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RECENT DEVELOPMENTS IN POSTHARVEST HANDLING, STORAGE AND TRANSPORT OF FRUITS, VEGETABLES AND ORNAMENTALS

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ABSTRACT

State-of-the-art techniques used in the handling, storage and transport of perishable horticultural produce are presented. Emphasis is given to methods of quality evaluation, cooling, packaging and storage. Equipment and instruments which can be used for estimation of produce quality both in the field and at the research laboratory level are highlighted. The applicability of techniques to current postharvest systems in the Caribbean is examined.

RESUMEN

Se presenta las técnicas avanzadísimas que se utilizan en el manejo, el almacenamiento y el transporte de productos hortícolas que no se conservan bien. Se hace hincapié en los métodos de evaluación cualitativa, la refrigeración, el empaquetado y el almacenamiento. Se destaca los equipos y los instrumentos que se pueden utilizar para estimaciones cualitativas de los productos agrícolas, tanto en el laboratorio de investigación como fuera. Se examina las posibilidades de la aplicación de estas técnicas a los sistemas agrícolas actualmente utilizados en el Caribe en el período posterior a la cosecha.

In the Caribbean region, there has been an intensification of efforts to increase agricultural production with the aim of increasing self-sufficiency in food production and opportunities for export of agricultural produce. Postharvest technology plays an important role in reducing the tremendous losses which occur in distributing products and maintaining quality specified by domestic and foreign markets.

Many of the techniques used to handle perishables in developed temperate countries are not directly applicable to tropical areas. This is mainly the result of the unique physiological requirements of tropical produce, as well as the lack of infrastructure and/or capital required to implement these technologies. The selection and adoption of appropriate postharvest technologies are critical to the development and success of production-marketing systems in tropical regions.

This paper examines techniques used for handling perishables and their adaptability to tropical systems of production and marketing. Recommendations for improvements in handling, storage and distribution of tropical perishables are also given.

Harvesting

In the Caribbean, as well as in the more developed regions, fruits and vegetables are predominately harvested manually. The advantages of hand harvesting include selective harvest (accurate maturity selection and multiple harvests), minimum damage and economy. In addition, the small sizes of holdings and the availability of family labour often preclude the use of mechanical harvesting methods in the Caribbean.

The use of harvesting aids for fruits and vegetables is rapidly increasing. Harvey and Jeffers (9) developed a harvesting aid that successfully lifted yams *(Dioscorea* spp*)*, sweet potatoes, carrots and onions. More recently Harvey (personal communication) designed a two-row mechanical harvesting aid which lifted cassava *(Manihot* spp*)* with low levels of tuber damage.

Other types of harvesting aids include belt conveyors which move the commodity to a central loading or in-field handling device, scoops with protruding rods on their ends used to comb through some berry crops, and platforms or movable worker positioners with bins and other containers for accumulating the produce, used in crops such as bananas and papayas.

Picking poles are used extensively for harvesting mangoes and papayas. In Hawaii papayas (var. 'Solo') are harvested with the aid of a long-handled suction cup which is positioned over the stylar end of the fruit. Twisting the handle removes the fruit from the tree. In Thailand, a papaya picking implement has been developed for small orchards on hilly terrain. The implement consists of a pole and a bag. The top half is made of canvas and the bottom of nylon mesh. The mesh enables the picker to see the fruit and accurately position the blade. The harvested fruit falls into the bag, which is then lowered to the ground (2).

Picking bags and aprons are also useful harvesting aids. One such apron, recently developed by CARDI, has two compartments which allow for in-field grading. Zippers at the base facilitate emptying and minimize bruising. The apron has been recommended for harvesting of ochroes, peppers and cotton. A similar bottom-dump picking bag is used in California for harvesting stone fruits. It is essentially an open-ended bag with a base fold, the corners of which are fastened with two cords which are hooked to the sides of the bag during filling. The bag is emptied by releasing the cords and allowing the produce to fall through the open base.

A fairly recent development is night harvesting using lights erected on a mobile boom. The practice is common for cantaloupes and has the advantage of reduced cooling needs by taking advantage of night temperatures.

Packaging and packaging materials

Packages for horticultural produce should provide:

- Protection against handling abuse in marketing and distribution channels.
- Accommodation for temperature management of the produce during pre-cooling, storage and ripening.

- Wet-strength and compressive-strength characteristics compatible with in-package cooling operations, high volume packaging operations and handling systems in distribution channels.
- Consumer appeal, if used for display and promotion.

Field containers

Metal or plastic buckets are typically used for softer fruits in most of the larger production systems. The trends toward standardization and metrication of package types, unitization of pallet loads, and the use of packages for display in consumer channels, have led to an increasing use of in-field packages for some commodities. Within organizations or geographical areas, however, the trend is now towards the use of returnable plastic containers.

In the Caribbean, woven baskets, polypropylene sacks and wooden crates are commonly used as field and shipping containers for harvested perishables. While these containers have the advantages of high capacity and economy, they are less than ideal with respect to the level of damage to the produce they contain. Possible improvement can be achieved by more careful filling using supplemental packaging materials such as liners, wraps, trays, cups, shims, and pads, stacking containers within their design limits, and proper venting of containers. As trends in unitization and metrication of package sizes continue, it will soon become necessary for Caribbean countries wishing to capitalize on the opportunities for export to conform to specifications for package size and design.

In the United States, trends in packaging have gone from wood to corrugated containers, from hand packing to mechanical volume-fill and tight-fill packing with vibration settling, and from single package handling to unitized handling on pallets and slip sheets.

Recent trends in the use of polyethylene as a packaging material include the use of pallet covers, liners, and shrink wraps for individual fruit. TECTROL Atmosphere bags have been used successfully for strawberry shipments. The bag is sealed onto the pallet and a modified atmosphere is then injected. The bag can be left in place through warehouse rotation and transit (30). Perforated polyethylene bags are used for lining banana boxes destined for distant markets (Ramirez, personal communication).

Individual shrink wrapping of fruit, is receiving increased attention. Experiments with temperate and tropical fruits indicate that this method has high potential for reducing moisture loss and decay as well as increasing shelf life (3, 11, 18).

Transport

Trends in the transportation of produce deal mainly with temperature management and minimization of damage caused by abrasion, vibration or compression. Many of the techniques, although simple and practical in concept, have tremendous effects on maintenance of quality of the harvested produce.

Some of these techniques include:-

- Grading of access roads to eliminate ruts, potholes and bumps.
- Restriction of transport speeds to levels that will avoid free movement of produce.
- Reduction of tyre pressures on vehicles to reduce shock absorbance by produce.
- Use of air suspension systems on transport equipment. Surface marking injury levels are proportional to acceleration levels of containers carrying produce. As much as a 50% reduction in acceleration level of containers was possible with the installation of air suspension systems on truck and trailer axles (15).
- Inspection of container surfaces to determine potential for injury to produce.

The following temperature protection practices would be useful, especially under Caribbean conditions.

- Shading of the harvested produce under natural or artificial shade.
- Covering loads with light-coloured (silver or white) tarpaulin. The tarpaulin should be supported to maintain an air space over the load. Wetting the tarpaulin will further reduce warming by providing an evaporative cooling surface.

Refrigerated containers, used mainly for commodities imported into the Caribbean, are increasingly being used for transport and short-term storage of perishables. Considerable progress is being made in improving temperature management capabilities of refrigerated containers. Major developments include the manufacture of bottom-air delivery trailers with 6-cm deep T-beam floors and modification of refrigeration units by adding higher capacity fans to overcome air resistance offered by tight loads (13).

Cooling

Effective cooling and temperature management are essential for successful marketing. The choice of a cooling method depends on product adaptability, rate of cooling desired, potential for re-warming, type of packaging, package handling system, and cost.

A recent development in room cooling is the use of cooling bays. A single large room is divided into bays, air channels are constructed to direct air flow into each bay. The advangage of the system is that when cooling is complete, the air supply can be reduced independently of other bays (15).

Under Caribbean conditions, room cooling, forced-air cooling, and evaporative cooling seem to be best suited to the postharvest handling systems currently in use. Evaporative cooling techniques are very energy efficient and economical. Their main limitation is that air can be cooled only to the wet bulb temperature. In the less humid islands such as Antigua and Barbados, low wet-bulb temperatures would facilitate the use of evaporative cooling as a pre-cooling method. Minimum temperatures can, however, be reduced in the more humid islands by using multi-stage systems (29).

Storage

Recent advances in the storage of perishables have focused on the modification of atmospheric composition (carbon dioxide, oxygen and ethylene levels) in the storage environment.

A promising new development currently under evaluation for controlled atmosphere (CA) storage, is

the use of nitrogen separators or generators. Compressed air is circulated through molecular sieve beds, which separate nitrogen from other components. The N_2 produced is then used to flush the CA room and reduce the oxygen level.

During the past few years, there has also been an increase in the use of molecular sieve scrubbers for carbon dioxide control.

Ethylene has both beneficial and harmful effects on harvested horticultural products. The beneficial effects of ethylene in controlling ripening can be achieved by applying ethylene in liquid or gaseous form or by using the ethylene evolved from ripening fruit. Liquid sources include C_2H_4 – releasing chemicals such as ethephon. This chemical is registered in the USA and widely used for preharvest applications. It is also very popular as a postharvest dip for accelerating ripening of tomatoes and bananas in Trinidad and Tobago. Calcium carbide has been in use for many years by Caribbean farmers for 'forcing' (inducing synchronized flowering) pineapples and for ripening tomatoes. Carbide, as it is more commonly known, releases acetylene when it reacts with water. Simple reactors are available and can be used in partially vented spaces to ripen or degreen fruits under conditions where ethylene is not available (Reid, personal communication). The method may have potential for commercial application in rural areas in the Caribbean where compounds like Ethrel may be unavailable or too expensive.

Shot, trickle and flow-through methods, are currently available for applying ethylene gas in ripening rooms. With shot systems, there are difficulties in temperature management and gas monitoring. Trickle and flow-through systems are more widely used and have been proven to be safe and efficient for citrus degreening (32) and tomato ripening (25).

The detrimental effects of ethylene include accelerated senescence and loss of green colour in cucumbers and leafy vegetables, accelerated ripening of fruits, russet spotting of lettuce, development of bitterness in carrots, sprouting of root crops, senescence and 'sleepiness' in flowers and abscission of florets and calyces in potted ornamentals and melongene, respectively.

Strategies for protecting harvested perishables from these effects include avoidance, removal and inhibition The elimination of sources of ethylene is the best method for protecting perishables, especially under Caribbean conditions. Compatible product mixes should be used during transport, storage and display; ethylene-sensitive commodities should be isolated from ethylene-generating commodities such as ripening and decomposing fruits, exhaust from internal combustion engines, and cigarette smoke.

The removal of ethylene from the air can be achieved by ventilation with fresh air. Where ventilation cannot be used for removal, ethylene can be scrubbed from the atmosphere by trapping and/or conversion to other products.

Despite the large number of reagents and techniques which have been tested for ethylene removal in storage, potassium permanganate is the only one in commercial use. The compound must be adsorbed on a suitable carrier with a large surface area in order to be effective. Celite, vermiculite, silica gel, alumina pellets, perlite and expanded glass have all been successfully used as carriers (23). A number of scrubbers are available in the form of a sachets, filters, blankets and tubes.

Studies carried out on the storage of bananas (14) and green plantains (10) in polythene bags containing potassium permanganate scrubbers have shown that ripening can be delayed for as long as 25 days, at tropical ambient temperatures. The method, therefore, has considerable potential for use in the Caribbean in inter-island trade of fruits, vegetables and root crops. Banana shippers have found that the use of permanganate scrubbers causes burning of the fruit and that the additional weight increase in shipping boxes results in uneconomical shipping rates (Ramirez, personal communication). Experiments in the Philippines on the shipment of tomatoes with potassium permanganate carriers showed no apparent delay in the ripening of the fruits (8).

New catalytic-type absorbers, which allow lower combustion temperatures for warming up of gases for the production of oxidation products from ethylene, are being developed (Reid, personal communication). Another technology for ethylene removal which seems promising but which has yet to be commercially developed is the use of UV light (22). Also, there is potential for biological removal of ethylene using soil bacteria as a sink for atmospheric ethylene (1).

Controlled Atmosphere, Modified Atmosphere and Low Pressure Storage (CAS, MAS and LPS, respectively) offer potential for inhibition of ethylene. The use of LPS systems is not widespread and attempts at hypobaric storage and transportation have met with limited success (23).

Postharvest treatments

Many postharvest treatments are often applied to fruits, vegetables and root crops in order to control physiological and pathological changes which may impair quality.

Treatments to control disease

A technique recently developed for cassava *(Manihot esculenta)* to control the two types of postharvest deterioration, vascular discolouration and microbial deterioration, involves dipping the harvested roots in a 0.4% thiabendazole solution and packing in polyethylene bags. The fungicide prevents microbial growth and the bags provide the temperatures and relative humidities needed for the prevention of the vascular discolouration (5). Treating and packing the roots must be done on the farm. A delay of as little as 4 hours after harvest can increase losses after one week of storage from 2% to over 30%. Two weeks is the maximum recommended storage time. After this period, starches are converted to sugars, giving cooked roots an undesirable sweet flavour.

During the past 15 years, postharvest chemical treatments have been introduced for the control of storage losses due to infection in many major food crops. Benomyl and related benzimidazole compounds are still standard postharvest fungicide treatments where their use is permitted.

The use of fungicide-impregnated pads and wraps may have some potential for use in shipped commodities in the Caribbean. Sumbali and Mehrotra (28) used iodine-potassium wrappers to control storage decay of pome fruits. Burning of citrus fruits in boxes containing spent biphenyl pads was, however, reported for some shipments exported from the

U.S. to Holland (Hoogendoorn, personal communication).

The future of current chemical treatments cannot be regarded as secure because of (1) the emergence of tolerant strains of *Botrytis* and *Penicillium;* (2) requirements for establishment of residue tolerances for postharvest chemical treatments and (3) standardization of practices for the application of chemicals to crops (6, 7). The latter two factors have important implications for the export of commodities from the Caribbean to Europe and the United States.

Although restriction of chemical usage may encourage new advances in nonchemical postharvest decay control, there may not be significant results for many years. In the meantime, expanded research on the best use of available and newly developed chemicals appears to be the most appropriate strategy to reduce postharvest losses caused by infection (17).

Insect control treatments

Insect control treatments currently used for harvested fruits and vegetables primarily involve the use of fumigants, such as ethylene dibromide (EDB), methyl bromide (MB), and hydrogen cyanide. EDB has recently been shown to be both carcinogenic and mutagenic; alternative treatments to EDB are being actively sought.

Cold treatments (10 days at 0 °C) have been found to give control of some fruit flies in apples, oranges and pomegranates. They are not suitable for highly perishable or chilling-sensitive commodities such as avocado, papaw, mango, tomato and pepper. Cold treatments may be used only for commodities which can be made tolerant to low temperatures or for commodities for which length of storage time is not critical (16).

Until very recently, a combination hot water/EDB treatment was used for control of Mediterranean fruit fly infestation in papayas shipped from Hawaii. Restriction on the use of EDB has led researchers at the USDA–ARS Laboratory in Hilo, Hawaii to develop a 1-hour double-dip heating treatment. Fruits are submerged in water at 42°C for 40 minutes, followed by 20 minutes at 49°C. The first dip kills eggs of the fruit fly which tend to lie 2 - 5mm under the skin of the fruit. The treatment has potential for use on other crops (27; Chan, personal communication).

The most publicized alternative treatment for insect control is the use of gamma radiation. A recent proposal by US Food and Drug Administration (FDA) to allow treatments up to 1 KGy (100 Krad) on foods (31), as well as promising results of studies on insect sterilization, make the use of radiation appear promising. A number of factors should, however, be considered. These include detrimental effects from dose levels below 1 KGy, logistics of application of the treatment, economics of the treatment, and social and public reaction to consumption of irradiated foods (4, 23).

The type of postharvest handling produce receives and the physiological and physical condition of the produce have an effect on losses incurred. For example, fruits with high vitality exhibit considerable resistance to fungal attack, while stressed or senescent fruits are often disease prone. Handling procedures should emphasize methods which maintain product quality and which directly or indirectly limit the potential for invasion and development of pathogens.

Treatments to retard ripening and senescence

Various coatings and dips are in use for delaying ripening in fruits. Coatings such as Tal Prolong® and Pick 'N' Save® utilize a modified micro-atmosphere around the product. They are transparent and tasteless sugar-based films which are non-toxic and edible. Reportedly, these products slow down respiration and metabolism as well as retard ripening by restricting the rate at which gases and water vapour move across the fruit skin. Pick 'N' Save® is being offered in a kit and is suitable for apples, pears, cherries and plums (12).

Calcium compounds have been used to dalay ripening and senescence in some fruits. Singh and Chauhan (26) showed that treatment of guavas *(Psidium guajava)* with calcium nitrate solution delayed the onset of senescence and maintained edible quality of the fruit for over 6 days. Recent studies in Australia with tomatoes, mangoes and avocadoes have shown that infiltration of calcium chloride into the freshly harvested fruits delays ripening. Treated tomatoes remained green indefinitely and the ripening time for mangoes and avocadoes was increased by about 40% (21).

Measurement and detection systems

Psychrometric properties of the air (such as temperature and relative humidity) and levels of atmospheric gases (such as ethylene, oxygen and carbon dioxide) are commonly measured storage parameters. A dewpoint hygrometer being developed for laboratory use is the chilled-mirror hygrometer. The morror mounted on the instrument is chilled to a specified dewpoint temperature. The onset of condensation on the surface of the mirror is detected by a change in reflectance which can then be easily measured electronically.

Ethylene detectors being developed for use in commercial storage include the Snoopy detector which can detect ethylene only at high levels (1 ppm). It has been tried with limited success in apple storages in England and New Zealand (19). Spot checks in transit shipments may easily be carried out using detector tubes which have a sensitivity limit of 1 ppm of ethylene. A new ethylene detector currently under development is a photoionization detector. The instrument is based on the reaction of ozone and ethylene. The wave length of the light emitted in the reaction is specific and can be easily measured after magnification in a photomultiplier tube.

Conclusions and recommendations

In the Caribbean, the benefits of several of the technologies described can be achieved using simple, yet effective practices. Careful harvesting, use of precooling methods such as evaporative and forced-air cooling, careful filling of produce into containers, the use of protective packaging materials, improvement in temperature management during transport and storage, avoidance and removal of ethylene during transport, storage and display, the use of ethylene releasing solutions for ripening, and the use of heat treatments for insect and disease control, offer the greatest benefits.

Sophisticated technologies such as controlled atmosphere, modified atmosphere and hypobaric (low pressure) storage need to be evaluated in terms

of their suitability for tropical commodities and in terms of their cost effectiveness. Cooling methods such as hydrocooling and vacuum cooling are unfeasable in the Caribbean due to the high level of quality control and operational skills required for efficient management of such facilities, in addition to their high costs.

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