used by small-scale handlers, known as either batch-type or continuous-flow type systems. Immersion hydro-coolers usually take longer to cool produce than shower type coolers, and are mostly used for bulk produce of a density greater than water (so it won't float) such as cherries. One of the benefits of using hydro-coolers is that they can be easily integrated into your packing operations, and become a step within a simple packing line.

Produce to be hydro-cooled can be spread out in a single or multiple layers, left in open field bins or be packed in vented plastic or wooden boxes. Containers need to be vented on the top to allow water to flow into the container and around the produce. Waxed cartons can be used, but these are expensive and will sometimes fail when exposed to long hydro-cooling times. Always sort before cooling, so you won't waste money by cooling culls.

Hydro-cooling requires a lot of power, since the water temperature must be kept very cold (with ice or mechanical refrigeration). The refrigeration capacity you will need depends upon the amount of produce you intend to cool per hour, the incoming temperature of the produce, and the external heat the hydro-cooler will have to deal with. Little information is available for small-scale users, but if you want to cool 1000 lbs of produce per hour, you will need about 0.4 ton of refrigeration capacity for a 11 °C (20 °F) temperature drop; 0.8 ton for a 24 °C (45 °F) temperature drop; or 1.5 tons for a 39 °C (70 °F) temperature drop. (The conversion for changing tons of refrigeration capacity to kilowatts of refrigeration capacity is: tons x 3.52 = kW). A hydro-cooler installed in a cold room will require about 30% less refrigeration capacity than an uninsulated cooler installed outdoors (Thompson, 1995).

Commercial hydro-coolers deliver water at a rate of about 10 to 15 gallons per square foot per minute (400-600 L/square meter/minute). A lower flow rate will be sufficient if you are cooling a single layer of bulk produce, while double this rate may be necessary if you stack boxes or bins 2
or 3 high in a batch-type cooler. If stacking boxes, make sure vents are aligned or the bottom layer of produce will not be cooled. The water must run down and into the containers, surrounding the produce with constantly moving cold water.

When using a hydro-coolers you must pay attention to the rate of cooling, which will depend on incoming produce temperature, water temperature, flow rate of water and the type of containers used, if any. Begin by taking temperature measurements (via temperature probe), then you can adjust the rate of produce flow for continuous-flow type or the time you leave containers inside a batch-type hydro-coolers. Small diameter produce such as asparagus and radishes will typically be cooled in less than 10 minutes, medium sized produce such as peaches and apples will take about 20-25 minutes, while large diameter produce such as melons can take one hour.

Times* for 7/8ths cooling of selected commodities using hydro-cooling.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Package type</th>
<th>Hydro-cooler type</th>
<th>Flow rate</th>
<th>Average time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>none (bunches)</td>
<td>immersion</td>
<td></td>
<td>6 minutes</td>
</tr>
<tr>
<td>Peaches</td>
<td>47 inch square bins</td>
<td>Shower free draining</td>
<td>150 gpm/bin</td>
<td>30 minutes</td>
</tr>
<tr>
<td></td>
<td>24 inches deep</td>
<td></td>
<td>0 1-inch holes, allowing bin to fill</td>
<td>24 minutes</td>
</tr>
<tr>
<td>Pears</td>
<td>open lug</td>
<td>Shower</td>
<td>4 gpm/ft²</td>
<td>42 minutes</td>
</tr>
<tr>
<td>Sweet corn</td>
<td>wirebound crates</td>
<td>Immersion no agitation plus agitation</td>
<td>46-84 minutes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shower free draining</td>
<td>5 gpm/ft²</td>
<td>45 minutes</td>
</tr>
</tbody>
</table>

* Times are approximate and should be used only as a guide. Carefully monitor produce temperature to determine the actual rate of cooling for your operation, climate, equipment and package types and arrangements.

Hydro-cooler Use and Maintenance

Water is recirculated in hydro-coolers and should be chlorinated with 100 to 150 ppm of available chlorine (60 ml per 40 L or 2 ounces of chlorine bleach per 10 gallons of water) to prevent the spread of decay. Several times during use each day, test for available chlorine using a chemical test kit and adjust as necessary. Organic matter ties up chlorine, so if the produce is especially dirty you will use more chlorine than usual. Washing produce before hydro-cooling will decrease this problem.

When mangoes are immersed in ice water for only ten minutes directly following harvest, pulp temperature is reduced by 10 to 15 °C from an ambient temperature of 40 to 45 °C.

Source: International Food World

Keep the pH of the water in the range of 6.5 to 7.5 to prevent corrosion problems and the release of toxic chlorine gas. Use litmus paper strips or an inexpensive electronic pH meter to measure pH, and add muriatic acid to decrease pH or lye to increase pH (be sure to follow directions on the labels of these products). At the end of each day the entire cooler should be drained and cleaned. Waste water may contain pesticide residues and chlorine, so be sure to follow local regulations on proper disposal methods.

About 25% of the energy used to run a hydro-cooler is required to remove heat conducted across exterior surfaces, pipes and from the air, and another 10% is used to offset the heating caused by the water pump. Insulating the hydro-cooler and keeping it in a cool location (inside a cold room or at the minimum in deep shade) will decrease the cost of operation. Starting with cooler produce (harvested in the early morning, kept in the shade during sorting and packing, using naturally cool well water to pre-rinse warm) will also decrease costs by decreasing cooling times.

To reduce hydro-cooler costs:

- insulate the hydro-cooler
- set it up in deep shade or inside a cold room
- start with produce harvested in the morning hours
CHAPTER 6: TEMPERATURE AND RELATIVE HUMIDITY CONTROL

Types of Hydro-Coolers

Batch type hydrocooler (cut-away view)

Continuous flow shower type hydrocooler (cut-away view)

Continuous flow immersion type hydrocooler (cut-away view)

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Chilling Injury

While cooling is very important, care must be taken to avoid chilling injury in sensitive crops. Chilling injury occurs when crops are stored or transported at temperatures lower than those recommended for proper postharvest handling. Tropical and subtropical produce is especially sensitive, and chilling injury can be seen regularly in tomatoes, peppers and cucumbers. Everyone is familiar with the various symptoms of chilling injury which include failure to ripen (bananas and tomatoes); development of pitting or sunken areas (oranges, melons and cucumbers); brown discoloration of tissues (avocados, cherimoyas, eggplant); increased susceptibility to decay (cucumbers, tomatoes, zucchini and beans); and lack of flavor development (tomatoes). Any of these symptoms will decrease the value of the produce you have to sell.

Many fruit and vegetable crops are susceptible to chilling injury when cooled below 13 to 16 °C (55 to 60 °F). Chilling injury reduces the quality of the product and shortens shelf life. Make sure you don't over-cool sensitive produce. Symptoms often appear only after the commodity is returned to warmer temperatures during marketing.

Prevent chilling injury by keeping these crops at their lowest safe temperature


<table>
<thead>
<tr>
<th>Commodity</th>
<th>Lowest safe temperature °C</th>
<th>°F</th>
<th>Chilling Injury Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples (Jonathan, McIntosh)</td>
<td>2-3</td>
<td>36-38</td>
<td>soft scald, brown core</td>
</tr>
<tr>
<td>Apples (Yellow Newton)</td>
<td>3-4</td>
<td>38-40</td>
<td>internal browning</td>
</tr>
<tr>
<td>Asparagus</td>
<td>0 °C</td>
<td>32-36</td>
<td>dull, grayish, limp tips</td>
</tr>
<tr>
<td>Avocados (Lula, Booth 1, Taylor)</td>
<td>4.5</td>
<td>41</td>
<td>grayish-brown</td>
</tr>
<tr>
<td>Avocados (Fuchs, Pollock)</td>
<td>13</td>
<td>55</td>
<td>discoloration</td>
</tr>
<tr>
<td>Avocados (Fuerte, Hass, Booth)</td>
<td>7-8</td>
<td>45-46</td>
<td>of the flesh</td>
</tr>
<tr>
<td>Bananas</td>
<td>12-13</td>
<td>54-55</td>
<td>dull color when</td>
</tr>
<tr>
<td>Beans (lima)</td>
<td>2-4</td>
<td>35-40</td>
<td>rusty brown specks, spots</td>
</tr>
<tr>
<td>Commodity</td>
<td>Lowest safe temperature °C</td>
<td>°F</td>
<td>Chilling Injury Symptoms</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------------------</td>
<td>-----</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Cranberries</td>
<td>2</td>
<td>36</td>
<td>rubbery texture</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>7</td>
<td>45</td>
<td>pitting, watersoaking, decay</td>
</tr>
<tr>
<td>Eggplants</td>
<td>7</td>
<td>45</td>
<td>surface scald, alternaria rot, blackening of seeds</td>
</tr>
<tr>
<td>Guavas</td>
<td>4.5</td>
<td>40</td>
<td>pulp injury, decay</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>10</td>
<td>50</td>
<td>scald, pitting, watery breakdown</td>
</tr>
<tr>
<td>Jicama</td>
<td>13-18</td>
<td>55-65</td>
<td>surface decay, discoloration</td>
</tr>
<tr>
<td>Lemons</td>
<td>11-13</td>
<td>52-55</td>
<td>pitting, red blotch, membrane staining</td>
</tr>
<tr>
<td>Limes</td>
<td>7-9</td>
<td>45-48</td>
<td>pitting, turning tan with time</td>
</tr>
<tr>
<td>Mangoes</td>
<td>10-13</td>
<td>50-55</td>
<td>uneven ripening, grayish skin</td>
</tr>
<tr>
<td>Melons</td>
<td>2-5</td>
<td>36-41</td>
<td>pitting, surface decay</td>
</tr>
<tr>
<td>Cantaloupe</td>
<td>7-10</td>
<td>45-50</td>
<td>reddish-tan discoloration, pitting</td>
</tr>
<tr>
<td>Honey Dew</td>
<td>7-10</td>
<td>45-50</td>
<td>surface decay, failure to ripen</td>
</tr>
<tr>
<td>Casaba</td>
<td>7-10</td>
<td>45-50</td>
<td>pitting, decay, failure to ripen</td>
</tr>
<tr>
<td>Crenshaw, Persian</td>
<td>7-10</td>
<td>45-50</td>
<td>pitting, decay, failure to ripen</td>
</tr>
<tr>
<td>Watermelon</td>
<td>4.5</td>
<td>40</td>
<td>pitting, off-flavor</td>
</tr>
<tr>
<td>Okra</td>
<td>7</td>
<td>45</td>
<td>discoloration, water-soaked areas, pitting, decay</td>
</tr>
<tr>
<td>Olives (fresh)</td>
<td>7</td>
<td>45</td>
<td>internal browning</td>
</tr>
<tr>
<td>Oranges (CA and AZ)</td>
<td>3</td>
<td>38</td>
<td>pitting, brown stain</td>
</tr>
<tr>
<td>Papayas</td>
<td>7</td>
<td>45</td>
<td>pitting, failure to ripen, off-flavor, decay</td>
</tr>
<tr>
<td>Peppers (sweet)</td>
<td>7</td>
<td>45</td>
<td>sheet pitting, alternaria rot, darkening of seed</td>
</tr>
<tr>
<td>Pineapples</td>
<td>7-10</td>
<td>45-50</td>
<td>dull green when ripe</td>
</tr>
<tr>
<td>Pomegranates</td>
<td>4.5</td>
<td>40</td>
<td>pitting, browning</td>
</tr>
<tr>
<td>Potatoes</td>
<td>3</td>
<td>38</td>
<td>sweetening</td>
</tr>
<tr>
<td>Chippewa, Sebago</td>
<td>3</td>
<td>38</td>
<td>mahogany browning</td>
</tr>
<tr>
<td>Pumpkins, squashes</td>
<td>10</td>
<td>50</td>
<td>decay, alternaria rot</td>
</tr>
<tr>
<td>Sweetpotatoes</td>
<td>13</td>
<td>55</td>
<td>decay, pitting, internal browning</td>
</tr>
<tr>
<td>Tomatoes, ripe</td>
<td>7-10</td>
<td>45-50</td>
<td>water soaking, softening, decay</td>
</tr>
<tr>
<td>mature-green</td>
<td>13</td>
<td>55</td>
<td>poor color when ripe, alternaria rot</td>
</tr>
</tbody>
</table>
Use of Ice
Crushed or flaked ice for package icing can be applied directly or as a slurry in water (liquid ice). The ice must come into direct contact with the produce in order to cool, and cannot simply be placed on top of the produce. The water used to make ice must be potable (clean). Flaked or crushed ice can be manufactured using commercial machinery, but operation and storage of ice is expensive. If you use ice only for a short time during the harvest season, it is probably less expensive to purchase block ice and crush it on site.

The use of ice to cool produce provides a high relative humidity environment around the product and can reduce the rate of water loss in commodities sensitive to moisture loss. Melting 1 lb of ice made from water has the cooling effect of 144 Btu. One lb or kg of ice will drop the temperature of produce 3 times its weight by about 50 °F (28 °C).

Package ice can be used only with water tolerant, non-chilling sensitive products and with water tolerant packages (waxed fiberboard, plastic or wood). Waxed or wooden containers are much more expensive than fiberboard. Using ice greatly increases the weight of the load, and some transport vehicles may exceed their rated carrying capacity before they are fully loaded. It is estimated that at least 10 lbs of ice must be added to a 20 lb carton of broccoli in order to provide cooling during long distance transport, and even more is required if you desire to have ice left in the container upon arrival at the destination market. Melting ice can damage fiberboard containers when produce is handled in mixed loads.

**PRODUCE SUITED FOR PACKAGE ICING:**

- anise, broccoli, brussels sprouts, cabbages, cantaloupes, carrots, celeriac, daikon, endive, escarole, green onions, leeks, lettuce, parsley, peas, spinach, radishes, rhubarb, rutabagas, sweet corn, turnips and turnip greens

Source: TRANSFRESH, 1988
Top ice doesn't do much cooling, but is sometimes used for certain products during transport to help maintain a high relative humidity. Top ice can be used only with water tolerant, non-chilling sensitive products and with water tolerant packages (waxed fiberboard, plastic or wood). Top-ice on loads should be applied in rows rather than a solid mass. It is important not to block air circulation inside the transport vehicle.

ALTERNATIVE COOLING STRATEGIES

Night Air Ventilation
Storage structures can be cooled using night air if the difference in day and night temperature is relatively large. The storage facility should be insulated and vents should be located at ground level. Vents can be opened at night, and fans can be used to pull cool air through the storeroom. The structure will best maintain cool temperatures during the heat of the day if it is well insulated and vents are closed early in the morning.

Radiant Cooling
Radiant cooling can be used to lower the air temperature in a storage structure if a solar collector is connected to the ventilation system of the building. By using the solar collector at night, heat will be lost to the outside environment. A hollow, shallow black box with a clear glass cover can transfer heat that rises from the building via infrared radiation to the night sky.
Temperatures inside the structure of 4 °C (about 8 °F) less than night temperature can be achieved. The collector must be covered with a light colored blanket or sheet of insulation such as Reflectix® during the day to prevent the accumulation of solar radiation.

Use of Well Water
Well water is often much cooler than air temperature in most regions of the world. The water temperature of a deep well tends to be in the same range as the average air temperature of the same locality. Well water can be used for hydro-cooling chilling sensitive crops and as a spray or mist to maintain high relative humidity in the storage environment.

High Altitude Storage
As a general rule, air temperatures decrease by 10 °C (18 °F) for every one kilometer increase in altitude. If you have an option to pack or store commodities at higher altitude, costs for cooling and cold storage can be reduced. Cooling and storage facilities operated at high altitude require less energy than those at sea level for the same results. In California when temperatures in the Central Valley reach 38 °C (100 °F), temperatures in the high Sierra mountains, only about 50 miles away, are likely to be 21 to 24 °C (70 to 75 °F).

RELATIVE HUMIDITY CONTROL
Another aspect to consider when handling fruits and vegetables is the relative humidity of the storage environment. Loss of water from produce is often associated with a loss of quality, as visual changes such as wilting or shrivelling and textural changes can take place. Leafy crops tend to lose water the most quickly. If using mechanical refrigeration for cooling, the larger the area of the refrigerator coils, the higher the relative humidity in the cold room will remain. It pays however, to remember that water loss may not always be undesirable, for example if your produce is destined for dehydration or processing to puree or sauces.
The rate of water loss can be estimated by using the commodity's transpiration coefficient and the VPD (the vapor pressure deficit, which is dependent upon the difference in temperature between the commodity and its environment and the relative humidity of the air around the commodity). Apples, potatoes, onions, pears and citrus fruits have relatively low transpiration coefficients, while peaches, leeks, carrots, celery, brussel sprouts and lettuce have very high transpiration coefficients. When handled at the same temperature and RH, carrots and lettuce will lose much more water than apples or potatoes. Reducing the difference in temperature and/or increasing RH will decrease the rate of water loss.

Water loss of 3 to 6% is generally enough to cause a noticeable loss of quality and value. Stone fruits (peaches, plums and apricots) look shriveled when they suffer water loss of 4 to 5%. Root crops (carrots, beets, turnips, radishes) will lose water much faster if their tops are left attached, since the leaves will continue to transpire, taking water from the roots. Reducing the rate of water loss slows the rate of shriveling and wilting, causes of serious postharvest losses. If you sell produce by weight, every bit of water lost is also lost profits. Produce handled and marketed at 27 °C (80 °F) and 60% RH (very adverse conditions, but not uncommon in the southwestern and western US during May through October, or in Punjab in April and May) can lose a lot of water in a short time.

Cornell University studies have demonstrated the following water losses for these crops under high temperature/low humidity conditions:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Water Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>8.4%</td>
</tr>
<tr>
<td>Snap beans</td>
<td>4.0%</td>
</tr>
<tr>
<td>Topped beets</td>
<td>3.1%</td>
</tr>
<tr>
<td>Topped carrots</td>
<td>3.6%</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>2.5%</td>
</tr>
<tr>
<td>Summer squash</td>
<td>2.2%</td>
</tr>
</tbody>
</table>
Maximum storage life and maximum percentage water loss before becoming unsaleable (becoming lowest grade or poor quality due to wilting or shriveling) for selected horticultural crops.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Maximum storage life at optimum conditions</th>
<th>Maximum % water loss before becoming unsaleable</th>
</tr>
</thead>
<tbody>
<tr>
<td>asparagus</td>
<td>2-3 weeks</td>
<td>8</td>
</tr>
<tr>
<td>beans (runner)</td>
<td>1-1.5 weeks</td>
<td>5</td>
</tr>
<tr>
<td>beets/topped</td>
<td>30-40 weeks</td>
<td>7</td>
</tr>
<tr>
<td>beets with tops</td>
<td>2-4 weeks</td>
<td>5</td>
</tr>
<tr>
<td>blackberries</td>
<td>1.5 weeks</td>
<td>6</td>
</tr>
<tr>
<td>brussels sprouts</td>
<td>4-6 weeks</td>
<td>8</td>
</tr>
<tr>
<td>cabbage (Primo)</td>
<td>6-12 weeks</td>
<td>7</td>
</tr>
<tr>
<td>cabbage (Decema)</td>
<td>40-50 weeks</td>
<td>10</td>
</tr>
<tr>
<td>carrots/topped</td>
<td>40-50 weeks</td>
<td>8</td>
</tr>
<tr>
<td>carrots with tops</td>
<td>2-3 weeks</td>
<td>4</td>
</tr>
<tr>
<td>cucumber</td>
<td>1.5-2 weeks</td>
<td>5</td>
</tr>
<tr>
<td>grapes (Thompson seedless)</td>
<td>4-10 weeks</td>
<td>2</td>
</tr>
<tr>
<td>lettuce</td>
<td>1.5-3 weeks</td>
<td>3</td>
</tr>
<tr>
<td>onion</td>
<td>30-35 weeks</td>
<td>10</td>
</tr>
<tr>
<td>parsnip</td>
<td>25-30 weeks</td>
<td>7</td>
</tr>
<tr>
<td>peas (in pod)</td>
<td>2-5 weeks</td>
<td>5</td>
</tr>
<tr>
<td>peaches</td>
<td>2-5 weeks</td>
<td>5</td>
</tr>
<tr>
<td>peppers</td>
<td>1.5-2 weeks</td>
<td>7</td>
</tr>
<tr>
<td>spinach</td>
<td>1.5-2 weeks</td>
<td>3</td>
</tr>
<tr>
<td>strawberries</td>
<td>2-3 weeks</td>
<td>7</td>
</tr>
<tr>
<td>tomato (1/4 ripe)</td>
<td>2-3 weeks</td>
<td>7</td>
</tr>
</tbody>
</table>


Increasing Relative Humidity

For fresh market produce, any method of increasing the relative humidity of the storage environment or decreasing the vapor pressure deficit (VPD) between the commodity and its environment will slow the rate of water loss. The best method of increasing RH is to reduce the temperature.

A common method of increasing RH in a storage room is to add moisture to the air around the commodity as mists, sprays, or, at last resort, by wetting the floor. Another way is to use vapor barriers such as waxes, polyethylene liners in boxes, coated boxes or a variety of inexpensive and recyclable packaging materials. Any added packaging materials will increase the difficulty of
efficient cooling, so vented liners (about 5% of the total area of the liner) are recommended. The liner vents must line up with the package vents to facilitate cooling of the produce inside. Vented liners will decrease VPD without seriously interfering with oxygen, carbon dioxide and ethylene movement.

**RH CAN BE CONTROLLED BY:**

- adding moisture to air (water mist or spray)
- regulating air movement and ventilation rates in relation to produce
- maintaining refrigeration coils in a cold room within 1 °C or 2°F of air temperature
- providing moisture barriers (insulation, liners, plastic films)
- wetting floors in storage rooms
- adding crushed ice to packages and displays (for tolerant crops)
- sprinkling produce during retail marketing (leafy vegetables, cool season root crops, immature fruit crops)

Source: Kader, 1992

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**PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE**
CHAPTER 6: TEMPERATURE AND RELATIVE HUMIDITY CONTROL

COMPARISON OF ESTIMATED COSTS AND EXPECTED BENEFITS RELATED TO COOLING HORTICULTURAL PRODUCE AND MAINTAINING THE COLD CHAIN DURING HANDLING, STORAGE, TRANSPORT AND MARKETING.

Costs:
- Equipment
- Power
- Labor

Benefits:
- Lower postharvest losses
- Longer shelf life
- Higher quality

McDonald’s attributes much of its success to the use of the cold chain and their attention to quality and HACCP.

Source: Times of India 13 July 1998

Example 1: Two tons of mangoes harvested at the peak of the season (June 15 to 20) are handled either at ambient temperatures (30 to 35 °C) or via an integrated cold chain (15 °C) where cooling costs are relatively high: $1000 ($0.25 / lb).

<table>
<thead>
<tr>
<th></th>
<th>Ambient temperature</th>
<th>Cold Chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postharvest losses</td>
<td>35%</td>
<td>10%</td>
</tr>
<tr>
<td>Quality classes:</td>
<td>20% highest</td>
<td>50% highest</td>
</tr>
<tr>
<td></td>
<td>50% second</td>
<td>30% second</td>
</tr>
<tr>
<td></td>
<td>30% lowest</td>
<td>20% lowest</td>
</tr>
<tr>
<td>Total volume sold</td>
<td>2600 lbs</td>
<td>3600 lbs</td>
</tr>
<tr>
<td>Marketing period</td>
<td>June 15-June 28</td>
<td>June 15 - August 1</td>
</tr>
<tr>
<td>Average price/lb</td>
<td>$0.50</td>
<td>$1.25</td>
</tr>
<tr>
<td>Sales - cost of cooling</td>
<td>$1300</td>
<td>$3500</td>
</tr>
</tbody>
</table>

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Example 2: 1000 kgs of mangoes harvested at the peak of the season (June 15 to 20) are handled either at ambient temperatures (30 to 35 °C) or via an integrated cold chain (15 °C) where cooling costs are relatively high: Rs 10,000 (R10/kg).

<table>
<thead>
<tr>
<th></th>
<th>Ambient temperature</th>
<th>Cold Chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postharvest losses</td>
<td>35%</td>
<td>10%</td>
</tr>
<tr>
<td>Quality classes:</td>
<td>20% highest</td>
<td>50% highest</td>
</tr>
<tr>
<td></td>
<td>50% second</td>
<td>30% second</td>
</tr>
<tr>
<td></td>
<td>30% lowest</td>
<td>20% lowest</td>
</tr>
<tr>
<td>Total volume sold</td>
<td>650 kg</td>
<td>900 kg</td>
</tr>
<tr>
<td>Marketing period</td>
<td>June 15-June 28</td>
<td>June 15 - August 1</td>
</tr>
<tr>
<td>Average price/lb</td>
<td>Rs 5</td>
<td>Rs 18</td>
</tr>
<tr>
<td>Potential Sales</td>
<td>Rs 3900</td>
<td>Rs 16,200</td>
</tr>
<tr>
<td>Sales - cost of cooling</td>
<td>Rs 3900</td>
<td>Rs 6,200</td>
</tr>
</tbody>
</table>

SOURCES OF COOLING AND RH CONTROL EQUIPMENT AND SUPPLIES

- air-exhaust doors/ louver: Industrial Ventilation, Inc.
- "Cool-and-Ship" (mobile cooler) plans: North Carolina State University Cooperative Extension
- evaporative cooling pads: Hydro-Gardens, Inc.
- forced-air cooling systems: Pressure Cool Co.
- hydro-coolers: Clarkesville Machine Works, Inc
- humidifiers: Industrial Ventilation, Inc.
ice-makers (3 to 6 ton/day, portable)  Semco Manufacturing Company
ice storage  Robic Refrigeration Inc.
             Semco Manufacturing Company
insulation  Jade Mountain
           Reflectix, Inc
mini-reefers  CMF Corp.
portable "hydro-chillers"  Semco Manufacturing Company
radiant barriers (screening, shadecloth)  Real Goods
refrigeration equipment  Calif. Controlled Atmospheres
                          Hydro-Gardens, Inc.
thermometers, temperature probes  Dickson
                                  International Ripening Corporation

For addresses and phone/FAX numbers of suppliers, please refer to Appendix D.

REFERENCES


Tugwell, B.L. No date. Coolroom construction for the fruit and vegetable grower. Department of Agriculture and Fisheries, South Australia. Special Bulletin 11.75.

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Sometimes you may want to store produce before marketing, either for the short term or over a longer period of time. One reason may be that you simply produced more than you can sell (although with production planning and a good marketing plan with multiple options this should not be happening often). You may need to store produce for a few days until you have enough produce to warrant long-distance transport, or while transport to a wholesale market can be arranged through a common carrier. For crops such as Bartlett pears or blood oranges, a few weeks of cold storage will enhance quality.

Another reason to put crops into storage after harvest may be because current market prices are low due to high local production and you anticipate an increase in prices when supplies decrease at the end of the season. Or perhaps you produced some crops with the idea of processing them to more stable, value-added products, and would like to do the processing after the rush of the production season has passed.

The red pigment of blood oranges can be developed by storing the fruits for 6 weeks after harvest at a temperature of 0 to 4°C (32 to 39°F).

Source: Singh 1998
There are few key factors to consider when storing fresh produce. Some cultivars have a naturally longer storage potential than others of the same commodity. If you are considering produce storage, you should first determine which varieties will give you the best results. The range of storage potential (postharvest performance rating according to maximum market life in weeks) is illustrated by selected stone fruits grown in California.

<table>
<thead>
<tr>
<th>Fruit/Cultivar</th>
<th>Maximum market life at 0 °C (32 °F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nectarines</td>
<td></td>
</tr>
<tr>
<td>August Red</td>
<td>6 weeks</td>
</tr>
<tr>
<td>Autumn Grand</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Early Diamond</td>
<td>5</td>
</tr>
<tr>
<td>Fairlane</td>
<td>3</td>
</tr>
<tr>
<td>Flamekist</td>
<td>3</td>
</tr>
<tr>
<td>Grandertli</td>
<td>6</td>
</tr>
<tr>
<td>Independence</td>
<td>5 - 6</td>
</tr>
<tr>
<td>May Grand</td>
<td>6</td>
</tr>
<tr>
<td>Summer Red</td>
<td>5</td>
</tr>
<tr>
<td>Peaches</td>
<td></td>
</tr>
<tr>
<td>August Sun</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Autumn Gem</td>
<td>1</td>
</tr>
<tr>
<td>Coronet</td>
<td>4</td>
</tr>
<tr>
<td>Fairtime</td>
<td>2</td>
</tr>
<tr>
<td>Fay Elberta</td>
<td>3 - 6</td>
</tr>
<tr>
<td>Kern Sun</td>
<td>5</td>
</tr>
<tr>
<td>Kings Lady</td>
<td>2</td>
</tr>
<tr>
<td>Snow Flame</td>
<td>5</td>
</tr>
<tr>
<td>Suncrest</td>
<td>2</td>
</tr>
<tr>
<td>Plums</td>
<td></td>
</tr>
<tr>
<td>Angeleno</td>
<td>4 - 5</td>
</tr>
<tr>
<td>Catalina</td>
<td>6</td>
</tr>
<tr>
<td>Durado</td>
<td>1</td>
</tr>
<tr>
<td>Grand Rosa</td>
<td>3</td>
</tr>
<tr>
<td>Kelsey</td>
<td>2</td>
</tr>
<tr>
<td>Red Beaut</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Royal Diamond</td>
<td>5 - 6</td>
</tr>
<tr>
<td>Simka</td>
<td>3</td>
</tr>
</tbody>
</table>

Indian banana cultivars vary greatly in keeping quality. The following have been rated—

very good: Nendran

good: Monthan, Poovan

poor: Basrai, Chakrakali

Source: Singh 1998

Next, lowering the temperature to the lowest safe handling temperature is of paramount importance. Even if you cannot provide the exact recommended conditions, any effort to lower temperature will be rewarded by longer shelf life, reduced losses and higher quality during marketing.

Finally, always handle produce gently and never store produce unless it is of the best quality. Damaged produce will lose water faster and have higher decay rates in storage when compared to undamaged produce.
CHAPTER 7: STORAGE PRACTICES AND STRUCTURES

CABBAGES STORED FOR 2 MONTHS IN KOREA

<table>
<thead>
<tr>
<th></th>
<th>Storage at 20 °C</th>
<th>Storage at 30 to 35 °C (ambient)</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight loss</td>
<td>3.6%</td>
<td>8.9%</td>
</tr>
<tr>
<td>weight of decayed produce</td>
<td>1.2%</td>
<td>33.5%</td>
</tr>
<tr>
<td>% marketable</td>
<td>95.2%</td>
<td>57.6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Non-wounded heads</th>
<th>Wounded heads</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight loss</td>
<td>8.2%</td>
<td>20.6%</td>
</tr>
<tr>
<td>weight of decayed produce</td>
<td>3.1%</td>
<td>18.4%</td>
</tr>
<tr>
<td>% marketable</td>
<td>88.7%</td>
<td>61.0%</td>
</tr>
</tbody>
</table>

Source: Thompson, A. K. 1996

This chapter describes the principles of proper storage and some of the simple storage practices and small structures that can be used on your own farm to make sure your crops are stored under conditions that will provide the maximum shelf life and maintenance of quality and value. If you prefer, larger storage structures can be used, perhaps by sharing the costs of construction and maintenance with others who are working cooperatively to market similar crops. It is important to follow recommendations for temperature, relative humidity (see Appendix B) and ventilation for specific commodities to ensure that the crops you store will be of high quality after storage.

Storage of Mangoes:

Varieties such as Alphonso and Dasherí can be kept successfully in cold storage for 40 to 60 days at a temperature of 9 °C (48 °F).

Source: Singh 1998
GENERAL DOs AND DON'Ts FOR STORAGE OF HIGH QUALITY HORTICULTURAL PRODUCE

Store only high quality produce, free of damage, decay and of proper maturity (not over-ripe or under-mature).

Know the requirements for the commodities you want to put into storage, and follow recommendations for proper temperature, relative humidity and ventilation.

Harvest most crops before a hard freeze, and don't handle crops for storage when they are wet.

Cure root, tuber and bulb crops before storage.

Avoid lower than recommended temperatures in storage-- many commodities are susceptible to damage from freezing or chilling.

Do NOT overload storage rooms or stack containers too close together.

Provide adequate ventilation in the storage room.

Provide shade for storage structures or paint buildings white or silver to reflect heat.

Overhanging roof extensions on storage structures are very helpful in shading the walls and ventilation openings from the sun's rays, and in providing protection from rain. An overhang of at least 1 meter (3 feet) is recommended.

Keep storage rooms clean.

Storage facilities should be protected from rodents by keeping the immediate outdoor area clean, and free from trash and weeds.

Containers must be well ventilated and strong enough to withstand stacking. Do NOT stack containers beyond their stacking strength.

Monitor temperature in the storage room by placing thermometers at a variety of locations.
Dos and Don'ts continued:

Don't store onions or garlic in high humidity environments.

Store crops in a dark room. This is especially important for potatoes, since light will stimulate solanine production (a toxic compound not destroyed by cooking).

Avoid storing ethylene sensitive commodities with those that produce ethylene.

Avoid storing produce known for emitting strong odors (apples, garlic, onions, turnips, cabbages, potatoes) with odor-absorbing commodities.

Inspect stored produce regularly for signs of injury, water loss, damage and disease. Remove damaged or diseased produce to prevent the spread of problems.

RECOMMENDED STORAGE TEMPERATURE/RELATIVE HUMIDITY COMPATIBILITY GROUPS

The four principal concerns regarding product compatibility:

- Temperature
- Moisture
- Ethylene
- Odor

Please refer to the tables in Appendix B for specific storage recommendations and approximate shelf-life for each commodity.

The following groups of commodities can be safely stored together since they have similar requirements for temperature and RH. Notice that some of the crops produce odors or ethylene and should be kept away from commodities sensitive to these compounds.

Be especially careful not to store chilling sensitive crops at low temperatures. Not only will you waste the money you spend on excess cooling, but you may have nothing of value to sell when
you remove them from storage. Damage symptoms will usually show up within a few days after you take the crops out of low temperature storage. Tomatoes suffering from chilling injury will be so damaged by *Alternaria* (black spots and sunken pits) that customers will be unlikely to buy from you again. See Chapter 6 for a list of symptoms suffered by each crop.

Compatibility Groups (source: McGregor, 1989)

**Group 1: Fruits and vegetables, 0 to 2°C (32 to 36°F), 90-95% relative humidity. Many products in this group produce ethylene.**

<table>
<thead>
<tr>
<th>Apples</th>
<th>Grapes (without sulfur dioxide)</th>
<th>Parsnips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apricots</td>
<td>Sulphur dioxide</td>
<td>Peaches</td>
</tr>
<tr>
<td>Asian pears</td>
<td>Horseradish</td>
<td>Pears</td>
</tr>
<tr>
<td>Barbados cherry</td>
<td>Kohlrabi</td>
<td>Persimmons</td>
</tr>
<tr>
<td>Beets, topped</td>
<td>Leeks</td>
<td>Plums</td>
</tr>
<tr>
<td>Berries (except cranberries)</td>
<td>Longan</td>
<td>Pomegranates</td>
</tr>
<tr>
<td>Cashew apple</td>
<td>Lychee</td>
<td>Quinces</td>
</tr>
<tr>
<td>Cherries</td>
<td>Mushrooms</td>
<td>Radishes</td>
</tr>
<tr>
<td>Coconuts</td>
<td>Nectarines</td>
<td>Rutabagas</td>
</tr>
<tr>
<td>Figs (not with apples)</td>
<td>Oranges* (Florida and Texas)</td>
<td>Turnips</td>
</tr>
</tbody>
</table>

*Citrus treated with biphenyl may give odors to other products*

**Group 2: Fruits and vegetables, 0 to 2°C (32 to 36°F), 95-100% relative humidity. Many products in this group are sensitive to ethylene.**

<table>
<thead>
<tr>
<th>Amaranth*</th>
<th>Corn, sweet*</th>
<th>Parsley*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anise*</td>
<td>Daikon*</td>
<td>Parsnips*</td>
</tr>
<tr>
<td>Artichokes*</td>
<td>Endive*</td>
<td>Peas*</td>
</tr>
<tr>
<td>Asparagus</td>
<td>Escarole*</td>
<td>Pomegranate</td>
</tr>
<tr>
<td>Bean sprouts</td>
<td>Grapes (without sulfur dioxide)</td>
<td>Radishes*</td>
</tr>
<tr>
<td>Beets*</td>
<td>Sulfur dioxide</td>
<td>Rhubarb</td>
</tr>
<tr>
<td>Belgian endive</td>
<td>Horseradish</td>
<td>Salsify</td>
</tr>
<tr>
<td>Berries (except cranberries)</td>
<td>Jerusalem artichoke</td>
<td>Rutabagas*</td>
</tr>
<tr>
<td>Beetroot</td>
<td>Kohlrabi*</td>
<td>Scorzonera</td>
</tr>
<tr>
<td>Bok choy</td>
<td>Leafy greens</td>
<td>Snow peas</td>
</tr>
<tr>
<td>Broccoli*</td>
<td>Leeks* (not with fruits or grapes)</td>
<td>Spinach*</td>
</tr>
<tr>
<td>Brussels sprouts*</td>
<td>Lettuce</td>
<td>Turnips*</td>
</tr>
<tr>
<td>Cabbage*</td>
<td>With figs, grapes, mushrooms, rhubarb, or corn</td>
<td>Waterchestnut</td>
</tr>
<tr>
<td>Carrots*</td>
<td>Celeriac*</td>
<td>Watercress*</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>Celery*</td>
<td></td>
</tr>
<tr>
<td>Cherries</td>
<td>Onions, green* (not with figs, grapes, mushrooms, rhubarb, or corn)</td>
<td></td>
</tr>
</tbody>
</table>

*These products can be top-iced*

**Group 3: Fruits and vegetables, 0 to 2°C (32 to 36°F), 65-75% relative humidity. Moisture will damage these products.**

| Garlic | Onions, dry |  |  |
|-------|-------------|  |  |
Compatibility Groups continued:

Group 4: Fruits and vegetables, 4.5°C (40°F), 90-95% relative humidity.
- cactus leaves
- cactus pears
- cajito
- cantaloupes
- clementine
- cranberries

Group 5: Fruits and vegetables, 10°C (50°F), 85-90% relative humidity. Many of these products are sensitive to ethylene. These products also are sensitive to chilling injury.
- beans
- calamondin
- chayote
- cucumber
- eggplant
- haricot vert

Group 6: Fruits and vegetables, 13 to 15°C (55 to 60°F), 85-90% relative humidity. Many of these products produce ethylene. These products also are sensitive to chilling injury.
- atemoya
- avocados
- babaco
- bananas
- bitter melon
- black sapote
- boniato
- breadfruit
- canistel
- carambola
- cherimoya
- coconuts
- feijoa
- ginger root

Group 7: Fruits and vegetables, 18 to 21°C (65 to 70°F), 85-90% relative humidity.
- jicama
- pears
- (for ripening)

*citrus treated with biphenyl may give odors to other products.
*"can be top-iced.

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Moisture loss rate of horticultural produce
Some crops will loss water more quickly than others, due to their high surface area (leafy vegetables), or naturally thin skin (summer squash). These commodities will require extra care to reduce water loss during storage and marketing. The loss of protective wax during handling and packing (tomatoes, cucumber, peppers) or damage via cuts or bruises will increase the rate of water loss in all commodities. Misting or wetting the floor of the storage room will help increase the relative humidity around the produce and decrease the rate of water loss. See Chapter 6 for more ideas for controlling RH during postharvest handling and storage.

Ethylene in the storage environment
Ethylene will cause are wide range of damage symptoms in sensitive commodities. Avoid handling or storing ethylene sensitive commodities with those that produce ethylene during ripening.

Undesirable effects of ethylene on sensitive crops include:
- Accelerated senescence (spinach, herbs, broccoli)
- Accelerated ripening (climacteric fruits)
- Loss of green color (snap beans broccoli, cucumber, leafy greens)
- Induction of leaf disorders (russet spotting in lettuce, death of leafy greens)
- Isocoumarin formation (bitter taste in carrots)
- Sprouting (potatoes)
- Abscission of florets (broccoli)
- Browning of pulp and/or seeds (eggplant, sweetpotato)
- Toughening (asparagus, turnips)
- Poor flavor (watermelon, parsnips, sweetpotato)
- Reduced effectiveness of CA storage (apples)

Sources of ethylene:
- Internal combustion engines
- Ripening fruits
- Leaks from ripening rooms
- Propane powered forklifts or other equipment
- Decomposing or wounded produce
- Cigarette smoke
- Rubber materials exposed to UV light or heat
CHAPTER 7: STORAGE PRACTICES AND STRUCTURES

Products that are ethylene producers or ethylene sensitive:

**Ethylene producers:**
- apples
- apricots
- avocados
- bananas, ripening
- cantaloupes
- cherimoya
- figs
- guavas
- honeydew melons
- kiwifruit, ripe
- mamey
- mangoes
- mangosteen
- nectarines
- papayas
- passionfruit
- peaches
- pears
- persimmons
- plantains
- plums
- prunes
- quinces
- rambutan
- tomatoes

**Ethylene sensitive:**
- bananas, unripe
- Belgian endive
- broccoli
- brussels sprouts
- cabbage
- carrots
- cauliflower
- chard
- cucumbers
- cut flowers
- eggplant
- florist greens
- green beans
- kiwifruit, unripe
- leafy greens
- lettuce
- okra
- parsley
- peas
- peppers
- potted plants
- spinach
- squash
- sweetpotatoes
- watercress
- watermelon
- yams

Measuring ethylene
- Sensitive measurement of ethylene gas is still expensive, requiring chromatographs costing from US$ 7000 to US$ 10,000 (required for levels <1 ppm)
- Low cost gas sampling tubes giving colorimetric reactions can be read down to 1 ppm (satisfactory for ripening room operations).

Overcoming undesirable effects of ethylene
- Eliminating sources of ethylene (combustion engine exhaust, ripening fruits)
- Ventilation (one air change per hour)
- Chemical removal by filtering air in storage (potassium permanganate scrubbers, UV lamps, activated charcoal, catalytic oxidizers)
- Inhibiting ethylene effects (controlled atmospheres -- low O₂/ high CO₂ reduces ethylene production rates)
Odor producers and odor absorbers
Some commodities should not be stored with others due to their tendency to give off or absorb odors released by other produce. The following is a list of combinations to avoid during long distance transport, storage and marketing.

**Products which produce or absorb odors**

<table>
<thead>
<tr>
<th>Odor produced by</th>
<th>Will be absorbed by</th>
</tr>
</thead>
<tbody>
<tr>
<td>apples</td>
<td>cabbage, carrots, celery, figs, onions,</td>
</tr>
<tr>
<td></td>
<td>meat, eggs, dairy products</td>
</tr>
<tr>
<td>avocados</td>
<td>pineapples</td>
</tr>
<tr>
<td>carrots</td>
<td>celery</td>
</tr>
<tr>
<td>citrus fruit</td>
<td>meat, eggs, dairy products</td>
</tr>
<tr>
<td>ginger root</td>
<td>eggplant</td>
</tr>
<tr>
<td>grapes fumigated w/ sulfur dioxide</td>
<td>other fruits and vegetables</td>
</tr>
<tr>
<td>leeks</td>
<td>figs, grapes</td>
</tr>
<tr>
<td>onions, dry</td>
<td>apples, celery, pears</td>
</tr>
<tr>
<td>onions, green</td>
<td>corn, figs, grapes, mushrooms, rhubarb</td>
</tr>
<tr>
<td>pears</td>
<td>cabbage, carrots, celery, onions, potatoes</td>
</tr>
<tr>
<td>potatoes</td>
<td>apples, pears</td>
</tr>
<tr>
<td>peppers, green</td>
<td>pineapples</td>
</tr>
<tr>
<td>&quot;strongly scented vegetables&quot;</td>
<td>citrus fruit</td>
</tr>
</tbody>
</table>

**STORAGE STRUCTURES**
There are a wide range of storage structures used throughout the world to successfully store horticultural produce. In general the structure needs to be kept cool (refrigerated, or at least ventilated and shaded) and the produce put into storage must be of high initial quality.

<table>
<thead>
<tr>
<th>Effect of surface color and orientation on effective outside temperature of a storage building:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outside air</strong></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>35°C, 95°F</td>
</tr>
<tr>
<td>Light colored south wall</td>
</tr>
<tr>
<td>Dark colored south wall</td>
</tr>
<tr>
<td>Dark colored flat roof</td>
</tr>
</tbody>
</table>

Source: Thompson, J.F. 1992
The air composition in the storage environment can be manipulated by increasing or decreasing the rate of ventilation (introduction of fresh air) or by using gas absorbers such as potassium permanganate (KMnO₄, an inexpensive compound that will absorb ethylene gas) or activated charcoal (more expensive than KMnO₄).

Placing materials on the floor beneath sacks or cartons of produce prevents dampness from reaching produce suited to dry conditions in storage. This helps to reduce the chance of fungal infection, while also improving ventilation and/or sanitation in the storeroom. Some examples of useful materials follow:

Ventilation in storage structures is improved if air inlets are located at the bottom of the store, while air outlets are at the top. A simple, light-proof exhaust vent is a pressure-relief flap.

Source: Potato Marketing Board (no date).

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Insulation

Any type of building or facility used for storage of horticultural crops should be insulated properly for maximum effectiveness. A well insulated refrigerated building will require less electricity to keep produce cool. If the structure is to be cooled by evaporative or night air ventilation, a well insulated building will hold the cooled air longer.

The amount of total insulation on the walls of storage buildings usually ranges from R20 to R40, and even higher amounts of insulation are used in the ceiling of new buildings (up to R60).

Insulation R-values are listed below for some common building materials. R refers to resistance to heat conduction, and the higher the R-value, the higher the material's resistance to heat conduction and the better the insulating property of the material. You will notice that most common building materials provide little or no insulation on their own. Therefore, in order to adequately insulate storage buildings you will need to add an appropriate thickness of insulation. The materials listed are readily available from local building supply companies. Costs will vary depending upon the amount purchased, with discounts for large volumes.

Reflectix is a new lightweight insulation material made from 2 layers of foil covered bubble wrap that has an extremely high R-value (R14) for a 1/4 inch thick sheet when used to insulate the inside of a roof. It is very easy to install and is especially useful for insulating windows since it reflects 97% of radiant heat to which it is exposed. The cost is approximately $0.50 per square foot.
### R-values of Common Building Materials and Types of Insulation

<table>
<thead>
<tr>
<th>Material</th>
<th>1-inch thickness</th>
<th>Full thickness of material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid concrete</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>8-inch concrete block, open core</td>
<td>1.11</td>
<td></td>
</tr>
<tr>
<td>8-inch concrete block with vermiculite fill</td>
<td>5.03</td>
<td></td>
</tr>
<tr>
<td>Lumber (fir or pine)</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Metal siding</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>3/8-inch plywood</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>1/2-inch plywood</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>Masonite particleboard</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>25/32-inch insulated sheathing</td>
<td>2.06</td>
<td></td>
</tr>
<tr>
<td>1/2-inch Sheetrock</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>1/2-inch wood lapsiding</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td><strong>Types of Insulation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batt and blanket insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass wool, mineral wool, fiberglass</td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td><strong>Fill-type insulation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td>Glass or mineral wool</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Vermiculite</td>
<td>2.20</td>
<td></td>
</tr>
<tr>
<td>Sawdust or wood shavings</td>
<td>2.22</td>
<td></td>
</tr>
<tr>
<td><strong>Rigid insulation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain expanded extruded polystyrene</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Expanded rubber</td>
<td>4.55</td>
<td></td>
</tr>
<tr>
<td>Expanded polystyrene molded beads</td>
<td>3.57</td>
<td></td>
</tr>
<tr>
<td>Aged expanded polyurethane</td>
<td>6.25</td>
<td></td>
</tr>
<tr>
<td>Glass fiber</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>Polysiocyanurate</td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>Wood or cane fiberboard</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>Reflectix®</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td><strong>Foamed-in-place insulation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprayed expanded polyethylene</td>
<td>6.25</td>
<td></td>
</tr>
</tbody>
</table>

Source: Boyette M.D. no date and unpublished marketing materials of insulation suppliers.
Commercially constructed cold rooms can be quite expensive, but fortunately the small-scale operator has many choices. Cold rooms can be self-constructed, purchased as prefabricated units (new or used), or made from refrigerated transportation equipment such as railway cars, highway vans or marine containers. A disadvantage when using any transport vehicle for cold storage is that they are not designed to provide high relative humidity environments. Wetting the floor or the walls can help increase RH but can lead to increased corrosion, mold development and reduced equipment life.

<table>
<thead>
<tr>
<th>Rail Cars:</th>
</tr>
</thead>
<tbody>
<tr>
<td>very sturdy, well insulated</td>
</tr>
<tr>
<td>refrigeration powered by electric motor</td>
</tr>
<tr>
<td>relatively low ceiling</td>
</tr>
<tr>
<td>high cost of getting rail car to farm site</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Highway Vans</th>
</tr>
</thead>
<tbody>
<tr>
<td>portable if wheels are left on</td>
</tr>
<tr>
<td>refrigeration powered by diesel engine</td>
</tr>
<tr>
<td>limited insulation, often leak air</td>
</tr>
<tr>
<td>small fans may not provide adequate ventilation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Marine Containers</th>
</tr>
</thead>
<tbody>
<tr>
<td>sturdy, deep T-beam floors</td>
</tr>
<tr>
<td>sufficient fan capacity for room cooling</td>
</tr>
<tr>
<td>refrigeration powered with 220 or 440 volt, three-phase electricity</td>
</tr>
</tbody>
</table>

Source: Thompson, J.F. 1992

Illustrated on the next page is the basic plan for a self-built cold room. For storage facilities that are refrigerated, using outside air for ventilation is wasteful of energy. For these systems, a simple recirculation system can be designed by adding a fan below floor level and providing a free space at one end of the storeroom for cool air to return to the inlet vents. For more detailed information about determining the cold room size best suited to your operation, evaluating choices when purchasing or building a cold room, refer to Thompson, J.F. and Spinoglio, M. 1994. Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center, University of California, Davis.
JOIST SPECIFICATIONS

- JOIST 24" @ 24" O.C.
- WALL GUARD 24" ON EDGE
- METAL SHIELD
- FOUNDATION

CONCRETE SLAB DETAILS

- A: Optional
  - 2" FOAM BOARD INSULATION
  - 15 psi COMPRESSION STRENGTH
- B: 6 MIL POLYTHYLENE, VAPOR BARRIER
- C: 2" SAND LAYER
- D: 4" GRAVEL LAYER
- FOUNDATION IS NECESSARY FOR LARGER UNITS

JOIST SPECIFICATIONS

- L = 10
- JOIST 24" @ 24" O.C.
- WALL GUARD 24" ON EDGE
- METAL SHIELD
- FOUNDATION

A Typical Cold Room (Source: Thompson and Spinoglio, 1994)
An evaporative cooler located in the peak of a storage structure can cool an entire room of stored produce such as sweetpotatoes or other chilling sensitive crops. The vents for outside air should be located at the base of the building so that cool air is circulated throughout the room before it can exit.

Where electricity is not available, wind-powered turbines can help increase air circulation and keep storerooms cooler by pulling air up through the building. Hot air inside the room will naturally move upwards toward the roof peak and exit through the vents in the turbine, creating wind which will spin the turbine and pull more warm air out of the storage room.

The turbine illustrated here can be constructed of sheet metal that is twisted to catch the wind, and attached to a central pole that acts as the axis of rotation. The turbine should be placed on the peak of the roof of a storage structure.

Night air ventilation
Storage structures can be cooled by ventilating at night when outside air is cool. For best results, air vents should be located at the base of the storage structure. An exhaust fan located at the top of the structure pulls the cool air through the storeroom. Vents should be closed at sunrise, and remain closed during the heat of the day.
Facilities located at higher altitudes can be especially effective, since air temperature decreases as altitude increases. Increased altitude therefore can make evaporative cooling, night cooling and radiant cooling more feasible.

Underground storage
One of the simplest methods for storing small quantities of produce is to use any available container, and create a cool environment for storage by burying the container using insulating materials and soil. The example provided here uses a wooden barrel and clean, dry straw for insulation.

Storage barrel:
Potato Pit Storage in India:

Dig a pit in a shady place, sprinkle it with water for a few days to cool the soil, then line the pit with neem leaves. Add a bamboo chimney to provide ventilation.

Source: Choudhury 1998

A root cellar can be constructed by digging out a pit to a depth of about 2 meters (7 to 8 feet) and framing the sides with wooden planks. The example illustrated here is about 3 by 4 meters (12 by 15 feet) in size, with a 35 cm square (one foot square) wooden chute as a roof vent.

Produce suitable for root cellaring
Source: Hart, 1995

- Apples
- Beets
- Cabbage
- Carrots
- Cauliflower
- Celery
- Chinese cabbage
- Endive
- Grapefruit
- Grapes
- Horseradish
- Kale
- Onions
- Oranges
- Parsnips
- Pears
- Peppers
- Potatoes
- Pumpkins
- Rutabagas
- Squash (winter)
- Tomatoes (mature green)
- Turnips
STORAGE OF ROOT AND TUBER CROPS

Root and tuber crops account for a majority of horticultural crops grown worldwide for food, and luckily, can be easily stored using simple structures. The recommended storage conditions for root and tuber crops are listed in the following table. Potatoes for processing are best kept at intermediate temperatures to limit the production of sugars which darken when heated during processing. Potatoes meant for consumption must also be stored in the dark, since the tubers will produce chlorophyll (turning green) and develop the toxic alkaloid solanine if kept in the light. Potatoes stored for use as "seed" are best stored in diffuse light (CIP, 1981). The chlorophyll and solanine that accumulate will aid to protect the seed potatoes from insect pests and decay organisms.

Tropical root and tuber crops must be stored at temperatures that will protect the crops from chilling, since chilling injury can cause internal browning, surface pitting and increased susceptibility to decay.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Temperature</th>
<th>RH(%)</th>
<th>Potential storage duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh market</td>
<td>4-7 °C</td>
<td>39-45</td>
<td>95-98 10 months</td>
</tr>
<tr>
<td>Processing</td>
<td>8-12 °C</td>
<td>54-74</td>
<td>95-98 10 months</td>
</tr>
<tr>
<td>Seed potatoes</td>
<td>0-2 °C</td>
<td>32-36</td>
<td>95-98 10 months</td>
</tr>
<tr>
<td>Cassava</td>
<td>5-8 °C</td>
<td>41-47</td>
<td>80-90 2-4 weeks</td>
</tr>
<tr>
<td></td>
<td>0-5 °C</td>
<td>32-41</td>
<td>85-95 6 months</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>12-14 °C</td>
<td>54-58</td>
<td>85-90 6 months</td>
</tr>
<tr>
<td>Yam</td>
<td>13-15 °C</td>
<td>55-59</td>
<td>near 100 6 months</td>
</tr>
<tr>
<td></td>
<td>27-30 °C</td>
<td>80-86</td>
<td>60-70 3-5 weeks</td>
</tr>
<tr>
<td>Ginger</td>
<td>12-14 °C</td>
<td>54-58</td>
<td>65-75 6 months</td>
</tr>
<tr>
<td>Jicama</td>
<td>12-15 °C</td>
<td>54-59</td>
<td>65-75 3 months</td>
</tr>
<tr>
<td>Taro</td>
<td>13-15 °C</td>
<td>55-59</td>
<td>85-90 4 months</td>
</tr>
</tbody>
</table>
When storing potatoes, a field storage clamp is a low cost technology that can be designed using locally available materials for ventilation and insulation. The example illustrated here has a wooden ventilator box and uses clean straw for insulation. The entire pile of potatoes and straw is covered with a layer of soil, which should not be highly compacted. Gently wetting the soil during hot, dry periods can assist via evaporative cooling.

In very cold regions, a second layer of straw and soil can be added. In hot regions, less soil is needed, but more ventilation can be added by constructing chimney type air outlets at the top of the clamp. Locating the clamp under trees or providing a roof or other protection from rainfall is a good idea if you will be storing produce during the rainy season.

Field storage clamp:

Field clamp/Pit storage

Maximum storage time: 6 months
Maximum volume: 500 kg
Use several clamps if you have more produce to store.

Source: CIP, 1981
For large quantities of potatoes, a self-supporting A-frame storehouse can be constructed. A pit is dug about 2.5 m (10 feet) deep and wooden air ducts are placed along the earthen floor. The roof of the building is constructed of wood, then covered with straw and soil. When loading potatoes into bulk storage, make sure the crop is evenly distributed. Uneven loads will slow air movement in some areas of the storage room and lead to higher storage losses.

![Diagram of A-frame storehouse]

Source: University of Idaho, no date

Onions, garlic and dried produce are best suited to low humidity in storage. Onions and garlic will sprout if stored at intermediate temperatures, so if you can't keep them cold, storage life will be greatly reduced. Pungent types of onions will store longer than mild onions, which are rarely stored for more than one month. The following table lists the storage conditions recommended for these crops.

<table>
<thead>
<tr>
<th>Storage Conditions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
</tr>
<tr>
<td>°C</td>
</tr>
<tr>
<td>Onions</td>
</tr>
<tr>
<td>0-5</td>
</tr>
<tr>
<td>28-30</td>
</tr>
<tr>
<td>Garlic</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>28-30</td>
</tr>
<tr>
<td>Dried fruits and vegetables</td>
</tr>
<tr>
<td>&lt;10</td>
</tr>
</tbody>
</table>
Controlled Atmosphere (C.A.) Storage

The cost of construction of a CA storage room is about 5% higher than for the same sized conventional cold room. CA storage is more expensive since the storage room must be completely gas sealed and gas composition must be monitored constantly to prevent damage to the produce. Refer to Appendix C for recommended atmospheric composition, temperature and storage life for specific commodities suited to CA storage.

A lower cost approach for controlled atmosphere storage of pallet loads of produce is also possible using a semi-permanent set-up for creating a gas-seal inside a conventional cold room. Any number of pallets can be accommodated inside a plastic tent. The gas seal is provided by a small trough constructed of sheet metal laid in a rectangular pattern into a concrete floor of a storage structure during construction. A very thick (7-mil) polyethylene sheet is put over the pallet load of produce, and the sheet is sealed by pushing a long piece of rubber tubing into the trough.

Typical layout of a C.A. tent:
(cross-section)

Layout of a seal in the trough on the storeroom floor:

Source: McDonald, 1982
COMPARISON OF ESTIMATED COSTS AND EXPECTED BENEFITS RELATED TO STORAGE OF HORTICULTURAL CROPS.

Costs:
Storage structure
Suitable packages
Temperature/RH management
Labor
Power

Benefits:
Longer shelf life, extended marketing period
Higher market prices due to off-season sales

Example 1: A variety of edible and decorative squash is grown and harvested in the U.S. in September. The market price during September is $0.25/lb, while the price during the holiday season (Halloween, Thanksgiving and Christmas) is an average of $0.60/lb. A simple underground storage structure, cooled by the natural properties of soil, deep shade and night air ventilation, is constructed to store 1000 lbs of squash for up to 3 months (in bulk, stacked on pallets). Useful life of the root cellar is 20 to 25 years. Assume that the produce loses 10% of its weight over 3 months, and the remaining 900 lbs is sold at $0.60/lb.

Costs: $180 for labor for root cellar construction.
$400 for materials (treated lumber for framing, ceiling, door; ventilation shaft and fan), floor and walls are bare soil.
Power for fan (runs for 6 hours per night for 3 months) = $15.00

Benefits:
(Expected sales during the holiday season) - (typical sales in September) =
(900 lbs x $0.60/lb) - (1000 x $0.25) =
$540 - $250 = $290.

The entire cost of construction of the root cellar is paid for during the first two years of operation; each additional year of operation results in an additional profit when produce is sold during the holiday season. $290 - $15 = $275

Example 2:
Ash gourd is grown and harvested in September and October. The market price during this time is Rs 1/kg, while the price during the festival season in November and December is an average of Rs 7/kg. A simple underground storage structure, cooled by the natural properties of soil, deep shade and night air ventilation, is constructed to store 8 quintals of squash for up to 3 months (in bulk, stacked on pallets). Useful life of the root cellar is 20 to 25 years. Assume that the produce loses 10% of its weight over 3 months, and the remaining 720 kg is sold at Rs 7/kg.
Costs: Rs 800 for labor for root cellar construction.
Rs 6600 for materials (treated lumber for framing, ceiling, door; ventilation shaft and fan), floor and walls are bare soil.
Power for fan (runs for 6 hours per night for 3 months) = Rs 100

Benefits:
(Expected sales during the festival season) - (typical sales in September) =
(720 kgs x $Rs 7/kg) - (800 x Rs 1/kg) =
Rs 5040 - Rs 800 = Rs 4240.

The entire cost of construction of the root cellar is paid for during the first two years of operation; each additional year of operation results in an additional profit when produce is sold during the holiday season.  Rs 4240 - Rs 100 = Rs 4140

SOURCES OF STORAGE EQUIPMENT AND SUPPLIES

C. A. equipment
                      California Controlled Atmospheres
ethylene absorbers, filters, scrubbers
                      DeltaTRAK Inc.
Ethylene Control, Inc
                      International Ripening Corp.
                      TUBAMET AG
fans, ventilation systems
                      Industrial Ventilation, Inc
12-volt evaporative coolers, air-conditioners, ceiling fans
                      Alternative Energy Engineering
Jade Mountain, Inc.
humidifiers
                      McCormick Fruit Tech
International Ripening Corp.
hygrometers (to measure RH)
                      International Ripening Corp.
insulation
                      Reflectix, Inc.
solar powered evaporative coolers
                      Jade Mountain, Inc.
solar powered fans and storage ventilators
                      Alternative Energy Engineering
temperature alarm/timer
                      International Ripening Corp.
temperature recorders
                      Monitor Company
thermometers. temperature/RH meters

DeltaTrak
International Ripening Corp.
McCormick Fruit Tech
Post-Harvest Technologies

For Addresses/Phone numbers please refer to Appendix D

REFERENCES


PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
CHAPTER 7: STORAGE PRACTICES AND STRUCTURES


Thompson, J. F. and Spinoglio, M. 1994. Small-scale cold rooms for perishable commodities. Family Farm Series, Small Farm Center, University of California, Davis.

University of Idaho. No date. Idaho Potato Storage. Agricultural Experiment Station, College of Agriculture, Bulletin 410.

Produce must often be transported as part of fresh handling, whether from the field to the packinghouse, from the packinghouse to storage facility, or to various destination markets. During transport, produce must be stacked in ways that minimize damage, then be braced and secured. An open air vehicle can be loaded in such a way that air can pass through the load, and provide some cooling of the produce as the vehicle moves. Traveling during cooler hours (night and early morning) can reduce the heat load on a vehicle that is transporting produce.

Refrigerated transport is highly recommended for most perishable horticultural produce. Temperature management is especially critical during long distance transport, and proper air flow is the most important factor in ensuring that the load stays cool. Loads must be stacked to enable proper air circulation to carry away heat from the produce itself as well as incoming heat from the atmosphere and off the road. Transport vehicles should be well insulated to maintain cool environments for pre-cooled commodities and loads should be braced away from the side walls and back door of the trailer.

Average road temperatures can be much higher than air temperatures during hot months of the year. In the western U.S., road surface temperatures can be 22 °C (40 °F) higher than the air temperature, making it difficult for refrigerated vehicles to maintain recommended temperatures.
Transit times under these conditions should be as short as possible, since deterioration will increase as temperatures increase.

Mixed loads can be a serious concern when recommended temperatures are not compatible (for example, when transporting chilling sensitive fruits with commodities that require very low temperatures). Try to avoid this situation, since either some of the produce will be injured by chilling or some of the produce will deteriorate more quickly than when handled at the recommended low temperature and your investments in postharvest handling technologies will largely be wasted.

Another problem arises when ethylene producing commodities and ethylene sensitive commodities are transported together. High ethylene producers (such as ripe bananas, apples, cantaloupe) can induce physiological disorders and/or undesirable changes in color, flavor and texture in ethylene sensitive commodities (such as lettuce, cucumbers, carrots, potatoes, sweet potatoes). Using ethylene scrubbers installed in the vehicle can reduce this problem during transport.

### C.A. Transport:
- avocados
- stone fruits
- pears
- mangoes
- asparagus
- tangerines

In 1996 only 2.5% of US produce imports/exports were shipped using controlled atmosphere. In addition to regular shipping charges, carriers charge a standard flat fee of $1500 ($1.50 per carton for a typical 1000 carton load) making C.A. transport viable only for high value commodities.

This chapter describes postharvest technologies for transporting horticultural commodities via open and refrigerated loads. Quality and food safety can be protected by using proper loading methods and patterns, recommended features of refrigerated vehicles, and bracing techniques. We have included a sample calculation of how you can determine the refrigeration capacity required for transporting for a specific load of produce. Completing the chapter is a simple example of the costs and benefits of using ice when transporting produce, designed to assist you to complete the worksheets to determine the return on investment when adopting specific postharvest transport practices for your operations.
GENERAL DOS AND DON'TS FOR TRANSPORTING HIGH QUALITY PRODUCE

Do NOT overload vehicles.

Prevent compression damage to produce by avoiding over-filling of containers (rounded sides or bulge-packing) and stacking heavier produce at the bottom of the load.

Use strong packages (half the stacking strength of a corrugated fibreboard container can be lost during a five day trip in a high humidity environment).

Avoid rough handling during loading and unloading.

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%.

Prevent vibration damage by using air suspension systems -- these will provide a more gentle ride during transportation.

Using suitable trays, place packing, use of plastic bags, container liners, or placing a soft pad at the top of a full box can reduce vibration damage.

Make sure the vehicle has adequate ventilation to prevent heat gain during transport.

Use a pre-loading checklist to ensure the vehicle is ready to use successfully.

Well aligned stack of cartons, has the strongest stacking strength possible
DO AND DON'TS FOR REFRIGERATED TRANSPORT:

Ensure that vehicles are well-insulated and have doors that seal tightly and securely.

Run through the check-list for refrigerated transport before handling each load.

Look for recommended design features when purchasing new or used transport vehicles.

Pre-cool refrigerated vehicles to suit produce requirements.

Load only pre-cooled produce into vehicles from a refrigerated dock.

Do NOT allow delays when loading on an open dock—delays will cause heat gain, especially if produce is exposed to full sun.

Turn off the refrigeration unit while loading from an open dock (leaving the unit on may cause ice to form on the refrigeration coils, blocking air circulation during transport).

Use high quality vented containers and load produce to ensure adequate air movement through the load to remove the heat generated by produce respiration.

Do NOT block air flow under or anywhere else in the load.

Monitor the supply air temperature and the return air temperature for obtaining the best performance of refrigeration units.

Avoid mixed loads if possible; or install ethylene scrubbers to prevent damage to ethylene sensitive commodities.

Do NOT transport chilling sensitive commodities when thermostats are set below 12-15 °C (53-59 °F).

Load produce away from the side walls to prevent heat gain from the external environment.

Make sure mixed sizes of containers or unpalletized produce does not block lengthwise air flow.

Do NOT turn off the refrigeration unit during delays in transport.
Dos and Don'ts continued:

Brace the load at least 5 cm (2") away from the side walls and at least 10 cm (4") away from the rear door.

Use a portable temperature recorder to verify temperature management during transport.

TRANSPORTATION METHODS

Open Vehicles: Bulk loads of produce should be carefully loaded so as not to cause mechanical damage. Vehicles can be padded or lined with a thick layer of straw. Woven mats or sacks can be used in the beds of small vehicles. Other loads should not be placed on top of the bulk commodity. Never stand upon the produce during loading or unloading.

TRANSPORTING OPEN LOADS:

Provide a thick layer of insulation and cushioning for bulk loads.

Load packaged produce in uniform stacks, braced securely to prevent damage.

Construct a wind catcher for moving air into the vehicle during transport.

Provide channels for passive air movement beneath and up through the load (exiting at the rear of the vehicle).

Provide shade for the load with a silver or light-colored canvas cover.

Cooling open loads is desirable whenever possible. A truck ventilating device can be constructed for an unrefrigerated open vehicle by covering the load loosely with canvas and fashioning a wind catcher from sheet metal. The scoop should be mounted at the front of the bed and should reach somewhat higher than the height of the cab. High transportation speeds and/or long distance transport during dry weather run the risk of causing excess drying of the crop.
Ventilating systems have been designed for hauling bulk loads of fresh produce. The first illustration shows a metal wind catching device which funnels air into a load covered by a canvas sheet. The second example was designed by R. Kasnire to transport fresh fava beans in Iran. The wind catcher and ducts were constructed using wooden crates. After removing their end panels the crates were wired together into the pattern shown below. Air flows upward through the load during transport, helping to keep the produce from overheating. This system has also been used in pick-up trucks, and for hauling bulk greens and green beans. Best results are obtained when transporting during the early morning hours, before sunrise.

Source: Pantastico, 1980
Portable Field-to-Market Coolers

This simple trailer cooler was constructed using a room-sized air conditioning unit powered by a diesel generator and an insulated storage box. The trailer can either be built as a unit with wheels, or the cooler can be loaded upon a pre-existing wagon or low-boy trailer.

The cooler is designed to be loaded at the field during the morning hours (when the air temperatures and produce temperatures are relatively low) and used to pre-cool produce during the period between harvest and packing or between field-packing and immediate marketing.
Similarly, an insulated cooler box was designed by Mejia (1991) to fit into a long-bed pick-up truck. Two standard pallet loads of produce can be cooled to 5 °C (40 °F) in about 4 hours from an ambient air temperature of 29 °C (85 °F). Mejia's design uses a stationery 3 ton mobile home air conditioning unit, to which the cooler box is connected after being loaded with produce in the field. Once produce is cooled, the box is sealed and transported to market.

REFRIGERATED TRANSPORT

Small-scale postharvest cold transport can be accomplished using a cargo van fitted with a high powered air conditioning system. If a pre-cooler is not available, a 4000 to 5000 Btu window model air conditioning unit can cool produce by 17 °C (30 °F) compared to the outside air temperature. It is a good idea to humidify the environment by misting the air with cool water or covering open crates of produce with wet towels or wet burlap cloth.

The condition of the inside of a refrigerated trailer affects its ability to maintain desired temperatures during transport. When renting, leasing or hiring an independent vehicle to transport your produce, you should always inspect the trailer before loading, and check these features: Any damage will let heat in and make temperature management much more difficult. Even when the buyer pays for shipment, checking for problems will save you time and money by helping you avoid losses and produce damage during transport.

Source: Kasmire and Hinsch, 1987
Refrigeration Systems Components (Source: Kasmire and Hinsch, 1987)

For Optimum Transit Temperature Management, Refrigerated Trailers Need These Features

- High capacity fan capable of circulating 2000 cfm at 1.5" static pressure
- Large area evaporator coil for high relative humidity
- Curved bottom edge of bulkhead
- Wind deflector to "turn" air upward
- Temperature sensors in supply and return air streams (thermometer)
- Insulated walls, doors, floor, and ceiling
- Solid front return-air bulkhead
- Air delivery duct
- T-floor or other deep floor for adequate return air space under the load
- Rear door standoffs

Pre-cooling vehicles before loading:
- Vehicles to be loaded at refrigerated docks should be pre-cooled to their desired thermostat set point.
- Vehicles to be rapidly loaded (15 to 20 minutes) at non-refrigerated docks should be pre-cooled to about 2 °C (5 °F) above their desired thermostat set point.
- Vehicles that will be loaded slowly (30 minutes or more) at non-refrigerated docks should be pre-cooled to about 2 °C (5 °F) lower than a temperature halfway between ambient air temperature and the desired set point.

This will prevent accumulation of excess moisture on the vehicle's inner surfaces and reduce subsequent cycling of the refrigeration unit.

Source: Picha, 1997

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Estimating Refrigeration Requirements

If you ever have any doubt that a refrigerated vehicle is of adequate capacity for the load you want to transport, calculate the number of Btus of heatload that must be handled by the refrigeration system to keep the load cool. Ashby (1995) contains all the tables and sample calculations to assist you to calculate heatload for your commodity and situation.

First you will need to calculate:
1) \( H_f \): the amount of field or sensible heat left in the commodity and the package. When produce is properly pre-cooled, this is very low, since the temperature differential is low.

\[
H_f \ (\text{Btu}) = \\
\text{specific heat of the produce & container} \\
x \ \text{weight of the produce & container} \\
x \ \text{temperature differential}
\]

2) \( H_r \): the produce's heat of respiration

\[
H_r \ (\text{Btu}) = \\
\text{respiration rate at average transit temperature} \\
x \ \text{time (in days)} \\
x \ \text{weight (in tons)}
\]

3) \( H_l \): the amount of heat leakage through the walls and floor of the trailer. Heat transfer coefficients have been calculated for specific vehicles by their manufacturers, and depends on many things including type and thickness of insulation, size and shape of the vehicle. As a vehicle ages and insulation breaks down, the coefficient tends to increase. The estimate of heat transfer for a new 48-foot trailer with 2.5" of foam sidewall insulation is 140 Btu/ degree °F/hour. The temperature differential refers to the difference between the thermostat setting and the average outside temperature.

\[
H_l \ (\text{Btu}) = \\
\text{the coefficient of heat transfer} \\
x \ \text{temperature differential} \\
x \ \text{time (hours)}
\]

4) How much heat can be absorbed by the refrigerant you are using:

Mechanical refrigeration units are rated according to the number of Btus per hour the unit can remove when the temperature is 100 °F outside versus 35 °F inside the trailer.

One pound of ice will absorb 144 Btus of heat.
One pound of liquid nitrogen will absorb approximately 175 Btus of heat.
Sample calculations for a load of produce.
Use these tables to calculate the amount of refrigeration needed to cool your load of produce:

| Specific heat above freezing for selected perishables (from ASHRAE, 1990) |
|-----------------------------|-----------------------------|
| Apples                      | 0.87 Btu/lb/°F              |
| Cantaloupe                  | 0.93                        |
| Green beans                 | 0.91                        |
| Grapes                      | 0.86                        |
| Potatoes                    | 0.82                        |
| Summer squash               | 0.95                        |

Approximate Heat of Respiration (from ASHRAE, 1990) in Btus/ton/24 hours

<table>
<thead>
<tr>
<th></th>
<th>32 °F</th>
<th>40 °F</th>
<th>60 °F</th>
<th>70 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>700</td>
<td>1,350</td>
<td>4,900</td>
<td>5,700</td>
</tr>
<tr>
<td>Cantaloupe</td>
<td>1,200</td>
<td>2,050</td>
<td>7,950</td>
<td>12,000</td>
</tr>
<tr>
<td>Green beans</td>
<td>7,250</td>
<td>10,300</td>
<td>38,100</td>
<td>49,200</td>
</tr>
<tr>
<td>Grapes</td>
<td>600</td>
<td>1,200</td>
<td>3,500</td>
<td>7,200</td>
</tr>
<tr>
<td>Potatoes (cured)</td>
<td>2,600</td>
<td>4,850</td>
<td>6,350</td>
<td></td>
</tr>
<tr>
<td>Summer squash</td>
<td>2,700</td>
<td>3,600</td>
<td>18,250</td>
<td>20,050</td>
</tr>
</tbody>
</table>

Assumptions:
Assume a refrigerated 24 ft trailer will be loaded with apples in 30 lb. fiberboard boxes. The trailer can hold 600 boxes, for a total produce weight of 18,000 lbs (9 tons). The boxes weigh 2 lbs each, so the total weight of the boxes is 1,200 lbs. The specific heat of most wood and fiberboard boxes is 0.44 Btu/lb/°F.

The specific heat of the apples is 0.87 Btu/lb/°F, at a loading temperature of 52 °F. The desired load temperature is 32 °F and the thermostat is set at 34 °F to avoid freezing damage. Average load temperature is assumed to be 40 °F. Transit time is three days during which outside average air temperature is 75 °F. The heat transfer coefficient for the trailer is 80 Btu/°F/hour.

\[
H_f(\text{apples}) = 0.87 \text{ Btu/lb/°F} \times 18,000 \text{ lbs} \times 20 \text{ °F} = 31,320 \text{ Btus}
\]
\[
H_f(\text{boxes}) = 0.44 \times 1,200 \times 20 = 10,560
\]
\[
H_f(\text{total}) = 41,880 \text{ Btus}
\]
\[
H_r = 1,350 \text{ Btu/ton/day} \times 3 \text{ days} \times 9 \text{ tons} = 36,450 \text{ Btus}
\]
\[
H_I = 80 \text{ Btu/°F/hour} \times (75 \text{ °F} - 34 \text{ °F}) \times 72 \text{ hours} = 236,160 \text{ Btus}
\]

\[
H_f(\text{total}) + H_r + H_I = \text{the amount of Btus the refrigeration unit must remove in three days.}
\]
\[
41,880 + 36,460 + 236,160 = 314,500 \text{ Btus}
\]

Amount of mechanical refrigeration needed = 314,500 Btu/72 hours = 4368 Btu/hour
Amount of ice needed = 314,500 Btu/144 Btu/lb = 2,184 lbs
Refrigerated Vehicles-- Pre-loading Checklist

__ Refrigeration unit operating properly?

__ Thermostat calibrated?

__ Refrigeration air chutes and ducts properly installed and in good repair?

__ Door seals in good condition?

__ Doors seal tightly when closed?

__ Walls free of cracks and holes?

__ Front bulkhead installed?

__ Floor drains open?

__ Inside of vehicle clean and odor-free?

__ Floor grooves free of debris?

__ Inside height, width, length adequate for load?

__ Load braces and other devices available to secure load?

__ Is the vehicle trailer pre-cooled (or pre-warmed)?
STACKING PATTERNS/PALLET AND SLIP SHEET LOADS
Containers should be loaded so that they are away from the side walls and the floor of the transport vehicle in order to minimize the conduction of heat from the outside environment. In the diagrams below, the numbers of cartons refer to how many cartons would be in contact with the walls and floor of the truck when fully loaded.

Only the load on the bottom right is fully protected from heat transfer. The use of pallets keeps the cartons off the floor, while center-loading leaves an insulating air space between the pallet loads and the outside walls.

Source: Ashby, B. H et al. 1987

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
BRACING THE LOAD
There should always be an air space between the last stack of produce and the back of the transport vehicle. The load should be braced to prevent shifting against the rear door during transit. If the load shifts, it can block air circulation, and fallen cartons can present great danger to workers who open the door at a destination market. A simple wooden brace can be constructed and installed to prevent damage during transport.

Wooden brace (rear door):

Wooden braces for side walls can be used, but they are heavy and can become expensive to build and transport. Air-filled bags made of vinyl can provide excellent bracing and 5 cm of added insulation (2" thick) against side walls. The bottom of the pallets are braced with wood blocks to prevent load shifting.
COSTS AND BENEFITS OF USING ICE FOR COOLING DURING TRANSPORT TO MARKET.

Costs:
Ice
Reduced amount of produce per load
(all other expenses are assumed to be the same)

Benefits:
Reduced water loss
Reduced decay rates
Higher quality during marketing
Longer shelf life

Example 1:

<table>
<thead>
<tr>
<th></th>
<th>with ice</th>
<th>no cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 ton pick-up load of mixed lettuces</td>
<td>750 lbs</td>
<td>1000 lbs</td>
</tr>
<tr>
<td>cartons @ $2.50 each (20 lbs/carton)</td>
<td>38 cartons = $95</td>
<td>50 cartons = $125</td>
</tr>
<tr>
<td>ice ($0.50/10 lbs)</td>
<td>$0.05/lb</td>
<td></td>
</tr>
<tr>
<td>water loss/decay rate losses</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>(37.50 lbs)</td>
<td>(100 lbs)</td>
</tr>
<tr>
<td>Produce available to sell</td>
<td>712.5 lbs</td>
<td>900 lbs</td>
</tr>
<tr>
<td>Quality grades</td>
<td></td>
<td></td>
</tr>
<tr>
<td>highest ($1.19/lb)</td>
<td>90%</td>
<td>60%</td>
</tr>
<tr>
<td>second ($0.69/lb)</td>
<td>10%</td>
<td>30%</td>
</tr>
<tr>
<td>lowest ($0.25/lb)</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>Market value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Costs containers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ice</td>
<td>($95)</td>
<td>($125)</td>
</tr>
<tr>
<td>Potential net sales per load</td>
<td>$704.50</td>
<td>$641</td>
</tr>
</tbody>
</table>

USE OF ICE DURING TRANSPORT:
Remember to consider the added weight of the ice when calculating vehicle loads.

Use package ice or apply ice in channels or windrows (do not block air flow by applying in a uniform solid layer).

Avoid setting the thermostat too low in a refrigerated vehicle (below 2 °C or 35 °F)--this will cause ice to freeze solid and create a barrier to air flow.
Example 2: Transporting fresh peas in wooden crates from Punjab to Gujarat State in December.

<table>
<thead>
<tr>
<th>Market location</th>
<th>with ice</th>
<th>no cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>open load of fresh peas</td>
<td>500 kg</td>
<td>700 kg</td>
</tr>
<tr>
<td>crates @ Rs 20 (20 kg/crate)</td>
<td>25 crates = Rs 500</td>
<td>35 crates = Rs 700</td>
</tr>
<tr>
<td>ice (Rs 25/100 kgs)</td>
<td>Rs 0.25/kg</td>
<td>0</td>
</tr>
<tr>
<td>water loss/decay rate</td>
<td>5%</td>
<td>15%</td>
</tr>
<tr>
<td>losses</td>
<td>(25 kg)</td>
<td>(105 kg)</td>
</tr>
<tr>
<td>Produce available to sell</td>
<td>475 kg</td>
<td>595 kg</td>
</tr>
<tr>
<td>Market value</td>
<td>Rs 20/kg</td>
<td>Rs 5/kg</td>
</tr>
<tr>
<td>Costs</td>
<td>Rs 5/kg</td>
<td>Rs 2975</td>
</tr>
<tr>
<td>containers</td>
<td>(Rs 500)</td>
<td>(Rs 700)</td>
</tr>
<tr>
<td>ice</td>
<td>(Rs 65)</td>
<td>0</td>
</tr>
<tr>
<td>Potential net sales per load</td>
<td>Rs 8925</td>
<td>Rs 2275</td>
</tr>
</tbody>
</table>

Profits will depend upon the cost of transport. Fees for freight can be quite high (up to Rs 6000 per load) before the use of ice for cooling peas in December becomes unprofitable.
SOURCES OF TRANSPORT EQUIPMENT AND SUPPLIES

ethylene absorbers  DeltaTRAK Inc.
ethylene scrubbers  TUBAMET AG
ice-packs, ice wraps,  Aladdin Industries, Inc.
freezable gel-filled or water-filled bags  Cargo Technology Corp
"cool guard"
loading guide  TransFRESH Corp.
mini-reefers (slip in cooler for pick-ups)  CMF Corp.
refrigeration system  Carrier Transicold
temperature/humidity data loggers  DeltaTRAK Inc.
    Dickson
    Sensitech Inc.
temperature recorders  DeltaTRAK Inc.
    Dickson
therma-cover  ThermaGard, Inc.
transport services  Roadway Express
    SeaLand Service, Inc.

For addresses and phone/FAX numbers for suppliers, please refer to Appendix D.
REFERENCES


Ashby, B. H. 1989. Transportation Tips. USDA OT-ID 8 to OD-ID 15


TransFRESH Corp. 1988. Fresh produce mixer and loading guide. Salinas, CA: TransFRESH


PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Many of the practices described so far in Part I are valuable because they help reduce pest problems during postharvest handling, storage and marketing. The first line of defense against insects and disease is good management during production. Monitoring to determine actual pest levels and a combination of appropriate genetic, biological, cultural, physical and chemical controls is usually enough to prevent serious pest damage. The second defence is careful harvesting and preparation for market in the field, since most diseases can't gain a good start without easy entry through cuts, bruises or injuries. Next, sorting out damaged, over-ripe or decaying produce will limit contamination of the remaining, healthy produce. Finally, even when the greatest care is taken, sometimes produce must be treated to control insects or decay-causing organisms.

Postharvest IPM Tools

Genetic: pest resistance
Biological: yeasts, antagonistic bacteria
Cultural: sanitation, decrease mechanical damage
Physical: sorting, heat treatment, temperature and RH management
Chemical: chlorinated wash water, pesticides
This chapter will review some of the postharvest technologies related to pest control and outline the practices recommended for postharvest Integrated Pest Management (IPM). Also provided is information that will help you to identify pest problems and implement specific postharvest IPM methods and treatments.

**GENERAL DOs AND DON'Ts FOR POSTHARVEST IPM**

Consider the entire system (production, harvest, postharvest and marketing) when developing pest management strategies.

**PRE-HARVEST**

Begin with cultivars offering some natural resistance to the pests you expect to have to deal with in your region.

Plant only good quality, clean seed or stock.

Use appropriate cultural practices during production to assist the produce to avoid and/or resist pest attack (proper planting density, fertilization, irrigation, pH modification, weeding, pruning, thinning, ventilation/air movement through the canopy).

Monitor fields/orchards to determine actual pest levels before implementing pest controls.

Use a combination of appropriate pest control methods (biological control, chemical pesticides, protectants, sanitation practices).

Keep fields and orchards free of debris and discarded produce. Eradicate diseased produce.

**HARVEST**

Avoid damage during harvest by handling produce gently.

Harvest at the proper maturity for produce to have the maximum resistance against pests.

Use sharp, clean tools for harvest and trimming processes.
Do's and Don'ts continued:

CURING
Cure root, tuber and bulb crops to heal harvest wounds and increase resistance to pests.

PACKINGHOUSE
Sort to remove any damaged, decayed, over-mature or under-ripe produce.
Wash or clean produce to remove soil and debris and to reduce the amount of inoculum on surfaces.

Trim senescent leaves from vegetables and remove dried flower parts from fruits.

Use appropriate postharvest treatments to manage pest problems (chemicals, heat, hot water, pesticides).

PACKING
Avoid over-use of liners that constrict air flow in the package and contribute to condensation (free moisture) and poor cooling efficiency.

Use ventilated plastic bags as liners for produce highly susceptible to water loss.

STORAGE
Avoid ethylene damage to sensitive commodities by using ethylene scrubbers and avoiding mixed lots of produce in storage.

Keep produce at its lowest safe temperature for maximum pest management.

Avoid chilling injury by keeping sensitive commodities at appropriate moderate temperatures.

Keep leafy vegetables, carrots, and cool season vegetables at very high relative humidity (98-100%) to reduce incidence of decay.

Store certain fruits at slightly lower RH than commonly recommended in order to reduce decay.

Store onions and garlic at low humidity to reduce decay (60-70% RH).
Most diseases cannot gain a good start without your help:
- wounds, cuts, bruises
- chilling injury
- free moisture on produce surface
- advanced stages of ripening or senescence

Common Postharvest Diseases

**FUNGAL DISEASES**

A variety of fungal diseases cause the greatest market and storage losses:

<table>
<thead>
<tr>
<th>Disease organism</th>
<th>Scientific name</th>
<th>Affects these crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternaria black rot</td>
<td><em>Alternaria citri</em></td>
<td>citrus</td>
</tr>
<tr>
<td>Alternaria rot</td>
<td><em>Alternaria alternata</em></td>
<td>tomatoes, peppers</td>
</tr>
<tr>
<td></td>
<td><em>Alternaria sp.</em></td>
<td>stone fruits</td>
</tr>
<tr>
<td>Black rot</td>
<td><em>Physalospora obtusa</em></td>
<td>apples, pears, quinces</td>
</tr>
<tr>
<td></td>
<td><em>Endocondiophora frimbriata</em></td>
<td>sweet potatoes</td>
</tr>
<tr>
<td>Blue mold</td>
<td><em>Penicillium expansum</em></td>
<td>apples, pears, quinces</td>
</tr>
<tr>
<td></td>
<td><em>Penicillium italicum</em></td>
<td>citrus</td>
</tr>
<tr>
<td></td>
<td><em>Penicillium sp.</em></td>
<td>grapes, berries, stone fruits</td>
</tr>
<tr>
<td>Bitter rot</td>
<td><em>Glomerella cingulata</em></td>
<td>apples, pears, quince</td>
</tr>
<tr>
<td>Brown rot</td>
<td><em>Monolinia fructicola</em></td>
<td>stone fruits</td>
</tr>
<tr>
<td>Buckeye rot</td>
<td><em>Phytophthera sp.</em></td>
<td>tomatoes, peppers</td>
</tr>
<tr>
<td>Bull's eye rot</td>
<td><em>Pezicula malicorticus</em></td>
<td>apples, pears, quince</td>
</tr>
<tr>
<td>Cladosporium rot</td>
<td><em>Cladosporium hebarum</em></td>
<td>grapes, small fruits</td>
</tr>
<tr>
<td>Crate rot</td>
<td><em>Rhizoctonia carotae</em></td>
<td>carrots</td>
</tr>
<tr>
<td>Fusarium tuber rot</td>
<td><em>Fusarium spp.</em></td>
<td>potatoes</td>
</tr>
<tr>
<td>Fusarium wilts</td>
<td><em>Fusarium spp.</em></td>
<td>potatoes</td>
</tr>
<tr>
<td>Fusarium rot</td>
<td><em>Fusarium spp.</em></td>
<td>leafy vegetables, root crops, onions, melons, beans</td>
</tr>
</tbody>
</table>
Fungal diseases continued:

<table>
<thead>
<tr>
<th>Disease organism</th>
<th>Scientific name</th>
<th>Affects these crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray mold</td>
<td><em>Botrytis cinerea</em></td>
<td>grapes, berries, stone fruits, tomatoes, peppers, leafy vegetables, root crops,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>onions, melons, beans</td>
</tr>
<tr>
<td>Green mold</td>
<td><em>Penicillium digitatum</em></td>
<td>citrus</td>
</tr>
<tr>
<td>Late blight</td>
<td><em>Phytophthora infestans</em></td>
<td>potatoes, tomatoes, peppers</td>
</tr>
<tr>
<td>Rhizopus rot</td>
<td><em>Rhizopus sp.</em></td>
<td>leafy vegetables, root crops, onions, melons, beans, sweetpotatoes</td>
</tr>
<tr>
<td></td>
<td><em>Rhizopus stolonifer</em></td>
<td>tomatoes, peppers, grapes, berries, stone fruits</td>
</tr>
<tr>
<td>Sour rot</td>
<td><em>Geotrichum candidum</em></td>
<td>citrus, stone fruits, tomatoes, peppers</td>
</tr>
<tr>
<td>Stem end rot</td>
<td><em>Phomopsis citri</em></td>
<td>citrus</td>
</tr>
<tr>
<td></td>
<td><em>Diplodia natalinsis</em></td>
<td>citrus</td>
</tr>
<tr>
<td>Watery soft rot</td>
<td><em>Sclerotinia sclerotiorum</em></td>
<td>leafy vegetables, root crops, onions, melons, beans</td>
</tr>
<tr>
<td>White rot</td>
<td><em>Botryosphaeria ribis</em></td>
<td>apples, pears, quince</td>
</tr>
</tbody>
</table>

**Bacterial Diseases**

In general, bacteria cause few losses in tree fruits or small fruits. Potatoes are highly susceptible to bacterial disease when injured during harvest or handling. The following bacterial diseases are most common and cause the greatest market and storage losses:

<table>
<thead>
<tr>
<th>Disease organism</th>
<th>Scientific name</th>
<th>Affects these crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial soft rot</td>
<td><em>Erwinia sp.</em></td>
<td>Leafy vegetables, root crops, beans, onions, peppers, melons, cucumbers, tomatoes</td>
</tr>
<tr>
<td></td>
<td><em>Erwinia carotovora</em></td>
<td>potatoes</td>
</tr>
<tr>
<td>Brown rot</td>
<td><em>Pseudomonas solanacearum</em></td>
<td>potatoes</td>
</tr>
<tr>
<td>Ring rot</td>
<td><em>Comybacterium sepedonicum</em></td>
<td>potatoes</td>
</tr>
<tr>
<td>Slimy soft rot</td>
<td><em>Clostridium spp.</em></td>
<td>potatoes</td>
</tr>
</tbody>
</table>
**Viral and Nematode Diseases**

These tend to be uncommon and of minor importance, with the following exceptions:

<table>
<thead>
<tr>
<th>Disease organism</th>
<th>Scientific/common name</th>
<th>Affects these crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net necrosis</td>
<td>potato leaf roll virus</td>
<td>potatoes</td>
</tr>
<tr>
<td>Root knot nematode</td>
<td><em>Meloidogyne</em> spp.</td>
<td>potatoes, carrots, root crops</td>
</tr>
</tbody>
</table>

Source: Moline 1984

**PRE-HARVEST AND HARVEST PRACTICES**

**Genetic Factors and Planting**

Begin by planting cultivars offering some natural resistance to the pests you expect to have to deal with in your region. Plant only good quality, clean seed or stock. Paying more for certified seed or planting materials will pay off in reduced costs for pest management and lower losses due to disease.

Genetic resistance to pest problems differs by variety:

<table>
<thead>
<tr>
<th>Problem</th>
<th>Low or no resistance</th>
<th>Good to high resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>'Gangrene'</td>
<td>'Blanka'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>'Gracia'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>'Vanessa'</td>
</tr>
<tr>
<td>Berries</td>
<td><em>Botrytis cinerea</em></td>
<td>soft varieties</td>
</tr>
<tr>
<td>Onions</td>
<td>neck rot</td>
<td>sweet varieties</td>
</tr>
</tbody>
</table>

Field and Orchard Management

As discussed in Chapter 2, keeping the field and orchard clean will prevent the buildup of pests and disease organisms, and minimize the opportunities for the produce to be attacked. Keep fields and orchards free of debris and discarded produce. Eradicate diseased produce by burning or removing waste. Using appropriate cultural practices during production will assist the produce to avoid and/or resist pest attack. Proper planting density will reduce susceptibility to pests, avoiding over-fertilization and over-irrigation will keep plants healthy. You may need to prune to ensure proper ventilation and adequate air movement through the canopy. Thinning not
only improves fruit size and quality, but protects trees from damage caused by over-weight branches.

Monitoring pest levels during production can save you a lot a expense by limiting your treatments to those that are actually necessary for pest control. Sampling kiwifruit sepals 4 months after fruit set for Botryis cinerea (gray mold) can predict incidence in storage. If less than 6% of fruits are determined to be infected, no pre-harvest fungicides are required (Michailides and Morgan, 1996).

Maturity at Harvest and Pest Management
Harvesting at the proper maturity will ensure that produce has the maximum level of natural protection against pests and diseases. As discussed in Chapter 3, this moment will differ for various commodities. Under-mature and over-ripe produce is often more susceptible to diseases and insect damage than produce at prime maturity. As produce ripens, the flesh and skin softens and offers less protection against pests. And when produce bruises more easily pests are allowed easy entry.

Temperature and RH Management
The importance of proper cooling cannot be over-emphasized. Chapter 6 provides many examples of how reducing temperature also reduces disease problems.

Handle and store at proper RH: While high humidity in the storage environment is important for maintenance of high quality produce, free water on the surface of commodities can enhance germination and penetration by pathogens. When cold commodities are removed from storage and left at higher ambient temperatures, moisture from the surrounding warm air condenses on the colder product's surfaces. A temporary increase in ventilation rate (using a fan) or increasing exposure of the commodity to drier air can help to evaporate the condensed moisture and to reduce the chances of infection.

Remember:
Serious disease problems can result from over-cooling chilling sensitive commodities.
Decay in fruits can be increased if free water is available from condensation and drips onto the produce. These fruits and vegetables will decay less when held at a lower RH than the typical recommendation of 95-99% (Spotts, 1984):

<table>
<thead>
<tr>
<th>Produce</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>apples</td>
<td>88%</td>
</tr>
<tr>
<td>grapes</td>
<td>60%</td>
</tr>
<tr>
<td>pears</td>
<td>90-95%</td>
</tr>
<tr>
<td>persimmon</td>
<td>75-83%</td>
</tr>
<tr>
<td>squash (winter)</td>
<td>40%</td>
</tr>
<tr>
<td>strawberry</td>
<td>85-90%</td>
</tr>
<tr>
<td>sweetpotatoes</td>
<td>79%</td>
</tr>
</tbody>
</table>

Remember, also, that increased rooting and decay will occur in onions and garlic when these crops are handled or stored in a high humidity environment.

POSTHARVEST TREATMENTS

Heat and Cold
Certain fungi and bacteria in their germination phase are susceptible to cold, and infections can be reduced by treating produce with a few days of storage at the coldest temperature the commodity can withstand without incurring damage. *Rhizopus stolonifer* and *Aspergillus niger* (black mold) can be killed when germinating by 2 or more days at 0 °C (32 °F). On the other hand, brief hot water dips or forced-air heating can also be effective, especially for reducing the microbial load for crops such as plums, peaches, papaya, cantaloupe and stone fruits, sweetpotatoes and tomatoes. See Chapter 4 for specific recommendation for heat treatments in the packinghouse.

Cold treatments can control some insect pests, and are currently used for the control of fruit flies. Treatment requires 10 days at 0 °C (32 °F) or below, or 14 days at 1.7 °C (35 °F) or below, so treatment is only suited to commodities capable of withstanding long-term low-temperature storage such as apples, pears, grapes, kiwifruit and persimmons. For produce packed before cold storage treatment, package vents should be screened to prevent the spread of insects during handling.
Control of storage insects in nuts and dried fruits and vegetables can be achieved by freezing, cold storage (less than 5 °C or 41 °F), heat treatments, or the exclusion of oxygen (0.5% or lower) using nitrogen. Packaging in insect-proof containers is needed to prevent subsequent insect infestation.

Hot water dips or heated air can also be used for direct control of postharvest insects. In mangoes, an effective treatment is 46.4 °C for 65 to 90 minutes, depending on size. Fruit should not be handled immediately after heat treatment. Whenever heat is used with fresh produce, clean, cool water showers or forced cold air should be provided to help return the fruits to their optimum temperature as soon as possible after completion of the treatment. Refer to the current USDA APHIS Plant Protection Quarantine Treatment Manual for the latest information and details on heat treatments.

SANITATION
Washing produce with chlorinated water can prevent decay caused by bacteria, mold and yeasts on the surface of produce. Calcium hypochlorite (powder) and sodium hypochlorite (liquid) are inexpensive and widely available. The effectiveness of the treatment will be decreased if organic matter is allowed to build up in the wash water. The effectiveness of chlorine increases as pH is reduced from pH 11 to pH 8, but at lower pH chlorine becomes unstable.

Fruits and vegetables can be washed with hypochlorite solution (25 ppm available chlorine for two minutes) then rinsed to control bacterial decay. Alternatively, these commodities can be dipped in hypochlorite solution (50 to 70ppm available chlorine) then rinsed with tap water for control of bacteria, yeasts and molds. Follow local regulations on disposal of chlorinated waste water.
PESTICIDES

A wide variety of chemicals are available for postharvest pest management. They are used in various ways—-as dips, sprays, dusts or applied on a pad of absorbent paper. Always follow label instructions and be aware that recommendations for use may differ by state and commodity. When using chemical pest controls, you need to consider cost, availability, regulations for proper use, and residue tolerances. Recently many chemical controls have been banned due to concerns over residues and the possible consequences for human health. Others, such as benomyl are no longer registered for postharvest applications. Whenever possible it is a good idea to try to reduce your reliance on chemical controls.

When using chemicals in solution in the field or packinghouse, make sure you get good coverage by applying to the run-off stage. Always use potable water for spraying—recent Cyclospora outbreaks in raspberries in Guatemala were traced to contaminated water used to apply pesticides. The low cost, simple equipment illustrated here can ensure postharvest chemicals are applied as intended. The tray has perforations on the base to allow the solution to drain and the produce to dry before further handling.

Some plant materials are useful as natural pesticides. The pesticidal properties of the seeds of the neem tree (as an oil or aqueous extract) are becoming more widely known and used throughout the world. Native to India, neem (Azadirachta indica) acts as a powerful pesticide on food crops but appears to be completely non-toxic to humans, mammals and beneficial insects (NRC, 1992). Any "natural pesticide" must be shown to be safe for humans before its approval by regulatory authorities.
Bioneem (developed by Ringer Corp. Minneapolis, MN, US) currently has EPA registration in all US states except AZ, CA and NY, but only for use on ornamentals. The EPA has also approved a neem-based biological pesticide developed by Tata Oil Mills Ltd. (TOMCo) for use on a wide range of food crops, fruits and grains during production. We expect to hear more about this bio-pesticide in the next few years, and eventually to be able to use it safely in postharvest horticulture applications.
CONTROLLED - MODIFIED ATMOSPHERE TREATMENTS

For commodities that tolerate high CO₂ levels, 15 to 20% CO₂-enriched air can be used as a fumigant to control decay-causing pathogens, such as Botrytis cinerea on strawberry, blueberry, blackberry, fresh fig and table grapes during transport. See Chapter 5 for a description of the method for modified atmosphere packaging within a pallet cover.

Low O₂ and/or high CO₂ have been used to kill certain insects in commodities that can tolerate these conditions. The effectiveness of insecticidal atmospheres depends upon the temperature, relative humidity, duration of exposure and life stage of the insect. The following are some examples from Mitcham et al (1997):

Insecticidal atmospheres (0.5% or lower O₂ and/or 40% or higher CO₂) have been shown to be an effective substitute for methyl bromide fumigation to disinfect dried fruits, nuts and vegetables.

The first and third instars of the greenheaded leafroller (Planotortrix excessana) and the first and fifth instars of the brownheaded leafroller (Ctenopseustis obliquana) and the light brown apple moth (Epiphyas postvittana) are completely killed in 2 months when apples are stored at 0.5 °C in 3% O₂ and 3% CO₂.

The eggs of the apple rust mite (Aculus schlechtendali) and the European red mite (Panonychus ulmi) are killed in 5.3 months when apples are stored at 2.8 °C in an atmosphere of 1% O₂ and 1% CO₂.

Codling moth larvae (Cydia pomonella) are killed in 3 months when apples are stored at 0 °C, 1.5-2% O₂ and less than 1% CO₂.

In kiwifruit, the adult two-spotted spider mite (Tetranychus urticae) is killed by 40°C, 0.4% O₂ and 20% CO₂ in only 7 hours.

When persimmons are stored at 20 °C, 0.5% O₂ and 5% CO₂, the third instar of leafrollers (Planotortrix excessana) is killed in 4 days and the larvae and adult mealy bug (Pseudococcus longispinus) is killed in 7 days.

Sweetpotato weevil (Cylas formicarius elegantulus) has been controlled at ambient temperature in stored tropical sweetpotatoes by treatment with low oxygen and high carbon dioxide atmospheres. At 25 °C (77 °F), storage in 2 to 4% O₂ and 40 to 60% CO₂ results in 100% mortality of adult weevils in 2 to 7 days.

Codling moth (Cydia pomonella) in stone fruits can be controlled at 25 °C (77 °F) by using atmospheres of 0.5% oxygen and 10% carbon dioxide for 2 to 3 days (adult or egg) or 6 to 12 days (pupa). Normal color and firmness changes during ripening are not affected by treatment.
COSTS AND BENEFITS OF POSTHARVEST IPM PRACTICES

Costs:
- materials
- labor
- power

Benefits:
- reduced decay rates or insect losses
- longer shelf life
- improved quality

Example 1:
Harvest 1000 lbs of green beans, sort, cool and pack beans for marketing in California within one week. Postharvest IPM in this case involves a quick hot water dip to reduce disease problems during storage and marketing.

<table>
<thead>
<tr>
<th></th>
<th>Minimal pest controls</th>
<th>Postharvest IPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>labor for harvest</td>
<td>$35</td>
<td>$35</td>
</tr>
<tr>
<td>labor for sorting/grading</td>
<td>$12</td>
<td>$12</td>
</tr>
<tr>
<td>hot water treatment</td>
<td></td>
<td>$10</td>
</tr>
<tr>
<td>ice bath</td>
<td>$10</td>
<td></td>
</tr>
<tr>
<td>postharvest losses</td>
<td>20%</td>
<td>5%</td>
</tr>
<tr>
<td>amount available to market</td>
<td>800 lbs</td>
<td>950 lbs</td>
</tr>
<tr>
<td>market value</td>
<td>$0.50/lb</td>
<td>$0.79/lb</td>
</tr>
<tr>
<td>costs: labor</td>
<td>($47)</td>
<td>($47)</td>
</tr>
<tr>
<td>pest control</td>
<td>0</td>
<td>($20)</td>
</tr>
<tr>
<td>Potential net sales</td>
<td>$353</td>
<td>$683</td>
</tr>
</tbody>
</table>
Example 2:
Harvest 400 kg of French green beans, sort, cool and pack beans for marketing in India within one week. Postharvest IPM in this case involves a quick hot water dip followed by an ice bath to reduce disease problems during storage and marketing.

<table>
<thead>
<tr>
<th>Minimal pest controls</th>
<th>Postharvest IPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>labor for harvest (6 hours @ Rs 80/day)</td>
<td>Rs 50</td>
</tr>
<tr>
<td>labor for sorting/grading</td>
<td>Rs 30</td>
</tr>
<tr>
<td>hot water treatment (0.5 minutes at 52 °C)</td>
<td>Rs 200</td>
</tr>
<tr>
<td>ice bath</td>
<td>Rs 200</td>
</tr>
<tr>
<td>postharvest losses</td>
<td>20%</td>
</tr>
<tr>
<td>amount available to market</td>
<td>320 kg</td>
</tr>
<tr>
<td>market value</td>
<td>Rs 10/kg</td>
</tr>
<tr>
<td></td>
<td>Rs 3200</td>
</tr>
<tr>
<td>costs: labor</td>
<td>(Rs 50)</td>
</tr>
<tr>
<td>pest control</td>
<td>0</td>
</tr>
<tr>
<td>Potential net sales</td>
<td>Rs 3150</td>
</tr>
</tbody>
</table>
CHAPTER 9: POSTHARVEST INTEGRATED PEST MANAGEMENT

SOURCES OF PEST MANAGEMENT EQUIPMENT AND SUPPLIES

- automatic chlorine dispenser: Orchard Equipment and Supply Co.
- fungicides: Brogdex Co.
- sulfur dioxide pads: Zellerbach

For addresses and phone/FAX numbers of suppliers, please refer to Appendix D.

REFERENCES


PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE


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PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
The number one issue among consumers, is maintenance and improvement of fresh produce safety from field to fork. Fresh fruits and vegetables are often thought of as healthful, nutritious foods having no risk of foodborne illness associated with their consumption. However, recent foodborne illness outbreaks in the U.S. have been traced to fresh fruits, vegetables and juices. These incidents have caused growers, shippers, distributors, retailers and importers to reevaluate fresh fruit and vegetable production and handling practices.

The probability of getting sick from eating a raw fruit or vegetable is very low, but a small probability does exist. Reducing the risk of food-borne illness from consumption of fresh fruits and vegetables is the responsibility of everyone, including growers, shippers, processors and consumers.

"Wholesale buyers are starting to expect documentation of prevention and critical control point programs for food safety down to the farm level. In the immediate future, agricultural producers will be charged with establishing and documenting methods of risk reduction and prevention." Suslow (1997).
It might help to remind consumers that the health benefits derived from eating at least 5 servings of fresh fruits and vegetables daily far outweigh the very small probability of contracting food borne illness.

Preventing contamination of fresh fruits and vegetables by human pathogens and dangerous levels of chemical residues is the best way to assure that foods are wholesome and safe for human consumption. This chapter will provide information on 1) potential hazards during production of raw produce, 2) sanitary postharvest handling of produce and 3) Hazard Analysis Critical Control Points (HACCP) principles as applied to handling fresh produce.

**General DOs and DON’Ts of Fresh Produce Food Safety**

Grazing animals, feedlots or other sources of fecal contamination should NOT be present on or adjacent to production land.

Prior land use should be investigated to assure that toxic compounds such as pesticides or heavy metals are NOT present at dangerous levels in production soil.

Fertilizers should have no detectable levels of human pathogens. Proper composting or use of inorganic fertilizers is highly recommended.

Irrigation water should have no detectable human pathogens, or unacceptable levels of pesticide residues, heavy metals or toxic compounds.

Employ only professional, licensed pesticide applicators.

Monitor and document all pesticide, fungicide and herbicide use, and maintain a safe period between application and produce harvest.
Dos and Don’ts continued:

Keep harvested produce up off the bare soil.

Avoid exposure to moist soil. There is an increased risk of aflatoxin infection, a carcinogenic toxin in nuts (pistachios and thin shelled almonds are especially susceptible).

Provide field latrine and hand wash stations for field workers.

Monitor and enforce field worker good personnel hygiene practices.

Use only clean and sanitary field containers.

Continuously monitor chlorine concentrations and pH of hydrocooling or wash water.

Clean and sanitize field tools, containers and packing lines on a frequent and scheduled basis.

Clean and sanitize forced air coolers, cold storage rooms and cooler drain tiles on a frequent and scheduled basis.

Clean and sanitize transport trucks on a frequent and scheduled basis.

Only use cleaning compounds and sanitizers that are approved for food contact surfaces.

Use transportation that is dedicated to hauling only produce. Do NOT use trucks which have been used to transport live animals.
FOOD SAFETY RISKS ASSOCIATED WITH PRODUCE

Physical Hazards: Examples of physical hazards which may become imbedded in produce during production handling or storage are such things as:
- fasteners (staples, nails, screws, bolts)
- pieces of glass
- wood splinters

Chemical Hazards: Examples of chemical hazards which may contaminate produce during production handling or storage are such things as:
- pesticides, fungicides, herbicides, rodenticides
- machine lubricants from forklifts or packing line equipment
- heavy metals (Lead, Mercury, Arsenic)
- industrial toxins
- compounds used to clean and sanitize equipment

Human Pathogens: There are four main types of human pathogens associated with fresh produce:
- soil associated pathogenic bacteria (*Clostridium botulinum, Listeria monocytogenes*)
- feces associated pathogenic bacteria (*Salmonella spp., Shigella spp., E. coli O157:H7 and others*)
- pathogenic parasites (*Cryptosporidium, Cyclospora*)
- pathogenic viruses (*Hepatitis, Enterovirus*).

Many of these pathogens are spread via a human (or domestic animal) to food to human transmission route. Handling of fruits and vegetables by infected field-workers or consumers, cross contamination, use of contaminated irrigation water, use of inadequately composted manure or contact with contaminated soil are just a few of the ways that transmission of human pathogens to food can occur.
FOOD SAFETY HAZARDS DURING THE PRODUCTION OF FRESH PRODUCE

While produce quality can be judged by outward appearance on such criteria as color, turgidity and aroma; food safety can not. Casual inspection of produce cannot determine if it is in fact safe and wholesome to consume. Management of growing conditions are paramount in preventing the contamination of fresh produce by physical hazards, harmful chemicals and human pathogens.

Land Use
The safety of food grown on any given piece of land is not only influenced by the current agricultural practices but also by former land use practices. Heavy metals and pesticide residues may remain in soils for long periods of time. Production land soil should be tested to assure that dangerously high levels of these compounds are not present. Former land use should also be investigated to assure that the production land was not used for hazardous waste disposal or for industrial purposes that may have left behind toxic residues. If production land was previously used for agricultural purposes, pesticide use records should be reviewed to assure that proper pesticide management practices were followed. Production acreage should not have been previously used as a feed lot or for animal grazing since fecal contamination of the soil may be extensive.

Fertilizers
Improperly or non composted organic fertilizers are a potential source of human pathogens. Human pathogens may persist in animal manures for weeks or even months. Proper composting (the heat treatment the manure undergoes as it breaks down) will reduce the risk of potential food borne illness. Unfortunately the persistence of many human pathogens in untreated agricultural soils is currently unknown. Use of inorganic fertilizers which have been certified to be free of heavy metals and other chemical contaminants is recommended.
Irrigation Water

Irrigation water is another potential way contaminants may be brought in contact with fruits and vegetables. Well water is less likely to be contaminated with human pathogens than surface water supplies, however, all irrigation water sources should be periodically tested for contamination by pesticides and human pathogens. Overhead irrigation systems are more likely to spread contamination since contaminated water is applied directly to the edible portions of fruits and vegetables.

Pesticide Usage

All pesticide usage should be done in strict accordance with manufacturer recommendations as well as federal and state ordinances. Monitoring and documentation of proper pesticide usage should be done to prevent unsafe levels or illegal residues from contaminating fruits and vegetables. All pesticide applications should be documented and proper records of application as well as tests for residues should be available and reviewed by management on a regular basis.

Harvest Operations

During harvesting operations field personnel may contaminate fresh fruits and vegetables by simply touching them with an unclean hand or knife blade. Portable field latrines as well as hand wash stations must be available and used by all harvest crew members. Monitoring and enforcement of field worker personnel hygiene practices such as washing hands after using the latrine are a must to reduce the risk of human pathogen contamination. Produce once harvested should not
be placed upon bare soils before being placed in clean and sanitary field containers. Field harvesting tools should be clean, sanitary and not be placed directly in contact with soil. Field containers should be cleaned and sanitized on a regular basis as well as being free of contaminants such as mud, industrial lubricants, metal fasteners or splinters.

**SANITARY POSTHARVEST HANDLING OF PRODUCE**

Depending upon the commodity, produce may field packaged in containers that will go all the way to the destination market or be temporarily placed in bulk bins, baskets or bags which will be transported to a packing shed. Employees, equipment, cold storage facilities, packaging materials and any water which will be contacting the harvested produce must be kept clean and sanitary to prevent contamination.

**Employee Hygiene**

Gloves, hairnets and clean smocks are commonly worn by packinghouse employees in export oriented packing sheds. The cleanliness and personnel hygiene of employees handling produce at all stages of production and handling must be managed to minimize the risk of contamination. Adequate bathroom facilities and handwash stations must be provided and used properly to prevent contamination of produce by packinghouse employees. Shoe or boot cleaning stations may also be in place to reduce the amount of field dirt and contamination which enters the packing shed from field operations. Employee training regarding sanitary food handling practices should be done when an employee is hired and reviewed before they begin work each season.

**Equipment**

Food contact surfaces on conveyor belts, dump tanks etc. should be cleaned and sanitized on a regular scheduled basis with food contact surface approved cleaning compounds. A 200 parts per million sodium hypochlorite (bleach) solution is an excellent example of a food contact surface
Avoid the use of steam when cleaning equipment.

Sanitizer. Sanitizers should be used only after thorough cleaning with abrasion to remove organic materials such as dirt or plant materials. Use of steam to clean equipment should be avoided since steam may actually cake organic materials and form a biofilm, which renders equipment almost impossible to sanitize. Steam may also aerosolize bacteria into the air and actually spread contamination throughout the packing house facility.

Cold Storage Facilities

Cold storage facilities and in particular refrigeration coils, refrigeration drip pans, forced air cooling fans, drain tiles, walls and floors should be cleaned and sanitized on a frequent and regular basis. The human pathogen *Listeria monocytogenes* can proliferate quite well at refrigerated temperatures and may contaminate produce cold stored produce if condensation from refrigeration units or ceilings drip on to the produce. Placing warm product with field heat into a cold room with insufficient refrigeration capacity will cause a temperature rise in the room and as the room cools a fog or mist will occur. As the water condenses out of the air and onto walls and ceilings, contamination from walls may end up dripping onto stored produce.

Packaging materials

All packaging materials should be made of food contact grade materials to assure that toxic compounds in the packaging materials do not leach out of package and into the produce. Toxic chemical residues may be present in some packaging materials due to use of recycled base materials. Empty packages such as boxes and plastic bags should be stored in an enclosed storage area to protect them from insects, rodents, dust, dirt and other potential sources of contamination. These actions protect not only against the potential loss of valuable materials but protects the integrity and safety of these materials.
Plastic field bins and totes are preferred to wooden containers since plastic surfaces are easier to clean and sanitize, which should be done after every use. If containers are not cleaned and sanitized after every use, they may become contaminated and then contaminate the next products which are placed in the container. Wooden containers or field totes are almost impossible to sanitize since they have a porous surface and wooden or metals fasteners such as nails from wooden containers may accidentally be introduced into produce. Cardboard field bins if reused should be visually inspected for cleanliness and lined with a polymeric plastic bag before reuse to prevent the risk of cross contamination.

Wash and Hydrocooling Water
All water which comes in contact with produce for washing or hydrocooling must be safe to drink. Water should contain between 100 and 150 parts per million total chlorine and have a pH of between 6 and 7.5. Chlorine use prevents the potential for cross contamination of all produce in the washing or hydrocooling system. It will not sterilize the produce. Scientific studies have demonstrated that washing produce in cold chlorinated water will reduce microbial populations by 100 to 1000 fold, but sterility is never achieved because microorganisms adhere so voraciously to the surface of produce and may be present in microscopic nooks and crannies on the surface of produce. Rinsing produce with cold chlorinated water will significantly reduce the number of microorganisms present on the produce but it will not remove all bacteria. Therefore, human pathogens can not be completely removed from produce by washing it in cold chlorinated water.

Refrigerated Transport
Produce is best shipped in temperature controlled refrigerated trucks. Maintaining perishables below 5°C even while being transported to destination markets will extend shelf-life and significantly reduce the growth rate of microbes including human pathogens. Temperatures used for transporting chilling sensitive produce will not protect against the growth of most pathogens. Trucks used during transportation should be cleaned and sanitized on a regular basis. Trucks which have been used to transport live animals, animal products or toxic materials should never be used to transport produce.
HAZARD ANALYSIS CRITICAL CONTROL POINTS (HACCP)

HACCP is a food safety system first developed by the Pillsbury Co. to reduce the risk associated with the food eaten by astronauts during space flights. HACCP is a system approach which:

- identifies potential sources of contamination in food production systems
- establishes methods for detecting the occurrence of contamination
- clearly prescribes what corrective actions will be taken to prevent consumption of contaminated food items.

HACCP is a systems approach method to assure the safety of a food product, it is NOT a means of assuring food quality.

The seven basic principles of HACCP are:

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of Hazards</td>
<td>Determine Critical Control Points (CCP) to Control the Identified Hazards</td>
</tr>
<tr>
<td></td>
<td>Establishment of Limits at each CCP</td>
</tr>
<tr>
<td></td>
<td>Establishment of CCP Monitoring Procedures</td>
</tr>
<tr>
<td></td>
<td>Establishment of Corrective Actions to be Taken When CCP Exceed Set Limits</td>
</tr>
<tr>
<td></td>
<td>Establishment of Record Keeping Systems to Document the HACCP Program</td>
</tr>
<tr>
<td></td>
<td>Establishment of Procedures to Verify that the HACCP is Functioning Properly</td>
</tr>
</tbody>
</table>

1. **Assessment of Hazards**

   Each unit operation should be evaluated to identify potential sources of microbial, chemical and physical hazards which may be introduced into produce. Areas which should be evaluated are growing and harvesting operations, packing shed operations, packaging material and storage as well as distribution. This process is best accomplished by a team of both management and production personnel.

   *Example:* Hydrocooling water contamination (microbial or chemical)

2. **Determine Critical Control Points (CCP) to Control the Identified Hazards**

   The next step in developing a HACCP program is to draw a flow diagram for your specific operation and then determine where each of the identified hazards may be monitored. Each point that will be monitored to control specific hazard is now designated a Critical Control Point (CCP). *Example:* Chlorine injection system on hydro cooler.
3. **Establishment of CCP Limits**

Once CCP have been identified, tolerance limits must be set to determine when corrective action needs to be taken. Tolerances must be observable and measurable.

*Example:* Hydro-cooler water must have a chlorine level of 100-150 ppm total chlorine and a pH of 6.0-7.5.

4. **Establishment of CCP Monitoring Procedures**

How often monitoring will be done, how measurements will taken and what documentation will be prepared must next be clearly defined.

*Example:* Hydro-cooler water pH and chlorine levels will be monitored using a test kit hourly and continuously with a strip chart recorder that has been calibrated daily. Hourly pH and chlorine level measurements will written down and be available for inspection at the hydro-cooler.

5. **Corrective Action When Deviations From CCP Limits Occur**

When a deviation from the prescribed limits occurs corrective action must be taken to eliminate the potential contamination. All deviations and corrective actions must be noted in a written form.

*Example:* Chlorine levels were determined to be below 25 ppm. Hydro-cooling of product was stopped, chlorine levels were adjusted and all produce that had been hydro-cooled in since the last in within critical limit chlorine measurement was taken were rehydro-cooled.

6. **HACCP Record Keeping Systems**

All paper work related to the HACCP system must be keep in an orderly and accessible manner. Records that should be kept include:

- Production Records
  - Supplier Audits
  - Pesticide Usage and Testing Results
  - Irrigation Water Test Results etc.

- Harvesting Records
  - Harvest Dates and Lot Numbers
  - Total Number of Boxes Harvested, etc.
All Critical Control Point Monitoring Records
Storage and Distribution Records
  Temperature Monitoring
  Truck Cleanliness, etc.
Deviations File: HACCP Deviations and Corrective Actions Taken

7. HACCP Verification

Periodic HACCP plan review including review of CCP records, deviations and random sampling to verify that the HACCP program must be done to assure that HACCP program is functioning properly. This review should be done either on a monthly or quarterly basis.

Food safety is becoming an ever more important aspect of produce marketing especially for those producers who wish to export. Ensuring that produce is safe to eat is in the best interest of everyone since we are all consumers. Investment in food safety programs will add cost to producing fresh fruits and vegetables, however it assures the long term success of a company much like a good insurance policy. While food safety programs cannot ensure the safety of all products they significantly reduce the probability and risk of food borne illness.

The following is an example of a CCP in a model HACCP program. The Critical Control Point (CCP) identified as #3 requires the careful monitoring of the pH and Cl level in wash water.

**HACCP Model**

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>CATEGORY</th>
<th>CCP</th>
<th>LIMIT</th>
<th>MONITORING</th>
<th>FREQ</th>
<th>CORRECTIVE ACTION</th>
<th>RECORD</th>
<th>VERIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washing</td>
<td>Microbial</td>
<td>#3</td>
<td>Free Cl₂ 2-7 ppm</td>
<td>Test kit Continuous strip chart</td>
<td>Once/ hour</td>
<td>Manually adjust water chemistry. Repair system. Hold produce from last correct reading and rewash.</td>
<td>Chlorine/ pH records</td>
<td>Random sampling. QA audit. Microbiological counts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water Cl₂ and pH</td>
<td>Total Cl₂ 100-150 ppm</td>
<td>pH 6.0-7.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
INFORMATION RESOURCES
To obtain more information about produce food safety programs contact the following organizations.

Davis Postharvest Consulting
Produce Food Safety Systems
P.O. Box 72711
Davis, CA 95617
Phone (530) 400-0430
FAX (530) 756-5440
davispc@jps.net

International Fresh-Cut Produce Association
“Food Safety Guidelines for the Fresh-cut Produce Industry 3rd Edition”
1600 Duke Street Suite 440
Alexandria, VA 22314
Phone (703) 299-6282

United Fresh Fruit and Vegetable Association
“Industrywide Guidance to Minimize Microbiological Food Safety Risks for Produce”
727 N. Washington St.
Alexandria, VA 22314
Phone (703) 836-3410

University of California
FoodSafe Program
Davis, CA 95616
Phone (530) 752-2647

Western Growers Association
“Voluntary Food Safety Guidelines for Fresh Produce”
P.O. Box 2130
Newport Beach, CA 92658
Phone (714) 863-1000
CHAPTER 10: FOOD SAFETY FOR FRESH PRODUCE

SOURCES OF FOOD SAFETY EQUIPMENT AND SUPPLIES

HACH Company (Microbiological testing supplies, water quality test kits and portable systems
P.O. Box 608
Loveland, CO 80539
In the U.S. (800) 227 4224 or FAX (970) 669 2932
Outside the U.S.: (970) 669 3050 or FAX (970) 669 2932

International Ripening Corporation (Temperature recorders, 'HACCP Manager' equipment)
1185 Pineridge Road
Norfolk, VA 23502
Phone (800) 472-7205

REFERENCES


Harris, L. (ed) 1997. Perishables Handling. Special Issue No. 91: Food Safety


United Fresh Fruit and Vegetable Association 1997. Industrywide Guidance to Minimize Food Safety Risks for Produce. Alexandria, VA UFFVA

Western Growers Association 1997. Voluntary Food Safety Guidelines for Fresh Produce. Newport Beach, CA. WGA

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
Comparison of estimated costs and expected benefits related to adopting postharvest technology for fresh handling and marketing.

If you need more facts to fill out any worksheet, it is recommended that you select one specific commodity that you produce, and actually use the new practice on one row of vegetables or on a small group of trees for one season or any suitable period of time. During this time collect information on yields, losses, grades of produce harvested, costs of labor, materials and equipment, and power requirements for your own operation in comparison to your current practice. Some of your expenses will not be affected at all, while others will be added or no longer be necessary when you change practices.
INSTRUCTIONS
Make copies of these blank worksheets and use a complete set for each commodity you produce and market. If you want to compare various postharvest technologies you may need to use several copies of the worksheets for each commodity.
Overhead costs should be reported by month, by season or by year, depending upon how you generally allocate costs of operation. The idea is to be able to determine how much of your overhead costs can be assigned to the commodity of interest. For example, if you produce and handle only one commodity, it will take on 100% of your overhead. If you produce and market equal amounts of 3 commodities, each can be assigned 1/3 of the total overhead.

Most of the costs for the topics listed in Worksheet 3 will have several components including capital costs (equipment or facilities), and recurring costs (supplies, labor and purchased power or fuel for running equipment).

Worksheet 1: Collect some basic information

Commodity ____________________________
Variety ______________________________

1. Overhead Costs:
Salaries (managers, office staff, etc.) Rs _______
Office expenses and supplies Rs _______
Maintenance, parts and repairs Rs _______
Utilities (gas, electric) Rs _______
Communications (Telephone, FAX, e-mail) Rs _______
Rent Rs _______
Other Rs _______

Total = Rs _______

Overhead costs affiliated with this commodity (base on the percent this commodity compared to your total production)

_____ % Rs _______ *

PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE
2. General information related to each practice:

Base upon previous experience with the commodity, your CSAM results (see Appendix A) or estimates provided by other producers/shippers, produce buyers, published literature on postharvest technology, cost/benefit examples provided in each chapter of this workbook or information available from your local Extension Service. Many recommended PHTs will reduce losses by minimizing decay, mechanical damage, and weight loss.

Current Practice (describe)

New Practice (describe)

<table>
<thead>
<tr>
<th>Expected yields</th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>____ kg</td>
<td>____ kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimated physical losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>amount of culls during pre-sorting</td>
</tr>
<tr>
<td>losses due to pests</td>
</tr>
<tr>
<td>losses due to mechanical damage</td>
</tr>
<tr>
<td>weight loss during handling/storage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum of losses</th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>____ kg</td>
<td>____ kg</td>
</tr>
</tbody>
</table>

How much will you have to sell?
(Expected yields - Estimated sum of losses)  ____ kg  ____ kg

Expected grades (should add up to the amount above)

<table>
<thead>
<tr>
<th></th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>highest</td>
<td>____ kg</td>
<td>____ kg</td>
</tr>
<tr>
<td>second</td>
<td>____ kg</td>
<td>____ kg</td>
</tr>
<tr>
<td>lowest</td>
<td>____ kg</td>
<td>____ kg</td>
</tr>
</tbody>
</table>

3. Market Prices (obtain from your buyers or past history):

Expected price per kg (wholesale)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>highest grade</td>
<td>Rs _________</td>
<td></td>
</tr>
<tr>
<td>second grade</td>
<td>Rs _________</td>
<td></td>
</tr>
<tr>
<td>lowest grade</td>
<td>Rs _________</td>
<td></td>
</tr>
</tbody>
</table>
Expected price per kg (retail)

- highest grade: Rs_______
- second grade: Rs_______
- lowest grade: Rs_______

**Worksheet 2: Comparison of Direct Costs**

Does one practice cost more than the other for production, preparation for market, postharvest handling, materials, power, equipment, storage, transport, marketing, etc.? Calculations should be based on expected yield, postharvest losses, hourly labor costs, and expected volumes to be handled. Specific details for recommended practices are included in the examples found at the end of each chapter of the book, with those costs that are expected to change listed individually under each category. If you find there are additional costs associated with your operation, please add these to the list.

**Current Practice**

**New Practice**

<table>
<thead>
<tr>
<th>Pre-Harvest</th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>seeds or planting materials</td>
<td>Rs_______</td>
<td>Rs_______</td>
</tr>
<tr>
<td>land preparation/planting</td>
<td>Rs_______</td>
<td>Rs_______</td>
</tr>
<tr>
<td>cultivation (pruning, thinning, mulching, etc)</td>
<td>Rs_______</td>
<td>Rs_______</td>
</tr>
<tr>
<td>preharvest treatments (pesticides, etc.)</td>
<td>Rs_______</td>
<td>Rs_______</td>
</tr>
<tr>
<td>irrigation</td>
<td>Rs_______</td>
<td>Rs_______</td>
</tr>
<tr>
<td>fertilization</td>
<td>Rs_______</td>
<td>Rs_______</td>
</tr>
<tr>
<td>other</td>
<td>Rs_______</td>
<td>Rs_______</td>
</tr>
<tr>
<td>Part</td>
<td>Current Practice</td>
<td>New Practice</td>
</tr>
<tr>
<td>------</td>
<td>-----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Harvest and Market Preparation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>labor and equipment for harvesting</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>field packing</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>curing</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>other</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>Packinghouse Operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre-sorting</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>washing/cleaning</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>sizing/grading</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>waxing</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>pest management</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>sanitation</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>packaging materials</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>packing</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>other</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>Temperature/RH Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre-cooling</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>cooling</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>storage</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>other</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vehicles</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>fuel</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>cooling</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
<tr>
<td>other</td>
<td>Rs _______</td>
<td>Rs _______</td>
</tr>
</tbody>
</table>
### PART I: WORKSHEETS

<table>
<thead>
<tr>
<th>Destination Handling</th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>ripening</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>re-sorting</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>display</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>other</td>
<td>Rs</td>
<td>Rs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other Costs</th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>marketing (fees, sales labor)</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>promotional activities</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>food safety program</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>other</td>
<td>Rs</td>
<td>Rs</td>
</tr>
</tbody>
</table>

**Total Direct Costs**

*Overhead Costs for this commodity*  
Rs | Rs

**Total Costs**

Total costs per kg of produce for sale  
Rs | Rs

---

**PART I: FRESH HANDLING TECHNOLOGIES FOR HORTICULTURAL PRODUCE**
Worksheet 3: Comparison of Benefits

Base upon expected yields and quality, amount of produce available for sale at various grades, and expected prices per kg collected in Worksheet 1. (kgs of produce at each grade x price/kg = expected sales at each grade). Do the calculations for either wholesale or retail prices or a combination if you will sell both ways.

**Current Practice**

**New Practice**

<table>
<thead>
<tr>
<th></th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Expected sales (wholesale)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>highest grade</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>second grade</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>lowest grade</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>Subtotal Sales (wholesale)</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>2. Expected sales (retail)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>highest grade</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>second grade</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>lowest grade</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>Subtotal Sales (retail)</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>3. Total Expected Sales</td>
<td>Rs</td>
<td>Rs</td>
</tr>
</tbody>
</table>

4. Comparative Advantage

(Total Expected Sales - Total Costs = Comparative Advantage)

refer to the total costs calculated for each practice in Worksheet 2

<table>
<thead>
<tr>
<th></th>
<th>Current practice</th>
<th>New practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current practice</td>
<td>Rs</td>
<td>Rs</td>
</tr>
<tr>
<td>New practice</td>
<td>Rs</td>
<td>Rs</td>
</tr>
</tbody>
</table>

Which practice is most profitable, and can provide the best economic opportunity?

(a) Rs

(b) Rs
Worksheet 4: Recovery of Invested Capital (ROIC)

If the new postharvest technology costs more than your current practice, how long will it take to pay for your investment in the new practice? An excellent return on investment would be a recovery time of less than one month, while a slower return may require an entire season (3 to 5 months). Any longer recovery period usually would not be considered a good return on investment.

**Current Practice**

**New Practice**

1. **Difference in total direct costs for new practice** = Rs
   (Actual capital outlay for new equipment and facilities, plus power costs, supplies and labor requirements for the new practice when compared to costs for the current practice over the entire season: see Worksheet 2)

2. **Interest rate (if capital is borrowed)** = _____% per annum; or _____% per month
   Cost of capital at three months = Rs __________
   Cost of capital at six months = Rs __________

3. **Difference in sales using the new practice** = Rs ______ per month
   (Subtract total expected sales using the current practice from total expected sales using the new practice: see Worksheet 3; divide the difference by number of months of sales)

4. **Calculate ROIC in months to recover invested capital:**

   \[
   \text{Difference in total direct costs} + \text{any interest paid} \times \text{Months to pay for investment.}
   \]

   \[
   \text{Difference in Sales per month}
   \]

   \[
   (Rs \underline{\text{_______}} + Rs \underline{\text{________}}) = \underline{\text{_______}} \text{Months}
   \]

   \[
   \underline{\text{Rs _________ per month}}
   \]