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Mango POSTHARVEST BEST MANAGEMENT PRACTICES MANUAL

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This document was originally developed using information compiled during the National Mango Board-sponsored 2007–09 research project, Monitoring and Evaluation of the Mango Supply Chain to Improve Mango Quality, and utilizing the experience and expertise of the following project participants:

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Revised October 2020 and March 2024 by Dr. Jeffrey K. Brecht, University of Florida.

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TABLE OF CONTENTS

Background and Purpose

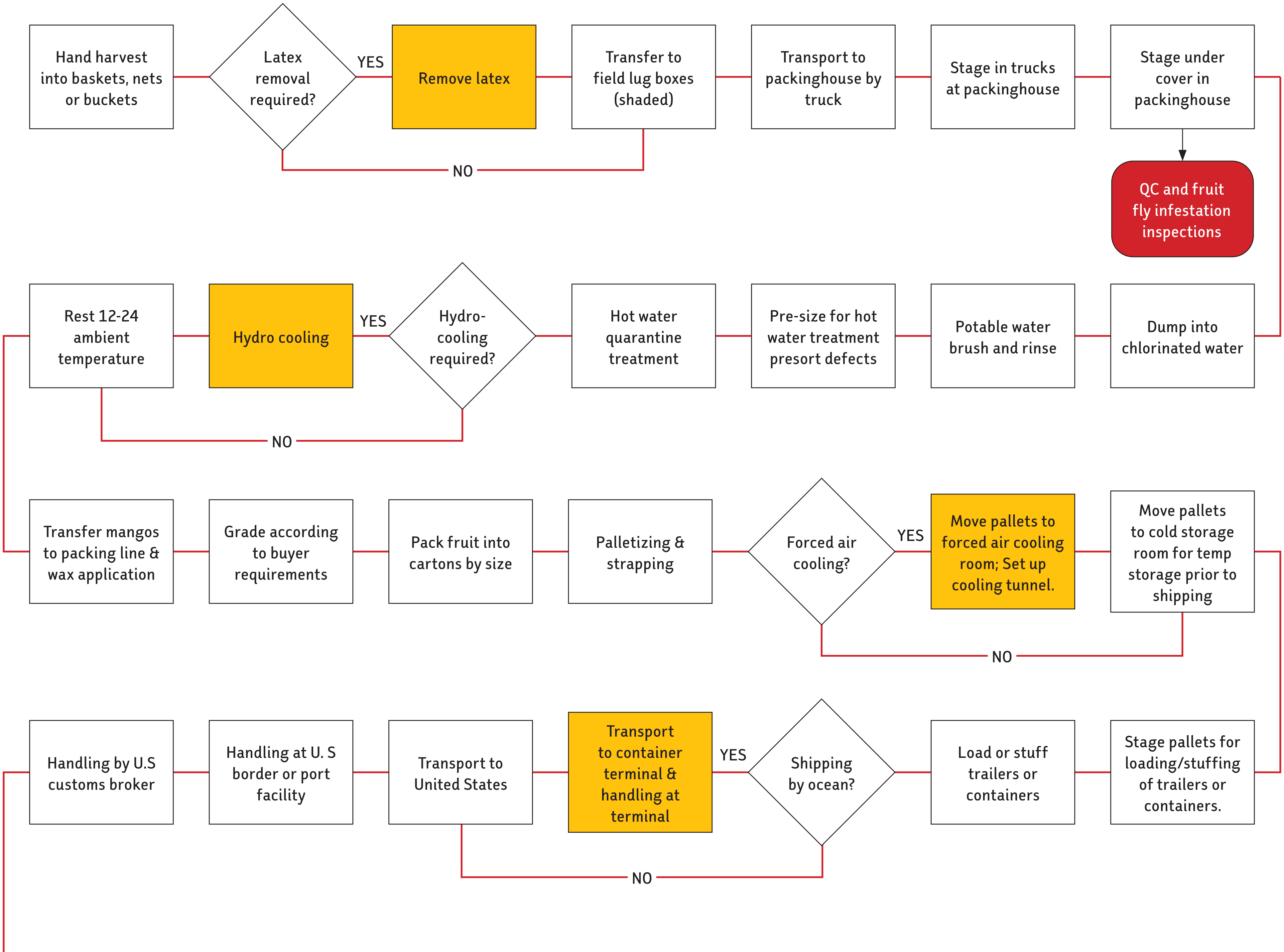
Improving the quality and consistency of the fresh mangos that are available to consumers in the United States is an important goal of the National Mango Board (NMB). The NMB-funded project, "Monitoring and Evaluation of the Mango Supply Chain to Improve Mango Quality" (referred to hereafter as the Mango Quality Project), was conducted from December 2007 through April 2009 to identify impediments to successfully meeting that goal. The final deliverable of the Mango Quality Project is this best management practices manual for harvesting and handling mangos marketed in the U.S. The manual includes quality-control procedures to use when monitoring the maturity and quality of mangos in commercial handling operations.

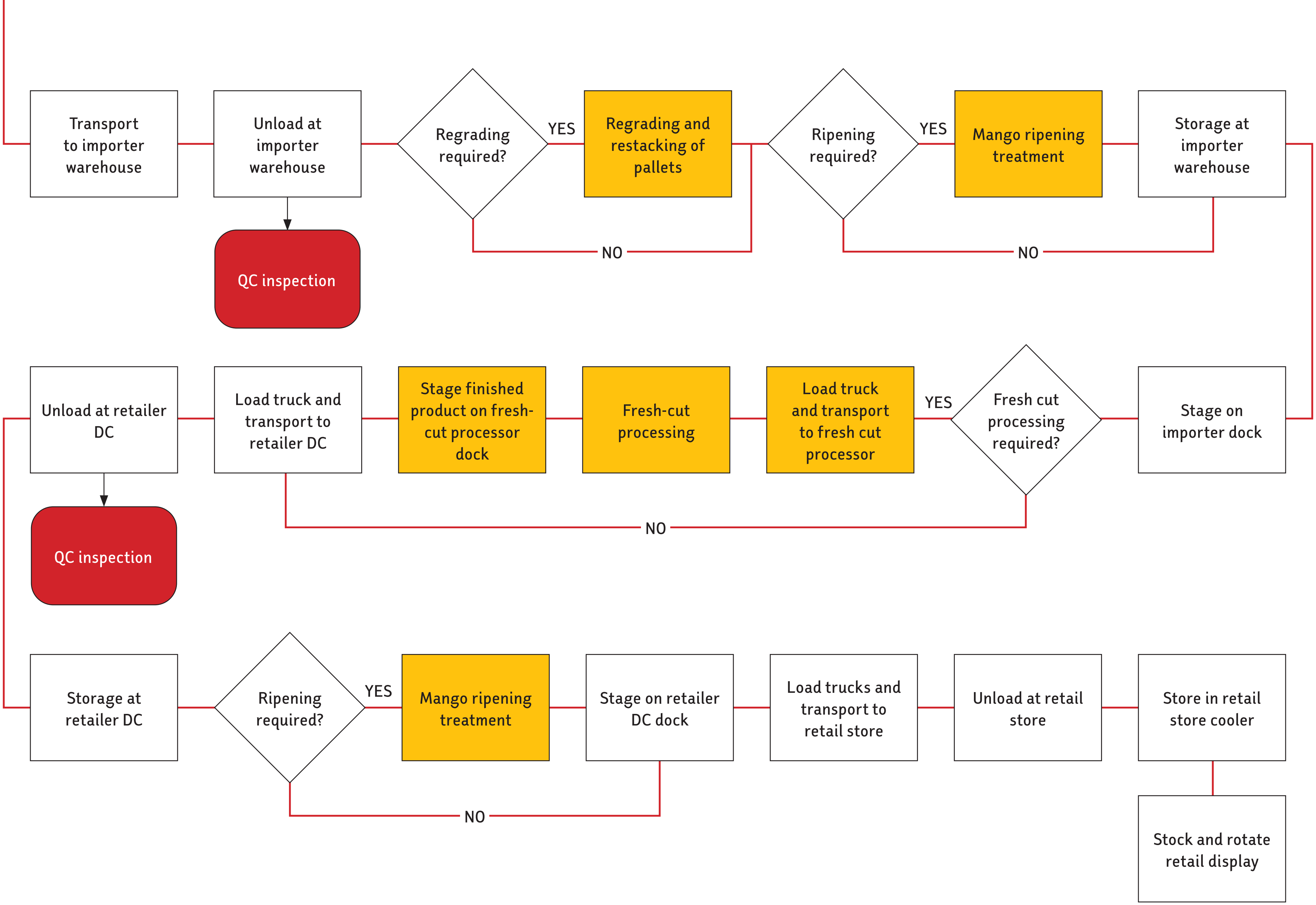
Providing outstanding-quality mangos in the market that consumers will want to purchase again and again requires a commitment to quality by each and every stakeholder involved in mango production and handling. The Mango Quality Project has identified mango harvest and handling practices that can be improved, such as better determination of proper harvest maturity; better temperature management before hot water treatment, after hot water treatment, prior to shipping and during shipping, and in the distribution centers in the U.S.; better packinghouse sorting and grading of fruit; better packaging and palletizing of mangos; and better management of retail mango displays.

The NMB *Best Management Practices Manual* includes instructions in its appendix for conducting quality-control program practices that include standard methods for 1) determining harvest maturity by visual inspection and measurement of soluble solids (°Brix), total solids and firmness; 2) water-quality measurements; 3) measuring water and fruit flesh temperatures during hot water treatment and post-hot-water hydrocooling; and 4) measuring ambient air and fruit flesh temperatures and relative humidity during subsequent precooling and storage, at trailer or marine container loading, and at distribution centers. This *Best Management Practices Manual* also contains color plates to be used as guides for determining stages of fruit maturity and ripeness and for identifying mango diseases and disorders, as well as mango quality assessment forms with instructions for standard methods for rating the incidence and severity of those disorders.

Every step in the handling of fresh mangos contributes to delivery of good quality and shelf life to customers. Therefore, attention to detail is required at each step in preparation and distribution. This manual outlines the major steps involved in mango handling and distribution and addresses the common problems and recommended best practices that will ensure delivery of the best possible quality mangos to your customers.

Harvest and Postharvest Process Map for Fresh Mangos




Transport to importer warehouse
Unload at importer warehouse
QC inspection
Regrading required?
YES
Regrading and restacking of pallets
NO
Ripening required?
YES
Mango ripening treatment
NO
Storage at importer warehouse
Stage on importer dock
Fresh cut processing required?
YES
Load truck and transport to fresh cut processor
Fresh-cut processing
Stage finished product on fresh-cut processor dock
Load truck and transport to retailer DC
NO
Unload at retailer DC
QC inspection
Storage at retailer DC
Ripening required?
YES
Mango ripening treatment
NO
Stage on retailer DC dock
Load trucks and transport to retail store
Unload at retail store
Store in retail store cooler
Stock and rotate retail display

Harvest

When to harvest is one of the most important decisions a grower faces when it comes to providing the marketplace with superior-quality fruit. Mangos picked before their optimum maturity may eventually ripen, but will develop inferior flavor and aroma, show increased susceptibility to chilling injury caused by low temperatures during transport, and have shortened shelf life.

Based on the collective experience of the mango industry, following are the most popular and effective harvest practices for yielding high-quality mangos.

WORKER TRAINING: HARVEST AND SANITATION PRACTICES

Because of the seasonal nature of the mango harvest, most mango farms in growing regions throughout Latin America employ temporary labor. It is a fact that in many cases, temporary harvest personnel return year after year to work in the farms. However, the seasonal nature of the harvest requires special focus on yearly retraining of harvest crews to assure optimum-quality mangos. Training must include harvest maturity indicators, latex removal procedures, good sanitation practices, and worker safety.

Harvest worker training

FRUIT SELECTION, INCLUDING MATURITY STAGE

The stage of maturity of mangos at the time of harvest is crucial for the eating quality of the ripe fruit. Selection of the appropriate fruit maturity can be based on several parameters, including fruit shape, peel color, peel texture, flesh firmness, flesh color development, soluble solids content, and latex content. Although the parameters employed for each variety of mango grown commercially might vary somewhat, all commercial growers use one or more of these parameters as an aid to harvest.

Fruit selection for harvest

In addition to varietal differences, growing regions, climatic conditions, and agronomic practices also influence the expression of maturity indicators in the mango fruit. Therefore, *growers must validate which parameters prove most effective and dependable for their own conditions*.

For details on how to determine mango fruit maturity and ripeness, see *Determining Mango Fruit Maturity* in the Appendix.

PICKING AND FRUIT ACCUMULATION PROCEDURES

Once the decision to harvest mangos has been made based on maturity index interpretation, harvest crews should follow recommended picking and field accumulation procedures. In commercial operations, the use of harvest aids—such as ladders, clippers, nets, and harvest baskets—is very common and helps speed up harvest. Instruct harvest workers not to carry or handle ladders by the rungs in order to avoid transferring soil from shoes to rungs to hands to fruit.

Harvested mangos should be protected from exposure to direct sunlight while they await transport to the packinghouse. On most commercial farms, mangos wait from 30 minutes to up to 6 hours before they are transported to the packinghouse. Direct exposure to sunlight results in higher flesh temperatures, which in turn accelerate metabolism and shorten potential shelf life.

Picking and accumulating fruit

Accumulation of mangos in the shade

Nets with a sharp blade attached are a common harvest aid used for mangos

LATEX REMOVAL PROCEDURES

Latex dripping from mango stems at harvest or during accumulation and transport causes peel damage that is aggravated when mangos are exposed to heat treatment. To prevent latex damage to peels, the following procedures are recommended:

1. Harvest mangos with a long stem (5 cm or longer) and accumulate the fruit in field boxes. Latex does not drip from fruit with a long stem attached.

Long stems

2. Trim stems to the abscission zone (approximately 1 cm) and immediately place the fruit with the stem end down to allow latex to drip without touching the fruit's peel. Various rack-like structures as shown in the picture below have been devised to hold the mango fruit while the latex drips and to protect the fruit from direct contact with the ground.

Latex removal on racks

Transport of mangos to the packinghouse

The duration of latex removal varies from 20 minutes to up to 4 hours, depending on how long it takes for the latex to stop dripping.

In Brazil, it is common practice to harvest mangos with a longer stem (over 5 cm) and carefully transport the fruit to the packinghouse where the stems are trimmed. Approximately 24 hours after harvest, latex will no longer drip from a mango fruit even if the stem is clipped shorter. Therefore, long-stem harvest is followed by a 12- to 24-hour waiting period at the packinghouse prior to re-trimming and running the mangos over the packingline.

Transport to Packinghouses

Under ideal conditions, the mango trees being harvested should be located a short distance from the packinghouse. If fruit transport requires traveling lengthy distances, producers should observe the considerations below to minimize the adverse effects on quality that transport to the packinghouse might cause to the mango fruit.

PROTECT FRUIT FROM DIRECT SUNLIGHT

After harvest, direct exposure to sunlight increases mango respiration and water loss, resulting in loss of shelf life. Transport vehicles should be covered to protect the top layers of fruit from direct exposure to sunlight while in transit.

SELECT A TRANSPORT METHOD THAT ALLOWS VENTILATION

In addition to protection from sunlight, it is important to select a transport truck that allows air circulation while in transit and especially while waiting for unloading at the packinghouse. It has been documented that waiting times for unloading mangos in a typical packinghouse can be anywhere from 2 hours to 2 days, depending on the volume of fruit being harvested at any time.

WHEN POSSIBLE, SHIP MANGOS DURING COOLER HOURS OF THE DAY

A growing trend among packinghouses in Peru, Brazil, and Guatemala is to harvest mangos in the morning and transport them to the packinghouse in the afternoon and at night. Transport during cooler hours of the day or at night favors lower fruit temperatures that could better preserve the quality and shelf life of mangos.

SCHEDULE DELIVERIES TO PACKINGHOUSE

Most commercial packinghouses exporting fruit to the U.S. use some sort of harvest schedule that allows for controlled quantities of mangos to arrive at the reception line. Whenever volumes of fruit harvested exceed the capacity of reception lines, the result is a longer-than-normal wait before mangos are unloaded. During their wait inside transport trucks, mangos are exposed to high ambient temperatures and poor ventilation.

It is becoming a common trend for reception personnel to work night shifts to favor cooler ambient temperatures while mangos wait for unloading. Night shifts likely mean higher labor costs for the reception line; however, the benefits in mango quality and shelf life resulting in reduced losses and greater sales will most likely outweigh those labor costs.

Fruit Staging at Packinghouses Prior to Packing

There are two very distinct mango packinghouse types with regard to mango staging prior to reception at packinghouses. The most common staging system involves a limited mango unloading area inside the packinghouse where reception personnel receive the fruit. This limited unloading area means that most of the mangos wait inside transport trucks for unloading. Unloaded fruit are almost immediately dumped on the reception line. In many cases, the empty field crates are simultaneously loaded back onto the truck and sent back to the production area. This system optimizes the use of space in the packinghouse and also the efficiency of resources on the reception line. The down side is that mangos wait for unloading under adverse conditions (high temperatures, poor ventilation, and direct sunlight) inside transport trucks.

Staging mangos in trucks at the packinghouse

The second type of mango staging system involves a large unloading area, where fruit are unloaded from trucks and clearly identified as lots to be processed in the reception line once quality-control and quarantine inspections have been conducted. A larger unloading area permits numerous trucks to be unloaded in a short period of time. Large, open unloading areas protect mangos awaiting reception from sunlight, provide appropriate ventilation, and permit a more representative sampling of mangos for both quarantine and quality-control purposes.

Staging mangos inside the packinghouse

It has been documented that mangos undergo rapid compositional changes in the hours following harvest. Significant changes in total soluble solids (TSS) content, flesh firmness, and skin and flesh color will occur in as little as 24 hours after harvest. A 24-hour wait period prior to heat treatment helps reduce injury symptoms stemming from heat treatment. Such a time delay prior to heat treatment might be very useful for low-maturity mangos. The average maturity (i.e., internal flesh color development) stage can easily change by one full stage in 24 hours under typical ambient temperatures, and TSS can increase by 2 to 3%, while flesh firmness decreases by 2 to 5 pounds-force (lbf).

Initial Fruit Inspection

INSECT QUARANTINE

Before mangos are unloaded at the packinghouse, an authorized inspector reviews the phytosanitary documentation accompanying the load and, in accordance with established government protocols, samples fruit in search of any evidence of fruit fly infestation. After sampling, the fruit are sliced sequentially down to the seed. The load is rejected if any evidence of fruit fly larvae is found.

Insect quarantine inspection

MATURITY AND QUALITY

Quality-control personnel should sample mangos (at least 25 fruit) from each load to assess fruit maturity and defects prior to packinghouse reception. It is strongly recommended that quality-control data from each load be used as a guide to adjust packinghouse practices (extent of sorting by maturity and defects) in order to assure optimum quality at retail markets.

Quality-control inspection

Personal cleanliness is critical

General Packinghouse Practices

WORKER TRAINING: HANDLING AND SANITATION PRACTICES (HUMAN AND FACILITY)

Packinghouses should conduct regular worker training at the beginning of each harvest season. Workers inspecting and handling mangos must be trained and must adhere to proper hand-washing and sanitizing procedures. A program of regular training (and retraining, as needed), along with monitoring by supervisors to ensure compliance, is an important management practice to ensure fruit quality and safety.

Packinghouse worker training

Workers should understand how careless handling of mangos can cause stress and injuries that can reduce fruit quality during marketing. Workers should also understand how personal and facility cleanliness reduces the risk of fruit contamination, which can have devastating consequences for their employer and thus for their own jobs.

Employee Sanitation Practices Checklist

Yes No

- ☐ ☐ Provide access to restroom facilities, soap, single-use paper towels, and clean water at all times.
- ☐ ☐ Provide a place for workers to remove aprons, smocks, and/or gloves and store them *outside* of the restroom.
- ☐ ☐ Instruct workers to wash hands before and after eating, smoking, and using the restroom.
- ☐ ☐ Monitor workers to ensure proper use of facilities. Hand-washing stations located outside of restrooms can aid supervisors in ensuring employee hygiene.
- ☐ ☐ Do not allow injured or ill workers to handle fruit.
- ☐ ☐ Do not allow workers to stand on fruit or on surfaces that will contact fruit.

Facility cleanliness

Packinghouse Equipment and Facilities Sanitation Checklist

Yes No

☐ ☐ Clean and sanitize bins, packingline equipment, refrigeration units, trucks, and other equipment prior to use. A chlorine solution of 200 ppm (parts per million) that is between 25 and 43°C (77 and 110°F) and adjusted to pH 7 with citric or acetic acid should be used for sanitization. (Cooler water reduces chlorine effectiveness; warmer water causes excessive off-gassing).

☐ ☐ Physically separate mangos that have been run over the packingline from mangos that have not been processed, culls, trash and trash receptacles, chemicals, or any other potential contaminants.

☐ ☐ Exclude pets, rodents, birds, and insects from storage and enclosed work areas.

☐ ☐ Do not transport soil, manure, chemicals, livestock, or other animals on trucks that are used to carry mangos.

Cleaning and sanitizing packingline equipment is critical. Just one source of pathogen introduction, at any point, can potentially inoculate all fruit that pass through the line.

Cleaning means physically removing debris, biofilm buildup, and any other residuals on the line. This is done with detergent and physical labor (such as scrubbing or a pressure washer).

Sanitation involves using sanitizers like chlorine or quaternary ammonia to kill microbes on clean surfaces. Sanitation is not effective until after a surface has first been cleaned. Regular cleaning and sanitation greatly reduces opportunities for pathogen buildup and inoculation to occur.

Many steps can easily be overlooked during cleaning. Here are some key points to remember:

- Remove debris accumulation from all surfaces.
- Clean all surfaces that fruit or employees may contact, including benches, tabletops, drains, walls, cooler coils, ceilings, etc., as appropriate.
- Clean using a top-to-bottom method to avoid re-soiling already clean surfaces.
- Never put fruit that have fallen from the line back into circulation.
- Have waste receptacles available for employee use; regularly empty and clean them.
- Properly store all cleaning equipment after the workday ends.

WATER MANAGEMENT: WATER QUALITY AND SANITATION

All water that is used in packinghouses should be clean and potable (safe to drink). The water in dump tanks, hot water quarantine treatment tanks, and hydrocoolers should be replaced with fresh, clean water on a regular basis, preferably daily, in order to minimize accumulation of dirt, fruit latex, trash, and agricultural chemicals from the field. Plant pathogens also accumulate, primarily in the dump tank water, throughout the packing day. Therefore, dump tank water must be sanitized to minimize the possibility of cross-contamination of fruit via infiltration of water and pathogenic microorganisms into scars, cuts, and punctures. Mangos should remain immersed in the dump tank water for no more than 30 seconds to minimize infiltration of pathogens into the fruit.

Monitoring water sanitation

The hot water treatment reduces the number of viable microorganisms *on the surface* of mangos, since it has been documented that the procedure significantly reduces anthracnose decay incidence. Therefore, care should be taken not to counteract this benefit of hot water treatment by allowing recontamination of mangos to occur during subsequent handling steps. However, the hot water treatment is *not* a kill step that results in sanitization of the mangos.

See *Water Sanitation Practices* in the Appendix for specific recommendations.

TEMPERATURE MANAGEMENT

Temperature management plays a critical role in ensuring that high-quality mangos are delivered to consumers.

Avoiding high temperatures and quickly reducing temperatures to the optimum for transport reduces the rate of physiological and biochemical change that occurs in mangos after harvest, minimizes water loss from the fruit, and slows the growth of decay-causing microorganisms (like those responsible for anthracnose and stem-end rot). Lower temperatures also reduce the potential for human pathogens to proliferate if fruit contamination occurs.

However, there is a limit to the low temperature that mangos can tolerate due to their susceptibility to chilling injury, a disorder that results in flavor loss, surface blemishes (lenticel darkening, scald, and pitting), and inhibition of ripening. The lowest safe temperature for long-term exposure (2 weeks or more) of *mature*, green mangos is 12°C (54°F); immature fruit can be injured even at temperatures above 12°C. As mangos ripen, they are able to tolerate progressively lower temperatures; however, the exact effects of time, temperature, variety, and ripeness stage on the development of chilling injury, especially related to flavor loss, are still not clear. The best practice to follow in most cases is to be conservative and avoid temperatures below 12°C. The exception is when mangos are being forced-air cooled or when mangos with flesh temperature higher than 12°C are held temporarily at the packinghouse before shipping, in which cases an air temperature of 10°C (50°F) may be used (see the sections on *Cooling Prior to Shipping* and *Storage Rooms* for further details).

Mango ripening can occur at temperatures between 15.5 and 30°C (60 and 86°F), but the best temperatures for ripening mangos are 20 to 22°C (68 to 72°F) to achieve the best combination of color, texture, and flavor.

See *Temperature Management Practices* in the Appendix for specific recommendations.

Fruit Washing and Sizing Before Hot Water Treatment

Upon arrival at the packinghouse, mangos should be processed as soon as possible unless they are being rested to avoid potential latex or hot water injury problems. If delays occur, trucks should be kept in the shade prior to unloading. Fruit left in the sun for just 1 hour can be 14°C (25°F) hotter than fruit held in the shade and can become sunburned. Also, flesh temperatures above 30°C (86°F) for extended periods after harvest can cause poor ripening and flavor.

Mangos are normally transferred into a water flume system (dump tank) at reception for gentle transfer to the sizing line. This transfer may be done manually or automatically, as long as the timing of the transfer is such that the fruit proceed regularly along the flume so that the fruit being dumped do not impact fruit already in the tank. After the fruit leave the dump tank, it is advisable to use a spray and brush operation to remove soil, latex, and other materials that may adhere to the fruit. This in turn keeps the hot water treatment water cleaner, extending the duration between required water changes.

Initial fruit washing by tank immersion (top), spraying (middle), and on a brush bed (bottom)

Sizing mangos for hot water treatment may be accomplished manually or automatically by weight or dimension. If dimensional sizing is used, fruit weights must be checked frequently to ensure that the proper fruit weight classifications are being achieved. Packers must follow the USDA APHIS protocol regarding size categories and sizing accuracy prior to hot water treatment (USDA APHIS PPQ, 2016).

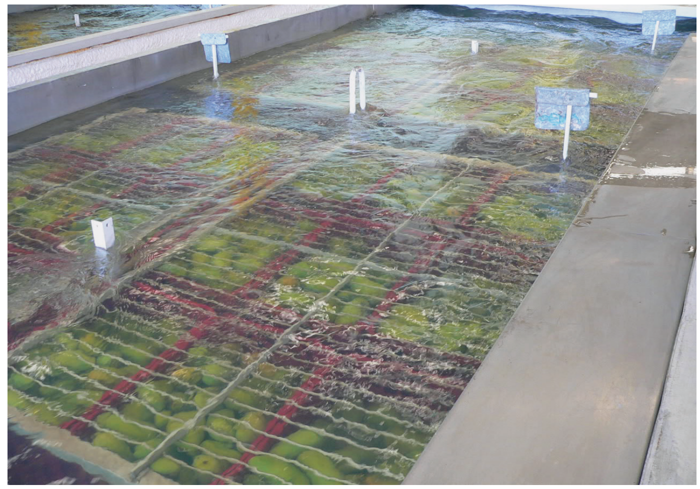
Initial fruit sizing by weight (top) and by dimension (bottom)

Hot Water Treatment Recommendations

Hot water treatment of mangos for quarantine security must be conducted in strict adherence to the USDA APHIS treatment protocols (USDA APHIS PPQ, 2016). USDA APHIS requires hot water treatment in 46.1°C (115°F) water for control of fruit flies, but the length of immersion varies with the general shape of the fruit and the fruit weight, as shown in the following table. All fruit must be graded by weight/size prior to hot water treatment to assure fruit fly control and reduce fruit injury.

A number of steps can be taken to improve the hot water treatment process and therefore improve the overall quality of mango fruit in the U.S. market.

- Assure fruit are mature (i.e., no stage 1 fruit) prior to treatment, as immature fruit are more susceptible to damage by hot water. (See *Determining Mango Fruit Maturity* in the Appendix for specific information on maturity stages.)
- Avoid latex contact with fruit surfaces during harvest; latex damage can be exacerbated by hot water.
- Use only potable water in the treatment tanks or sanitize the water prior to the first time the water is heated.
- Improve temperature control in hot water tanks, where needed, to allow treatment at the lowest allowable temperature. Even 0.5°C (1°F) above the required temperature can make a difference in fruit tolerance.



A hot water treatment tank

USDA APHIS Hot Water Treatment Protocols

Mango shape	Fruit weight (grams)	Time required (minutes)
Rounded[1]	≤ 500	75
	501–700	90
	701–900	110[3]
Flat[2]	≤ 375	65
	376–570	75

[1]Rounded varieties: 'Tommy Atkins', 'Kent', 'Haden', 'Keitt'
[2]Flat varieties: 'Frances', 'Honey', 'Manila'
[3]Only approved for Mexico and Central America

Post-Hot-Water Treatment Cooling

HYDROCOOLING AFTER HOT WATER TREATMENT

Hydrocooling mango fruit after hot water treatment decreases the flesh temperature much more rapidly than holding in air and can reduce hot water injury.

Hydrocooling is approved by USDA APHIS immediately following the hot water treatment if 10 minutes is added to the heat treatment time; alternatively, fruit may be hydrocooled after a waiting period of at least 30 minutes at ambient temperature with no change to the heat treatment

Post-hot-water treatment hydrocooling

time (USDA APHIS PPQ, 2016). APHIS requires that the hydrocooler water be no colder than 21.1°C (70°F).

SANITATION OF HYDROCOOLER WATER

Hydrocooler water must be properly sanitized with chlorine or other sanitizers to prevent the possible spread of decay or human pathogens, such as *Salmonella enterica*. When *warm* hot-water-treated fruit are placed into the *cool* hydrocooler water, water can be sucked into the fruit, internalizing any contamination that is present in the water.

A number of steps can be taken to improve the post-hot water treatment hydrocooling process and therefore improve the overall quality of mango fruit on the market in the U.S.

- Always hydrocool fruit immediately after heat treatment (after adding the additional 10 minutes to the hot water protocol). Waiting 30 minutes following the standard hot water treatment protocol is another option, but it is not as good for fruit quality as immediate hydrocooling.
- Maintain hydrocooler water at 21 to 22°C (70 to 72°F) during hydrocooling by having a system with sufficient cooling capacity provided by a condenser to remove heat from the volume of fruit to be hydrocooled.
- Hydrocooling should be for a sufficient length of time to reach a fruit flesh temperature of 27 to 29°C (80 to 85°F), which corresponds to ¾ cooling from 46°C using 21 to 22°C water. Cooling time depends on fruit size, but this is likely to require 30 minutes or more. Providing water circulation within the hydrocooler tank speeds the cooling process.
- Maintain free chlorine levels of 50 to 100 ppm in the hydrocooler water and adjust the water to pH 7. Automated sanitation systems that monitor oxidation reduction potential (ORP) give the most consistent results.

Cool the water to the desired temperature, add chlorine to 100 ppm free chlorine at pH 7.0 based on DPD and pH tests, respectively, then start ORP measurements. Once the ORP reading has stabilized (about 5 min), use that reading as the set point. The system adds buffer, acid or base, and chlorine product to maintain the set point. ***Operators should test free chlorine and pH every 1 to 2 hours during operation to verify that the ORP sensor is working properly and hasn't become fouled***.

Measuring hydrocooler water temperature

Measuring mango flesh temperature following hydrocooling

PRACTICES BETWEEN HOT WATER TREATMENT AND PACKING

Temperature management practices between the hot water treatment and packing depend on whether the mangos were hydrocooled or not.

- For hydrocooled mangos, pack the fruit as soon as possible after post-hot-water treatment hydrocooling to minimize re-warming of the fruit.
- If it is necessary or desired to hold the fruit for 12 to 24 hours after hydrocooling and before packing, transfer the field crates of fruit to a cold room at 10 to 15°C (50 to 59°F).
- If a cold room is not available and the mangos will be held in ambient conditions until packed, bins should have at

least 20 cm (8 inches) of space between the stacks of field crates and the area should be ventilated (overhead paddle fans), or some other means of reducing the temperature around the fruit should be used. Note that holding mangos in ambient conditions will compromise quality.

Field crates containing mangos after hot water treatment showing spacing between stacks

Packingline Practices

Mechanical injuries hasten deterioration and ripening as well as providing infection sites for decay organisms. Therefore, mangos must be carefully handled during packinghouse operations to minimize bruising, cuts, punctures, and abrasions. Sorting and grading operations are also critical; workers must be thoroughly trained and supervised to ensure removal of injured mangos, which could later develop decay during shipping, and blemished or misshapen mangos that will not be acceptable in the market.

DUMPING ONTO PACKINGLINES

Introducing fruit onto the packingline may be accomplished either by manual dumping of field lug boxes or by automated systems that tilt and dump the boxes. In either case, the first key consideration is a gentle transfer that does not injure the fruit. A drop of no greater than 30 cm (12 inches) is recommended.

The second key consideration is to regulate the rate of dumping so that the packingline conveyor is completely covered by a single layer of fruit. This reduces the potential for fruit injury by avoiding rolling fruit that can build up momentum before impacting other fruit or the packingline components.

Manual (top) and automated (bottom) dumping of mangos onto a packingline

A single layer of fruit on a conveyor

FRUIT GRADING AND REMOVAL OF INJURED/ DAMAGED FRUIT

Fruit grading at the packinghouse is done to remove unmarketable fruit. This eliminates the waste of time, money, and energy that accompanies shipping unmarketable fruit to the U.S. that must eventually be removed from palletized cartons and discarded.

Fruit with the following defects should be removed prior to waxing and packing:

- Physical injuries such as cuts, scrapes, and bruises, which favor development of shriveling and decay
- Any evidence of decay or incipient decay
- Misshapen fruit and flat (immature) fruit; also, pale-colored ('blond') fruit, which are susceptible to several physiological disorders
- Fruit with lenticel damage, surface scald, or collapsed areas, which are symptoms of hot water damage

Fruit grading

A 'resting' period following hot water treatment is recommended if there is a likelihood that hot water damage has occurred. This improves the chances of identifying the affected fruit during grading on the packingline (see section on *Hot Water Treatment Recommendations*).

FRUIT WAXING

Waxing mango fruit, usually with carnauba-based formulations, improves their appearance by increasing the natural fruit gloss and reducing water loss, which causes mangos to appear dull. Brushing during wax application helps to obtain uniform wax distribution on the fruit. If spraying is used during wax application, care must be taken to prevent wax inhalation by workers. Waxes must be applied according to label instructions. Full-strength wax application can damage mangos—especially the less mature fruit, which are susceptible to lenticel and peel damage that can develop after a period of refrigerated storage and transport. Water-soluble coatings should be avoided because they can be dissolved during later handling when condensation occurs on fruit surfaces, such as when cold fruit are transferred to warmer temperatures.

Mangos entering a fruit waxer

Unwaxed (left) and waxed (right) mangos

FRUIT SIZING

Hand sizing mangos according to the number of fruit of the same size that fill a standard carton is acceptable. Mechanical and electronic sizers that use fruit dimensions or weight to sort by size are also available and may increase packingline speed.

CARTON FILLING

It is important to train packingline workers to pack mango cartons without injuring the fruit. While mango cartons should be packed tightly in order to immobilize the fruit during transit to avoid vibration injury (surface abrasion), the fruit should not be forced into the cartons by pounding, etc. Care must also be taken to avoid placing fruit in cartons so that they protrude above the top of the carton since that will lead to pressure bruising or crushing of fruit when the cartons are stacked on pallets.

Automated fruit sizing on the packingline

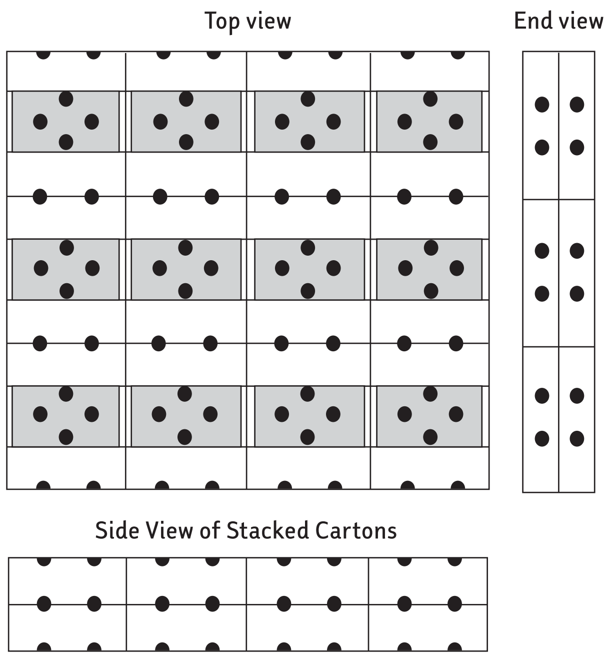
Manual fruit sizing and carton filling

Package Design and Labeling Criteria and Recommendations

Packaging for mangos primarily serves to protect the fruit from injuries caused by cuts, compression, vibration, and impacts. Packaging also can either facilitate or interfere with good temperature management. Another important function of packaging is to identify and advertise the product and the company selling the mangos.

Recommendations for mango packaging are as follows:

- Mangos should be handled in single-layer cartons with or without lids and with base dimensions that result in 100% coverage of the surface area on the standard 100 X 120 cm (40 X 48 inch) pallets currently used in the U.S.
- Mango carton construction must be sufficiently strong to withstand forces that can occur during distribution.
  - Cartons for mangos shipped shorter distances by truck can be single walled.
  - Cartons for mangos shipped longer distances by ocean require double wall construction.
  - Corner bracing provides essential stacking strength on the pallet for less expense than increasing the fiber weight of the entire carton.
- Cyclical humidity conditions cause delamination of the glue between the liners and medium of a fiberboard package. Corrugated fiberboard cartons must especially be protected from direct contact with water and condensation (sweating), which severely weakens them.
- Ventilation holes should be properly located and oriented to allow airflow during cooling, shipping, and storage without compromising strength.
  - A carton with ventilation holes covering about 5% of each ventilated carton face allows adequate heat exchange for effective temperature management.
  - Cartons for mangos shipped by ocean must be ventilated on the top and bottom to facilitate vertical airflow in bottom-air delivery marine containers.
  - All mango cartons require sidewall ventilation to accommodate the horizontal airflow during forced-air cooling and in top-air delivery truck trailers.
  - Ventilation holes placed along the bottom and top horizontal edges can accommodate both bottom-air and top-air delivery systems (see figure on next page). Vent holes should never be located near the vertical corners of the carton.
- Labeling on mango cartons should provide the following information:
  - Identity of the product (mango and variety name)
  - Amount contained (count and net weight)
  - Source (country of origin, grower, packer, shipper/exporter; traceback code)
  - Special treatments (waxing, etc.; APHIS hot water treatment certification number)
  - Responsible party in the U.S. with contact information
- Store carton stock in a clean, air-conditioned storage area. Make up cartons as needed. Do not store assembled cartons because they can become contaminated by insects and animal pests.



Top, side, and end views of prototype mango cartons on a standard, 40 X 48 inch pallet illustrating some approaches that could be taken to achieve the recommended features described in this manual. This carton is a 4.5-kg capacity, double wall, partially lidded design, with base dimensions for 100% coverage of the surface area on standard pallets, at least 5% ventilation area on every surface, and the vent holes arranged to facilitate both horizontal air flow for forced-air cooling and truck transport as well as vertical air flow for marine transport. The top and side views illustrate how the top and bottom corner vent holes match up when the cartons are stacked.

Palletization and Staging for Cooling/Storage/Shipping

Palletization facilitates handling efficiency and reduces physical injury to mangos by reducing handling of individual cartons.

- Use good-quality, standard, repairable, four-way entry pallets (40 x 48 inches; 100 x 120 cm).
  **Note: Mango retailers' most common complaint is the use by some in the mango industry of cheap pallets that fail during handling!*
- Pallet boards should not block carton air vents.
- The footprint of pallets should be designed to facilitate conditioned airflow through and around cartons in order for the vertical (i.e., bottom to top) air delivery of seagoing refrigerated containers and the horizontal (i.e., rear to front) airflow of over-the-road trailers to maintain optimum temperatures during transit.
- Examine cartons and do not stack those that are damaged, improperly constructed, or have fruit protruding above the top edge of the carton.
- When stacking cartons of mangos onto pallets, be sure that the first layer of cartons is placed completely within the outside edges of the pallet. If the cartons overhang the pallet, carton failure is imminent. Failure of bottom-stowed cartons on pallets can result in the unitized pallet leaning over or completely collapsing.
- Carefully stack mango cartons on pallets in register so that the corners of all cartons in a column line up precisely. Otherwise, the stacking strength of the cartons will be severely compromised and pallet leaning and collapse will result.

Corner view of a pallet with four-way entry, cartons lined up and within edges of pallet, corner bracing and strapping, and pallet board inserted between carton layers to maintain correct stacking orientation.

- Prior to stacking cartons on a pallet, a few drops of glue may be placed on the cartons to stabilize them when stacked.
- Corner braces and strapping should be used to stabilize and secure pallets and must be sufficiently strong to ensure the integrity of the pallets during the rough, extreme conditions that they are likely to encounter during shipping. The tension on strapping should be sufficient to hold the corner braces and cartons in place but not so tight as to crush the corners of the cartons, thereby causing carton failure, reduced stacking strength, and leaning pallets.
- Completed pallets should be transferred to a refrigerated area as soon as possible.

Corner bracing and strapping being applied to a pallet

Cooling Prior to Shipping

Packed and palletized mangos should be cooled as rapidly as possible to their optimum shipping and storage temperature (12°C [54°F] for mature green mangos). Lowering the temperature slows fruit metabolism (including ripening), reduces water loss, and slows the initiation and spread of decay. *Since mature green mangos are susceptible to chilling injury at temperatures below 12°C (with severity determined by exposure time and temperature), they should not be cooled below this point.*

ROOM COOLING

Rapid cooling requires good contact between the refrigerated air in the postharvest environment and the product in the package. Heat transfer in room cooling is achieved by cold, refrigerated air coming into contact with exposed pallet surfaces, with the heat from the interior of the pallet slowly transferred by conduction to the surface. Thus, room cooling is a relatively slow cooling method that typically requires 24 to 48 hours for palletized mangos.

Room cooling

FORCED-AIR COOLING

It is recommended that mangos be forced-air cooled in order to remove heat from the fruit as rapidly as possible. Forced-air (or 'pressure') cooling improves heat transfer compared to room cooling by creating a pressure differential from one side of a pallet to the opposite side that pulls the cold, refrigerated air through the ventilation holes in the cartons, directly past the fruit within the pallet. Properly designed forced-air cooling systems are capable of reducing mango flesh temperatures from an initial range of 30 to 40°C (86 to 104°F) down to around 12 to 15°C (54 to 59°F) within 2 to 4 hours.

Forced-air cooling tunnels

HYDROCOOLING

Hydrocooling involves immersing or drenching produce in cold water to remove heat. Although hydrocooling cools faster than forced-air cooling, it is not typically used to cool mangos prior to shipping due to logistical and sanitization management challenges.

Hydrocooling presents several logistical challenges. Water sanitation management is critical to avoid transfer of decay pathogens between fruit. Hydrocooling must either be applied before packing, in which case the fruit must

Mangos being lowered into a hydrocooler

be thoroughly dried prior to packing, or the fruit to be hydrocooled must be packed in water-resistant shipping cartons.

Guidelines for room cooler and forced-air cooler design can be found in the publication *Commercial Cooling of Fruits, Vegetables and Flowers*, available from the Postharvest Technology Research & Information Center (http://postharvest.ucdavis.edu/bookstore/Commercial_Cooling/).

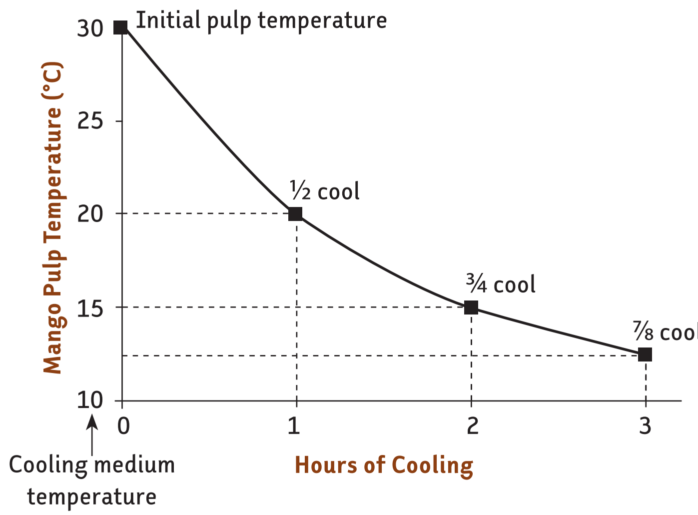
For both room cooling and forced-air cooling, it is recommended that the room air temperature be maintained at 10°C (50°F). In both cases, *the intent is for the mangos to be exposed to 10°C air only temporarily*. The flesh temperature of mangos should not be allowed to fall below their lowest safe temperature of 12°C.

- Once ¾ to ⅞ cooling has been achieved by forced-air cooling, the mangos should be transferred from the forced-air cooler to a 10°C storage room to complete cooling.
- Mangos that are room cooled or transferred from forced-air cooling should ideally be loaded onto transport vehicles only when the fruit flesh temperature reaches 12°C.

The concept of ¾ or ⅞ cooling relates to the characteristic time that it takes a cooling system to remove sufficient heat to reduce the difference between the cooling medium temperature and the product temperature by 75% or 87.5%. An example would be using 10°C air to reduce the temperature of 30°C mangos (i.e., mangos that are 20°C warmer than the cooling medium) down to either 15°C (i.e., 15°C cooler = ¾ cooling) or 12.5°C (i.e., 17.5°C cooler = ⅞ cooling).

[*]Note: Forced-air cooling actually reduces water loss compared to room cooling by cooling the surface of the fruit extremely rapidly, which reduces the water vapor gradient across the fruit skin, thus slowing water movement out of the fruit.

- Problems with excessive water loss encountered with forced-air cooling are due to the bad management practice of leaving pallets on the forced-air cooler past the time when ¾ to ⅞ cooling has been achieved.



Cooling curve for a precooling system with a 1/2-cooling time of 1 hour. The fruit are cooled from an initial fruit flesh temperature of 30°C to 12.5°C (7/8 cool) in 3 hours using 10°C air as the cooling medium. (Based on a 20°C difference between the 30°C initial fruit temperature and the 10°C cooling medium temperature.)

Storage Rooms

Temporarily holding mangos in a 10 to 12°C (50 to 54°F) storage room prior to loading onto marine containers or truck trailers is an important part of good temperature management.

- Refrigeration capacity in mango storage rooms should be sufficient to maintain uniform *product* temperature (within 1°C [2°F]) throughout the load. This requires both sufficient cooling capacity and adequate air circulation.
  - A rule of thumb for airflow in cold-storage rooms used for room cooling is 0.052 to 0.104 cubic meters per second (cms) per 1,000 kilograms of produce capacity (100 to 200 cubic feet per minute [cfm] per ton).
  - To *maintain* produce temperature, a lower airflow of 0.0104 to 0.0208 cms per 1,000 kilograms of produce capacity (20 to 40 cfm per ton) is all that is required.
  - The room should be loaded in such a way that air flows uniformly past all of the pallets.

- It is necessary to humidify storage rooms if mangos are likely to be held for more than a few days, especially if the room is used for room cooling since the high airflow rate can cause excessive water loss. The ideal relative humidity range for mangos is 85 to 95%.
- The humidification system should be able to maintain uniform (within 2 to 3%) relative humidity levels and be designed to distribute the moisture uniformly throughout the storage space. This minimizes problems with condensation, which can lead to weakening of fiberboard cartons.

A storage room humidification unit

Holding Sample Lots of Fruit for Quality Control

For quality control (QC), it is recommended that a representative sample (at least 25 randomly selected fruit or one carton of each fruit size) from each lot that passes through the packinghouse be retained in the storage room while the rest of the lot is being shipped to the U.S. and until the lot is delivered to the buyer. At that time, the QC fruit sample should be transferred to an air-conditioned room, such as an office, at 24 to 25°C to complete ripening. This procedure allows the packer/shipper to compare the fruit quality under ideal storage and ripening conditions to the reported quality of the shipped fruit, and can provide evidence as to whether any discrepancies that might be noticed by receivers are due to the different conditions to which the mangos were exposed during distribution as opposed to problems with initial fruit condition.

Quality-control samples retained from shipped lots of mangos

Shipping

STAGING FRUIT FOR LOADING

The area in which mangos are staged for loading onto marine containers or truck trailers should be refrigerated at 10 to 12°C (50 to 54°F). Dock doors should remain closed until a trailer or container has been backed up against the door.

- Mangos should be stowed in precooled reefer containers or trailers from a staging area that is properly refrigerated (i.e., cooler than 12°C). Cold tunnels should be situated tightly between the climate-controlled loading dock door and the rear (door end) of the reefer container or trailer. The cold tunnels prevent outside ambient air from entering the refrigerated dock and the interior of precooled containers.

Mangos being loaded from an enclosed dock

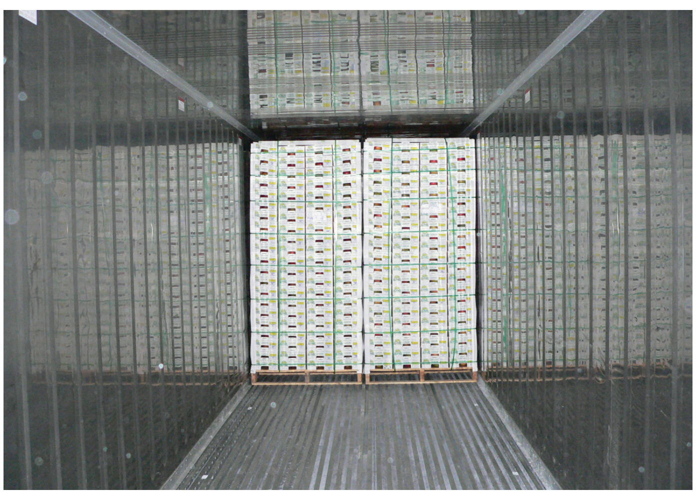
- When mangos are loaded in a hot, humid ambient environment (loading area), moist air can enter the interior of the precooled container when the trailer or container doors are opened. Consequently, some transportation companies have advised shippers to

precool the reefer container only if the loading dock is adequately refrigerated (i.e., cooler than 12°C) and cold tunnels are installed (see discussion below). The primary concern is that moisture might condense on the interior surfaces and ceiling of the precooled container and drip onto the cartons.
- If the staging area is not properly refrigerated (i.e., warmer than 12°C), the mangos should be staged in the storage room and quickly loaded directly into the container or trailer. Moreover, condensation can potentially form on the exposed cartons ('cargo sweat') when the refrigerated cargo is transferred from the cold room to a hot, humid dock or open space.

PREPARING REFRIGERATED CONTAINERS AND TRAILERS

Marine containers and truck trailers should be cleaned, sanitized, and precooled to the desired shipping temperature (12°C is recommended) prior to backing up to the dock.

- The purpose of precooling is to cool the interior surface of the marine container or truck trailer to the desired carrying temperature. If the interior of the reefer container is hot, the cargo can potentially be temperature abused by contact with the hot sidewalls and floors. Failure to precool containers and trailers results in heat transfer from the container or trailer body, which warms the fruit.



Inside of a marine container

- Marine container and truck trailer reefer units should be turned off during loading. Running the reefer unit while loading the cargo can cause icing of the evaporator coil, inferior cooling of the mangos, and/or the transfer of unwanted hot or cold ambient air and exhaust fumes into the cargo space.

Recommended actions prior to loading refrigerated containers and trailers

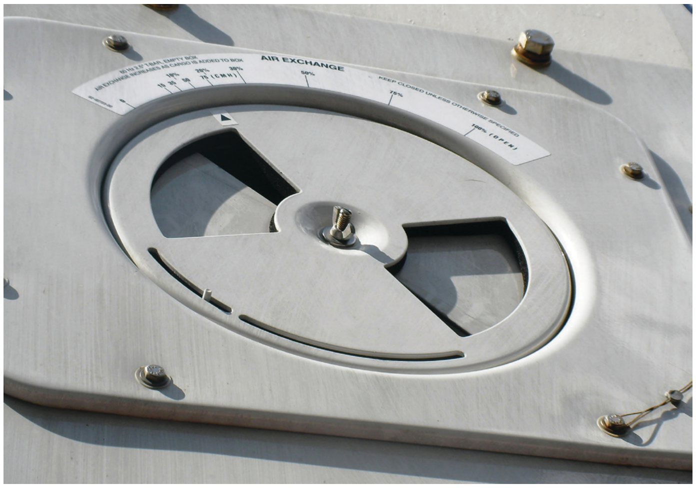
Inspect containers and trailers to ensure that they are clean and in good repair.

Yes	No	
☐	☐	No holes or unrepaired damage to walls, ceiling, or floor
☐	☐	Trailer air delivery chute intact
☐	☐	Floor clean and swept free of debris; no bad odors
☐	☐	Door seals undamaged (this is the most common source of leaks)

- Containers and trailers that do not meet the above criteria should be repaired, cleaned, or rejected and replaced, as appropriate.
- Sanitize the interior surfaces of *clean* containers and trailers, including the refrigeration coils, with a warm chlorine solution as described in the section on *General Packinghouse Practices*, or with other available sanitizer products, such as dry-on-contact foggers.
- Precool containers and trailers. The reefer unit should be set to 10°C (50°F) and run in continuous mode for at least 30 minutes with the doors closed. Using a calibrated infrared thermometer (preferable) or probe thermometer, verify that the wall temperature is at 12°C (54°F). If not, continue cooling until the desired temperature is reached, then set the reefer set point at 12°C and begin loading.
  - › If the reefer unit is not able to bring the wall temperature down to 12°C, the container or trailer must be rejected.

Neither reefer trailers nor container reefers have sufficient refrigeration capacity to adequately and uniformly cool a load of mangos that is significantly above the desired shipping temperature at the time of loading.

- The fresh air exchange on a marine container with both container and mangos properly precooled before loading can be closed for the first 24 hours, after which time the fresh air exchange should be set to 45 cfm (76 cmh).
  - › *Don't* specify percent opening or partial opening, like "¼ open", for fresh air exchange. Specify 'cfm' (cubic feet per minute) or 'cmh' (cubic meters per hour).



Fresh air exchange on a marine container

LOADING REFRIGERATED TRAILERS AND CONTAINERS

Proper stowing is essential for adequate temperature management. The stowage patterns required for bottom-air delivery (i.e., marine) containers and top-air delivery (i.e., truck) trailers are different.

It is recommended that mangos always be shipped as unitized pallets of single-layer cartons. Attention should be given to ensuring that cartons are stacked squarely on pallets so that their weight is evenly distributed on the carton corners. Also pay attention to vent alignment—either vertically (marine containers) or horizontally (truck trailers), as appropriate—so that air can flow properly through the load. Finally, do not use wraps, interior sheets, or anything else that may block carton vents and interfere with airflow.

Inside of a container being loaded; red line shown

Bottom-air delivery containers

A simple and effective way to properly stow 20 40 x 48 inch pallets of mangos is to load 11 pallets sideways into the container and 9 pallets lengthways into the container. The open floor space at the rear of the load should be covered with heavy corrugated paper or the equivalent. Moreover, the forklift pocket openings at the aft end of the load should be covered with heavy corrugated paper or the equivalent by stapling or taping the paper onto the open ends of two pallets.

In some instances, 21 pallets of mangos can fit into 40 ft. reefer containers. An effective way to stow 21 pallets in a container is to load 8 pallets sideways into the container and 7 pallets lengthways, followed by 4 pallets pin wheeled and 2 pallets at the rear of the load stowed straight into the container, one lengthways and one sideways. Since there are vertical channels between pin wheeled pallets and at the rear of the load, closed cell foam blocks should be snuggly inserted at the top of the vertical gap between pin wheeled pallets to prevent conditioned air from short cycling through the channel. 'Short cycling' means finding a premature path back to the refrigeration unit, thereby resulting in insufficient and non-uniform cooling of the mangos. As with a 20-pallet stow, the forklift pocket openings at the aft end of the load should be covered with heavy corrugated paper or the equivalent by stapling or taping the paper onto the open ends of two pallets.

Loading recommendations for bottom-air delivery containers:

Yes No

☐ ☐ Cargo should cover the entire floor of the container as a solid block with little or no separation between the pallets or between the load and the container walls.

☐ ☐ Pallets and/or cartons should be stacked as a solid block in the container without any space between the cargo and the walls of the container.

(Vertical gaps allow the air delivered from the reefer to take the path of least resistance and short cycle—bypassing part of the load, which will not be cooled.)

☐ ☐ Leave space above the load for air to properly circulate; *do not* stow cargo above the red line on the interior container wall.

☐ ☐ Do not use slip sheets.

Top-air delivery trailers

Refrigerated truck trailers are equipped with top-air delivery systems, which means that the conditioned air is delivered from the reefer unit to the mango cargo space via an air chute (plenum) attached to the trailer's ceiling. The air returns horizontally and passively from the cargo space through a front bulkhead and back to the refrigeration unit.

Inside of a trailer being loaded; the air delivery chute is shown

Mangos should be loaded into reefer trailers so as to meet the following two objectives:

- Heat from all sources can be removed by the refrigeration systems and air circulation.
- The load is protected as much as possible from physical damage caused by load shifting, overhead weight, or vibration.

Top-air delivery reefer trailers require a horizontal airflow loading pattern. This loading pattern is critical because it maximizes the exposure of the cargo to the flow of circulating conditioned air. The pattern should also allow for the most efficient use of space in the trailer.

The load can be stacked to within 7.5 cm (3 inches) of the air distribution plenum (air delivery chute) in the ceiling of the trailer, provided that the total weight of the cargo permits that many cartons to be loaded safely and legally.

The movement of conditioned air in a top-air delivery trailer is passive and not pressurized. Because conditioned air delivered from the reefer unit takes the path of least resistance, all air passages should be approximately the same size. Non-uniform spacing between pallets or cartons can cause undesirable temperature variations throughout the load. Conditioned air passages should be clear of loose material or debris that may restrict air movement. The floors should be clean and cleared of all loose material before the reefer trailer is loaded.

Loading recommendations for top-air delivery trailers:

Yes No

☐ ☐ Use a centerline-loading pattern so that pallets do not contact the trailer sidewalls. This prevents outside heat from being conducted through the trailer walls and into the fruit.

☐ ☐ Use spacers or air bags between the pallets and the walls to prevent the load from shifting during transport.

☐ ☐ Leave space above and below the load for air to properly circulate; *do not* stow cargo above the red line on the interior trailer wall.

☐ ☐ Leave a space between the last pallets and the door of the trailer to permit return air to flow horizontally from the rear to the front of the load through the carton vent holes.

☐ ☐ Use load locks after the last pallets to prevent load shifting.

Use of blocking and air bags to stabilize loads in containers and trailers. Note the temperature recorder in the picture on the left.

PLACEMENT OF TEMPERATURE RECORDERS

Portable temperature recorders are good insurance to know if a load of mangos was maintained at the desired shipping temperature. In case of a dispute, the transportation company may not share their temperature records from the reefer unit with the shipper, receiver, or other cargo interests.

The shipper should carefully install recorders in each shipment and completely fill out labels on strip recorders. The shipper should also mark the date and local time on the label or data file and document the specific location of each recorder in the load on the preloading form.

It is recommended that three temperature monitors be placed in each container or trailer load:

- Inside the first pallet near the front bulkhead of the reefer unit to detect any occurrences of short cycling of refrigerated air
- Inside a pallet near the center of the load (position 9, 10, 11, or 12) where product heating is most likely to occur
- On the outside rear face of the last pallet at eye level to record air temperature at the farthest point from the reefer unit. *If only one temperature recorder is being used, place it here.*

Do not place temperature recorders directly on container or trailer walls. This may result in elevated readings that do not accurately reflect the air temperature in the load space.

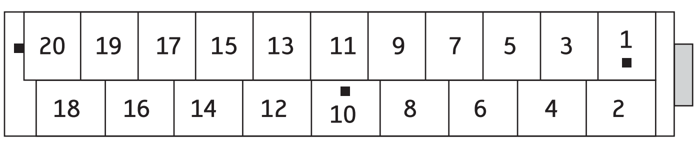


Diagram of a 40 ft. container or trailer with 20, 100 x 120 cm (40 x 48 inch) pallets showing recommended positions for placement of temperature recorders (■)

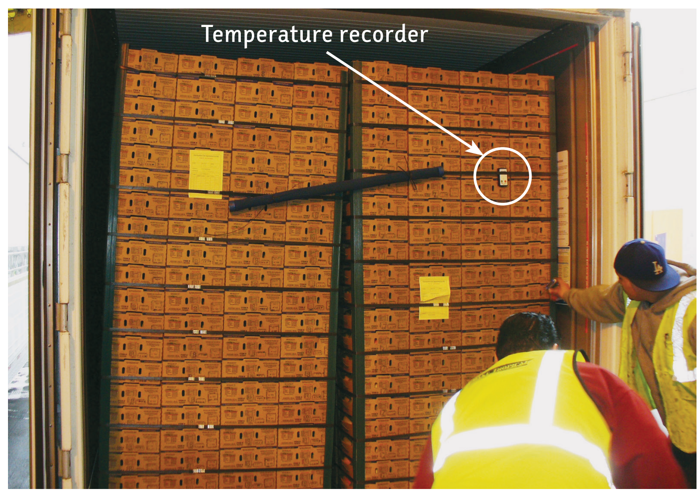
See *Trailer and Container Inspection and Loading Practices* in the Appendix for additional information.

Unloading at Importer/ Distribution Center (DC); Holding on Dock at Importer/DC

Mangos should be unloaded directly from the container or trailer onto a refrigerated receiving dock at the importer or DC in order to maintain the integrity of the cold chain. Holding time on the receiving dock should be limited to that required for identifying and recording the load and retrieving temperature recorders.

Recommendations:

- Marine container and truck trailer reefer units should be turned off while they are being unloaded. Running reefer units while unloading the cargo can cause the transfer of unwanted hot or cold ambient air and exhaust fumes into the cargo space.
- Pallets of mangos should be moved from the container or trailer directly to the cold-storage area; don't hold pallets on the receiving dock.
- There should be space available immediately inside the cold-storage area to hold mangos for inspection prior to stowing the pallets in the cold room and/or on pallet racks.
- Receivers should retrieve every temperature recorder from the shipment, document the specific location of each recorder in the load, retain and copy the entire label and strip chart or recorder download, judiciously review the temperature records, and send the recorders to the manufacturer for post-trip calibration if temperature management problems are suspected.



Retrieving a temperature recorder upon arrival

Inspection at Importer/DC

The quality-control (QC) inspection that is performed upon arrival at the importer or DC determines whether a shipment will be accepted or rejected, as well as its potential utilization. This is an extremely important quality-control point that has a great effect on the company's bottom line. It should never be rushed or cursory.

Recommendations:

- Assign no more than one or two people to conduct QC inspections for uniform and repeatable results. If additional inspectors are required due to the volume of mangos being inspected, these inspectors must be

adequately trained and certified to assure uniform and repeatable results.
- Take single-carton samples in a standard pattern from the front, middle, and rear (door) areas of the load, sampling the top, center, and bottom of the pallets on both the left and the right at each of those three areas, for a total of 18 sample cartons.
- Immediately measure the flesh temperature as the pallets are being unloaded and the samples are being collected.
- Take mango flesh temperature readings from three basic areas within the trailer or container (i.e., the front, the middle and the rear door areas). Ideally, the temperature at the upper left, upper right, center, lower left, and lower right should be measured in all three areas during an inspection (for a total of 15 readings; see *Temperature Management Practices* in the Appendix).
- Document the visual appearance of the fruit, cartons, and pallets with a standard battery of digital photographs (see *Taking Digital Photographs* in the Appendix).
- Evaluate the fruit for 1) overall condition and ripeness; 2) flesh color, firmness, and soluble solids (°Brix); and 3) incidence and severity of defects, damage, disorders, and decay, both externally and internally.

A quality control station at a receiver facility

A sample QC inspection form with instructions, which was used during the Mango Quality Project, is included in the appendix of this manual.

Sorting Fruit at Importer/DC

- Mango fruit may be sorted to meet customers' specifications at the import facility; however, it is best if this type of sorting is done mainly at the packinghouse in the growing area.
- Fruit that do not make the grade may be suitable for another market outlet depending on the condition. Chilled mangos should never be marketed.
- A simple sorting table can be used to sort the fruit for visual appearance, damage, decay, excess softening, or chilling injury to meet grade standards or customer specifications.
  - Tables should be at a comfortable height for workers.
  - Adequate lighting should be directed onto the sorting table and not into the sorters' eyes.
  - Belts to transport and rotate the fruit assist speed and accuracy.
  - Fruit must be handled gently by workers and equipment to prevent impact injury during sorting and repacking.

Mangos being sorted at a receiver facility

- Fruit should be returned to the same cartons after sorting to maintain traceback capability.
- Fruit should be packed and re-palletized gently.

Storage at Importer/DC

- Pallets should be stored on racks in a cold room set to a temperature between 12°C and 15°C (54°F and 59°F); a temperature of 10°C (50°F) can be tolerated for a few days if necessary.

Refrigerated storage at a receiver facility

- Maintain relative humidity at 90 to 95%.
- Scrub ethylene gas from the cold room air with an absorbent or provide one full fresh air exchange each day.

Mango Ripening

Mangos marketed in the U.S. are usually picked partially ripe (stages 2 to 3 on a 5-point scale) to withstand the postharvest handling steps required to bring them from the production areas to the retail market. These mangos must be fully ripened at the wholesale, retail, or consumer level to attain optimal quality. Exposure to ethylene gas ensures faster and more uniform ripening. Providing ready-to-eat mangos to retail markets increases sales. The quality of mangos when ripe depends upon maturity at harvest (the more mature, the better the flavor when ripe), avoiding chilling injury and physical injuries during postharvest handling, and minimizing anthracnose incidence. Also, there are major differences in flavor quality and fiber content among cultivars, including those marketed in the U.S., such as Honey, Haden, Keitt, Kent, and Tommy Atkins.

CHANGES ASSOCIATED WITH RIPENING

As mangos ripen, the following compositional and physiological changes occur:

1. Skin color changes from green to yellow (in some cultivars).

Skin color changes during mango ripening

2. Flesh color changes from greenish white to yellow to orange (in all cultivars).
3. Carotenoids (yellow and orange colors) increase and chlorophyll content (green color) decreases, which is related to the skin and flesh color changes noted above.
4. Flesh firmness decreases and juiciness increases.

Flesh color changes during mango ripening

5. Starch is converted into sugars, which leads to increased sweetness.
6. Titratable acidity and associated sourness or tartness decrease.
7. Total soluble solids (TSS) content (combination of sugars, acids, soluble pectins, and other soluble constituents) and associated sweetness increase.
8. Characteristic aroma volatiles increase.
9. Carbon dioxide production rate increases 4-fold from around 40–50 to around 160–200 mg/kg·hr at 20°C (68°F).
10. Ethylene production rate increases 10-fold from around 0.2–0.4 to around 2–4 µl/kg-hr at 20°C (68°F).

RIPENING ROOMS

Most distribution centers have special rooms for fruit ripening that are used extensively for bananas and may also be used for avocados, kiwifruit, mangos, tomatoes, nectarines, peaches, plums, and European pears. Pressurized or forced-air ripening rooms allow better control of ripening compared with older methods of space-stacking boxes in a warm room. The new designs force temperature-controlled air through the boxes, maintaining fairly uniform product temperatures.

Ethylene gas is added from ethylene generators or gas cylinders via flow regulators on a schedule appropriate to maintain approximately 100 ppm ethylene in the ripening room. Carbon dioxide levels are kept below 1% by ventilating the rooms with outside air once per day. Ethylene and carbon dioxide concentrations can be measured with gas detector tubes or portable gas analyzers.

Mangos in a ripening room at a distribution center

OPTIMAL RIPENING CONDITIONS FOR MANGOS

Fruit temperature is the most important factor in ripening mature mangos. Ripening at continuous temperatures of 15.5 to 18°C (60 to 65°F) may result in the most attractive skin color, but flavor remains tart; these mangos require an additional 2 to 3 days at 21 to 24°C (70 to 75°F) to attain sweet flavor. Ripening continuously at 27 to 30°C (80 to 86°F) may result in mottled skin and strong flavor; ripening is retarded above 30°C (86°F). Thus, the best temperatures for ripening mangos are 20 to 22°C (68 to 72°F). However, the initial 24-48 hour ethylene application can be done at lower temperatures such as those used for banana ripening [15.5 to 18°C (60 to 65°F)]. Those low initial temperatures lengthen the total time to ripen, but don't compromise the final mango quality as long as the ripening is completed at 20 to 22°C (68 to 72°F). The optimal relative humidity range is between 90% and 95% to prevent excessive water loss and shriveling.

Ethylene (100 ppm) should be applied for 24 to 48 hours (depending on maturity since less mature mangos require longer duration). Ethylene accelerates ripening, provided that carbon dioxide concentration is kept below 1%. After triggering ripening with ethylene for 24 hours, mangos kept at 18 to 22°C (65 to 72°F) will ripen in 5 to 9 days. Once ripened, mangos can be kept at 10 to 13°C (50 to 55°F) and 90 to 95% relative humidity for up to 1 week.

Flesh firmness is a good indicator of ripeness stage and can be used for managing mango ripening, as shown in the table.

Ripeness stage	Flesh firmness (pounds-force [lbf] with 5/16 inch tip penetrometer)	Notes
Mature green	> 14	Treat with ethylene for 48 hours
Partially ripe	10-14	Treat with ethylene for 24 hours
Firm ripe	6-10	Best stage to send to retail stores
Soft ripe	2-6	Best stage for eating
Overripe	< 2	Good for juice

Staging for Loading at Importer/DC

- The dock staging area should be protected from the sun and refrigerated where possible.
- If the dock area cannot be properly refrigerated, stage loads in the cold-storage area instead. Load pallets directly from the cold room into the trailer to avoid warming.
- Air temperatures of 12 to 15°C (54 to 59°F) in the staging area are ideal.

Transport to Retail Stores

Problems occurring during transport to retail stores:

- Hasty loading operations at the DC can cause damage to pallets, which creates unstable conditions for the mango cartons, leading to potential for further damage.
- Normally, trailers used to deliver mangos do not use air bags to protect pallets from movement (leaning) during delivery.
- Mangos can be injured if placed too close to the trailer refrigeration unit. Reefer units can exhibit serious variations in temperature that can cause drying, freezing, or chilling of mangos that are directly exposed to delivery air.
- Mangos are typically delivered to retail stores in truck trailers containing a wide variety of produce and other food items. The carrying temperature chosen is always a compromise among the products being carried and may not be best for mangos.
- Older trailers used for delivering mangos may not maintain temperature well due to air leaks and may have dripping condensation that can damage fiberboard cartons.

Preparing an order for delivery to a retail store

Recommendations to avoid common problems during transport to retail stores:

- Train DC personnel in general mango-handling practices, emphasizing the importance of classifying mango fruit by maturity-ripeness stage and quality (incidence and severity of defects).
- If sorting is required before mangos are delivered to retail stores, ensure that DC personnel know how to distribute mangos according to their size and position into the mango cartons, as well as how to recognize the most important external defects to take into account when mangos are being sorted.
- Set up pallets and secure them so as to avoid any mechanical damage.
- Inspect trailers to ensure cleanliness; clean and sanitize if necessary before loading any product.
- Set up a regular schedule to inspect trailers for damage, leaking water, and reefer unit operation.
- Develop a delivery plan that ensures mangos are loaded into trailers in the most conducive location for maintaining their optimum temperature when several commodities are being delivered in mixed loads, and supervise the operation.
- Use air bags or other bracing materials in between the pallets and between pallets and trailer walls.
- Avoid fruit damage due to poor temperature control. The carrying temperature of trailers used to transport mangos from the DC to retail stores should not be lower than 10°C (50°F), and care should be taken to minimize exposure of mangos to extreme outside temperatures during loading and unloading.

Unloading at Stores/Holding on Docks at Stores

Upon arrival at the retail store, products are unloaded according to the requirements of the store purchase order. Depending on the arrival time and the availability of personnel to receive the products, the receiving process can vary widely from one retail store to another. Sometimes, the trailer remains open awaiting the store personnel responsible for the reception process; the temperature inside the trailer can warm (or chill) significantly during such delays.

Unloading an order at a retail store

Recommendations to avoid common problems during unloading at store/holding on dock at store:

- Minimize the time that trailer doors are open at the retail store. Trucks deliver products to more than one retail store, and the drop-off time at each store cumulatively exposes mangos to damaging outside temperature extremes (hot or cold).
- Train retail store personnel in produce temperature sensitivity, including that of mangos. Show them how mango fruit suffer due to exposure to temperature extremes.
- Designate retail store personnel to help in product unloading to minimize product exposure to damaging outside temperatures.
- Perform a QC inspection at the retail store upon delivery and provide prompt feedback to the DC regarding the results of the inspection. Use the information to make

improvements to mango handling practices at the DC and during delivery.

Storage in Walk-In Coolers at Stores

The majority of retail stores do not receive shipments of mangos every day, so they commonly keep an inventory of mangos in a walk-in produce cooler for 2, 3, or 4 days. The temperature of these storage rooms is typically maintained at 5°C (41°F), which is damaging to mangos. Ironically, the temperature of many retail store walk-in coolers is too high during operating hours because of numerous entries and exits by personnel, and too low during the hours when the store is closed. Many retail stores protect their walk-in produce coolers by using strip curtains, but damage to the curtains or purposely cutting them allows warm air to enter the cooler. Wall thermometers in these coolers are often poorly monitored and maintained or placed improperly, leading to inaccurate temperature readings.

A retail store back room

Recommendations to avoid common problems during storage in the back room or walk-in cooler at stores:

- The produce manager of a retail store should regularly inspect the back room and cooler area. The following points should be emphasized:
  - › Walk-in cooler doors should be kept open only for the time necessary to enter or exit.
  - › Strip curtains should be used on the walk-in cooler doors and must be kept in good repair.
  - › Calibrated thermometers should be placed in the back room and cooler and positioned away from doors or radiant heat sources (motors or lights) in order to indicate representative temperatures.
  - › Placement of produce in the cooler room should take into account product temperature requirements.

Mangos for sale at retail stores should not be placed in a cooler that is below 10°C (50°F). If no such cooler space is available, mangos should be ordered more frequently and held at back room temperatures for no more than a day or two.

Stocking and Display Preparation and Rotation

Product storage at the retail store in the back room or in a walk-in cooler is the last step in the cool chain for mangos that extends all their way back to the country of origin. Maintaining good temperature control right up to when the mangos are displayed for sale by retailers has a positive effect on the shelf life of mangos, minimizing shrink, mechanical injuries, and water loss so that retail stores realize maximum sales.

It is desirable to display mangos that are ready to eat so as to cause a major visual impact and showcase their best organoleptic characteristics. Mangos should be displayed in an open area in the retail store, not in a refrigerated product merchandiser. This allows the fruit aroma to develop and attract shoppers. Mangos should not to be displayed as a large mountain or pyramid of fruit because ripe mangos become susceptible to compression bruising that can occur just from the weight of one mango on top of another.

A retail store mango display including different ripeness stages

A program of regular cleaning and sanitation of the produce area is key to keeping the mango display pleasing and attractive. Rotating the mango display frequently to remove damaged, shriveled, and overripe mangos by moving older mangos from the bottom to the top or center of the display is an important management practice that encourages greater overall mango sales. If possible, when adding new mangos to those already displayed, it is a good idea to keep the mangos separated by variety and ripeness stage (firmness) so that shoppers can more easily locate the mangos that they prefer.

Recommendations to avoid common stocking and display preparation and rotation problems:

- Place mangos on display as soon as they are delivered to the retail store; order more frequently to avoid storing mangos at the store.
- Display mangos on floor displays at ambient temperature, not in refrigerated displays.
- Display mangos according to size, ripeness stage, and variety. Avoid building a large pile of ripe fruit so as to prevent damage due to compression.
- Consider having two different displays for mangos. Locate fruit that are less ripe and will be ready to eat in a day or two on one side and riper fruit that are ready to eat right away on the other side.
- Inspect the mango display several times each day and immediately remove overripe, shriveled, leaking, injured, and damaged or decayed fruit.
- Maintain a good cleaning and sanitation program for mango displays so that mangos always show their best quality to customers.

Recordkeeping

Keeping records is an important part of a quality control (QC) program at any stage of mango handling. If whatever is done is not recorded, it is as if it was never done when the time comes to show an inspector that best practices were followed. Each operation should assign an employee to be responsible for the QC program. The QC manager should bring together the most knowledgeable people in the operation to prepare a list of all the operations and procedures conducted in the facility, such as those described in this manual. The QC manager should then develop a form for recording that all of those operations and procedures are being done—and done correctly and on a regular basis.

APPENDIX: QUALITY CONTROL PROCEDURES

Determining Mango Fruit Maturity

Only mature mangos should be harvested to ensure good flavor quality when fully ripe. In the *U.S. Standards for Grades of Mangos* (2007), "mature" is defined as the stage of development that ensures the proper completion of the ripening process. To fulfill this expectation, a mango must have begun to ripen internally (stage 2) at the time of harvest. An immature-harvested (stage 1) mango will not ripen properly and will never develop acceptable flavor and aroma.

Many maturity indices have been tested, including number of days from full bloom, fruit shape, specific gravity, skin color, flesh color, starch content, total solids (dry matter content), total soluble solids, and titratable acidity. The change in fruit shape (fullness of the shoulders; shoulders rising above the stem attachment point) and the change in skin color from dark green to light green to yellow (in some cultivars) are the most commonly used maturity indices. Red blush develops on the skin of some mango cultivars and may become more prominent as the ground color changes from green to yellow with ripening, but it is not a dependable maturity index.

The extent of yellow color development in the flesh is a reliable maturity index in all cultivars.

Although it is difficult to judge harvest maturity, properly training individuals to look for the following characteristics when selecting mangos to be harvested can be helpful. These criteria can also be used to sort harvested mangos by maturity and ripeness stage at the shipping point (packinghouse) or the receiving point (importer's facility or distribution center) to reduce variability in ripening and deterioration rates during subsequent handling. Some on-line sorting equipment based on firmness (deformation force), soluble solids content (near-infrared light), and/or severity of defects is commercially available.

FRUIT SHAPE

As mangos mature, they swell and develop what many growers call 'shoulders', referring to the expansion growth around the fruit stem. In addition, fruit of cultivars such as Keitt, Kent, Haden, and Tommy Atkins gradually change shape from flat to round, developing what are referred to as 'cheeks'. Full cheeks or outgrown shoulders, as well as fruit shape, are considered reliable indices of harvest maturity for many cultivars.

Irrigation influences mango fruit shape, such that mangos harvested from trees without irrigation have more slender fruit, appearing to be immature even though maturity might be adequate. Mangos produced on farms with adequate irrigation have fuller cheeks and thus rounder shape.

Immature (left) and mature (right) mangos as shown by shoulder development and fullness of the cheeks

EXTERNAL APPEARANCE

The changes in external color do not always correlate with internal fruit maturity. Cultivars such as Keitt remain green even when fully ripe, while others like Honey change from green to yellow. The proportion of red blush on cultivars such as Tommy Atkins is greatly affected by the position of fruit on the tree and sunlight received during fruit growth and development rather than actual physiological development. Red blush on fruit should not be used as a sole indicator of harvest maturity in cultivars with the red blush characteristic.

A ripe Kent mango with green skin

Lenticels are natural openings present in the mango peel, the main purpose of which is to facilitate gas exchange. In Kent mangos, lenticels become more prominent as fruit mature. Lenticel size or prominence is a harvest indicator often used in South America. Lenticel expansion does not appear to be as evident in other commercial varieties; however, Haden mangos are considered to be fully mature when the red blush begins to lighten and the green lenticel spots turn yellow.

Prominent lenticels on a Kent mango (top) and yellow lenticels on a Haden mango (bottom)

As mangos mature, a distinct change in glossiness becomes evident, probably due to changes in the composition of peel waxes. The result is that mangos, especially Tommy Atkins, develop off-white shades of green on the peel (like 'bloom' on grapes), easily recognized by harvesters as a sign of maturity.

LATEX APPEARANCE

The latex or sap that exudes from the stem (pedicel) as soon as the mango fruit is detached from the tree changes from a viscous, milky liquid to a transparent fluid as the mango fruit matures and begins to ripen. The amount of pressure inside the vascular tissues of mangos is affected by the amount of latex inside the tissues, probably because the tree stores water inside the fruit. Very hard fruit have rigid flesh that may restrict the expansion of vascular vessels as they fill with latex. This pressure is evident when the mangos are harvested and latex squirts from the stem.

Mature Tommy Atkins fruit showing whitish 'bloom'

Some commercial mango operations measure the amount or force of the latex squirt as an indicator of fruit maturity and/or its propensity to be damaged by hot water treatment. At a given turgidity level (pressure level influenced by the amount of water inside the fruit), a mango with more advanced maturity has a weaker latex squirt. Because the force of the latex squirt is affected by both turgidity and fruit maturity, the squirt is highly variable. Therefore, it is not possible to quantify a relationship between latex squirt and fruit maturity. In most cases, however, a mango with advanced ripeness has no latex squirt at all. One commercial practice is to allow an additional period of rest (24 to 48 hours) prior to heat treatment when more than 30% of the fruit in a representative sample have a strong latex squirt.

Latex squirting from a mango

TOTAL SOLUBLE SOLIDS (TSS)

Sugars are the major soluble solid in fruit juice; therefore, TSS can be used as an estimate of sugar content. However, organic acids, amino acids, phenolic compounds, and soluble pectins also contribute to TSS. Starch suspended in the juice of immature or unripe mangos can interfere with the TSS measurement and result in erroneously high readings. Also, TSS in mangos at harvest is highly influenced by irrigation schedules and rain. Mangos harvested from fields where irrigation is ongoing or under rainy conditions tend to have lower TSS when compared to mangos of similar maturities harvested from farms where irrigation is withdrawn prior to harvest. Because of these potential problems, TSS is probably a better indicator of ripe mango quality than a measure of harvest maturity.

Handheld digital scale (right) and visual scale (left) refractometers

The TSS can be determined in a small sample of fruit juice using a refractometer that measures the refractive index, which indicates how much a light beam is slowed down when it passes through the fruit juice. The refractometer has a scale for refractive index and another for equivalent °Brix or percent TSS, which can be read directly. Digital refractometers remove potential operator error in reading values.

The TSS levels in mature green mangos (minimum of 7 to 9% at harvest) increase with ripening to reach 14 to 20% in ripe fruit. Minimum acceptable TSS levels may differ for mangos intended for export, depending on the shipping distance. Thus, the minimum TSS for mangos exported to the U.S. from South America may be lower than for fruit exported from Central America and Mexico, but the total solids (dry matter) content should be similar.

Measuring mango fruit TSS with a refractometer

Juice is most commonly extracted by squeezing half of a fruit directly onto the prism of a handheld refractometer. However, hand squeezing firm fruit at harvest can vary from person to person and give variable results. Hand squeezing can result in an overestimation of TSS content because juice drips out of the ripest portion of the fruit first.

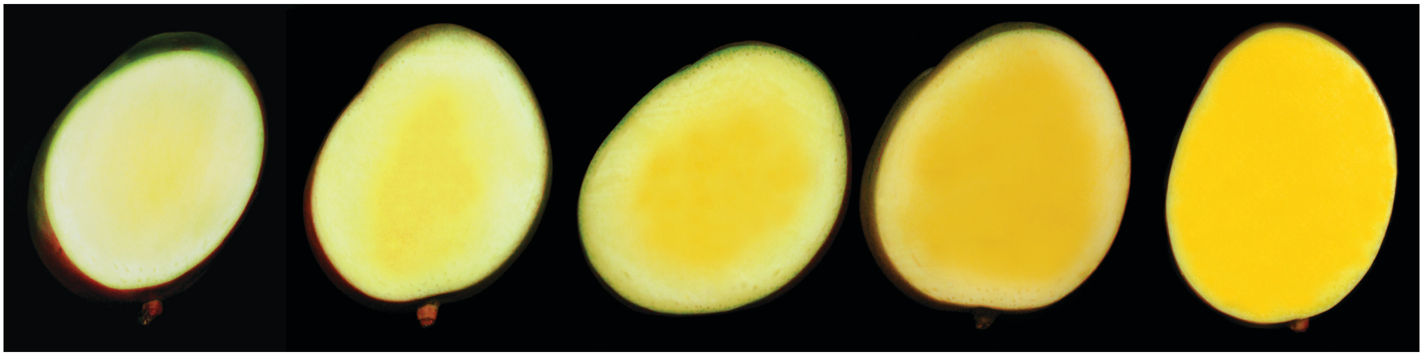
Another method used to obtain juice from very firm fruit is to slice off the cheek portion of the fruit and then scrape the edge of a knife along the exposed flesh, collecting a small amount of juice on the knife blade, which is then dripped onto the refractometer prism.

The best approach is to juice the whole fruit flesh, using a manual juicer, and then measure TSS content. However, the process of juicing whole fruit is considered too time consuming and cumbersome for the mango industry.

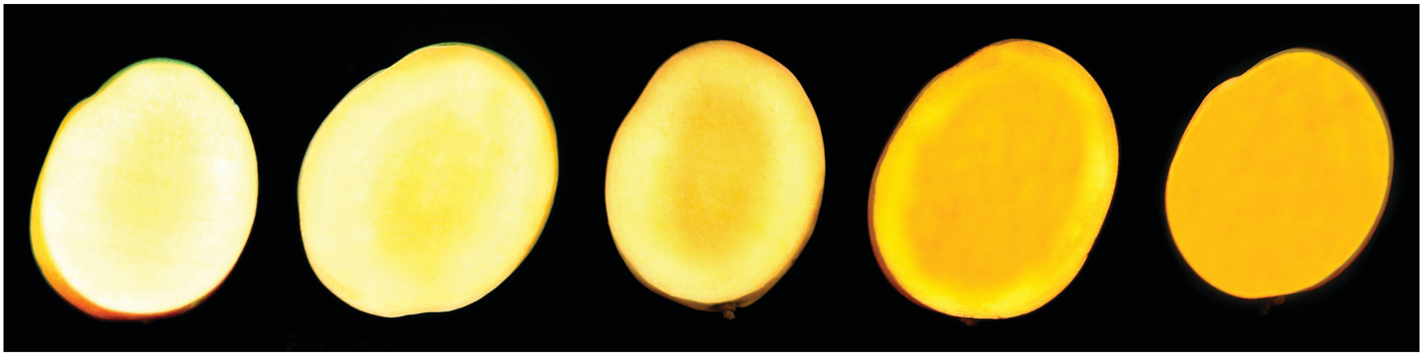
To make things easy and quick, part of the flesh tissue from both cheeks can be used to measure TSS content. Take out flesh tissue from the equatorial region (2 to 3 plugs) of each side of a mango using a potato peeler and juice it with a lemon squeezer; use the resulting juice to determine the TSS content with a digital refractometer.

FLESH COLOR

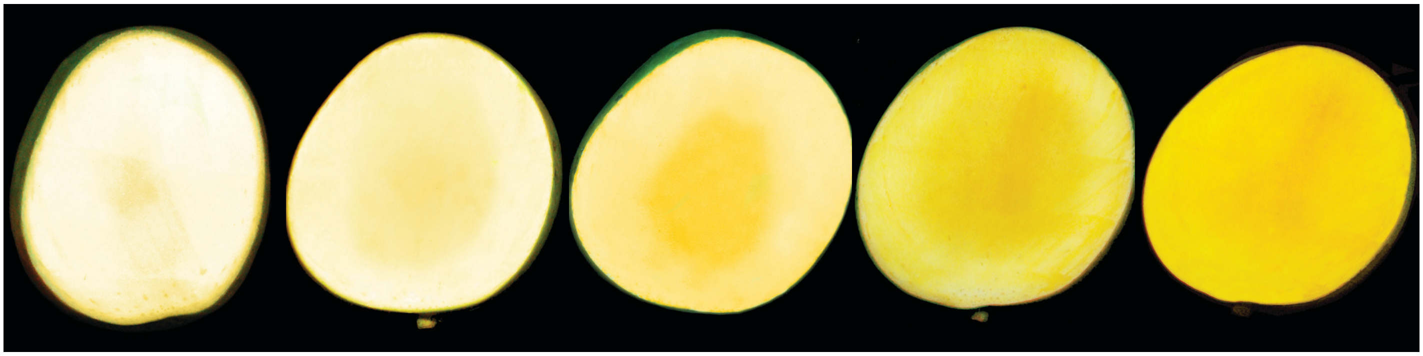
Maturity can be indicated by flesh color (e.g., about 75% of the area showing yellow color equals stage 3 on the 5-point scale shown in the accompanying photographs) and can be related to external factors for each cultivar grown in each production area. These external factors include fruit size, fruit shape (fullness of the shoulders), and skin ground color (change from dark green to light green to yellowish green). The harvest crews should be trained to pick only those mangos that match the maturity indices.



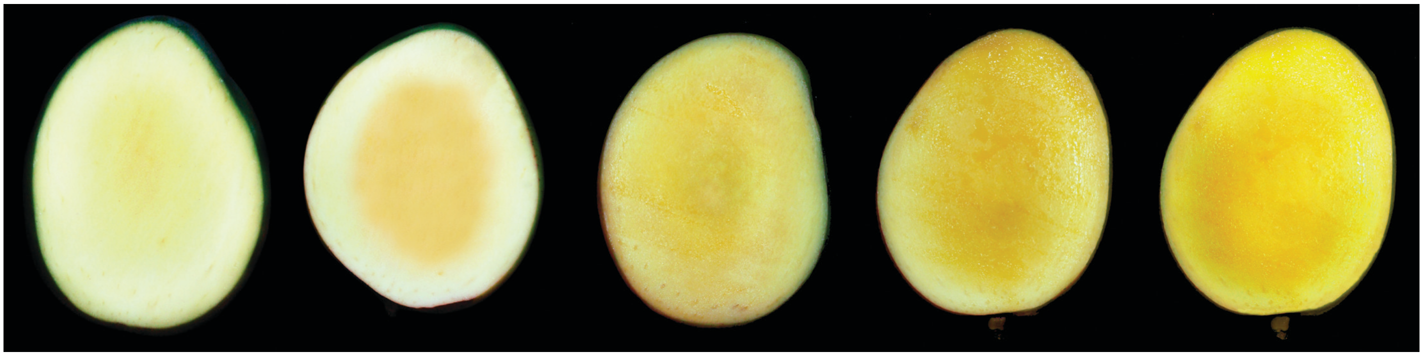
Internal flesh color development (1 to 5 scale; left to right) for Tommy Atkins mango



Internal flesh color development (1 to 5 scale; left to right) for Haden mango



Internal flesh color development (1 to5 scale; left to right) for Kent mango



Internal flesh color development (1 to 5 scale; left to right) for Keitt mango

Internal flesh color development (1 to 5 scale; left to right) for Honey mango

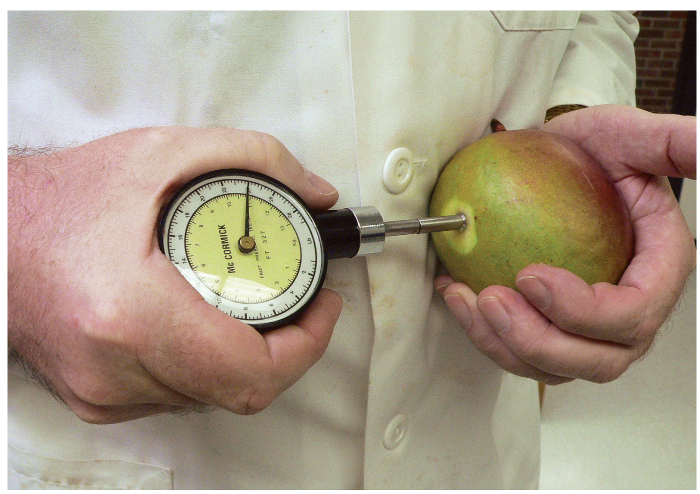
Internal flesh color development (1 to 5 scale; left to right) for Francis mango

FRUIT FIRMNESS

Firmness of mango fruit decreases with maturation and ripening on the tree and continues decreasing during harvesting, postharvest handling, and storage. Firmness should not be used as the only harvest index, but it can be used as an index of ripeness stage. Minimum flesh firmness for mangos exported from South America should be between 15 and 20 lbf at the time of reception at packinghouses. Lower flesh firmness ratings might be acceptable as long as they coincide with adequate TSS and flesh color ratings. Mangos that are shipped shorter distances than from South America, such as from Mexico and Central America, can have lower initial firmness (10 *to* 15 lbf), but flesh color is a better index of proper maturity.

The concept of maximum firmness might be useful for early season mangos as an indicator of immaturity. Mangos with high flesh firmness (22 lbf and above) will probably have higher incidence of immature fruit and heat treatment damage.

Many destructive and nondestructive methods have been used to measure mango fruit firmness. The most common method for measuring firmness is based on flesh penetration force on both cheeks (with skin removed) using a penetrometer with an 8 mm (5/16 inch) tip. Because mangos ripen (and the flesh softens) from the inside out, the depth at which the skin is removed prior to measurement should be consistent from fruit to fruit for accurate measurements. A better method is to slice the fruit in half lengthways and take the measurements on either side of the seed, midway between the seed surface and the skin. See: *Inspection/Assessment of Mangos at Farm/Packinghouse/Importer/DC/Retail Level* in the *Mango Quality Assessment Form* below.



Measuring mango flesh firmness with a penetrometer

Alternatively, a Rex durometer can be used to measure the firmness (as deformation force) of mature green mangos nondestructively by taking at least two separate readings, at random, around the equatorial region of the fruit.

DRY MATTER (TOTAL SOLIDS) CONTENT

Dry matter (DM) content is a better indicator of harvest maturity than TSS and is directly related to both the TSS and the eating quality of ripe mangos. In Australia, the DM content of the flesh tissue is considered to be a much better harvest maturity index than flesh color and initial TSS. For example, in Keitt mangos, accumulation of 18 to 20% DM content can be used as a reliable harvest maturity index. A similar range of DM content combined with other harvest indices, such as flesh color and firmness, can be used for other mango cultivars.

The DM content can be measured quickly by evaporating the water from preweighed fruit tissue in a microwave oven.

Measuring mango dry matter content with a microwave oven

Peel tissue should not be included when determining DM content. Peel tissue has higher DM content than flesh tissue and may lead to overestimation of results when measuring DM content. Flesh tissue from hard green mangos can be grated manually or sliced thin using a potato peeler. Place a sample portion of about 5 grams of tissue (weighed to the nearest hundredth of a gram) into a Petri dish or microwavable container, adjust the microwave power so that the tissue dries without burning, and reweigh immediately after drying. Repeat microwave applications in 1-minute intervals until the weight is constant (minimum drying time is about 4 to 7 minutes).

Water Sanitation Practices

CONTROL OF POSTHARVEST DECAY PATHOGENS

Mangos are susceptible to infection by several decay-causing fungi. The fruit can also be contaminated with bacterial and viral human pathogens, beginning with field operations. Bacteria are much easier to kill than fungi since the former lack cell wall structures. In addition, decaying tissues may be more likely to harbor human pathogens. One study showed that *Salmonella* was much more prevalent and grew much faster on tomatoes infected with bacterial soft rot (*Erwinia carotovora*). Therefore, control strategies must consider both of these scenarios.

There are three primary fungal diseases affecting mango fruit; namely, alternaria rot, or black spot (*Alternaria alternata*); anthracnose (*Colletotrichum gloeosporioides* [Penz.]); and stem-end rot (caused by several fungal species). Since inoculation occurs in the field, preharvest control measures are essential for minimizing postharvest decay. Once infected, the decay spreads as the fruit ripens and softens during handling and shipping. Postharvest decay is more prevalent during wet weather conditions in the field that favor pathogen growth.

Like other fresh fruits and vegetables, mangos have natural defenses provided by the waxy peel, or epidermis. However, microorganisms can enter the fruit in several ways. The peel contains open lenticels that are large enough to allow direct entry of fungal and bacterial pathogens into the flesh. This entry can occur in the field when rain or overhead irrigation carries spores and bacteria over the fruit surface. Pathogens can also accumulate in packinghouse wash tanks and recirculated water that is not properly sanitized, infiltrating into the fruit when it enters the contaminated water. During handling, decaying fruit also reduce the quality of neighboring fruit in the carton by producing spores that discolor or infect nearby fruit, by accelerating ethylene production that hastens ripening or the development of physiological disorders, and by facilitating the spread of the decay organism to adjacent fruit directly ('nesting') or by juices released from infected tissues.

Careless handling during harvest and packing operations causes mechanical injuries that provide other ports of entry for pathogens. Punctures, cuts, and abrasions break these natural physical barriers and, in the process, rupture cells in the flesh. The released cellular contents (water and nutrients) promote pathogen growth. Although bruises may not actually rupture the epidermis, the resulting stressed tissues are more susceptible to pathogen attack.

Following are several ways to minimize the development of postharvest decay:

- **Practice good sanitation in the field and throughout the entire harvest and postharvest handling chain.** There is a direct relationship between the population of decay pathogens in the field and on the equipment and the development of fruit decay. Thus, the presence of decaying plant material in the field (e.g., leaf litter, rotting fruit, dead plants, etc.) and dirty harvesting and handling equipment results in higher rates of decay.

- › Frequently clean and sanitize harvest and hauling equipment, packing areas and equipment, and shipping containers. Daily cleaning and sanitizing is recommended.
- › Sanitize and frequently monitor the quality of all recirculated water systems and assure fresh water is free of pathogens (see *Sanitation of recirculated water* below for further information).

- **Use postharvest treatments to eradicate or suppress the growth and development of decay pathogens.** Hot water treatment, irradiation, and synthetic compounds or biological agents are also effective. However, these treatments or products must be used in strict accordance with the regulations of the permitting agency of the destination country.
- **Reduce decay development with rapid cooling.** Pathogenic microorganisms proliferate best at warmer temperatures. Mangos tolerate hydrocooling; however, application of forced-air cooling after packing dries fruit surfaces and wounds, making the fruit less favorable for decay growth.
- **Store and transport mangos at their lowest safe temperature and relative humidity (12°C [54°F] and 85% RH).** Storing and/or handling mangos below recommended temperatures can cause chilling injury that greatly promotes decay and causes off flavors and aromas during ripening. Fungal spores germinate under high humidity (i.e., > 95% RH) or in the presence of free water on the product. Fluctuating temperatures during storage and shipping cause condensation to form on fruit surfaces.
- **Extend postharvest life with controlled or modified atmospheres.** These treatments, in conjunction with proper temperature management, further retard fruit senescence and delay decay development.

Rigorous attention to these details helps keep product decay below the limits specified by the USDA grade standards and helps reduce financial losses.

SANITATION OF RECIRCULATED WATER

Properly sanitizing water (especially recirculated water) used in dump tanks, hydrocoolers, and for other purposes in packinghouses is important for delivering sound produce to the consumer. Not only do unsanitary conditions promote direct product loss through decay, but also rising food safety concerns about human pathogens are increasingly important to consumers. Because water is one of the best carriers of pathogens, it must be treated (either chemically or physically) to prevent the accumulation of pathogens in the water and prevent cross-contamination of sound produce. However, these treatments are not particularly effective at reducing pathogens already present on the surface of the produce. It is much more effective to prevent cross-contamination of uninfected fruit by following Good Agricultural Practices that provide specific guidelines in the field regarding water quality, use of manure and municipal biosolids, harvesting practices, and worker sanitation.

Freshly harvested fruit can harbor large populations of pathogens, particularly during warm, rainy weather. When these fruit are brought to the packinghouse and immersed in recirculated water handling systems (such as dump tanks, flumes, overhead sprays, hot water systems, and hydrocoolers), pathogens wash off the fruit surfaces. Properly sanitizing the water reduces the accumulation of pathogens, virtually eliminating the inoculation of the other mangos and reducing the incidence of decay during shipping and handling. Properly sanitized water also kills bacteria responsible for foodborne infections in humans. Any sanitizer must be approved for application by the regulatory authority where the crop will be sold.

Many postharvest decay problems result from the incorrect use of sanitizers used to treat recirculated water. Generally, packers that follow the recommended guidelines below (Sargent et al., 2008) have negligible problems with postharvest decay. This section addresses the critical factors necessary for effective sanitation of systems that employ recirculated water. Emphasis is given to the use of chlorine since it is the predominant method used by fresh produce packers to sanitize water systems.

Chlorine

Chlorine efficacy. There are several advantages to using chlorine—namely, it effectively kills a broad range of pathogens, acts relatively quickly, and is relatively inexpensive. It also leaves very little residue or film on surfaces. The most commonly used forms of chlorine are sodium hypochlorite, calcium hypochlorite, chlorine dioxide, and chlorine gas.

Once added to the water system, the chlorine compound breaks apart into 'free chlorine'. (It is also called 'available chlorine' or 'unreacted chlorine'.) Free chlorine is the form (hypochlorous acid) that kills pathogens, and its efficacy is pH dependent. 'Total chlorine' represents all forms of chlorine in the water. The chlorine product is added to the water on an as-needed basis to replace the chlorine lost due to chlorine demand. 'Chlorine demand' refers to the reactions that cause free chlorine to become inactivated and, therefore, ineffective at sanitizing the water. This occurs when hypochlorous acid comes into contact with organic matter, chemicals, microorganisms, and fruit surfaces. ***For these reasons, always measure free chlorine not total chlorine.***

Free chlorine is most effective when the water pH ranges from 6.5 to 7.5. If the pH is above 8.0, the chlorine acts very slowly and requires a higher concentration to achieve a rapid kill of the pathogens in the water. Concentrated chlorine compounds have a very high pH, and the addition of chlorine to the water while packing raises the water pH. Water pH is lowered by use of a food-grade product, such as citric acid. In contrast, if the pH is below 6.5, then the chlorine is too reactive; it is more corrosive to equipment and it is more difficult to maintain effective concentrations. ***For these reasons, decay pathogens, particularly fungi, are effectively controlled in recirculated water with free chlorine ranging from 100 to 150 ppm and pH from 6.5 to 7.5.***

Other factors. Chlorine efficacy can also be affected by the initial level of inoculum present on the fruit surface, the water temperature, the exposure time of the fruit in the water, and the absence of stagnant areas. For example, numerous studies on tomato handling have resulted in the following additional recommendations that can be applied to mangos:

- Dump tank water should be heated to 5.6°C (10°F) above the incoming flesh temperature to reduce infiltration of water (and pathogens) into the fruit.
- The fruit should not be in the tank for more than 2 minutes or submerged more than a few inches to minimize infiltration. Flumes must be designed such that fruit move through the system promptly and do not become caught in eddies.
- **Dump tanks should be drained, cleaned, and sanitized on a daily basis.**
- **After each use, packingline components, packing areas, and floors must be cleaned and sanitized.**
- **Prior to working on the packingline, workers must wash their hands thoroughly.**

Vigilance. Chlorine efficacy must be maintained at all times during packing. The recirculated water must be routinely monitored for free chlorine concentration and pH, and adjusted accordingly. ***All recirculated water should be changed on a daily basis, or more frequently if the water becomes extremely dirty due to buildup of organic matter.*** High salt concentrations may also accumulate in the water and cause injury to the peel. Certain types of corrosion associated with water chlorination can damage concrete tanks. Local environmental codes must be consulted for proper disposal of chlorinated water.

Maintaining sanitary water. There are several ways to maintain adequate chlorine concentrations. Automated systems are commercially available that continuously monitor and record the pH and the oxidation reduction potential (ORP) of the water. The ORP value is correlated to free chlorine concentration, and when the ORP reading falls below a set point value, a chlorine product is automatically added to the water. Buffers or acidifiers are also added to maintain the appropriate pH levels. ***Samples should be taken manually every 1 to 2 hours to verify that the automated equipment is performing properly.***

Monitoring dump tank water chlorine levels manually

Other less sophisticated systems continuously dispense chlorine products, but they require frequent manual measurement of the free chlorine concentration to verify the amount of chlorine being added. Packinghouse managers must be vigilant with these systems because the chlorine demand can change abruptly, such as with the addition of product from a different field, a different grower, or a different field crew. If free chlorine measurements are not taken often enough, free chlorine levels in the water can quickly dissipate, potentially leading to an accumulation of hazardous microorganisms in the water.

Chlorine products can be manually added, but free chlorine and pH measurements must be made at least every 30 minutes in order to maintain minimal conditions for sanitary water. With all additions of sanitizer and pH adjustment, the products must be mixed well with the water stream. For example, toxic chlorine gas is released into the packinghouse air when pockets of extremely low pH (< 4.0) are created.

Alternate sanitizers

Other antimicrobial chemicals have been approved by the U.S. Environmental Protection Agency (EPA) for contact with food products. However, mango packer/shippers must verify that the sanitizer is approved for the specific application by the regulatory authority where the crop will be sold. Following are some of the approved sanitizers and a discussion of the advantages and disadvantages of using each.

Chlorine dioxide (ClO_2). Chlorine dioxide is a synthetically produced yellowish-green gas with an odor like chlorine. Chlorine dioxide is much more specific for killing microorganisms than is chlorine, with a typical use concentration of between 1 and 5 ppm over a pH range of 6 to 10. Unlike chlorine, however, ClO_2 does not hydrolyze in water. Thus, it remains a gas while in solution. However, ClO_2 readily off-gasses when the water is agitated, such as when spray washers are used, creating worker and equipment hazards. Chlorine dioxide is usually generated on-site because the concentrated gas can be explosive and decomposes rapidly when exposed to light or temperatures above 50°C (122°F). There are no simple methods to monitor ClO_2 concentration.

Ozone (O_3). Ozone is a water-soluble gas that forms when electricity or UV light splits O_2 molecules and forms O_3. Ozone gas is one of the strongest sanitizers available; however, it is also a very strong oxidizing agent and is highly corrosive to equipment, including rubber, some plastics, and fiberglass. An expert panel declared O_3 to be Generally Recognized as Safe (GRAS) in 1997, and O_3 is currently legal for food contact applications (USDA AMS, 2007b). Although O_3 is not particularly soluble in water (30 ppm at 20°C [68°F]), concentrations of 0.5 to 2 ppm are effective against pathogens in clean water with no soil or organic matter. In practice, even concentrations of 10 ppm are difficult to obtain, and concentrations of 5 ppm or less are more common. There have been reports that O_3 may induce resistance to subsequent fungal attacks in some horticultural products.

Ozone decomposes quickly in water. It has a half-life of 15 to 20 minutes in clean water but less than 1 minute in water containing suspended soil particles and organic matter. Thus, ozonated water should be filtered to remove these particulates. Cooler temperatures of hydrocooler water may also extend ozone's half-life. The antimicrobial activity of O_3 is stable between pH 6 and 8 but decomposes more rapidly at higher pH levels. Ozone breaks down to O_2, and no other toxic byproducts have been reported. Ozone efficacy is diminished when iron, manganese, copper, nickel, hydrogen sulfide, or ammonia are dissolved in the water.

Because of its strong oxidizing potential, O_3 is toxic to humans and must be generated on-site. Prolonged exposure to more than 4 ppm O_3 in the air can be lethal. Ozone has a pungent odor that can be detected by humans at 0.01 to 0.04 ppm. The U.S. Occupational Safety and Health Administration (OSHA) has set worker safety limits in the air of 0.1 ppm exposure over an 8-hour period and 0.3 ppm over a 15-minute period. At concentrations in water above 1 ppm, off-gassing can result in concentrations in the air that exceed OSHA limits of 0.1 ppm.

Peroxyacetic acid (PAA). Peroxyacetic acid (e.g., Tsunami®, VigorOx®, etc.) is a strong oxidizer formed from hydrogen peroxide and acetic acid. The concentrated product (up to 40% PAA) has a pungent odor and is highly toxic to humans. PAA is very soluble in water with very little off-gassing, and it leaves no known toxic breakdown products or residue on the produce. Unlike chlorine and ozone, it has good stability in water containing organic matter, which can greatly increase the longevity of the sanitizer, and it is not corrosive to equipment. PAA is most active in acidic environments with pH between 3.5 and 7, but activity declines rapidly above pH 7 to 8. High temperatures and metal ion contamination also reduce its activity. PAA is not as effective against fungal spores as chlorine.

SPECIAL GUIDELINES FOR SANITIZING ORGANICALLY GROWN MANGOS

Organically grown mangos must also be handled, packed, and shipped according to certification standards, such as those of the National Organic Program, which was established by the USDA Agricultural Marketing Service (USDA AMS, 2007a).

Maintaining sanitary conditions is more challenging for organic crops because of the limited number of approved sanitizers. Sanitation and worker hygiene are critical during all handling and washing operations to minimize the risk of spreading human pathogens from contaminated to uncontaminated fruit. Studies have shown that properly washed hands are as hygienic as using plastic gloves. All surfaces that contact the crop must be regularly cleaned and sanitized. This includes picking containers, benches, cutting and trimming tools, and reused containers. Thoroughly brushing contact surfaces with soapy water followed by rinsing with potable water is very effective in removing debris and pathogens and eliminating their buildup.

Cleaning operations are also a challenge. Wiping fruit with a reused cloth is not appropriate since microorganisms that accumulate on the cloth can be transferred to other fruit. The best method for washing or rinsing mangos is by carefully brushing them under running, potable water. Detergents are not recommended for direct washing of the crop since they can favor the uptake of microorganisms, increasing postharvest decay. Further, many detergents contain synthetic surfactants that are prohibited for use in organic systems. Wash and rinse water can contain chlorine as long as it meets state and federal standards for drinking water (maximum of 4 ppm of residual chlorine in the U.S.) measured at discharge (U.S. E.P.A., 2019). Citric acid is permitted for adjusting water pH to the range of 6.5 to 7.5, which makes chlorine most effective for sanitizing.

Washing in tanks or tubs is another commonly used method. For organic crops, this reused water presents challenges because many postharvest fungi and bacteria survive treatment with low concentrations of chlorine and can inoculate sound crops. Ozone is permissible for sanitizing water prior to use; however, it is most effective for sanitizing water that is used in once-over applications (not recirculated water). Mangos may also benefit from a 5-minute, agitated soaking in a 35% solution of white vinegar (acetic acid), which was shown to be effective in sanitizing iceberg lettuce. Other sanitizers approved for organic crops include calcium chloride, sodium chloride, hydrogen peroxide, and peroxyacetic acid. Carnauba wax and wood resin wax can be used to coat organic crops.

Temperature Management Practices

Temperature management is one of the most important factors for maintaining mango quality during handling and shipping operations. Proper management of fruit temperature makes it feasible to export from producing areas to distant markets. Phytosanitary regulations and Best Management Practices (BMPs) for food safety require mango temperature history to be accurately documented. However, mango temperature can only be properly managed when flesh temperature and heating/cooling systems are accurately measured. It is more accurate to measure flesh temperature than air temperature, where feasible, because this is a better indicator of the progression of fruit ripening. Air temperature changes quickly, and its fluctuation does not reflect the slower change in flesh temperature.

This section provides protocols for accurately measuring temperature throughout the distribution process.

TEMPERATURE MEASUREMENT

Temperature probe selection

Many types of thermometers are available for commercial use. A handheld thermometer with a rigid probe is most useful for flesh temperature measurement. The least expensive models use a bimetallic strip with either analog or digital readout. Response time varies from 1 to 2 minutes. Other thermometers use thermistor or thermocouple technology and have a relatively fast response time of 15 to 60 seconds, depending upon the thickness of the probe. For greatest accuracy, thermometers for fresh produce should be selected with a narrow temperature range of -5 to 60°C (23 to 140°F).

Regulatory requirements and BMPs depend upon continuous, remote temperature measurement, in which stationary probes are mounted in hot water and hydrocooler tanks, forced-air cooler tunnels, cold rooms, and refrigerated trailers and marine containers. These readings are logged directly to a computer, data logger, or printout.

Use of glass, mercury thermometers is strongly discouraged since they are easily broken, causing injury to workers and contamination of the fruit and work area. Glass thermometers should never be used to measure flesh temperature. Although they are very accurate and serve well as a calibration reference, they should only be used in a controlled area, such as the quality-control laboratory. Mercury thermometer response time is slower than that of digital thermometers, requiring about 2 minutes to equilibrate.

Infrared (IR) thermometers provide a quick and remote temperature reading, but they are not nearly as accurate as other sensor types. IR thermometers function best under constant temperature conditions, such as a cold room. Under fluctuating temperature conditions, they can provide a false temperature reading. For example, when a pallet is transferred to a warmer temperature, the exposed carton surfaces warm quickly. The IR thermometer measures the surface temperature, not the flesh temperature, which can lead to the incorrect conclusion that the load was shipped at the warmer temperature.

Measuring surface temperature with an infrared thermometer

Thermometer calibration

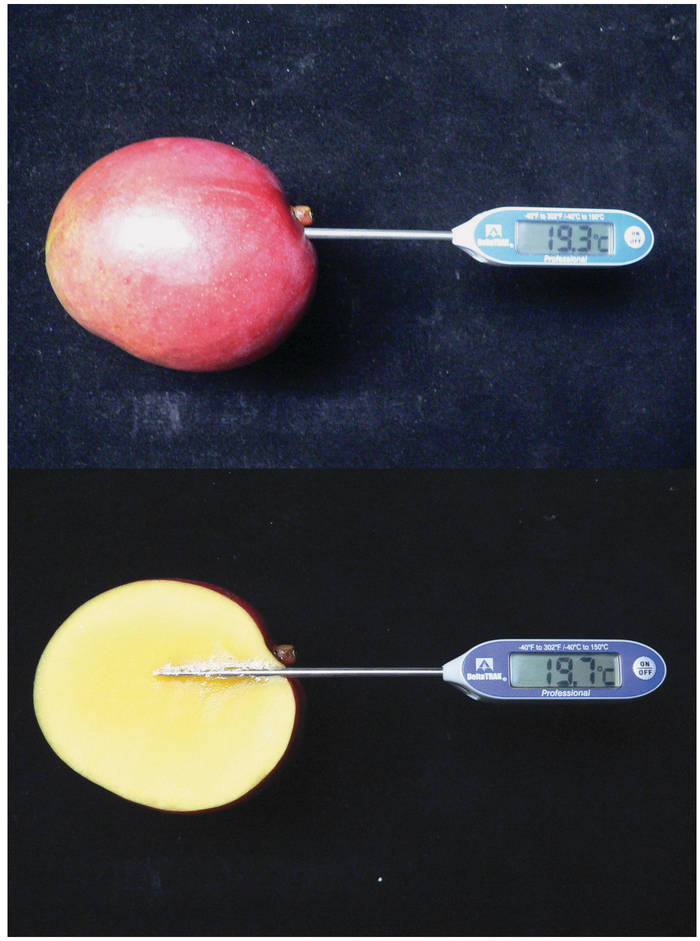
Temperature probes must be calibrated on a regular basis—for example, once per year at the start of each season is sufficient. The easiest method is to mix crushed ice and water in a small container. When the probe is immersed in the center of the mixture, it should equilibrate at 0°C (32°F). If the reading is not accurate, the probe must be adjusted to 0°C. To determine if the sensor is accurate over a range of temperatures, it can also be immersed in boiling water (assuming it measures at higher temperatures) to verify a 100°C (212°F) reading.

FRUIT TEMPERATURE MEASUREMENT

Mango flesh temperatures can vary widely, depending upon where the fruit is located. Fruit selected for measurement of flesh temperature should reflect the average temperature of that particular lot of fruit. The turbulent water in a hot water tank warms the fruit fairly uniformly; therefore, all fruit should have similar flesh temperatures following treatment. However, once the fruit are packed into cartons and palletized, cooling occurs at a much slower rate due to the increased barriers to airflow. In this latter situation, fruit sampled closer to the center of the pallet provide the most accurate measurement, as compared to fruit next to the outer, exposed sides of the carton. Fruit sampled for flesh temperature are always discarded.

Positioning of the temperature probe

Proper location of the sensor is critical for accurate temperature measurement. Flesh temperature is best determined by measuring the mass average temperature of the fruit, which is measured at a depth of two thirds of the fruit radius. For mangos, the probe is inserted into the stem-end shoulder and down along the flat side of the seed to the equator of the fruit.



Mango flesh temperature measurement showing proper placement of the probe to measure the fruit mass average temperature

To determine temperatures of hot water, hydrocooler water, or cooling air, the probe should be located near the return side of the heating or cooling medium rather than in the supply side or near an exit door.

EVALUATING HOT WATER TREATMENT SYSTEMS

Hot water treatment is rigidly monitored by USDA APHIS inspectors, and packers must follow these regulations (USDA APHIS PPQ, 2016).

EVALUATING HYDROCOOLING SYSTEMS

Following hot water treatment, mangos may be hydrocooled. Hydrocooling is a very efficient method for cooling mangos. Because the heat capacity of water is much higher than air, hydrocooling removes heat from the fruit at a much faster rate than air at the same temperature. Adequate refrigeration capacity is essential for optimal hydrocooling because the chilled water must remain at constant set point temperature (≥ 70°F [21°C]) throughout the hydrocooling cycle. If the refrigeration capacity is too low, the water temperature gradually rises during cooling, extending the cooling time. Water temperatures should be measured at the supply (coldest) side and at the return (warmest) side. The cooling cycle is complete when ¾ to ⅞ of the field heat has been removed from the fruit, which occurs approximately when supply and return water temperatures are the same.

EVALUATING MANGO FRUIT TEMPERATURE DURING STAGING

Following hot water treatment and hydrocooling, the crates are transferred from the hot water immersion frame and palletized. At this point, the fruit are sampled for flesh temperature, as described above. When the pallets are moved to the staging area, they must be arranged so as to facilitate adequate air movement between the pallets. Fans must have sufficient volume to ensure proper air movement and must be located to provide uniform air movement throughout the area. After holding at the staging area under ambient temperatures, the fruit are sampled again prior to packing to measure flesh temperature. Ambient air temperatures must be monitored during staging, and length of staging should be adjusted accordingly.

EVALUATING ROOM COOLING AND FORCED-AIR COOLING SYSTEMS

Following packing, the cartons are palletized and fitted with corner braces and straps. If they are to be room cooled, pallet arrangement is critical and should be similar to the arrangement during staging. As in the staging area, the cold-room fans must have sufficient volume to ensure proper air movement throughout the room. Pallets to be forced-air cooled should be arranged according to the guidelines in the *Cooling Prior to Shipping* section. Fan volume and refrigeration capacity must be sufficient to achieve ¾ to ⅞ cooling. Prior testing with each carton type and mango size will determine the length of time necessary for cooling based on incoming flesh temperatures. Air temperature for cold rooms and forced-air coolers should be monitored at all times.

EVALUATING TRAILER AND MARINE CONTAINER TEMPERATURES

Prior to loading, flesh temperature is measured; if it is not at shipping temperature, it is not loaded. The refrigerated trailer or container is cooled to shipping temperature and inspected for adequate airflow. If all is appropriate at this point, the trailer or container is stuffed as described previously in the section *Loading refrigerated trailers and containers*, to ensure proper air distribution. Air temperature should be set according to specifications in the bill of lading and monitored continuously during transit.

Upon arrival at the receiver, several pallets are unloaded and flesh temperature is verified. Fruit flesh temperature measurements should be taken through the carton vent holes if possible. Make sure that the tip of the probe is placed in the center of the sample. Allow sufficient time for the recorder to stabilize at the correct reading before recording the temperature. If it is necessary to cut holes in a carton in order to take readings, be careful not to damage fruit with the box cutter and replace and tape the portion of the carton that was removed. Place a sticker with the date and the inspector's name on the area removed to make the destination parties aware of the reason the carton was damaged. If the flesh temperature meets the receiver's criteria, the pallets are released for further quality-control inspection.

EVALUATING MANGO FRUIT TEMPERATURE IN DCS AND RETAIL STORES

At the DC, mangos should be held under recommended temperatures and relative humidity according to the guidelines previously in the section on *Storage at the Importer/DC*, and air temperatures should be monitored. Temperature management from the DC to the retail store is monitored during loading, shipping, and receiving, as detailed above.

Measuring Relative Humidity, Air Velocity, and Pressure Drops in Storage Rooms, Trailers, or Containers

RELATIVE HUMIDITY

Relative humidity (RH) is the ratio of the water vapor pressure in the air to the maximum amount of water vapor that air can hold at the same temperature. It is normally expressed as a percent. The RH is an important property to know because it provides an indication of the tendency of fruit to lose water. Since the air spaces inside of a fruit are saturated with water, the tendency is always for that water to move out of the fruit and into the surrounding air. Also, warm air has a much greater water-holding capacity than cold air, so a warm fruit placed in a cold storage room can lose excessive amounts of water if the storage room air is not highly humidified and the fruit temperature is not quickly lowered to the room temperature.

Relative humidity is measured with a psychrometer, which uses the difference in temperature measured by two thermometers with dry or wet bulbs to determine the drying capacity of the air. A sling psychrometer consists of dry and wet bulb thermometers and a handle for swinging the psychrometer in order to provide the necessary airflow for adequate evaporation of water from the wet bulb. A portable psychrometer has a battery-powered fan instead of a handle.

Using a sling psychrometer to measure relative humidity in the air

An accurate wet bulb temperature reading is dependent on: 1) sensitivity and accuracy of the thermometer; 2) maintaining an adequate air speed past the wick (a minimum of 4.5 meters per second or 15 feet per second) for 20 seconds; 3) shielding the thermometer from radiation, such as from motors and lights; 4) using distilled or deionized water to wet the wick; and 5) using a cotton wick. Read the wet bulb temperature quickly once air movement has stopped; repeat until two readings are nearly identical to be assured that the lowest temperature has been reached.

AIR VELOCITY

Uniform temperature in cold-storage rooms requires uniform air movement. Dead spots where air movement is minimal result in localized hot spots for produce in those areas. It is a good management practice to explore the refrigerated areas of a mango-handling facility and measure the air velocity at various locations in a grid pattern to determine if modifications are needed to achieve better air distribution.

Forced-air coolers should also be subjected to air velocity measurements. To ensure even pressure drop across pallets and even cooling, the air velocity should be less than 7.5 meters per second (1,500 feet per minute) in the air return plenum (inside the tunnel) and the air supply area (Thompson et al., 2002). Pay special attention to the space between a wall and the outside of a tunnel. If the air velocity is higher, the width of that tunnel or air supply area must be widened.

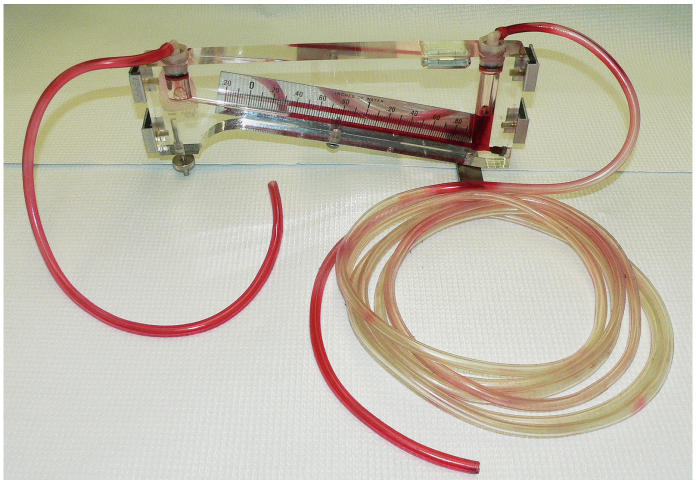
Air velocity can be measured using a vane anemometer, hot wire anemometer, or Pitot tube, with vane anemometers being the simplest, most inexpensive, and easiest to use. Vane anemometers also tend to be more accurate in practical application because the reading is less likely to be affected by stray air currents, unlike hot wire anemometers and Pitot tubes, which measure a smaller cross section of air. A vane anemometer is used by simply holding the device perpendicular to the airflow being measured so that the air catches and turns the vanes; the air velocity is calculated from the speed of the turning vanes.

Vane anemometers used to measure air velocity

PRESSURE DROPS

Rapid forced-air cooling requires high airflow rates through the pallets. These rates are related to the pressure drop across the pallets in the cooling tunnel. A static pressure gauge or manometer can be used to measure the pressure drop from outside to inside a cooling tunnel. This can be a convenient way for operators to monitor whether the tunnel has been well formed, or if air is short cycling past the cartons of fruit, slowing cooling.

A manometer has two tubes: a low-pressure tube and a high-pressure tube. The low-pressure tube should be placed inside the tunnel as far as possible from the fan. The high-pressure tube should be placed outside the tunnel in the cold-storage room air. The pressure drop can vary from essentially zero for a cooling tunnel with excessive openings for the air to short cycle through, to as much as 5 cm (2 inches) water column for a very tight tunnel, possibly with cartons that have minimal ventilation hole area. A pressure drop of 1.3 cm (0.5 inch) water column is typical for a well-designed and managed system.



A manometer for measuring pressure differences

A pressure gauge installed in the return-air plenum to measure the pressure drop between the forced-air cooler fan inlet and outlet is another convenient way to monitor occurrence of short-cycling air. Unusually low pressure in the return air plenum indicates that air is short cycling and that it is necessary to locate and plug the hole(s).

Trailer and Container Inspection and Loading Practices

Containers and trailers must always be inspected prior to loading with cargo. Refer to the PEB Commodities, Inc. *Refrigerated Container/Trailer Loading Checklist* below for items to inspect and record. The temperature of the mangos at the time they are loaded onto the container or trailer should always be recorded using the procedures described in *Temperature Management Practices* above.

Use the *Refrigerated Container/Trailer Loading Diagram* below to make a record of mango stowage in the container or trailer.

PEB Commodities, Inc.

Refrigerated Container/Trailer Loading Check List

Shipper	Temperature Setting (°F/°C)
Commodity	Air Exchange (cfm/cmh)
Transportation Carrier	Carton Count
Container ID	Pulp Temperatures (°F/°C)
Truckers B/L#	Security Seal #
Temp. Recorder # (s)	CA Setting
Vessel Voyage	Reefer Unit Mfg.

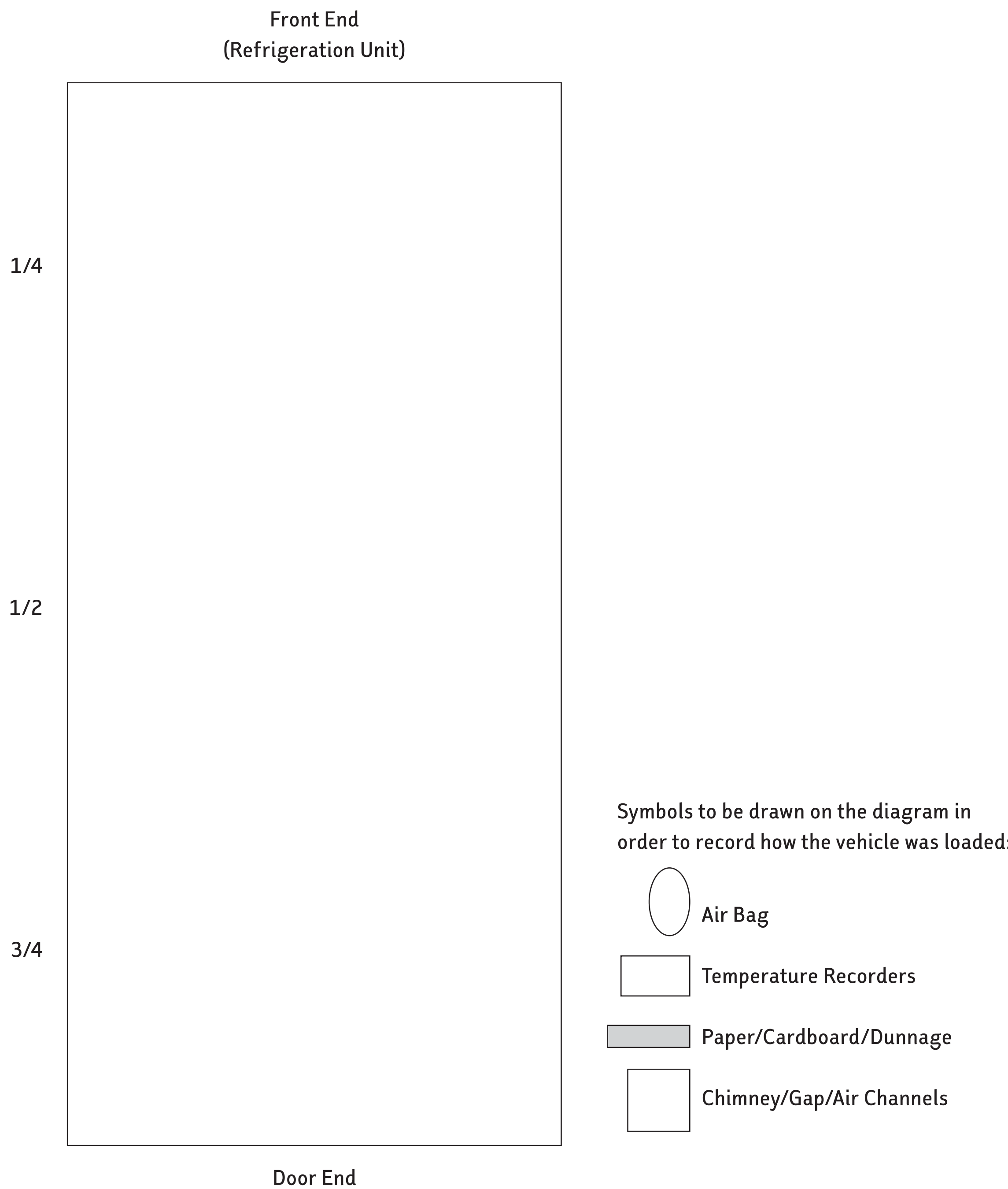
Container Check List	**Yes (✓)**	**No (✓)**
Container Precooled to Carrying Temperature		
Partlow Chart Attached		
Microprocessor Reefer Unit		
Portable Temperature Recorder(s)		
MGset Attached (Nose or Belly Mount)		
Thermostat Setting Correct		
Fresh Air Exchange Correct		
Handstow		
Palletized		
Stowage above red line		

Container Condition	**Okay (✓)**	**Problem (✓)**	**Describe Problem**
Interior Cleanliness			
Interior Odor			
Damage			
Rear Doors			
Door Seals			
Floor Drains & Kazoos			
Reefer Unit Operational			
MGset Unit Operational			
Adequate MGset Fuel			
Photos (see photo exhibits)			
Loading Pattern (see illustration, next page)			

Inspector Signature ________________________________ Driver Signature ____________________________________

PEB Commodities, Inc.

Refrigerated Container/Trailer Loading Diagram



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Evaluating Mango Ripening Facilities and Practices

Mangos that have begun to ripen can be recognized by a change in the skin ground color from green to yellowish green and by the development of yellow color in the flesh near the pit. These fruit are capable of ripening to completion without added ethylene being required; however, ripening is faster and more uniform (within a lot of fruit) when the fruit are treated with 100 ppm ethylene at 20 to 22°C (68 to 72°F). Without ethylene, the ripening rate varies from fruit to fruit, and it takes longer for a lot of mangos to reach a salable condition; the more advanced fruit may develop shrivel and decay while the less advanced fruit may not have ripened to completion, which reduces overall sales.

Modern ripening facilities, used mostly for ripening bananas, employ a design very similar to forced-air cooling that is called 'pressure ripening'. By forcing warm air containing ethylene through the pallets where it comes in direct contact with the fruit within the cartons, ripening can be precisely managed to obtain a very uniform product. A well-controlled ripening procedure produces fruit that possess uniformly good eating quality and allows retailers to offer consumers mangos that are either 'ready to eat' or a day or two away from being ready to eat.

The physical parameters involved in ripening fruit are 1) temperature and temperature uniformity, 2) ethylene concentration, 3) air velocity and pressure drop, 4) relative humidity, and 5) carbon dioxide concentration. Temperature measurement procedures are discussed in the *Temperature Management Practices* section and are not repeated here.

Ethylene concentration can be measured using various commercially available infrared and electrochemical devices, which can be used to automate the gas injection, control an ethylene generator, or monitor ethylene flushing or scrubbing. An ethylene concentration of 100 ppm is recommended for mango ripening, but as low as 10 ppm is as effective. Higher ethylene concentrations have no greater effect than 100 ppm, but caution is required because ethylene in air is explosive within the range of 2.7% (27,000 ppm) to 36%.

It is necessary to locate ripening rooms away from storage areas containing produce that could be damaged by exposure to ethylene. It is also recommended that ripening rooms have a separate ventilation system from that of storage areas to further reduce the chance of ethylene exposure to at-risk products. Portable ethylene detectors are available that can be used to monitor ethylene concentrations around the ripening rooms and storage areas.

Adequate air movement through cartons is the key to a well-managed ripening facility. The air velocity through cartons is related to the pressure differential across pallets, as explained for forced-air cooling. Air velocity and pressure drop should be measured initially in a mango ripening facility, the same way as they are measured in forced-air coolers. This ensures that the setup is properly designed to achieve about 0.3 liters per second per kilogram of fruit (0.3 cubic feet per minute per pound) air velocity through the cartons and 0.8 cm (0.3 inch) water column drop across the pallets for cartons with approximately 5% vent hole area.

For routine management of ripening, it is easier to measure temperature than to measure air velocity or pressure drops. Therefore, it is recommended that calibrated probe thermometers be used to measure mango flesh temperatures in various locations in the ripening room. It should not be too difficult to determine where the highest and lowest fruit temperatures occur in the facility. Thereafter, it is recommended that the flesh temperature difference between the warmest and coolest fruit be routinely monitored and should not exceed 0.6°C (1°F) near the end of the ripening treatment.

Relative humidity during mango ripening should be maintained between 85 and 95% using humidifiers to quickly raise the humidity level when the ripening room doors are closed. The alternative is to rely on water vapor lost from the mangos to provide the necessary humidity!

Carbon dioxide is produced by mangos as a product of respiration, which greatly increases during ripening. Carbon dioxide interferes with ethylene action in promoting ripening. Thus, it is recommended that ripening rooms be vented during ripening treatment, beginning 24 hours after the treatment is initiated and repeated every 12 hours thereafter. Ventilation can be accomplished by opening the ripening room doors for 20 minutes or by using a fan with an automatic timer or sensor.

Carbon dioxide concentration in ripening rooms should be maintained below 1% during ripening treatment. Infrared analyzers are available for monitoring carbon dioxide concentrations in ripening rooms.

Mango Maturity, Disorder, and Disease Identification

Mangos are susceptible to many physical, physiological, and pathological defects, including the following (arranged alphabetically within each of the two groups):

DEFECTS OF PREHARVEST ORIGIN

- Anthracnose
- Insect damage
- Jelly seed
- Lenticel damage (spots)
- Misshapen
- Scab
- Scars (russeting)
- Skin breaks and cracks
- Soft nose
- Stem-end cavity
- Sunburn and sunscald

Mangos exhibiting any of these defects are usually eliminated at the packinghouse, but anthracnose symptoms often do not appear until the mangos ripen, resulting in significant losses at destination markets and consumer homes.

DEFECTS OF HARVESTING AND POSTHARVEST HANDLING ORIGIN

- Bruising
- Decay
- Elevated carbon dioxide injury
- External (skin) discoloration (due to heat injury or chilling injury)
- Immature (poor quality when ripe)
- Internal (flesh) discoloration (due to heat injury or chilling injury)
- Not well trimmed (stem is longer than 12.7 mm [0.5 inch])
- Overripe (too soft)
- Sapburn
- Shriveling (water loss)
- Sunken discolored areas (due to chilling injury)
- Sunken shoulder areas (due to heat damage to the flesh below)
- Uneven (blotchy) ripening (due to heat injury or chilling injury)
- Void spaces in the flesh (due to heat injury or irradiation damage)

Causes and Symptoms of the Major Defects

ANTHRACNOSE

Anthracnose is caused by the fungus *Colletotrichum gloeosporioides*. Symptoms include small, dark spots that enlarge to irregular, dark brown to black areas as the fruit ripens. Infection occurs during flowering and fruit set, and its severity increases with high humidity and rainfall. The fungus often remains dormant on green fruits and develops as the fruit ripens and loses its natural resistance. Preharvest fungicide treatments and postharvest heat treatments reduce incidence and severity of anthracnose.

Anthracnose decay

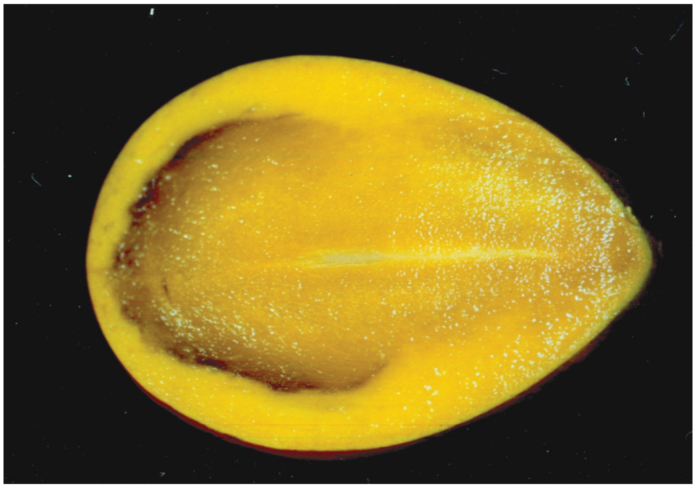
INSECT DAMAGE

Insect feeding (piercing or chewing) and egg laying can cause visible blemishes on mango fruit. The appearance of the damage varies from pinpricks to larger wounds, which may become necrotic or infected by decay organisms.

Insect damage

FLESH DISORDERS

Larger and riper mangos are more likely to develop some preharvest physiological disorders, such as flesh breakdown (stem-end breakdown, stem-end cavity). Internal physiological disorders of mangos include jelly seed (disintegration of the flesh around the seed into a jellylike mass), soft nose (partial ripening of the flesh at the distal end of the fruit), and stem-end cavity (necrosis of the flesh around the cavity). Susceptibility to jelly seed varies among cultivars, and Tommy Atkins is among the more susceptible group. Some of these disorders can be reduced by increasing fruit calcium content via proper preharvest calcium applications.



Jelly seed

SAPBURN

Sapburn (brown to black discoloration of mango skin) results from latex exudate from the cut stem at harvest. The latex released immediately upon harvesting is called 'spurt' sap and causes more injury to the skin compared to 'ooze' sap, which is released more slowly over a period of an hour. If it spreads over the fruit and stays on the fruit skin for longer than 1 to 2 hours or is allowed to dry, chemicals in the sap can cause brown or black blotches on the outer peel tissue. Time of harvest is an important factor. Harvesting mangos during the early morning hours helps minimize sap injury. In addition to keeping the fruit in an inverted position on special de-sapping trays, washing solutions such as lime (0.5%), sodium bicarbonate (1%), aluminum potassium sulfate-alum (1%), and detergents have been used to remove sap and prevent sap injury.

Sapburn caused by latex

MECHANICAL DAMAGE

Surface abrasions, wounding (cuts, skin breaks, and cracks), compression bruising, and vibration bruising are among the types of mechanical damage that can occur during harvesting and postharvest handling operations. Mechanical damage increases mango susceptibility to water loss (shriveling) and infection by decay-causing fungi. Careful handling during harvesting, transport to the packinghouse, packinghouse operations, transportation to destination markets, and at wholesale and retail markets is the main strategy for reducing the incidence and severity of mechanical damage.

Skin breaks, cracks, and bruises

Scab

Russeting

Misshapen mango fruit

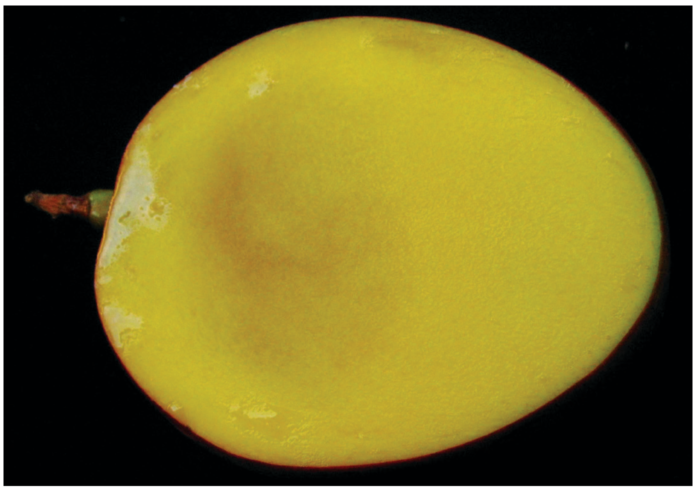
CHILLING INJURY

Chilling injury symptoms include lenticel spot (red or brown lenticel discoloration), uneven ripening, poor color and flavor, surface pitting, grayish scald-like skin discoloration, increased susceptibility to decay, and, in severe cases, flesh browning. Chilling injury symptoms and severity depend on the cultivar, maturity and ripeness stage (riper mangos are less susceptible), and temperature and duration of exposure, which are cumulative. Exposure of mature-green mangos to temperatures below 12°C (54°F) and exposure of partially ripe mangos to temperatures below 10°C (50°F) can result in chilling injury. In all cases, relative humidity should be kept between 90 and 95% to minimize water loss and shriveling. Avoiding exposure of mangos to chilling temperatures throughout their postharvest life is the main strategy for reducing incidence and severity of chilling injury.

Shrunken, discolored areas due to chilling injury

Lenticel spot, which may develop as a result of either chilling injury or heat injury

External (skin) discoloration that may develop as a result of either chilling injury or heat injury

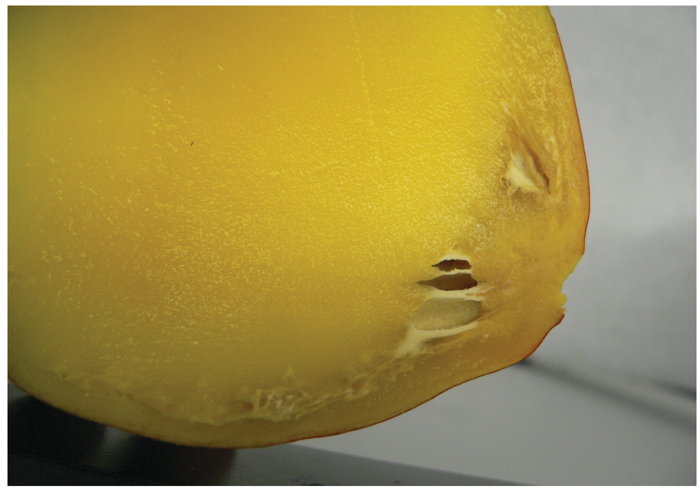


Internal flesh discoloration that may develop as a result of either chilling injury or heat injury

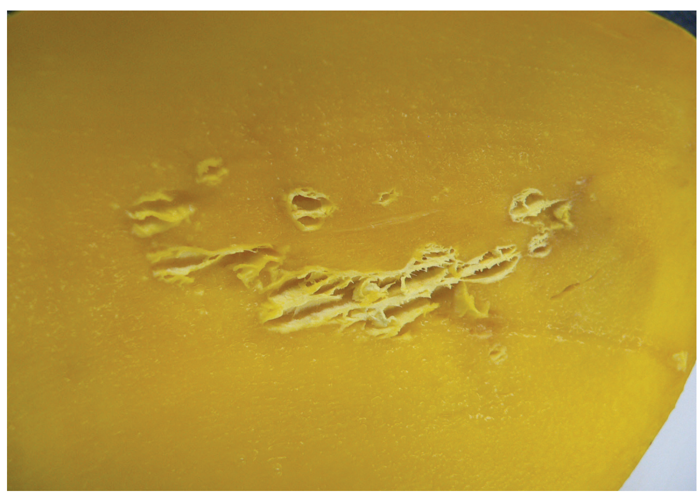
HEAT DAMAGE

Heat injury results from exceeding the time and/or temperature combinations recommended for decay and/or insect control, but most commonly occurs when immature mangos are treated. Symptoms include lenticel spot (brown lenticel discoloration), skin scald, shoulder collapse, blotchy coloration, uneven ripening, and void spaces in the flesh due to tissue death. Heat injuries can be reduced by effective monitoring and management of heat treatment and prompt cooling after heat treatment. Mangos should be protected from water loss, which can be higher after heat treatment, by maintaining 90 to 95% relative humidity and/or using plastic film liners or bags.

Shrunken shoulder areas due to heat injury



Stem-end cavity caused by heat injury



Void spaces in the flesh due to heat injury or irradiation damage

Uneven, blotchy ripening due to heat injury

Sunburn (left) and sunscald (right)

STEM-END ROT

Stem-end rot results from infection of mangos by the fungus *Lasiodiplodia theobromae*, which grows from the pedicel ('stem') into a circular black lesion around the pedicel 'and mechanically damaged areas of the skin, especially if the mangos are exposed to high temperature and high relative humidity. Field hygiene (removal of dead flower parts, leaves, and twigs) and preharvest fungicide treatments reduce the incidence of stem-end rot.

Stem-end rot

MISCELLANEOUS DISEASES, DISORDERS, AND OTHER QUALITY PROBLEMS

An immature-harvested mango showing failure of normal ripening to occur

Overripe fruit (too soft)

Shriveling from water loss

Mangos with stems that are not well trimmed

Elevated carbon dioxide injury

Mango Quality Assessment Procedures

The Mango Quality Assessment form included later in this publication was used during the Mango Quality Project, in which mango handling practices both outside and inside the U.S. were monitored as well as mango fruit quality in U.S. markets for more than a year. It can be modified and used to evaluate and record handling practices and fruit quality in most mango handling operations.

Taking Digital Photographs

The requirements for taking photographs as part of the inspection process are quite basic, but good photography is essential to a quality inspection.

A good-quality digital camera must be used. Color accuracy is paramount for an accurate picture of the condition of samples, and good resolution enables the viewer to read the photo cards placed next to the photographed items. X-Rite ColorChecker® reference colors (red, yellow, and green) or equivalent, and a black velvet background should be used when possible. A protocol for taking images is required so that photos can be analyzed with color/shape software. Additionally, the inspector should always have at least a 1 GB flash card and an extra set of charged batteries.

On bright days with strong shadows, it may be necessary to use fill flash techniques to get good exposures. Samples should be brought out into the light to be photographed unless it is raining. This is particularly true on overcast days when there is not much light or if the photographs are being taken in a very shaded area.

All samples should be photographed from as close as possible to obtain maximum clarity, and then cut and photographed again as closely as possible to show the condition of the interiors of the fruit samples. The photo card should be placed at the same distance from the lens as the samples being photographed to avoid depth of field or auto focus problems, and/or confusion as to which samples were taken from which lots. In the event serious problems are found on some samples and not on others, the samples should be labeled as to the location from which they were taken.

Every inspection should include a standard battery of photographs, such as those listed below. In addition, photos should be taken of any unusual occurrences or problems, such as mangos with unusual defects, housekeeping matters, a dirty truck or container interior, and obvious and serious stowage, airflow, or carton problems.

Standard photographs for each type of inspection should be developed. Examples of photographs that should be taken for loading or unloading a transit vehicle are listed below.

- A general photograph of the entire front (machinery) end of the transit vehicle
- A close-up of the thermostat set point and current temperature readings, along with the Partlow chart and a PTI ('pretrip inspection') sticker, if present
- A close-up of the fresh air exchange vents showing their settings
- A close-up of the missing drain rubber boots ('kazoos')
- A close-up of the security door seal(s)
- A general photograph of the rear of the entire load with the doors open
- A photograph down the top of the load showing any temperature recorders, ethylene/CO_2 scrubbers, and the red line
- A close-up of the sample carton(s) lifted in the air at an angle and the adjoining cartons to show all packaging vents and the packaging code

- A close-up of the top of the unopened sample carton(s)
- A close-up of the opened sample carton(s), showing the contents
- A close-up showing the manufacturer and the carton strength certificate
- A close-up of representative and random sample products (Take picture in macro mode as close as possible to show detail)
- A close-up of the representative and random sample products cut with an OXO mango slicer and placed on top of the contents of the carton(s) (Take picture in macro mode as close as possible to show detail)
- A close-up of the replacement customs seal if the inspection is a tailgate

References

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MANGO QUALITY ASSESSMENT FORM

Supplier Information Farm/Packinghouse/Importer/DC/Retail (Circle one)

Name of Facility: ______________________________ Date: __________ Time: ____________

Address______________________________ Phone Number____________ Fax: ____________

E-Mail Address______________________________ Contact(s): ______________________________

Inspection Details

Inspection Type (check one): Farm ____ Packinghouse/Shipper ____ Preload ____ Border Crossing ____ Consignee/Repacker ____

DC ____ Retailer ____

Date of Inspection (d/m/y) ____________ Start Time (local) ________ Finish Time (local) ________ (24-hour time)

Special Instructions (if any)

____

____

Heat Treatment Code for Packinghouse: ______

Person(s) Attending	Organization	Representing

General Information–Mango Farm

Temperature Data to be Recorded in °C or °F (CIRCLE ONE)

Air Temperature: ________° Relative Humidity: _____________% Rainy season: Yes / No

Irrigation prior to harvest: Yes / No Date of Last Irrigation: ____________ Pesticide use at harvest: Yes / No

Harvest Operations: Use of clippers: Yes / No Use of ladders: Yes / No Harvest Aids: Yes / No

Maturity indices employed at harvest (circle): Days from flower to harvest Shoulders Size Weight Peel Color Flesh Color Brix

Other Maturity Indices: _________________ Observations: ____

Harvest Crew Training: Yes / No Wages based on (circle one): Time / Weight / Units Other: ___________________________

Peduncle left on fruit: Yes / No Average Length: _______ cm. Shade after harvest: Yes / No

Latex (sap) removal practices: ____

Mango sorting at farm: Yes / No Fruit wash at farm: _____________________________ Time lapse before shipping: _____ min.

Distance from farm to packinghouse: __________________ km Transit time from farm to packinghouse: _________ min.

Transport Type: Open Bed Truck / Covered Truck / Other Transport during: Morning /Afternoon /Night / Anytime

General Observations or Comments:

____

____

____

Packinghouse / Importer/ Distribution Center Operations

1. PACKINGHOUSE RECEIVING AREA

Shaded Mango Waiting Area: Yes / No Approximate wait time: ______ min. Air temperature: ______°

Pulp Temperature at unload: ______° Mango Unload: Dry Dump / Wet Dump Description: ____________________________________

Sanitizer: _______________________ Concentration: ___________________ Frequency of sanitizer adjustment: ___________________

Water Temperature: ______° Water pH: ____________ Frequency of water exchange: _________________

Fresh Water wash after dump: Yes / No Sanitizer and concentration: ____

Sizing operation: Manual / Machine Description: ____

2. PACKINGHOUSE HEAT TREATMENT AREA

No. of hot water tanks: ______ Hot water tank temperature: at outlet ______° at inlet: ______° Temperature schedule: Constant / Decreasing

Water Temperature setpoint(s): _____________ Number of cages per tank: _____________ Boxes per cage: _____________

Water heating method: Direct steam injection into tank / Hot water injection into tank Water pH: ________

Sanitizer: _______________________ Concentration: ___________________ Frequency of water exchange: ________________

Pulp temperature after heat treatment: ______° Hydrocooling: Yes / No Cold Water Temp: ______° Duration: ______ min.

Time delay between heat and hydrocooling: ________ min. Chlorination: Yes / No Pulp Temp after hydrocool: ______°

Frequency of water exchange: ___________________________ pH of Water: _________

Additional Comments:

____

____

____

3. POST-HOT-WATER TREATMENT COOLING PROCEDURES (ROOM COOLING)

Waiting Time before packing: ________ min. Air temp. at wait area: ________ ° Fans for air circulation: Yes / No

Approximate pallet spacing: __________ cm between rows _____________ cm between lines

Air temp. at packing area: ________ °

Comments:

____

____

4. MANGO PACKING LINE

Packing line entry: Dry Dump:________ Manual:________ Automatic:________ Wet Dump: ________ Manual:________ Automatic: ________

Drops > 1 ft.: Yes / No 90° Turns (#): ________ Other comments: ____

Waxing: Yes / No Wax formulation: _________________ Air Dry: Yes / No Air Temperature for drying: ________ °

Fruit sorting at packing tables: Yes/No Adequate cushioning for packing tables: Yes/No Adequate lighting for packing: Yes/No

Carton Assembly: Manual / Machine Adequate Carton venting: Yes / No Carton Burst Strength (psi) ______

Vents align in pallet: Yes / No Cross Stacking in pallet: Yes / No Number of boxes per pallet: ________ Number of straps: ________

Pallet dimensions (footprint): ________ x ________ cm Braces: Cardboard / Plastic

Comments:

____

____

5. COOLING AND LOADING PROCEDURES

Storage Room temperature: ________ º   Relative Humidity: ________ %   Forced-air cooling: Yes / No   Duration: ________ min.

Forced-air temp. gradient: coolest location (outside, next to fan) ________ º   warmest location (inside, farthest from fan): ________ º

Forced-air humidification: Yes / No   Relative Humidity: ________ %   Wood pallet vent blocking: Yes / No

Refrigerated loading dock: Yes / No   Sea Container Inspection and Pre-cool before load: Yes / No   Temp. setting: ________ º

Humidity set point: __________%Air Exchange Setting: ________ CFM   Utilization of Temp. Recorder: Yes / No

Cooling equipment manufacturer: Thermo King / Daikin / Carrier   Power generator location: Nose mounted / Belly mounted

Location of temp. recorder(s): _________________________ # of cartons in shipment: ________________

Stowage pattern: _________________________   Stacked above Red Line: Yes / No   Blocking/bracing ________________

Container drains closed: Yes / No   Air shocks on Truck: Yes / No   Approximate distance to shipping port: _____________ km

Controlled Atmosphere settings: _____________________   BL # : ____

Container # : ___________________________________   Vessel/Voyage: ______________________________________

Load Port: _____________________________________   Final Destination:____________________________________

Discharge Port: _________________________________   Consignee: ___________________________________ ______

Estimated Voyage duration: __________________ days.

Comments:

____

____

Container/Trailer Loading Diagram

Front End (Nose)

TOP VIEW

1/4

1/2

3/4

Door End

Show Following Items on Diagram:

- Air Bag
- Temperature Recorders
- Paper/Cardboard/Dunnage
- Chimney/Gap/Air Channels

Documentation

(if available)

	Attached
Bill of Lading	☐
Commercial Invoice	☐
Packing List	☐
Customs Declaration	☐
Delivery/Tally Receipt	☐
Certificate of Insurance	☐
Quarantine Inspections	☐
Temperature Records	☐
Photographs	☐
Laboratory Analyses	☐
Blocking/Bracing Diagram	☐
Government Report(s)	☐
QC Inspection Info	☐
Other	☐

Inspection/Assessment of Mangos at Farm/Packinghouse/Importer/DC/ Retail Level

Procedure

After collecting the appropriate general information about the facility supplying the fruit, proceed to assess mango quality. In the case of a farm visit, sample fruit prior to transport from farm to packinghouse. In the case of a packinghouse visit, sample fruit ready for loading and export. It is recommended that at least 10 fruit of the same variety be sampled at random. Focus on external quality parameters prior to slicing the fruit in order to observe internal quality.

At the Distribution Center, evaluate the overall condition of the fruit and make note of the ripeness stage and any external defects that you observe. Photograph the fruit in cartons.

At Retail level:

1. Note general condition of fruit on display: *Excellent*, *Very Good*, *Good*, *Fair*, *Poor.*
2. Estimate and record the approximate percentage of red coloration on peel for fruit on display. Red coloration on the peel is preferred by the consumer, although not all mango varieties present red coloration on the peel.
3. Purchase 10 mangos chosen at random from the predominate label; if more than one label is available, sample 10 fruit from the additional labels.
   Note: If the mangos on display are green and hard, purchase an additional 5 to 10 fruit to hold 5 days at 20°C for evaluation of 1) ability to ripen; 2) appearance of physiological injury symptoms.

DURING FRUIT EVALUATION (at the lab)

Choose a table with good lighting to proceed with fruit evaluation. Surface blemishes are rated based on the percentage of fruit surface affected by the defect. In numerous cases, fruit will have more than one defect. Rate the percentage of the fruit affected by each defect. Refer to rating scales proposed for each parameter of mango quality to be evaluated (see *Recommended Rating Scales for Mango Evaluation* later in this form).

Procedure

Number each fruit with a paint pen. Photograph the fruit on both sides in groups of five against black velvet. Place the color reference plates next to the fruit for image analysis.

1. Rate external ground color (*Green, Turning, or Yellow*).
2. Evaluate the external appearance of individual fruit. Refer to the section on *Mango Maturity, Disorder, and Disease Identification* in the Appendix of the *Mango Postharvest BMP Manual* for illustrated examples.
   - Blemishes (mechanical injury, hot water scald, lenticel spots, insect damage, stem-end collapse, etc.)
   - Mango peel shrivel due to water loss
   - External symptoms of decay (anthracnose spots, stem-end rot, etc.)
3. **Before proceeding to slice the fruit, be sure to first evaluate the fruit firmness by hand feel.**
4. Slice the mangos with the OXO mango slicer. Rate the ripeness of individual fruit using the 1 to 5 mango pulp color scale. Photograph internal appearance.
5. Measure fruit firmness using an Effe-gi-type fruit firmness tester with a 5/16 inch (8 mm) Magness-Taylor-type round tip. Measure flesh firmness at two locations around the equator of the fruit and on either side of the seed (at least 5 mm from the peel; see photo on page 13). Express measurements in pounds-force (lbf).
6. Evaluate the internal appearance of individual fruit. Refer to the section on *Mango Maturity, Disorder, and Disease Identification* in the Appendix of the *Mango Postharvest BMP Manual* for illustrated examples.
   - Note if there is internal bruising (in seed cavity, below peel, or both)
   - Note if there is presence of vascular browning in tissue adjacent to the peel
   - Note if there is characteristic mango odor to fruit pulp
7. Evaluate for presence of signs of internal disorders or decay.
   - Stem-end rot
   - Note if external body rots extend into flesh
   - Note if jelly seed, soft nose, or stem-end breakdown are present
   - Note if internal heat or chilling injury symptoms are present

Date: ______________________ Variety: ______________________ Time of day: ______________

Facility name: ______________________ Location: ______________________

Evaluator: ______________________ Label/Origin: ______________________

STORE DISPLAY EVALUATION

Comments: ____

Overall Condition of Fruit Surveyed:

Excellent	V. Good	Good	Fair	Poor

Average Percentage of Blush on the Peel (visual estimation):

0-20%	21-40%	41-60%	61-80%	81-100%

LAB EVALUATION AT TIME OF SURVEY OF EXTERNAL APPEARANCE

Fruit #	Fruit Size	Ground Color			Peduncle Trimming		Heat or Chilling Injury		Fruit Shrivel (0-3)	Scars and Cuts (0-3)	Stem-End Collapse (0-3)	Sap Burn (0-3)	External Decay (severity 0-3)	
		G	T	Y	(Yes/ No)	Length >/< 1/2 inch	Lenticel Spots (0-3)	Peel Discoloration (0-3)					Anthracnose	Stem End Rot
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

INTERNAL APPEARANCE RIPENESS, INTERNAL DECAY

Fruit #	Fruit Firmness (hand scale 1-5)	Bruising (0-3)	Flesh Ripeness (color 1-5)	Flesh Firmness (lbs-force)	Vascular Browning (0-3)	Soluble Solids Content (°Brix)	Mango Odor (1-3)	Internal Disorders or Decay		Date when Ripe (lab-ripened fruit only)
								(Yes/No)	Description/Severity (0-3)	
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

OBSERVATIONS:

___

___

___

Recommended Rating Scales For Mango Evaluation

Note: refer to "*Mangos. Inspection Instructions – Combined Market and Shipping Point,*" available from USDA AMS. References to "area" are based on fruit 3 inches in diameter and should be adjusted for significantly smaller and larger fruit. For scoring defects, use a 0–3 scale in which 0 = *none*, and scores of 1, 2 and 3 correspond to "*Injury,*" "*Damage,*" and "*Serious Damage*," respectively, in the Inspection Instructions.

EXTERNAL QUALITY EVALUATIONS

Overall Condition: Score the display as a whole based on the overall appearance in terms of fruit appearance.

Peel Coloration (% Red Coloration): Mangos can possess several skin colorations depending on the variety, ripeness stage, growing region (climatic conditions), and pruning practices (light penetration inside the canopy). In general, skin blush (reddish pink to purple color) is the result of good light penetration in the canopy and cool night temperatures. On the other hand, shades of yellow, orange, or lack of green color in the peel can be signs of fruit ripening.

During commercial harvest, pickers harvest fruit that are physiologically mature; however, different ripeness stages will be present in the tree at the same harvest time. Mango peel color is often judged based on the percentage of fruit surface showing reddish coloration; however, changes in peel color denoting ripening include destruction of chlorophyll and onset of carotenoid pigments development, not red color. Some varieties remain green when ripe. Several produce marketing specialists agreed that U.S. consumers prefer mangos with blush on their peels.

Fruit Size: When exporting mangos, they are usually commercialized in 4-kg boxes containing different numbers of fruit, depending on their size. Mango packinghouses usually pack boxes with either 6, 7, 8, 9, 10, 12, 14, or 16 mangos per box—thus, average fruit weights for those sizes are approximately 667, 571, 550, 444, 400, 333, 286, and 250 grams, respectively.

When the U.S. market has abundant fruit offerings, size requirements become stricter, usually requiring mangos to be no smaller than a size 10.

Ground Color: Identify the color of the skin, excluding the portion with red color (i.e., 'blush'), as G = *green*, T = *turning* (light greenish yellow), or Y = *yellow*. When describing ground color, consider the predominate color even though varying degrees of color are present.

Peduncle Trimming: Indicate if the peduncle is present or not (Y/N); if present, the peduncle should be no longer than approximately ½ inch if it was broken off at the natural abscission zone (indicate greater than [>] or less than [<] ½ inch length).

Lenticel Spots: Lenticels are natural openings in mango peels that facilitate the gas exchange involved in respiration. Lenticels turn dark and necrotic during postharvest storage. This is especially evident in mangos treated with hot water. Lenticel spotting could be an initial symptom of hot water injury to the fruit peel, or a symptom of chilling injury. Lenticel spotting should be judged based on the percentage of surface area of the fruit that is affected and scored using a scale of 0 to 3:

0 = *no lenticel spot*
1 = *slight lenticel spot*
2 = *moderate lenticel spot*
3 = *severe lenticel spot*

No Score = 5% or less of the fruit surface affected
Slight = > 5% up to 15% of the fruit surface affected
Moderate = > 15% up to 25% of the fruit surface affected
Severe = > 25% of the fruit surface affected

Peel Discoloration Due to Hot Water Injury or Chilling Injury: Mangos are susceptible to exposure to hot water above 116°F. In many cases, such as with immature fruit, the peel becomes scarred by exposure to hot water. A distinct brown discoloration and even necrotic tissue without any definite pattern are symptoms of hot water scald.

Due to their subtropical origin, mangos are also susceptible to chilling injury at storage temperatures below 10°C (50°F). The mango cultivar, maturity at harvest, and length of storage period influence symptom severity. Mangos with chilling injury may show lenticel spots, a rough, 'pebbly' surface, gray skin discoloration, and dullness or lack of shine on the peel.

Peel discoloration should be judged based on the percentage of surface area of the fruit that is affected and scored using a scale of 0 to 3. **Note whether the discoloration (for the entire sample) appears to be due to heat injury or chilling injury (or both) by circling the appropriate heading(s).**

0 = *no peel discoloration*
1 = *slight peel discoloration*
2 = *moderate peel discoloration*
3 = *severe peel discoloration*

No Score = 5% or less of the fruit surface affected
Slight = > 5% up to 15% of the fruit surface affected
Moderate = > 15% up to 25% of the fruit surface affected
Severe = > 25% of the fruit surface affected

Fruit Shrivel Due to Water Loss: Even though most packinghouses exporting to the U.S. utilize wax coatings on mangos to limit water loss and improve fruit shine, it is probable that after lengthy handling periods, mangos will begin to show signs of water loss. Changes in peel texture (i.e., shriveling) and dull coloration might be interpreted as symptoms of water loss. Since shriveling would probably occur throughout the surface of the fruit, especially when fully ripe, it is recommended to rate shriveling on a scale of 0 to 3:

0 = *no shriveling*
1 = *slight shriveling of the peel*
2 = *moderate shriveling of the peel*
3 = *severe shriveling of the peel*

No Score = 5% or less of the fruit surface affected
Slight = > 5% up to 15% of the fruit surface affected
Moderate = > 15% up to 25% of the fruit surface affected
Severe = > 25% of the fruit surface affected

Scars and Cuts: The Inspection Instructions distinguish between scars and cuts ("mechanical damage" or "skin breaks") that are healed *versus* fresh and unhealed. Healed scars and cuts are considered "quality" or permanent defects that do not change during storage and shipment; unhealed scars and cuts are condition defects. Score scars and cuts that are condition defects only using a scale of 0 to 3:

0 = *no scars or cuts*
1 = *slight injury*
2 = *moderate injury*
3 = *severe injury*

Slight = The injury exceeds a circle that is ¼ inch in diameter or ¼ inch in length.
Moderate = The injury cuts into the flesh or exceeds a circle that is ½ inch in diameter or ½ inch in length.
Severe = The injury cuts into the flesh or exceeds a circle that is 1 inch in diameter or 1 inch in length.

Stem-End Collapse: This is a mango disorder, especially evident in 'Tommy Atkins' fruit, in which the tissues surrounding the stem-end of the fruit collapse, causing fruit deformation. Upon peel removal, empty cavities are evident where the vascular tissues were present. Usually, immature mangos are more susceptible to stem-end collapse, although it is claimed that cultural practices, such as irrigation withdrawal prior to harvest and time delays from harvest to heat treatment, might reduce the symptoms. Stem-end collapse should be rated on a scale of 0 to 3.

0 = *no stem-end collapse*
1 = *very slight stem-end collapse*
2 = *moderate stem-end collapse*
3 = *severe stem-end collapse*

No Score = 5% or less of the fruit surface affected
Slight = > 5% up to 10% of the fruit surface affected
Moderate = > 10%, but < 15% of the fruit surface affected
Severe = > 15% of the fruit surface affected

Note: In the Inspection Instructions, this disorder is called "Sunken Areas with Underlying Flesh Discolored" and "Sunken Discolored Areas."

Sap Burn: The sap or latex transported through the vascular tissues of the mango tree and fruit are sometimes harmful to the peel. The procedures involved in handling of fruit during harvest and transport to packinghouses often result in sap from the mango stem dripping over the peel tissues, causing a streak of necrotic tissue and lenticel spots. Sap burn should be judged on a scale of 0 to 3. Sap that is clear or not dark enough to detract, or that does not affect the appearance of the fruit should not be scored as sap burn.

0 = *no sap burn*
1 = *slight sap burn*
2 = *moderate sap burn*
3 = *severe sap burn*

No Score = 5% or less of the fruit surface affected
Slight = > 5% up to 15% of the fruit surface affected
Moderate = > 15% up to 25% of the fruit surface affected
Severe = > 25% of the fruit surface affected

External Decay: There are several pathogens that affect mangos postharvest, mostly fungal infections. Disease presence should be noted with a severity judgment. If possible, under observations, the surveyor should try to identify the causal agent for the decay. Decay severity should be judged using a scale of 0 to 3. **Note:** The definitions of the rating scores differ for anthracnose compared with any other type of decay.

0 = *no surface decay*
1 = *early (slight) surface decay*
2 = *moderate surface decay*
3 = *advanced (severe) surface decay*

Stem-end Rot Incidence: Stem end rot is a decay symptom most probably caused by fungal or bacterial infection (*Dothiorella* sp. or *Erwinia pantoea*). The disease affects Tommy Atkins fruit grown in various countries and is a major concern among growers. Preliminary research has shown that stem-end rot is reduced by as much as 50% in fruit treated with hot water, making this the most effective treatment available.

Early (slight) (1) = ≤ 10% of the fruit surface affected
Moderate (2) = > 10 up to 25% of the fruit surface affected
Advanced (severe) (3) = > 25% of the fruit surface affected

Anthracnose Incidence: Anthracnose is a fungal disease that usually becomes evident in ripe mangos after 2- to 3-week postharvest storage periods. The disease appears as necrotic spots on the fruit peel that increase in size with increased severity of the disease. Peel lesions eventually cause flesh symptoms, such as softening of the tissue immediately underneath the anthracnose lesions.

Injury (1) = > 5% up to 15% of the fruit surface affected
Damage (2) = > 15% up to 25% of the fruit surface affected
Serious damage (3) = > 25% of the fruit surface affected

INTERNAL QUALITY EVALUATIONS

Fruit Firmness (hand pressure scale of 1 to 5 in half-point increments): 1 = *very hard* (no "give" in the fruit), 2 = *sprung* (can feel the flesh deform [break] 2 to 3 mm under extreme finger force; very rubbery), 3 = *near ripe* (2 to 3 mm deformation achieved with slight finger pressure; fruit deforms with extreme hand pressure), 4 = *ripe or eating soft* (whole fruit deforms with moderate hand pressure), and 5 = *overripe* (whole fruit deforms with slight hand pressure).

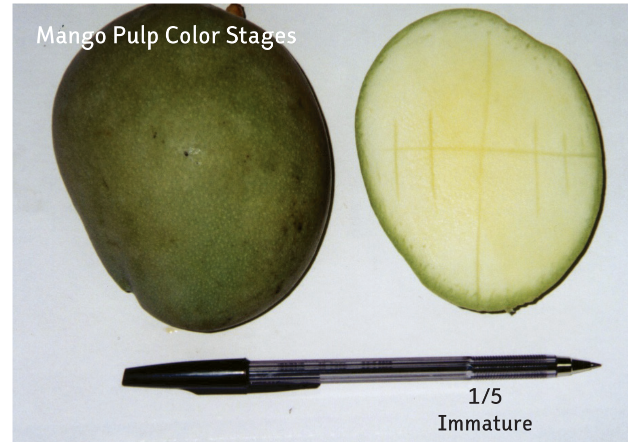
Bruising: Careless or rough handling may result in depressions or flat spots on mango fruit in which the peel is often not injured, but the underlying flesh is damaged and discolored. Bruises should be scored on the basis of depth, area, and discoloration using a scale of 0 to 3:

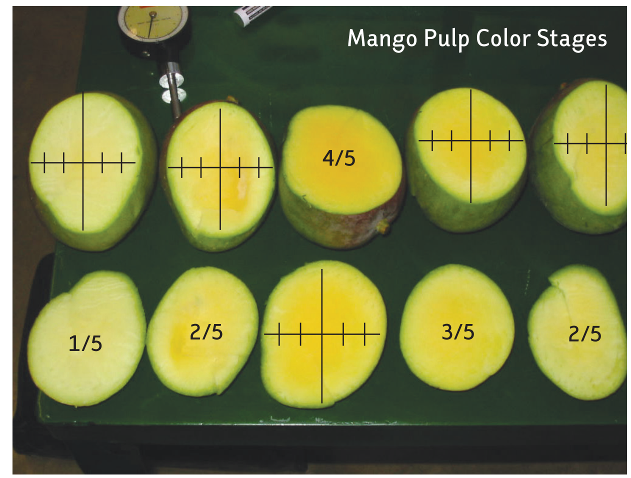
0 = *no bruises*
1 = *slight bruising*
2 = *moderate bruising*
3 = *severe bruising*

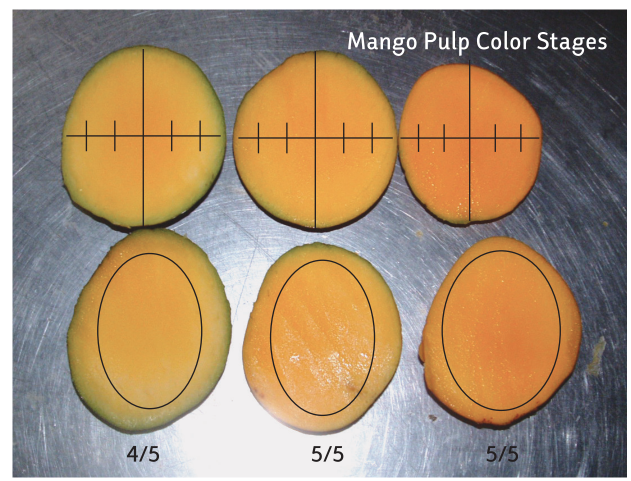
Slight = Slight surface indentation and discoloration of the flesh extending > ⅛ inch in depth and > ½ inch in diameter.
Moderate = Surface indentation and discoloration of the flesh extending > ¼ inch in depth and > ¾ inch in diameter.
Severe = Surface indentation and discoloration of the flesh extending > ½ inch in depth and > 1 inch in diameter.

Flesh Ripeness: In most field operations, fruit maturity and ripeness is rated based on a 5-point flesh color scale. The scale focuses on the proportion of white or green to yellow-orange segments showing in the mango flesh (see photos on right). A fruit with ¼ of its flesh surface showing yellow coloration would receive a color rating of 2; a fruit with ½ of its flesh surface showing yellow coloration would receive a color rating of 3; and so on, with fruit showing 100% yellow-orange flesh coloration rated as a 5. Mangos with flesh that has no yellow coloration, only white or green, would receive a rating of 1 and would be considered immature.

In numerous harvest operations for export, growers aim to harvest fruit with ¼ to ½ of the flesh showing yellow-orange coloration (i.e., stages 2 to 3). Fruit harvested at stages 1 and 2 have a higher incidence of heat-treatment-related blemishes, such as stem-end







collapse (Tommy Atkins), lenticel spotting, and hot water scald, compared to fruit harvested at stages 3 and higher.

Flesh Firmness (lbs force)**:** Due to the activity of numerous enzymes during ripening, mango fruit lose firmness and yield to the touch as they ripen. A measurement of the fruit's firmness is an indication of the rate of ripening. Firmer fruit are preferred in the market. Fruit firmness should be measured using a portable firmness tester (Effe-gi type) with a 5/16 inch (8 mm) diameter Magness-Taylor probe. Measurements should be taken at two opposite sites between the peel and the mango seed (see photo below). The average of both measurements should be reported for each fruit.


Mango Pulp Firmness Evaluation

Vascular Browning: This is a symptom of injury caused by exposure to hot water, especially with immature fruit. The vascular strands in the fruit flesh take on a distinct brown discoloration that begins with the vascular strands near the surface of the fruit and extends inward as the disorder becomes more severe. Vascular discoloration should be judged based on the intensity of the brown discoloration and its depth into the flesh using a scale of 0 to 3:

0 = *no vascular discoloration*
1 = *slight vascular discoloration*
2 = *moderate vascular discoloration*
3 = *severe vascular discoloration*

Slight = Slight discoloration extending to a depth of no more than 5 mm into the flesh
Moderate = Moderate discoloration extending to a depth of more than 10 mm into the flesh
Severe = Severe discoloration extending to a depth of 15 mm or farther into the flesh

Soluble Solids Content (°Brix): Soluble solids content is a measure that correlates well with mango sweetness and sugar content since the major soluble constituent in the fruit is fructose. Soluble solids content should be measured from mango juice samples obtained upon squeezing the mango cheek that resulted from slicing for flesh color ratings.

Mango Odor: The odor of mango fruit can indicate degree of ripeness, or it can indicate disorders, such as fermentation or decay. Mango odor should be rated as follows:

1 = *unripe odor*
2 = *normal ripe odor*
3 = *off odor* (describe under "Observations")

Internal Disorders or Decay: Mangos are subject to many different disorders that may cause internal discoloration or flesh breakdown. Look for stem-end rot in the flesh that may not have been apparent externally and note if external body rots extend into the flesh.

Internal breakdown is a suite of disorders that is initiated before harvest but causes serious damage to postharvest mangos. There are three types of internal breakdown: 'jelly seed', 'soft nose', and 'stem-end breakdown'. The affected flesh in all three of these disorders appears to be soft, overripe, water soaked, or jelly like.

Chilling injury and *heat injury* may also cause diffuse gray or brown internal flesh discoloration that is distinct from the vascular discoloration caused by heat injury in that it affects the mesocarp tissue (flesh) only. It is also distinct from bruising due to the tissue being intact. Internal starchy or pithy tissue and cavitations (other than at the stem end) should be scored in this category.

Mangos damaged by freezing exhibit water-soaked tissue extending from the surface of the fruit into the flesh.

Internal damage and decay should be scored on the basis of the area affected using a scale of 0 to 3:

0 = *no damage or decay*
1 = *slight damage or decay*
2 = *moderate damage or decay*
3 = *severe damage or decay*

Slight = Any damage or decay affecting an area up to ¾ inch in diameter
Moderate = Damage or decay affecting an area more than ¾ inch up to 1½ inches in diameter
Severe = Damage or decay affecting an area more than 1½ inches in diameter