Chapter

Robotic Heat Treatments for Mango and Prickly Pear Increase Shelf Life and Reduce Pathogen Infection

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Abstract

Mexico is the main exporter of mango fruits and prickly pears, so new postharvest techniques to increase shelf life are studied. Thermal treatments on both fruits can affect their cuticle so it was reviewed. When mango latex remains within the fruits, it avoids sap burn and decreases anthracnose and stem end rot infestation, so two systems were developed to minimize latex de-sapping. A gripper cuts stems 0.5 cm long and cauterizes them with a hot knife implement. A heating gun applied paraffin wax to mangoes without the stem end and protected them better against anthracnose lesions. Physicochemical analysis of several mango varieties was carried out after harvesting, at market place and after pedicel cutting and cauterizing. Keitt mangoes showed the lower quantity of total soluble solids (TSSs) and total acidity (TA). When the pedicel was cauterized, TSS dropped. Two grippers were developed to cryo-cauterize prickly pears as this system is more energy-efficient than hot cauterization. A six-finger gripper moved over a pneumatic actuator toward a dry ice chamber to optimize pear cryo-cauterization. Gripper's strong grasping damaged the fruits due to excessive compression. TSS and TA of cryo-cauterized fruit remained constant during the three months of fruit storage.

Keywords: mango fruits, anthracnose, grippers, prickly pear, paraffin wax, cryo-cauterization, total soluble solid concentration, stem end rot

1. Introduction

Every country develops studies for their main fruit chains to determine main losses and provide solutions for reducing them. When fruit shelf life cannot be increased, processing will avoid fruit spoilage. Food losses and waste are estimated globally in 1.3 billion tons annually. Commercialization loss was estimated in 9.5 tons/week in Salvador, Brazil, in highly perishable fruits such as banana, papaya, and tomato [1]. The annual loss of fruits during postharvest operation represents in Sri Lanka about 210,000 metric tons of fruit, which corresponds to 30–40% of the harvest, representing a loss of US$90 million [2]. Mexico is the leading producer of prickly pear plants with 230,000 hectares, being 67,000 for fruit production [3]. Mexico is also the world leader in exporting fresh mangoes in 2019 [4]. Postharvest losses of fresh mango fruits in Pakistan were reported to average 69% [5] but

sometimes reach 100% under disease-favorable environments. In the 2014 season, an increase in mango stem end rot (SER) at Israel caused a 30–40% loss of the harvested fruit [6]. This disease occurs in mango, avocado, and citrus fruit [7].

The rind or exocarp includes the hard cases of nuts or the shell of watermelon. The peel forms the pericarp, meanwhile the pulp or edible portion of the fruit is the endocarp [8]. Fruit or vegetable peel or rind appears as its outer protective layer. Watermelon, a round fruit, has a firm outer rind that surrounds a white inner rind layer. The interior edible pulp of red or yellow color is the endocarp. The outer walls of the epidermal cells of all plant organs are coated with a cuticular membrane [9]. Physical properties and chemical composition of the fruit cuticle change markedly during its development [10]. During early fruit development, maximum cuticle deposition rates per unit area appear increasing cuticle thickness. Cuticle composition changes after depositions of wax, phenolic compounds, and polysaccharides [11].

Fleshy fruit cuticles and vegetative organs have similar compounds, but fruit cuticles are thicker [12, 13]. The hydrophobic nature of fruit cuticle makes it an effective barrier to reduce water loss. Cuticle permeance differs between mango fruits receiving sunshine and those growing under the canopy shade [14]. In addition, intracuticular waxes limit movement of surface water into the fruit and reduce transpiration. Cuticular wax load increases during fruit development leading to a thicker mango cuticle at maturity [15].

The fruit cuticle provides an important physical barrier against pathogens [16] avoiding fungal colonization on sweet oranges [17]. Industrial food wastes such as peels from juice production provide raw material for obtaining wax compounds [18]. The cuticle also provides protection against environmental conditions, where excessive solar radiation produces physiological disorders such as sunscald [19]. Cuticle strength and rigidity decrease as it becomes warmer [20]. The cuticle inner surface is fully hydrated, meanwhile the cuticle outer surface in contact with the atmosphere is less hydrated. Although waxes are present in both sides of the cuticle, water absorption takes place [10]. Cuticle swelling and softening alter its mechanical properties. Fruit cracking is triggered by cuticle breaking, linked to rainwater and high humidity [21, 22].

Handling fruits up to 15 days after harvest has a profound effect on its final quality because fruits are still alive and vulnerable to adverse conditions [23]. Throughout fruit ripening, softening results from the modification of polymers within the primary cell wall [24]. Cuticle and wax deposition increased during the first 15 days of postharvest shelf life in mango fruits of cultivars "Kent," "Tommy Atkins," and "Ataúlfo" [25]. Mango fruits with higher wax deposition in their cuticle were more resistant to fruit fly attack [26]; also fruits presented lower transpiration and deterioration. Pectin solubilization during fruit ripening is directly related with the ripe fruit texture [27]. Fruits showing a melting texture, such as avocado, kiwifruit, tomato, and peach, soften in a short time [28]. Fruits having a crispy texture during maturation, such as apple or watermelon, present low pectin solubilization [29]. The simplest postharvest procedure to increase fruits shelf life consists of storing them under controlled temperature and humidity conditions. However, rheological and mechanical properties of fruit cuticles are affected [20]. Peach firmness dropped after being stored at low temperatures. It was associated to a reduction of covalently bound pectins [30]. Apricot controlled-atmosphere treatments showed also pectin degradation [31].

Mango fruit pedicel (**Figure 1a**) presents an internal network of resin ducts, and the latex is kept under plant turgor pressure [32]. When the pedicel is broken or cut, a secretion of milky-viscous sap leaves the fruit [33]. This latex contains oily antifungal resorcinol [34]. The contact of the fruit surface with the sap exudate (**Figure 1c**) can

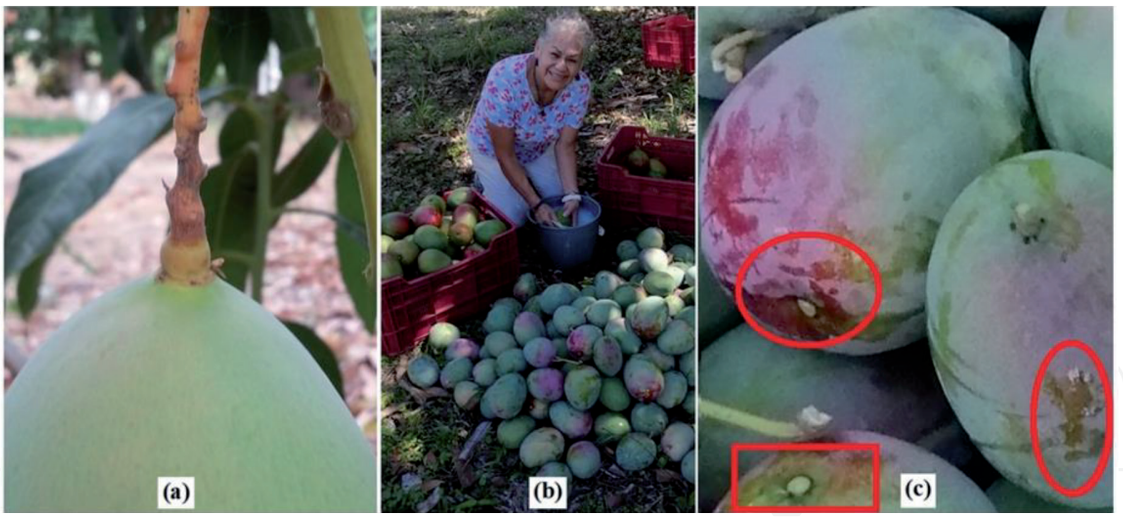

Figure 1.
Mango fruit (a) pedicel, (b) washing, and (c) showing latex in the peel.

lead to skin injury (sap burn) and develop under-skin browning [32]. This injury decreases mango quality after damaging seriously its skin, and if the fruit contacts the soil, it can be easily infected. These fruits are rejected at the entrance of fresh fruit packinghouses [35]. Lenticels also appear after sap exudation showing symptoms of early sap burn injury [36]. A delay in the appearance of stem end rot was noted by keeping a short pedicel at harvest [6, 34]. Mango fruits harvested with stems have more sap and less incidence of anthracnose [37].

Opuntia species present fleshy edible fruits (tunas) with thick rinds and relatively large round seeds. Prickly pear fruits are consumed in the local Mexican market and exported to the United States, Canada, Japan, and Europe [38, 39]. Edible prickly pear fruits and cladodes are used as food for livestock [40]. Fruit pulp and peel present a high quantity of carotenoids, betalain content, polyphenolic content, and ascorbic acid [41, 42]. Those pigments have revalorized prickly pear production for agro industries and pharmaceutical use [3, 43]. The fruit is perishable, and after being stored for nine days at room temperature, it starts rotting [44]. Ready-to-eat (RTE) fruit storage includes controlled atmosphere storage of minimally processed cactus pear fruits at 2°C reducing browning content [45]. Cactus pear peeled and stored within passive-modified atmosphere at low temperature limited fruit decay [46].

Heat transfer within fruits stored at a cold storage warehouse after harvesting has been studied before long-term shipping [47–49]. Harvested fruits are treated with different technologies to delay ripening, preventing physiological and pathological disorders [49]. Producers sometimes target distant markets, so they must harvest their tomatoes in a mature green state to allow longer ripening and senescence periods [50]. Excessive field heat increases fruit metabolic activity, so immediate cooling after harvest is recommended [51]. Low and high temperatures lead to the denaturation of enzymes, modifying fruit's respiration rate [52]. Stone fruits such as plums and mangoes have a seed inside and present different thermophysical parameters within the pulp [53, 54]. The contact surface between the seed and the pulp is the deepest point that can be reached in the fruit and becomes a thermal center. The finite element method can simulate heat transfer within food products that present irregular geometries [55].

Hot water immersion and hot air treatments at temperatures between 40 and 60°C from seconds to several hours control pathogens in apples, pears, citrus, and melons [56]. Postharvest quality of apples improved after being heated with air during one day at 40°C [57]. Heat treatment caused important changes in

epicuticular wax altering microcrack structure. Mandarins were immersed in hydrothermal treatments, maintaining the fruit surface temperature at 50°C for 2.5 min [58]. Once the mandarin peel heats up, thermal energy transfers by conduction to subsequent layers toward the center. Heat transfer stops after reaching an equilibrium condition [59]. Thermally treated mandarins present higher TSS (total soluble solids), lower maturity index, and similar citric acid content.

Mango fruit must be treated to ensure that it is free of fruit flies, so that importing markets allow their acceptance [60]. Small mango fruits weighing less than 375 g require 65 min of immersion in hot water at 46.1°C [61]. A thermocouple was inserted at the surface of the endocarp and another in the center of the mango fruit to record temperature changes during hot water immersion. The temperature at the center of the fruit continued increasing for 10 min after removing the fruit from the hot water bath [61]. Although the hot water treatment reduces fruit firmness, it influences positively in oxidative processes, cell wall changes, and steady-state levels of protein [62].

2. Mango treatment

Thermal treatment application maintains mango fruit quality and produces higher economic returns. Cauterization is a very useful technique that can close any tissue after applying heat. After harvesting, all the wounds of the fruit that were cauterized and sealed hermetically avoiding transpiration and increasing shelf life.

2.1 Mango after farm harvest

Postharvest mango quality depends on proper harvesting and even better production practices. Mangoes are generally handpicked or retrieved with poles adapted with a cutting blade and a bag [63]. The blade end breaks the pedicel and latex covers the fruit peel (**Figure 1c**). Although de-sapping after harvest avoids peel sap burn, it reduces fruit protection against anthracnose and stem end rot. The main cause of mango sap burn is attributed to a deposit of volatile compounds such as terpinolene and car-3-ene through the lenticels [64]. Stem trim cutting results in latex stains deposited on the fruit surface. The sap stored in the fruit ducts under high pressure falls on the peel of mango fruit [65]. Delatexing can be done by inverting freshly de-stemmed fruits on plastic or steel mesh racks for 30 min. Another technique is to dip freshly de-stemmed fruits in 1% alum solution (one-half kg powdered alum per 50 L of water) for 1 min; fruits should dry before packing [65]. The contact of latex with mango skin induces lenticel discoloration, resulting in red spots caused by the synthesis of anthocyanins [66]; these spots can also be induced by chilling injury [64]. Resorcinols and gallotannins are inhibitory to major postharvest pathogens including anthracnose [67].

If a 1 cm long pedicel remains attached to the fruit after harvest, latex will not leave the fruit avoiding sap burn. More than 80% of sap flow was observed within the first minute of stalk removal [37]. Sap pH varies between 4.43 and 4.6, and the ratio of nonaqueous fluid (oil) to aqueous fluid is of 1:6.5 [37]. The best hour for harvesting mango fruits was just after midday [68]. Early morning harvesting causes a rapid flow of sap from the pedicel end. High solar radiation and vapor pressure deficit increased stem water flow within mature fruit during the morning and decreased after midday [69]. Pedicel cutting place does not affect sap output flow. If stem is cut at the abscission zone, delayed ripening of mango fruit results [68].

2.2 Mango diseases

Two of the main diseases of mango fruits are anthracnose and stem end rot. Anthracnose caused by the *Colletotrichum gloeosporioides* at the green stage cannot be perceived, and the infection is noted when the mango ripens. Anthracnose produces the enzymes polygalacturonase and pectolyase, which degrade the cell wall [70]. If mango fruit is healthy, the polyphenol oxidase (PPO) enzyme is found within chloroplasts and the phenolic compounds in vacuoles, both being separated, avoiding any reaction.

Stem end rot (SER) is a disease caused by *Lasiodiplodia theobromae*. At the beginning, it appears as a small dark-brown area in the peel around the base of the fruit stem end, progressing into soft decay at the stem end [6]. Ethylene, a phytohormone, controls most of the ripening events linked with climacteric fruits. Small amounts of ethylene maintain fruit resistance to pathogens [71].

2.3 Mango pedicel treatment

If latex is retained within the fruit at harvest, it reduces anthracnose and stem end rot (SER) development during ripening. Fruit ripening parameters are not affected by pedicel length, and substantially less number of diseases appear compared with fruits harvested without stems. Anthracnose lesions decrease when mango fruit is harvested with a long stem [33]. SER onset in fruits with short pedicel was later than in fruit without stems [6]. Latex aqueous phase having chitinase contributes to fruit resistance against SER [67]. Two systems were developed to minimize latex de-sapping:

1. Cut stems 0.5 cm long and cauterize them with a hot knife implement.

2. If harvest brings fruits without stems, fruits are washed, dried and a wax is applied at the stem end.

Automatic fruit harvesting follows different picking patterns including bending, lifting, twisting, and pulling [72]. Modern soft grippers employ soft and flexible materials for holding the fruits [73]. Mechanical cutting devices for fruits consist of knifes [74, 75], scissors [76], and hot wires [77]. Knives used to cut stems have to be continuously immersed in skimmed milk. This action avoids virus invasion and should take place before contacting each plant. Therefore, it is not practical for automated processes [74]. A scissor employed to cut tomato stalks was articulated by a finger phalanx, but could also be fixed to the gripper palm [76].

Nichrome wire electrodes were mounted at a thermal cutting end effector. A high voltage of 300 V cuts 1 mm sweet pepper stems in 2 s [77]. As the diameter doubled, the cutting period increased to 5 s after applying the same voltage between electrodes [77]. Thermal stem cut ceased fungal or bacterial infestation, increasing pepper shelf life over 15 days. Peppers harvested by normal scissors showed physical changes after the fifth day and perished after nine days. Mechanical cutting is suitable for cucumbers where peduncle direction is uniform [74]. Laser cutting of variable-diameter tomato peduncles (1.5–5 mm) was studied [78]. It became impossible to cut off a peduncle directly by focusing a laser beam on it, as the focusing spot is smaller than the peduncle size. After tomato peduncle drilling, laser cut a 5 mm diameter stem in 15.2 s [78].

A harvesting robot requires a transmission system to drive the end effector [79]. A robot gripper with four pneumatic fingers has been used with mango fruits. The gripper can handle various shapes and sizes and has been used to determine fruit

firmness [79]. A gripper was also developed to handle mango fruits and estimate their ripeness. This robot integrated accelerometers and optical sensors and worked without contacting the fruit [80]. Two robots were used for tomato grafting, cutting 240 plants per hour. The graft is accomplished when both plants are placed in intimate contact between them, and a clip is pressed against them [81].

Mango fruits collected at the Mexican Pacific coast were green, firm, and starting to ripe. The developed gripper to hold the fruit presented integrated soft cushions (**Figure 3(a** and **b)**) to protect the fruit and move it for cutting the stem. Two linear knifes were used by the trimmer equipment. One knife was fixed, meanwhile the other was ejected by a 24 VDC (direct current voltage) linear actuator. Preliminary tests show successful results in stem cutting with only one movement. The mango enters the transporting system, but not all the fruits have attached pedicels. Those having the pedicel were cut by a warm knife having a temperature of 35°C. An image of the mango peduncle or abscission zone was obtained with a X800 digital microscope. The effect of anthracnose infestation was analyzed after fruit matured.

Wax was applied to mango fruits without the stem end. Paraffin was warmed up in the interior of a conventional gun (**Figure 3a**) and applied to the mango abscission orifice to avoid fungal or bacteria infestation. The manual gun uses paraffin sticks that melt after being heated by an electric resistance. When the trigger is squeezed, liquid wax leaves the gun through an output nozzle. Better results are obtained after applying pressure with a conical stamp over the liquid wax placed at the fruit peduncle orifice (**Figures 1a** and **2b**). An industrial wax application gun pressurizes the hot fluid with a pneumatic system (**Figure 3b**). A camera at the top provides information of whether the fruit has a 1 cm long stem and would only apply wax when there is no pedicel.

2.4 Mango pedicel and abscission microscope images

Large latex channel openings were seen at and below the abscission zone close to the fruit. High volume of latex spurts out through these channels after detaching the pedicel from the fruit [82]. Latex canals are seen as large perforations in the fruit peel reaching the outer pulp [34, 82]. After cutting the Keitt mango pedicel 2 cm away from the abscission zone, it was cauterized at 35°C, showing latex channels (**Figure 4a**). Cauterization at 35°C does not heat mango peel tissue (**Figure 4b**). If the stalk was cauterized at 45°C, the cells surrounding the channels were burnt and reduced in size (**Figure 4c**). Latex channels are clearly observed within red

Figure 2.
Robotic gripper (a) with mango pedicel, (b) without mango pedicel and having wounds, (c) cauterizer knife machine.

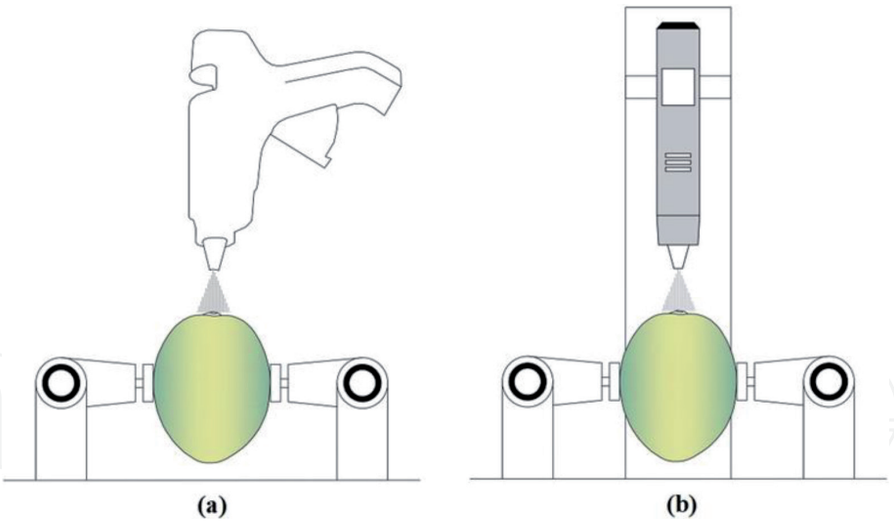

Figure 3.
Robotic arms handling a mango fruit for (a) manual, and (b) industrial wax application.

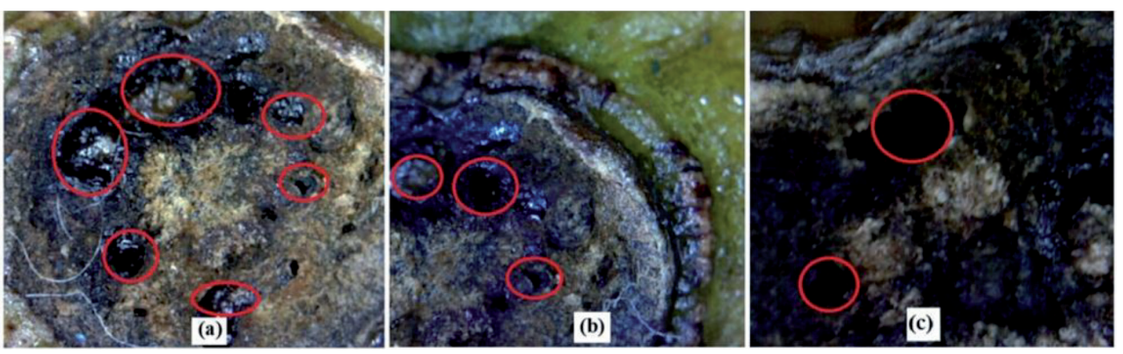

Figure 4.
Transverse section of Keitt mango fruit stem, showing the latex canals after cauterization at (a) 35°C on the abscission zone, (b) 35°C on the pedicel, and (c) 45°C on the pedicel.

circles in the green tissue just after removing the pedicel (**Figure 5a**). If the stem gets cauterized, latex channels are still present after cutting the pedicel with a razor blade, 0.5 cm toward the fruit abscission end (**Figure 5b**). If honey covers the green tissue, it will enclose the latex channels (**Figure 5c**).

3. Prickly pear treatments and measurements

Cactus pear (*Opuntia ficus-indica L.*) is an important fruit, but its consumption is limited by the presence of spines and glochids on its surface. Fresh-cut, ready-to-eat (RTE) cactus pears have higher preference than the whole fruits [83]. Actually, cactus pear at the green-yellow ripening stage is processed as a ready-to-eat fruit and stored for nine days in modified atmosphere packaging at 4°C [84]. Green yellow fruits present intermediate peel thickness and pulp softness, which is suited for peeling and for RTE fruits [85].

Cauterization prototypes were developed to increase prickly pear shelf life and decrease fruit diseases. A review on cauterization techniques including high-temperature contact and cryo-cauterization was presented [38]; both of these systems are patented [86, 87]. A cauterizer for harvested fruits applied 100 kPa of pressure at 200°C during 30 s [88]. Cactus pears subjected to a cauterization treatment were cut at the top-peduncle section, leaving a sealing area of 13 cm^2. The system is efficient in controlling postharvest diseases, but its excessive heat application

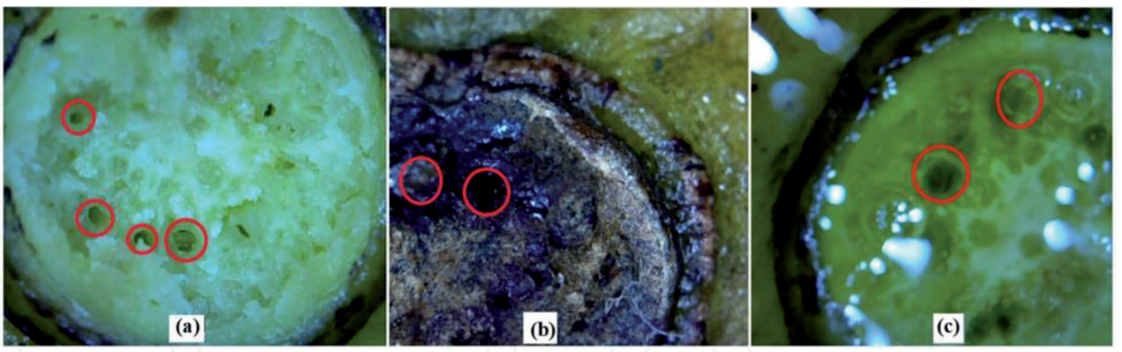

Figure 5.
Transverse section of Keitt mango showing the latex canals after (a) removing the pedicel, (b) cauterizing, and (c) removing the stem and adding honey.

results in expensive energy consumption [88]. Pulp temperature increased to 86°C after heating the fruit at 200°C for 45 s [88].

Prickly pear and their cladodes have natural polymers, and several eco-friendly materials are under development [89]. Cactus mucilage can be used as gelling, stabilizing, or encapsulating agent. The use of this bio-polymer material opens new opportunities in the food packaging. It is also used as a flocculating agent for heavy metals in water [90]. All these properties open new economic opportunities for cactus produce.

3.1 Prickly pear automatic cold cauterization

Several mechanisms have been developed for detaching the fruit from the cladode [91] and for fruit cold cauterization [92]. A harvesting arm with four degrees of freedom is used as hydraulic piston to collect prickly pears [91]. Cryo-cauterization results from pressing the fruit sliced area against a dry ice wall. The thermal shock maintained cactus pear over 120 days without further cooling [44]. Energy consumption of cryo-cauterization was minimum as no resistance was used; meanwhile the cauterizer working at 200°C employed 13 W per fruit [88]. The first automatic fruit cauterizer uses sensors and mechanisms to detect when the prickly pear is present within the metal container, rotate it 90° counterclockwise, displace it against the dry ice wall and deposit it again into the original band. The processing of 1000 fruits took a little more than 500 min [92]. Further development to simplify the system used a two-finger gripper that picks the fruit (**Figure 6a**). The most significant features to select a gripper include its opening range, its maximum applied force, its type of movement (angular, parallel or self-centered), and the grasp strategy (external or internal grasp). The robotic end effector uses two fingers to press the thick fruit peel without damaging it. The mechanism rotates the fruit by180° until it touches the ice pad (**Figure 6b**). However, dry ice melts in 5 h and has to be replaced in both systems. The last prototype has a gripper that grasps the fruit more efficiently with six fingers (**Figure 6c**). The gripper moves horizontally toward the dry ice chamber by sliding on pneumatic actuators. In the slider actuators, the gripper is mounted to the carriage. Precise slicing of the top-peduncle section is done by means of a circular blade. Once the fruit is sliced, it moves further to the left until it presses the dry ice chamber. With additional volume of dry ice within the chamber, it can last more than one day.

3.2 Prickly pear temperature measurements

Thermocouple sensors are being used for monitoring temperature within the fruit. Sensors were added below mesocarp and in the center of the fruit to study fruit changes during hot water treatments [58]. Three thermocouples of type J were

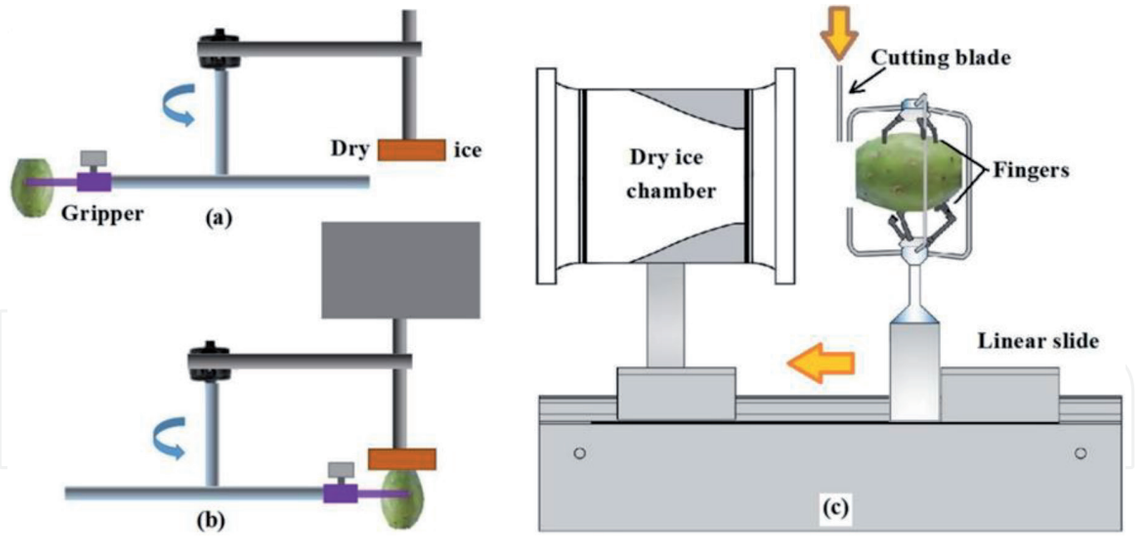

Figure 6.
Rotating gripper (a) picking the fruit, (b) contacting the heating surface, and (c) over a linear mechanism sliding toward the dry ice chamber.

inserted in the flat prickly pear surface to study variations during cauterization. As well after keeping the fruits for nine and 15 days at ambient storage, 10 prickly pears were cut nearby the sealed surface and in the middle of the fruit to measure TSS changes. Fruits stored for nine and 15 days at ambient storage were cut nearby the sealed surface and in the middle of the fruit to measure TSS and acidity changes.

4. Mango physicochemical analyses

Mango cuticle is thin and does not resist the high thermal gradient required by cauterization operations. Therefore, thermal treatments have to be applied carefully, mainly in the mango fruit abscission-pedicel interface.

Average biochemical maturity properties of fruits at early harvest for Haden, Kent, and Keitt were analyzed. These properties include pH, total soluble solids (TSS, °Brix), ascorbic acid (mg.100 g^{-1}), moisture content (%), and dry matter content DM (%). Kent and Keitt late varieties were harvested 137 and 148 days after fruit set, respectively. These results are similar with those obtained at Ghana plantations [93]. Mango trees with higher fertilization delayed fruit firmness decay. At the moment of harvest, fruits were green and firm for all varieties and fertilization regimes. After nine days of storage at 25°C, firmness decreased to 16.93 N for Kent fruits and remained firmer for Keitt mangoes. Chemical composition changes result from physiological and biochemical events controlled during fruit ripening [94]. Pectins are responsible for fruit texture and rise in the fifth week of mango fruit setting until the stone is formed. Pectins are responsible for fruit texture and rise five weeks after mango fruit setting until the stone is formed. Afterward, pectin content decreases, and fruit starts softening due to enzymatic degradation [64].

Fruits were harvested at a very green stage showing low TSS, acidity, and pH values (**Table 1**). As fruits mature nine days after, firmness decreased to 25.73, 16.93, and 32.91 N for Haden, Kent, and Keitt fruit, respectively (**Table 2**). After mango harvest, quality losses occur, affecting the content of nutritional components at different points during the handling chain [65].

Kent mangoes show a rapid decrease in firmness during ripening [95]. Kent mango trees with normal fertilization level produce fruits with high respiratory activity, lower ascorbic acid concentration, and fruit firmness drop [95].

Variety	Pulp pH	TSS (°Brix)	TA (% citric acid)	DM (%)	Firmness N
Haden	3.81	9.72	2.11	16.27	113.27
Kent	3.98	6.42	1.45	17.84	122.42
Keitt	3.66	7.63	2.43	17.85	121.05

Table 1.
Physicochemical analyses of different mango varieties considering pulp pH, TSS (total soluble solids), TA (Titratable acidity), DM (dry matter), and firmness of just harvested fruit.

Variety	Pulp pH	TSS (°Brix)	TA (% citric acid)	DM (%)	Firmness N
		18.32/	0.24/	19.20/	25.73/
Haden	5.12	17.56*	0.33*	18.86*	32.42*
		17.98/	0.21/	18.96/	16.93/
Kent	4.43	17.18*	0.31*	18.09*	22.42*
		15.72/	0.18/	18.55/	32.91/
Keitt	5.67	15.03*	0.27*	17.96	35.72*

Measurements of fruits without latex removal.

Table 2.
Physicochemical analyses of different mango varieties considering pulp pH, TSS (total soluble solids), TA (Titratable acidity), DM (dry matter), and firmness in the market place.

Lower content of potassium within tissues is related to higher acidity, while lower pulp pH responds to the fertilization regime [96]. Keitt mangoes showed the lower quantity of total soluble solids (15.72°Brix) and a low acidity of 0.18 (**Table 2**). On the other hand, Ca applications increased citric acid content in "Haden" mango fruits [97]; meanwhile pulp pH jumped to 5.12. Keitt mango showed higher vitamin C content than Kent and Haden fruits in their ripe phases, because of the inhibition of polyphenol oxidase (PPO). This mango variety provides better color and flavor retention during processing [98]. Mango refrigerated at 4°C tends to maintain the same TSS and TA during nine days of storage (**Figure 7a** and **b**). If the pedicel gets cauterized, mango TSS drops. Titratable acidity (**Figure 7b**) was significantly affected by fruit respiration, consuming organic acid.

4.1 Mango latex and diseases

Fruit fly control and removal of surface fungal diseases can be carried out by hot water immersion [99] and by hot air application. Hot water immersion is relatively easy to use, economic, and can provide accurate monitoring of fruit and water temperature. Mango fruits immersed in hot water at 52°C for 5 min eliminated anthracnose fungal infection [60]. Anthracnose infestation was not present after storing the fruit for 15 days at ambient temperature [100]. The effect of hot water treatment on pulp TSS was insignificant and mango visual quality remained outstanding. If green mature fruits are dipped for 20 min in water heated to 53°C, it will control both anthracnose and SER. If water is heated below 52°C, it is not effective to control anthracnose, and at 5 degrees warmer, it will scald the peel [101]. Hot water immersion without waxing affects the natural wax layer of the fruit surface, enhancing its senescence. Fruits coated with wax delay the ripening and extend their shelf life [102]. Keitt and Tommy Atkins mango fruits develop yellow pigments in the skin after hot water immersion [60]. TSS content of fruits immersed in hot water increased to 20°Brix, meanwhile untreated fruits remained at 17° Brix.

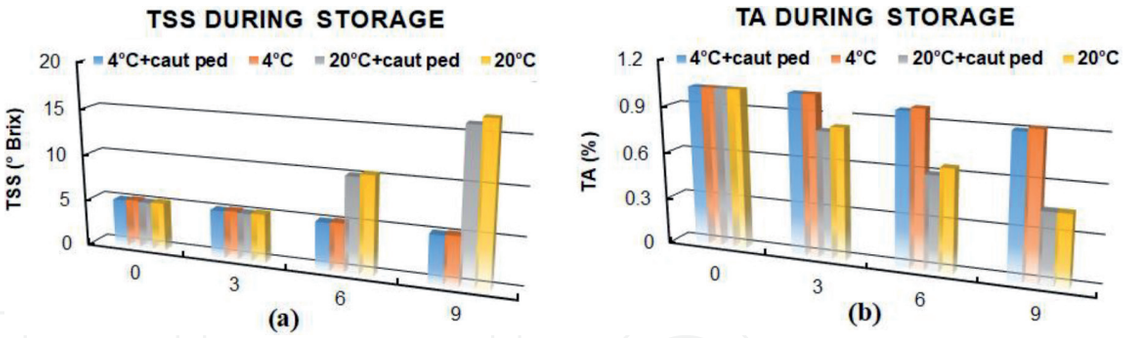

Figure 7.
Keitt mango (a) total soluble solid (TSS) concentration, and (b) Titratable acidity (TA) during the nine days of storage at 4 and 20°C with and without pedicel cauterization.

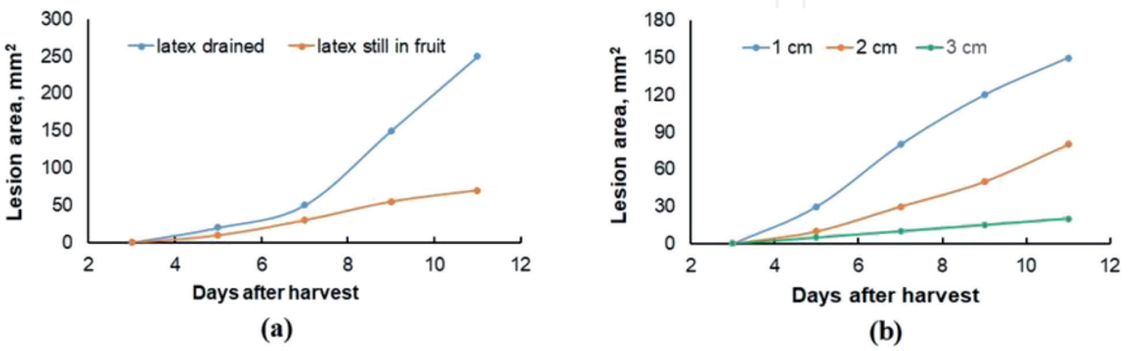

Figure 8.
Keitt mango anthracnose lesion area after several days of harvest (a) with and without latex, and (b) after petiole trimming.

In mangoes infected with SER, immersed in hot water and stored for 13 days, TSS content reached 19°Brix; fruits remained in 14°Brix if they were untreated [103].

At immature stage, anthracnose is not perceived, and the infection appears when mango ripens. Mango latex contains antifungal resorcinols and chitinase, so its retention during harvest will protect fruits against anthracnose and stem end rot [67]. Stem trimming deposits latex stains on the fruit surface, as pressurized sap stored in mango ducts falls on the fruit peel [65, 104]. Keitt mango fruit that preserved latex at harvest developed slightly smaller anthracnose lesions than fruits in which latex was drained (**Figure 8**). Keitt mango lesion area increases to 200 mm^2 after 10 days when fruits do not have latex (**Figure 8a**). Mango lesion

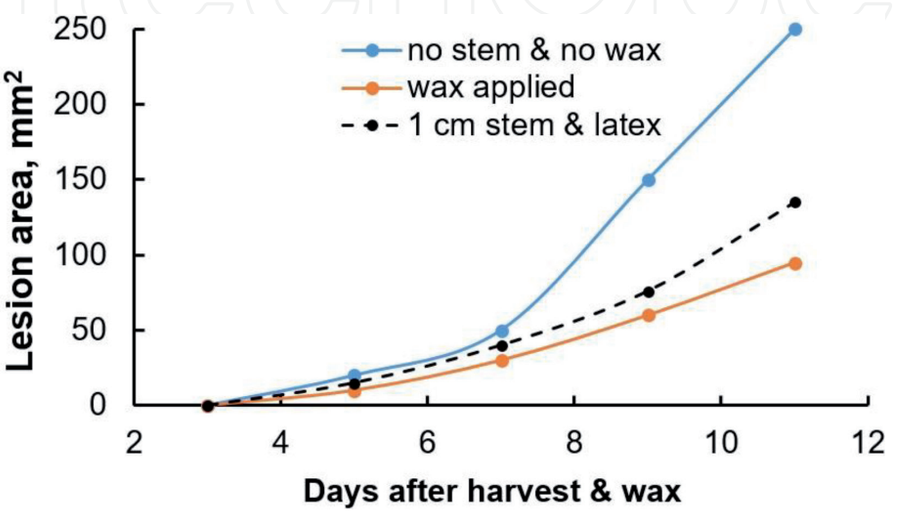

Figure 9.
Anthracnose lesion area several days of harvest for fruits cauterized and for mangoes after wax application.

corresponds to the black spot area growing on the fruit peel. When latex is present, the lesion only increases to 50 mm^2. The size of the remaining stem is correlated to the lesion area (**Figure 8a**). As it is longer and cauterized, less sap leaves the fruit, and it is more protected against pathogen infections. Higher anthracnose infection was noted in Keitt trees when more nitrogen was applied during fruit development [105]. This result was also found after analyzing "Willard" mango fruits [34].

When Keitt mango fruit stems were cauterized or their peduncle orifice covered with wax just after harvest, latex fluid remained within the fruit. Average anthracnose lesion was 38 and 54% smaller for wax and cauterization treatments, respectively, with respect to the control treatment after 11 days (**Figure 9**); no stem, wax, and latex were present on control fruits.

5. Prickly pear grippers and deformation experiments

Gripper suction cups grasp products by means of pressure difference [106, 107]. These grippers can be joined with other mechanisms easily, but are impractical for high-temperature grasping [108]. Modern granular-material grippers align themselves in malleable shapes to grasp the end product [108–110]. The prickly pear gripper used a grasping force of 40 N with a holding time of 30 s. The cauterizer robot (**Figure 6a**) presents a gripper moved by a mechanism containing two DC motors. One of the gripper fingers´ remains static during grasping, meanwhile the opposite finger presses the fruit; this finger moves using a DC motor. The second prototype used a pneumatic actuator. The slide actuator (**Figure 6b**) transports the six-finger gripper until a sensor detects its contact against the dry ice wall. A timer ensures that the fruit surface contacts the dry ice block during the right period. The pneumatic slider returns the fruit back to the pick and place area; this process takes 25 s. The end effector damaged the prickly pear during grasping and cauterization, when the fingers did not allow fruit movement. Fruit compression plotted in the vertical axis of **Figure 10** corresponds to the prickly pear deflection caused by finger pressing.

Prickly pears were sliced and cauterized by the robotic systems. Large prickly pears present an average diameter of 15 mm at the sliced section; smaller pears present a larger slice diameter ranging between 30 and 35 mm. Two clusters appear after plotting fruit firmness against pear compression (**Figure 10**). The black marks within the red circle show big fruits having firmness within 13 and 16 Ncm^{-2}. Fruit

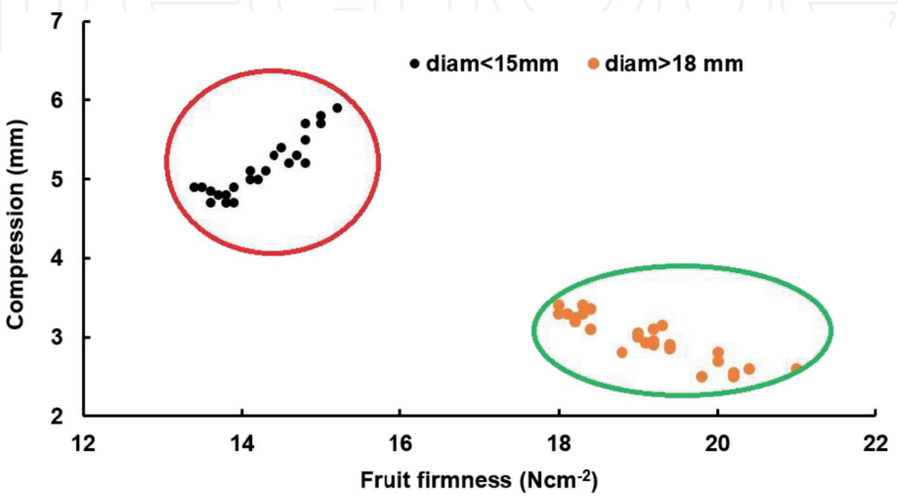

Figure 10.
Fruit firmness vs. compression for prickly pears having different slice diameter.

damage during processing decreased for pears compressed less than 3 mm. Orange markers show fruits with higher firmness (17.5–21.5 Ncm^{-2}), where the slicing area rises.

Prickly pear is a desert fruit with a thick peel. Pear firmness decreases once it is sliced (**Table 3**), and the fruit is destroyed when compression overpasses 5.2 mm. Red data in **Table 3** shows prickly pear values suffering some kind of damage. As the cauterizing diameter (ϱ) increases, fruit firmness drops and a lower pressure should be applied to avoid its destruction. Yellow fruits are softer and their tissue compresses easily. Therefore, yellow fruits are unable to withstand the cauterizing force (**Table 3**). As the prickly pear sliced area receives an orthogonal force, the airspaces within the pulp fill up. Pulp deformation takes place, growing sideways until the peel cannot withstand the pressure and explodes.

5.1 Prickly pear physicochemical analyses and measurements

Temperature measurements 2 mm within the pulp sliced area and at the middle of the prickly pear differ (**Figure 11**). The thermocouple placed 2 mm away from the sliced area reached only −4°C after 50 s, being hotter than the temperature of the dry ice block (−78°C). For the rotating robot (**Figure 6a**), fruit temperature decays after 50 s once the gripper contacts the dry ice surface, reaching its minimum temperature 10 s later. The green area in **Figure 11** shows negative pear temperature values in the sliced area during fruit cauterization contact. The complete temperature signal within the prickly pear during the cauterization cycle is shown in **Figure 11**. Fruit cauterization ended 125 s later, arriving to 17.4°C 145 s after; At this moment the slide system returned the pear back. Pulp temperature measurements acquired 15 mm below the sliced area were almost constant during the 6 min (**Figure 11**, dot line). Tissue temperature returns quicker to its natural thermal state (17.4°C) with the sliding system as shown by the red line, **Figure 11**. Cell walls have a more rigid contact when touching the dry ice chamber surface. Similar results were achieved by prickly pears that contacted the dry ice for 25 s.

TTS and total acidity (TA) were measured every 15 days after cutting three fruits at the center. TSS and TA monitoring was repeated in fruits stored for three months. Total soluble solids (TSS) concentration estimates the sugar content in the fruit and determines its degree of sweetness [111]. TSS concentration of prickly pears of cultivar "Blanca Cristalina" just after cryo-cauterization remained in 13.5°Brix. Measurements taken one, two, and three months later showed values of 13.4, 13.3, and 13.2°Brix, respectively. TSS minimum variations show that cryo-cauterization preserves fruit quality. Blanca Cristalina and Esmeralda fruits present 13.6 and

Diameter (mm)	Color	Firmness (Ncm^{-2})		Compression (mm)		Damage (%)
		Min	Max	Min	Max	
<15	green	16.12	16.82	2.5	3.2	0
15 < ϱ < 25	green	15.28	15.94	2.8	4.1	0
25 < ϱ < 35	green	14.47	15.35	4.2	5.5	50
<15	yellow	14.21	14.72	4.9	5.5	100
15 < ϱ < 25	yellow	13.73	14.15	5.1	5.5	100
25 < ϱ < 35	yellow	13.04	13.57	5.3	5.5	100

Table 3.
Green and yellow prickly pear firmness and compression having different slice diameters.

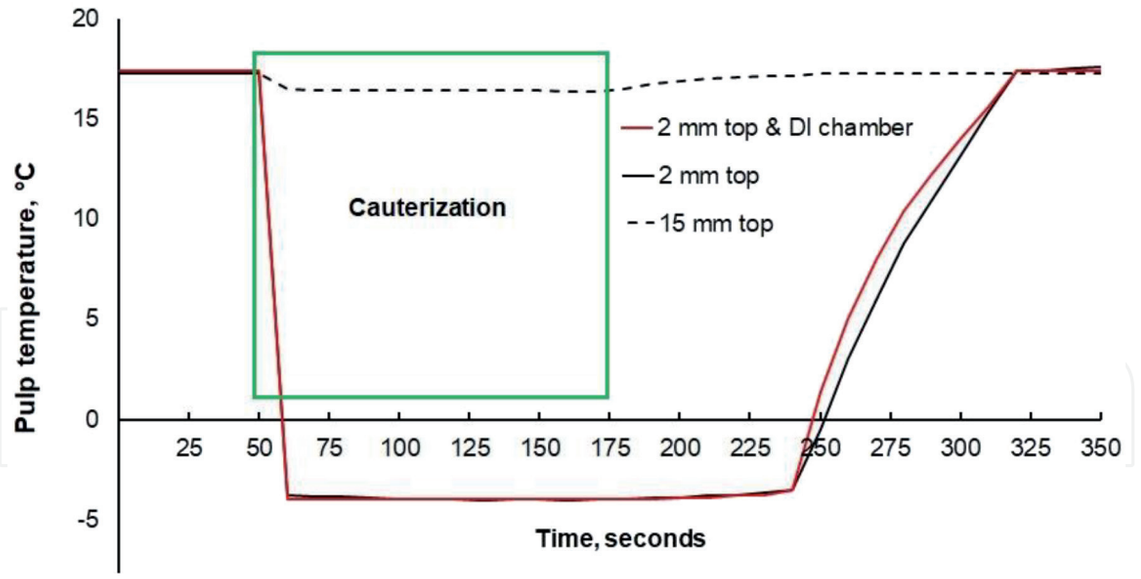

Figure 11.
Prickly pear pulp temperature monitored 2 mm and 15 mm away from the sliced surface during cauterization.

14°Brix at harvest, respectively [112]. Twenty-eight days later, TSS concentration was of 11.4 and 12° Brix for Blanca Cristalina and Esmeralda pears [112]. Cactus pears from the "Orito" cultivar presented 14.9°Brix after harvest and 14°Brix after 28 days later [111]. Blanca Cristalina TA values remained constant at 0.25% during the three months, so fruits remain acid and fruit acceptance high [111]. Blanca Cristalina and Esmeralda presented 0.27 and 0.29% of citric acid at harvest, respectively. After four weeks, it decreased to 0.18% in Blanca Cristalina [112]. For all the varieties, pulp citric acid decreased during ripening [113]. Although in these experiments cuticle thickness was not measured after heat treatments. Cuticle thickness reduction on some varieties was due to the effect of heat treatments [114]. The resistance provided by the cuticle against mechanical damage depends on the cuticle structure [115].

6. Conclusions

An increase in the quality and shelf life of mango fruit and prickly pear will increase their marketing worldwide. The first step to increase mango quality is to reduce fungal diseases such as anthracnose and stem end rot that appear due to environmental changes. Thermal treatments on mango fruits preserve their quality and reduce postharvest fruit disease infestation. Mango fruits must be harvested with care as mechanical damage of the stem end can start rotting in the fruit. Latex de-sapping after field harvest will reduce fruit sap burn.

Mango latex that contains antifungal resorcinols and chitinase should remain within the fruit to decrease anthracnose and stem end rot infestation. Stem channel thickness where latex flows can decrease after cauterization or by applying liquid paraffin. Two systems were developed to maintain latex after harvesting.

In the first system, a gripper grabbed the mango fruit and proceeded to cut the stem by means of two hot knifes maintained at 45°C. The cauterized pedicel presented burnt cells at the surface and reduced in size toward the stem end. This technique decreased anthracnose infestation by 50% after 11 days of storage when compared with de-sapped mango fruits. TSS concentration drops after pedicel cauterization. In the second equipment, warm paraffin wax was applied by a conventional gun to mango fruits without the stem end. Average

anthracnose lesion was 38% smaller for paraffin application after 11 storage days than in untreated infested mangoes.

Prickly pears are native fruits from Mexico that grow in arid zones and have very important nutritional properties. Cauterization increased prickly pear fruits' shelf life over two months. Hot and cold cauterizer equipment extended shelf life without pathogen damage as the treatment seals the fruit and avoids dehydration. Two grippers were developed to cryo-cauterize prickly pears as this system is more energy-efficient than hot cauterization. The first gripper uses two fingers to press the thick fruit peel without damaging it. In this robotic system, the biggest disadvantage is the reduced dry ice pad duration. Warm air moves around the dry ice pad and melts in 5 h, so it has to be replaced. The second robotic system was more efficient as the dry ice block was within a chamber isolated from the air. Dry ice lasted for more than one day. This system used a six-finger gripper that moved over a pneumatic actuator, cryo-cauterizing a pear every 25 s. When the gripper contacted the dry ice wall, the temperature inside the fruit 2 mm away from the fruit sliced area was of −4°C. The temperature was measured with a thermocouple inserted in the fruit. Another temperature measurement was taken inside the pear 15 mm away from the sliced zone and the colder temperature was of 16°C. Gripper grasping damaged yellow fruits and its compression should be limited to 3 mm in green fruits. TSS and TA remained constant in cryo-cauterized fruit during the three months of fruit storage.

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Conflict of interest

The authors declare no conflict of interest.

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