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Preservation of Postharvest Quality of Fresh Bamboo Shoots via Suppression of Lignification, Browning, and Decay: A Review

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Bamboo shoot, the peeled, growing meristematic tissue of several edible species of bamboo, is a desirable food crop because, once cooked, it is high in protein and vitamins, low in fat, and has a hedonically pleasurable crisp texture. The potential exists for bamboo shoot to become a lucrative crop for Florida growers given typical returns of $3.50 per pound wholesale. When striving to preserve shelf life of fresh bamboo shoot, growers and packers face issues such as lignification (toughening of tender edible tissue to a woody, inedible state), yellowing, moisture loss, and chilling injury. This review discusses the three main categories of techniques available to packers to address these concerns: environmental management, applied compounds, and packaging. Environmental management techniques range from the very simple, beginning with field temperatures at harvest and transport time, heat treatment, thorough cooling techniques like hydrocooling and forced-air cooling, proper storage conditions, to the more complex such as ultraviolet light, hypobaric storage, and hydrostatic pressure, to sophisticated techniques unlikely to be applied in the packinghouse, such as gamma radiation. Applied compounds such as 1-methylcyclopropene (1-MCP), brassinolide, melatonin, oxalic acid, salicylic acid, and chlorine dioxide in combination with chitosan have also been reported to have beneficial effects in suppressing lignification and otherwise preserving edible quality of bamboo shoot. Packaging films focus on the composition of the film overwrap, use of perforations, modified atmosphere packaging, and packing density. Further, practical studies are suggested to determine the appropriate storage temperature and to compare these techniques individually and in combination to determine which are the most effective and the most realistic under typical packinghouse conditions.

Bamboo refers to a group of nearly 1500 species of plants in the grass family (*Poaceae*) that have firm stems and grow to heights ranging from 4 to 30 meters. The peeled, actively growing shoot tip, known as meristematic tissue, is referred to as the 'bamboo shoot', a somewhat crunchy vegetable that must be processed for consumption by pickling, drying, or other methods. The leading producer and exporter of bamboo shoot, and subsequently bamboo shoot research, is China. Current production values are difficult to find, but in 1999, China alone consumed over 1.3 million tons of bamboo shoot from 4 million hectares of production. India was another key production center with nearly 3 million ha (Collins and Keilar, 2005).

Bamboo shoot has potential to become more desirable to the consumer due to its nutritional composition—it is low in fat but high in proteins and vitamins (Nongdam and Tikendra, 2014). A fresh bamboo shoot of the highest consumable quality will be crunchy/crisp in texture yet firm rather than woody, with a sweet flavor. Freshly processed bamboo shoots are reported to have better flavor than those that are canned. Ideal pulp tissue color is cream-colored to pale yellow; however, over time the fresh shoot darkens to a deeper yellow or browning as one sign of senescence.

Not all bamboo species produce edible shoot tips; some are simply too woody to consume. Genera usually cultivated for consumption and discussed in this review include *Bambusa*, *Phyllostachys*, and *Zizania*. It is important to note that the edible species contain cyanogenic glucosides that break down to toxic hydrogen cyanide—harmful to an adult when as little as 0.002 ounce (57 mg) is consumed raw. These compounds are readily inactivated by boiling for 30 min.

Sheaths (bracts) surround and protect the edible shoot. The entire shoot is harvested by sawing at approximately 30–45 cm in length (Fig. 1), then transported in bulk to the packing facility. For fresh market the sheaths are cleaned (Figs. 2–4). There are several postharvest challenges that bamboo shoot farmers and packer/shippers face. Lignification is the toughening of the shoot tissue that renders it inedible. Lignin is quickly synthesized in living plant tissues during room temperature storage by the enzymes phenylalanine ammonia lyase (PAL), cinnamyl alcohol dehydrogenase (CAD), and peroxidase (POD). This process also occurs with asparagus, another actively growing shoot tip. Other postharvest challenges include discoloration of the sheath, proliferation of decay-causing microorganisms, moisture loss, and yellowing or browning at the cut surface. The edible shoots are also susceptible to chilling injury which is characterized by lignification and watersoaking.

Many solutions have been identified to address these concerns and extend the quality of fresh bamboo shoots. The following sections review pertinent literature that describes tests in which intact bamboo shoots (sheath and shoot tips, as in Fig. 2) were stored under various conditions while the quality changes refer to the edible shoot portion. They are grouped here under environmental management, applied compounds, and packaging. Proper cooling is the most important factor in maintaining postharvest quality; other treatments, while considered secondary, can further extend shelf life beyond that obtained by cooling alone.

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Fig 1. Bamboo shoot in process of harvest.

Fig. 2. Freshly harvested bamboo shoots after cleaning/brushing in the packinghouse. (Credit: Kevin Barley, OnlyMoso).

Fig. 3. Edible portion of the bamboo shoot.

Fig. 4. Edible bamboo shoot, sliced open.

Environmental Management

Temperature management. Refrigeration is a key factor in preserving postharvest quality of fresh bamboo shoots. Temperatures ranging from 1, 2, and 5 °C have been investigated compared with warmer alternatives and in each case, the warmer alternative resulted in quicker loss of quality. Room-temperature storage at 20 to 25 °C without packaging resulted in a 25% loss in the product's fresh weight due to transpiration through the cut end of this rapidly expanding tissue, limiting usable shelf life to a single day (Kleinhenz et al., 2000). Higher storage temperatures also favor growth of decay microbes. Chen et al. (1989) observed that bamboo shoots stored at 30 °C (ambient temperature in their region) for 5 d contained twice the crude fiber content of shoots stored at 5 °C. Their work found that lower temperature storage suppressed activity of the enzymes PAL and POD, thus delaying lignification. Chang and Yen (2008) also verified that shoots remained marketable after 6 d at 5 °C whereas those stored at 25 °C were no longer marketable.

Other researchers reported that bamboo shoots stored for 10 d at 2 °C were 10 N softer, contained higher amounts of total soluble sugars, had lower cellulose and lignin contents, and demonstrated lower PAL activity than shoots stored at 20 °C (Luo et al., 2008). However, during long-term storage (30 d) shoots stored at 2 °C continued to toughen, indicating that the lignification was only delayed by the cold temperature, but not prevented. This delay then subsequent increase in lignification was reflected in increased lignin and cellulose contents and PAL activity and a corresponding decrease in sugars. After this long storage period (30 d), chilling injury was implicated in the lignification of tissue due to the visual observation of watersoaking. Shoots stored at 1 °C developed only minor yellowing, while those stored at 8 °C developed dark, soft patches after 6 d of storage (Kleinhenz et al., 2000).

Cooling methods. Rapid cooling ("precooling") has long been employed to maximize postharvest life (shelf life) of fresh produce by reducing the pulp temperature shortly after harvest. Techniques like hydrocooling (showering with or immersing in near-freezing water) and forced-air cooling (using high-velocity fans to draw refrigerated air through freshly-harvested product) are the most commonly employed methods for a wide variety of fruit and vegetable commodities.

During cooling, the field heat (also called sensible heat) from the product is transferred to the cooling medium (air, water, crushed ice). Effective cooling depends on careful management of three factors: time, temperature and contact. To maximize cooling, 1) the product must remain in the cooler for sufficient time to remove heat, 2) the cooling medium must be maintained at constant temperature throughout the cooling cycle, and 3) the cooling medium must have continuous, intimate contact with the surfaces of the crop. If the crop is packed in containers with insufficient vent or drain openings or if the containers are incorrectly stacked on pallets so that the vent holes do not align, the flow of the cooling medium can be severely restricted, significantly extending cooling times (Sargent et al., 2008).

Effective cooling significantly benefits the shipping life of the product, and a widely accepted definition of commercial cooling for perishable crops is: "The rapid removal of at least 7/8 of the field heat from the crop by a compatible cooling method". The time required to remove 7/8 of the field heat is called the "7/8 Cooling Time", and is the most effective and efficient time (Fig. 5). Removal of the remaining 1/8 of the field heat occurs during subsequent refrigerated storage and handling with minimal effect on crop quality. Although the cooling curve in Fig. 5 was

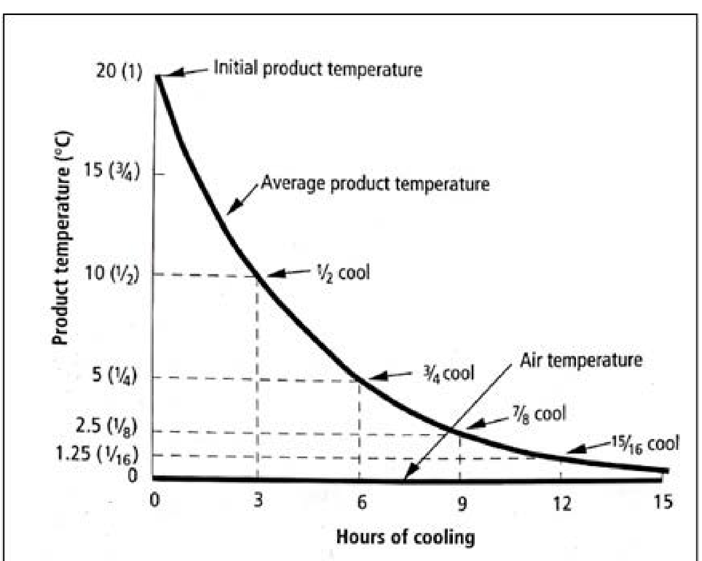

Fig. 5. Ideal cooling curve showing intermediate cooling times. Source: Thompson et al., 2008.

based on room cooling, the intermediate time/temperature relationships (i.e., 1/2 Cooling; 3/4 Cooling) can be extrapolated to other cooling methods.

Kleinhenz and Midmore (2002) stated that hydrocooling reduces pulp temperature more rapidly than air cooling, and the rate at which a shoot cools is affected by the weight of the shoot, with smaller shoots cooling more rapidly. They reported that 2.5 h of hydrocooling was necessary to cool 1 kg of bamboo shoots from 30 °C to 1 °C using ice water, compared with 10 h of room cooling (air temperature not specified). It is critical that an approved sanitizer be added to the hydrocooling water and maintained during cooling to avoid accumulation of decay pathogens in the water during cooling (Sargent et al., 2008). Chang and Yen (2008) found that hydrocooling reduced internal temperature of the bamboo shoot more rapidly than forced-air cooling. They also noted that soluble solids content was higher in forced-air cooled bamboo shoots. Soluble solids content (SSC), or degrees Brix as a measure of sweetness, is around 5–7 °Brix for bamboo shoot depending on storage temperature; the longer a shoot was hydrocooled, the lower the SSC. These authors ultimately recommended that a two-step combination be employed for maximum cooling benefit with minimum loss of nutritional value. First, hydrocooling water was maintained at 5 °C, cooling the pulp of freshly harvested bamboo shoots to below 10 °C after 20 min. Second, the shoots were then transferred to forced-air cooling for a second 20-min cycle in 5 °C air. Nutritional composition, therefore, was maximized, and the cooling air dried the cut surfaces and sheath tissues, thus reducing the potential for decay to develop during subsequent handling and shipping. However, actual cooling times and storage temperatures for this cooling procedure need to be verified under Florida conditions, particularly regarding effects on shoot quality and shelf life. Forced-air cooling may benefit nutritional composition, and drying the cut surface and sheath tissues may reduce the potential for decay to develop during subsequent handling and shipping.

Heat treatment. Elevated temperatures can slow or stop the activity of the enzymes involved in lignification. Bamboo shoots pretreated for 5 h at 45 °C/90% relative humidity (RH) had lower amounts of lignin and cellulose during storage for 12 d at 20 °C/90% RH compared to unheated control tissue held constantly at 20 °C (Luo et al., 2012). Under these conditions, lignin was initially just below 0.50% and increased to nearly 0.75% in unheated control shoots but to less than 0.65% in heated shoots. Cellulose, which was initially just above 0.8%, was approximately 1.05% in control shoots and approximately 0.95% in treated shoots. PAL and POD enzyme activity was also higher in control tissue than in heat treated tissue.

Ultraviolet (UV) light. Ultraviolet light, at wavelengths of 100-400 nanometers (nm), is invisible to the human eye. The UV spectrum is divided into UV-A (400–315 nm), UV-B (314–280 nm), and UV-C (100–279 nm). All three types of UV light have been documented as potentially beneficial to preserving the shelf life of a wide range of commodities, either by inactivating pathogens by exposing them to sufficient energy to disrupt the nucleic acids or by stimulating the tissue to form beneficial secondary metabolites that can protect it from pathogen attack. In this case, UV-C (254 nm) has been observed to retard toughening in bamboo shoots (Bo et al., 2019) by inducing the formation of antioxidants that remove reactive oxygen species (ROS) and hydrogen peroxide (H_2O_2) that stimulate lignification. Bamboo shoots pretreated with a 4.24-kJ/m² (kiloJoules per square meter) dose of UV-C light (254 nm) for 8 min, then stored for 8 d at 10 °C were more tender, a "cutting force" that was 25 Newtons (N) lower and a higher total phenolic content than untreated controls.

Gamma radiation Gamma rays are a high-energy radiation created by the degradation of the atomic nucleus. They have the shortest wavelength, shorter than X-rays or UV light, and are measured in "Gray" (Gy) units, defined as the absorption of one Joule of radiation energy per kg of matter. Bamboo shoots pretreated with 0.5 kGy of gamma radiation (40 min, room temperature) then stored for 28 d at 2 °C/90% RH were more tender (20% increase in firmness vs. a 30% increase), had a 7-d longer shelf life, and had 12% higher phenolic content as compared to untreated controls (Zeng et al., 2015). These authors also found that the gamma radiation suppressed PAL and POD enzymatic activity, and that overall decay was 71% lower than control shoots throughout the storage period. Fresh, peeled bamboo shoots packaged in vacuum-sealed polyethylene bags in cartons were pretreated with 0.3 kGy of gamma radiation; after 45 d at 4 °C these shoots had approximately half as much browning and lignin and cellulose contents as compared to the non-irradiated controls (Wang et al., 2019). As with the previous report, PAL and POD activities were reduced in irradiated tissue.

Hydrostatic pressure. Hydrostatic pressure is defined as the force per unit of area exerted by a fluid, and is measured in Pascals, as is air pressure. High hydrostatic pressure can interfere with the functionality of the enzymes PAL and POD which regulate the lignification of shoot tissue. Bamboo shoots pretreated in polyethylene bags for 10 min in a high-pressure chamber (600 MegaPascals, MPa) and stored at 4 °C for 7 d exhibited 25% lower lignin content, cellulose content, and overall firmness when compared to untreated controls (Miao et al., 2011). The authors noted that flavor, color, and nutritional content were not investigated, and so further research is necessary to determine if overall quality is preserved by this treatment.

Hypobaric storage. The standard pressure of the Earth's atmosphere is 101 kilopascals (kPa). Storage in low-pressure or 'hypobaric' atmosphere at a pressure of 50 kPa was effectiveat maintaining edible quality of bamboo shoots after 35 d at 2 °C/90 to 95% RH. Treated shoots were more tender (20 N softer), exhibited less browning, and contained less cellulose and lignin compared with controls stored in standard atmospheric pressure (Chen et al., 2013). Initial lignin content of 0.48 g/100 g (fresh weight basis, FW) increased to 1.06 g/100 g FW in control tissue but only to 0.62 g/100 gFW in treated tissue.

Applied Compounds

1-MCP. 1-methylcyclopropene (1-MCP) is a gaseous compound that inhibits ethylene by out-competing it for binding with its receptor molecule. There are several commercial products, such as SmartFresh™ (AgroFresh, Philadelphia, PA) and Hazel 100™ sachet technology (Hazel Technologies, Inc., Chicago IL). Blocking ethylene action slows senescent processes that make crops unmarketable. It has been validated in the literature to delay ripening of many fruit and vegetable commodities, including fresh bamboo shoots. 1-MCP was effective at slowing lignification in bamboo shoots at either room temperature (20 °C) or at 2 °C. At 2 °C toughening was delayed, a benefit also observed in asparagus (Liu and Jiang, 2006). Bamboo shoots treated with 1-MCP at 20 °C also received a higher subjective visual rating than control tissue by a sensory panel.

Bamboo shoots pretreated with 1 $\mu L \cdot L^{-1}$ 1-MCP for 8 h at 20 °C and stored for 12 d at 20 °C/90% RH had 50% less lignin content when compared to untreated controls (Luo et al., 2007). Lignin content of control shoots nearly doubled, while treated shoots only exhibited a 50% increase. Cellulose content of control shoots did not increase as much as lignin but still increased more than in treated shoots. Control shoots also exhibited twice as much activity of the enzymes PAL, POD, and CAD as treated shoots, which explains the higher percentage of tissue toughening. In a later study, these authors reported that bamboo shoots pretreated as above and stored for 40 d at 2 °C/90% RH developed 1/3 less chilling injury (as indicated by watersoaking) and were an average of 5 N softer than untreated controls throughout storage (Luo et al., 2008).

Bamboo shoots were pretreated with 0.5 $\mu L \cdot L^{-1}$ 1-MCP (powder form converted to gaseous phase by contact with water) for 20 h at 20 °C and stored for 9 d at 20 °C/90 to 95% RH; they were rated twice as visually appealing as untreated controls on days 3, 6, and 9 (Song et al., 2011). Lignin synthesis was suppressed in treated shoots as well as activities of PAL and POD. The reduction in enzymatic activity was found to be the 1-MCP-induced suppression of a specific gene called *ZcExp*.

In addition to extending shelf life of the shoots, 1-MCP may also retain sheath color longer, as reported in other crops such as leafy greens and broccoli.

Melatonin. Melatonin is an antioxidant compound found in both plants and animals. In plants it often serves as protection against environmental stresses. The cut bases of whole bamboo shoots were immersed for 1 min in 1.0 mM solution of melatonin; after storage for 12 d at 4 °C/80 to 85% RH they were softer, less yellow, and appeared brighter compared with untreated controls (Li et al., 2019). The melatonin inhibited the enzymes that trigger lignification.

Brassinolide. Brassinolide is a plant hormone and a steroid. Bamboo shoots pretreated with a 10-min aqueous dip of 0.5 μM brassinolide and stored for 42 d at 1 °C/95% RH had only 1/3 of the incidence of visually-evaluated chilling injury (browning or watersoaking) compared with controls dipped in distilled water (Fig. 6a) (Liu et al., 2016). Electrolyte leakage is another method that quantifies tissue membrane breakdown in response to chilling injury; it was also lower in treated tissue (39.7%) compared with 49.0% in control tissue (Fig. 6b).

Oxalic acid. Oxalic acid is an organic acid found in many plants. It has historically been used in many applications such as cleaning and as a mordant (fixative) for dyes and is now being investigated for its many benefits on fruit and vegetable shelf life (Zheng & Brecht, 2018). Bamboo shoots pretreated with a 10-min dip in 10 mmol/L oxalic acid solution and stored for 20 d at 6 ± 1 °C/85 to 90% RH exhibited less browning and were approximately 1/3 (5 N) softer compared with controls dipped in water (Zheng et al. 2019). Disease incidence was also halved by oxalic acid treatment. After 12 d, lignin content rose from an initial content below 0.4% to approximately 1.3% in control tissue, but this increase was suppressed to only 0.8% in treated tissue.

Salicylic acid. Salicylic acid, a plant hormone most familiar to humans as the principal ingredient in aspirin, forms an important component of plant defense against pathogens. Bamboo shoots pretreated with a 15-min dip in 1.0 mM salicylic acid and stored for 50 d at 1°C had half as many incidences of chilling injury, half as much browning, and 10% lower incidence of disease compared with controls dipped in distilled water (Luo et al., 2012). This

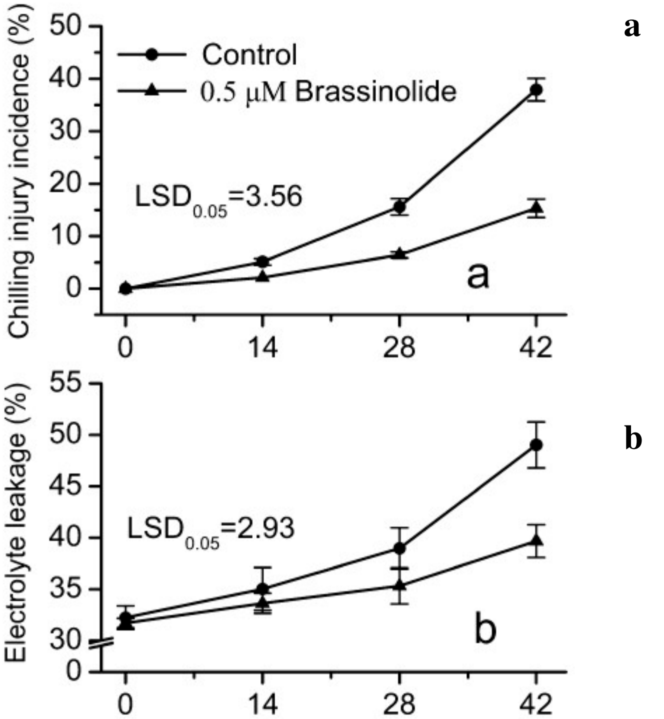

Fig. 6. Effect of brassinolide treatment on chilling injury incidence (a) and electrolyte leakage (b) of bamboo shoots during storage at 1°C. Values are the means ± standard deviation (SD) (n=3) (Liu et al., 2016).

preservation of quality is attributed to the suppression of PAL, PPO, and POD synthesis, retarding quality degradation.

Chlorine dioxide + chitosan. Chlorine dioxide (ClO_2) is a sanitizer approved to disinfect food and food contact surfaces in either aqueous or gaseous forms. Chitosan is a linear polysaccharide derived from crustacean shells, useful for creating films that act as a semipermeable barrier. Combined aqueous chlorine dioxide and chitosan coating were found to be more effective at reducing microbial counts and delaying lignification and browning than when treated separately. Bamboo shoots pretreated with a 3-min dip in 28 mg/L ClO_2 followed by a 3-min dip in 1.5% chitosan solution and stored for 6 d at 4°C/60-70% RH had lower microbial count, less toughening, and delayed browning and lignification compared with controls; shoots dipped in either treatment alone still benefited, but the benefits were greater when the two treatments were used in combination (Yang et al., 2011).

Other compounds. Other applied compounds have been identified in the literature as having a positive effect on storage quality but are not approved for contact with food in the United States (Yang et al., 2010, Yang et al., 2015, Li et al., 2019, U.S. Food and Drug Administration, 2018).

Packaging

Many of the environmental and chemical studies cited above also employed film overwraps or bags to reduce moisture loss from fresh shoots and protect exposed cut tissue from pathogens. Polyethylene (PE) and polyvinyl chloride (PVC) are both effective packaging materials.

Perforated LDPE film. Storage of fresh bamboo shoots in low-density polyethylene (LPDE) film at 20 to 25 °C extended the shelf life to 6 d and reduced weight loss to about 2%, which is considered acceptable when < 5% (Kleinhenz et al. 2000). Weight loss of 5% water content renders the shoot visually unacceptable, as the cut end dries out and develops cracks. However, storing fresh shoots in macro-perforated (8.94% vent area) LDPE bags at 1 °C for 30 d resulted in a retention of over 90% of the initial fresh weight; those held at 8 °C still maintained over 80% of initial fresh weight. In contrast, when stored at 11 °C, fresh weight was less than 80% while the shoots stored at 25 °C had less than 20% of their initial fresh weight. Therefore, the conclusion from the above experiment was that shoots stored in macro-perforated, LDPE bags at 1°C did not reach the 5% weight loss threshold until day 17 of storage, in contrast to the threshold being reached from 10 d to as little as 1 d at the progressively warmer storage temperatures.

The authors also reported that properly sized and spaced perforations retain sufficient internal RH to reduce moisture loss while minimizing condensation of free moisture which promotes decay. Multiple types of plastic packaging were compared for shoots stored in macro-perforated LDPE bag, micro-perforated LDPE bag, unperforated LDPE bag, unperforated LDPE film, heat-sealed PVC film, and a control in an open fiberboard carton for 28 d at 1 °C. The micro-perforated LDPE (35 μm thick, 0.01% area perforated) retained the highest fresh weight and had one of the lowest condensation indices. In contrast, although the unperforated LDPE bag lost less water, it had more than twice as much condensation.

In another report Kleinhenz and Midmore (2002) recommended combining the advantages of temperature control (hydrocooling) with packaging using the appropriate material and perforation size (Table 1). They reported that weight loss was 5% for hydrocooled shoots stored at 1 °C in microperforated LDPE bags (35μm thick, 0.01% perforation) after 28 d, that additionally suppressed discoloration and fungal growth. Recommended as a good second-choice option was the non-perforated 10.5 µm LDPE film, which also resulted in a 28+ day shelf life at 1°C. These authors also recommended that the packaging fit the shoots snugly so that the bag is in "intimate contact" with the commodity to minimize pulp temperature fluctuations observed when there was more air space within the bag.

Modified Atmosphere Packaging (MAP). Properly designed MAP films create a desirable atmosphere around the refrigerated crop that further inhibits respiration while suppressing growth of pathogens. MAP involves use of a selectively permeable, plastic membrane calculated to allow accumulation of the respiring crop's carbon dioxide (CO_2) as it consumes oxygen (O_2) so that the commodity establishes a beneficial low-O_2, high-CO_2 environment. Under these conditions the rate of respiration is reduced, decreasing enzymatic action such as PPO and POD, therefore delaying programmed cell death (PCD). PCD is the biological mechanism by which cells naturally reach the end of their life cycle through regulated processes, rather than due to exposure to an external event. MAP is used to prolong the shelf life of many fruits and vegetables—for example, it is the innovation that allows a high-respiring crop like fresh-cut broccoli to stay fresh on supermarket shelves; otherwise, use of impermeable films would allow O_2 to be completely consumed, resulting in anaerobic conditions that would quickly render the crop unmarketable. Precautions must also be taken to minimize accumulation of free moisture in the sealed bag or container.

MAP's potential benefit to bamboo shoots was explored by Shen et al. (2006). Peeled shoots were either sealed in 0.04 mm thick LDPE bags to create a modified atmosphere (2% O_2/5% CO_2) or left in ambient air (controls) during storage at 10 °C. After

Table 1. Influence of packaging material and storage temperature on shelf life (days) of bamboo (*B. oldhamii*) shoots (data collated from all experiments). (Kleinhenz and Midmore, 2002).

Packaging material	Storage temperature 1 °C	2 °C	8 °C	11 °C	20 °C	25 °C
Control (open storage)	7	6	__[z]	__	1.5	__
Macro-perforated LDPE[y] bag	17	__	6–10	5	__	1
Micro-perforated LDPE bag	28	__	__	__	__	__
LDPE film	28	20	__	__	6	__
LDPE bag	21	__	6–10	__	__	__
Heat-sealed PVC[x] film	14	__	__	__	__	__

[z]Not assessed.
[y]LDPE = low-density polyethylene.
[x]PVC = polyvinyl chloride.

10 d of storage, POD and PPO activity in the MAP treatment was halved compared with controls; the browning index for the former was 1 (trace browning; 0 = no browning) compared with a rating of 5 (“extremely severe”) for the latter.

In Song et al. (2013), shoots were minimally processed (outer leaf sheaths removed, and a 5-cm slice of tissue removed from cut end) and placed in either open or sealed 0.05-mm thick LDPE bags with an O_2 transmission rate of 1.2×10^{-14} M/m^2/s/Pa and a CO_2 transmission rate of 10.8×10^{-14} M m^2/s/Pa before storage at 2 °C/90% for 60 d or 20 °C/90% RH for 9 d. Sensory quality was subjectively rated on a scale of 1 to 6 with 6 as the highest quality. At 20 °C the sensory quality was unaffected by MAP and declined from 5 to 1 by day 9, but at 2 °C, MAP slowed the decline in sensory quality over 60 d and halved the accumulation of lignin. This second study is important because it indicated that initial flushing with premixed O_2/CO_2 gas was unnecessary in that the sealed shoots established an effective modified atmosphere.

Packing density. Chang and Yen (2008) reported that bamboo shoots sealed in a 0.06 mm polyethylene (PE) bag packed too tightly (8/bag) produced anaerobic conditions and subsequent development of off-odors during storage at 1 °C. However, bamboo shoots packed 5 per bag had a higher SSC and produced a beneficial modified atmosphere necessary to keep the product fresh during 16 d of marine transport from Taiwan to Japan.

Future Areas for Research

Extensive studies have been performed, exploring environmental conditions, chemical treatments, and packaging methods to extend the quality of fresh bamboo shoots for the fresh market. Temperature management has repeatedly been demonstrated to be the most critical and readily applicable method to extend postharvest quality and shelf life of fresh bamboo shoots. However, it was also noted that the ideal lowest safe temperature has not been precisely identified; this may actually vary by bamboo cultivar. Storage in air for 10 d at 2 °C resulted in higher quality product than at 20 °C, but after 30 d chilling injury was apparent at the former temperature. Therefore, straightforward storage tests are necessary to compare shoot quality during storage at 1, 2, and, 4 °C, with those stored at 10 °C.

The studies highlighted in this review have largely tested single variables or variations of the same treatment and compared with untreated controls. For example, the hypobaric atmosphere study evaluated standard atmosphere against 75, 50, and 25 kPa of pressure. Comparing combined treatments with two or more of the above cited methods with untreated controls would provide very useful information for the farmer, packer, and shipper. Therefore, it is suggested to determine the most effective of the above treatments and then evaluate these simultaneously. One potential scenario would be to treat bamboo shoots with 1-MCP, melatonin, hydrocooling, heat treatment, or UV-C exposure then store at the same temperature and evaluate shoot quality over time, always comparing with the current handling method as the control. Treatment with gamma radiation, hydrostatic or hypobaric (low) pressure may not be the most cost-effective or feasible options.

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