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Cauterizer Technology Increases Cactus Pear Shelf Life

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Additional information is available at the end of the chapter

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Abstract

Cactus pear is a food of nutraceutical and functional importance worldwide. Improvements in cactus pear shelf life will allow international 1-month refrigerated shipments for supplying good-quality fruit to the European markets. The perishable fruit is chilling sensitive and hot water treatments by immersion, increased shelf life to 1 month. Harvest tools are important to avoid fruit damage to the stem end, which leads to pathogens attack and fruit decay. A light wire-cutting tool detached 300 fruits h⁻¹ without leaving the worker with pain. A hot cauterizer (HC) performed better than a cold cauterizer (CC) extending fruit shelf life to 2 months; 85% of the HC-processed fruits were marketable after 2-month storage at ambient temperature. After removal of the prickly pear peduncle, the pulp contacts a hot flat metal surface at 200°C. A pressure of 100 kPa during 30 s assures proper heat transfer and surface healing. An automated HC process-line cauterizes 250 kg h⁻¹.

Keywords: hot cauterizer, cactus pear shelf line, hot cauterizer line, automation

1. Introduction

Opuntia ficus-indica domesticated probably 9000 years ago [1] in central Mexico is consumed as fresh fruit since ancient times. Cactus pears of the Cactaceae family are endemic from America [2, 3], growing more than 3,000,000 ha of *Opuntias* in their native natural habitat [4]. Once introduced into Spain from Mexico, the species spread throughout the Mediterranean [5], and today, cacti are cultivated in southern Spain, France, Greece, Israel, Italy, and Turkey. The Arabs took them from southern Spain to the north of Africa being now cultivated in Algeria, Egypt, Morocco, and Tunisia [6]; Tunisia cultivates 400,000 ha [7].

More than 70% of all the *Opuntia* species grows in the arid and semiarid regions of Mexico, Argentina, Peru, and Chile [8]. The largest area for fruit production is found in Mexico, with an

estimated cultivation area of 72,000 ha for prickly pear fruit growth and 10,500 ha for cladodes [9]. Peru has approximately 35,000 ha of wild plants used for cochineal breeding [5], while Brazil has 40,000 ha for forage. People living in Angola, Australia, India, and South Africa [10, 11] are looking for plant species that can adapt to arid and semiarid zones that can provide food and materials [6]. Italy cultivates 2500 ha for cactus pear production and Chile around 1100 ha.

1.1. Importance of prickly pear

The cultivation of prickly pear started as a resource for erosion control [12, 13]. Its intended effect on the microenvironment was not noticeable in soil properties [14]. Rehabilitation of degraded steppes requires revegetation with an herbaceous layer, contributing to the improvement of soil quality [15]. Research on cactus pear concluded that it is a food of nutraceutical and functional importance [16, 17]. Cactus leaves are low in proteins and used as dairy cattle fodder [18]. It imparts better flavor and quality to the milk and enhances butter color [19]. In the cultivation of cactus pear, cladode and prickly pear fruits are produced. Cladodes (“nopal”) with a production of 600,000 metric tones per annum in Mexico is consumed as a vegetable.

Cactus pear that has a high-water use efficiency (WUE) might play an increasingly important role in the agricultural systems of arid and semiarid regions under increased atmospheric CO₂ concentrations in the future [20]. For example, a doubling of atmospheric CO₂ concentration would lead to an increase in cactus pear biomass production from 23 to 55% due to increased WUE [4, 20]. Crassulacean acid metabolism (CAM) plants as prickly pear opens its stomata during the night to fix CO₂ as malic acid and converts it into sugar during the day [21]. Reduced rainfall caused by the climatic change will favor CAM plants with higher WUE [22], while the high potential productivity of *Opuntia* species may be used to slow the tendency of increasing atmospheric CO₂ levels [20].

1.2. Cactus pear production

About 100,000 ha are devoted to *Opuntia* fruit and cladode commercial production in more than 20 countries [23]. Commercial plantations use two types of production systems: traditional or intensive (microtunnel system). Prickly pear production with densities of 600–700 plants ha⁻¹ allows easy machinery access, making orchard management more efficient [24]. As production declined by 29% between 2003 and 2010 [25], autosustainable farms of higher densities were required. New traditional systems plant 2–3 years old cladodes with a density of 15,000–40,000 plants ha⁻¹. Commercial plantations are located in regions with summer rainfall of 600–800 mm, providing yields from 30 to 80 tones ha⁻¹ [26]. The *Opuntia* plant blooms once a year in Italy, while in countries like Chile and Israel, it blooms twice. Harvesting season differs according to variety, agro-climatic conditions, and forced blooming mechanisms [27].

The microtunnel system uses planting densities of 120,000–160,000 plants ha⁻¹, and beds with plastic sheet covers reduce the risk of frost damage in winter. Higher yields of 263 tones ha⁻¹ are obtained during the entire year [9, 28]. Transparent plastic microtunnels produce cochineal, and the plants resisted three cycles, compared with green raffia canvas cultivars that resisted two cycles [29, 30].

Foreign markets, primarily the USA and Canada, are a growing opportunity for fresh and processed nopal edible cactus stems. The nutraceutical characteristics of nopal have raised interest in European and Asian markets [31]. Cladode stems are beneficial for the treatment of various diseases [32], being a good source of vitamin C [33], minerals [34], and soluble and insoluble fibers [31].

After conducting market studies to confirm that the future product will find markets, cactus pear-processing industries will be established [6, 35]. Cactus pear products may find a valuable niche in consumers that make healthy lifestyle and eating choices. It also includes vegetarians, health centers, and hospitals, where diet and medical care demand high-fiber, high-vitamin content, antioxidants, sugar-free foods, and similar attributes. It is critical to ascertain whether any competitors exist for the product and how successful they are.

1.3. Cactus pear composition and chemical contents

The cactus-pear fruit is an oval, elongated berry, with a thick pericarp, and a fleshy and juicy pulp that contains many hard-coated seeds [36]. The pericarp composed of a thick peel of commercially ripe fruits of *Opuntia ficus-indica* (L.) Mill. accounts for 33–55% of the fruit weight. Sepulveda and Saenz [37] cultivated this variety in Chile, and the proportion of peel with respect to the fruit weight was of 50.5 g (100 g⁻¹), with 49.5 g of edible fruit, 78.9% of pulp, and 20.1% of seeds. Research carried out with different varieties encountered that the pulp weight accounts from 45 to 67% of the total fruit weight, and the seeds volume within the pulp varied from 2 to 10%. The large variability depends on cultural practices, fruit load, climate, and harvesting season [38–40].

The pulp presents high pH values (5.3–7.1) and very low acidity (0.05–0.18%) that strongly influences the processing operations [41, 42]. No differences in soluble solids, acidity, and pH were noted in summer- and autumn-harvested fruits [43]. Sugars of the reducing type represent 10% of the pulp and range from 10–17°Brix. The fruit pulp is very sweet being glucose the predominant sugar and fructose the second sugar [37, 44, 45].

Cactus pear is higher in vitamin C than fruits such as apple, pear, grape, and banana [46]. *Opuntia ficus-indica* (L.) Mill. shows a vitamin C content ranging from 180 to 300 mg kg⁻¹ [47–49]. Ascorbic acid content was higher in summer-harvested fruits, while fruit weight was higher in autumn-harvested fruits [43]. Pectin and mucilage presence influences fruit pulp viscosity due to their capacity to hold and bind water. Total pectin content of cactus pear fluctuates from 5.32 to 14.19%, while the mucilage content varies between 3.78 and 8.5% [50].

Cactus pear pulp presents a good source of potassium (217 mg 100 g⁻¹) and a low level of sodium (0.6–1.19 mg 100 g⁻¹) being an advantage for people with renal and blood pressure problems [37]. Prickly pears are rich in calcium and phosphorus, 15.4–32.8 and 12.8–27.6 mg 100 g⁻¹, respectively [37, 51].

Cactus fruits are rich sources of yellow orange betaxanthins and red-violet betacyanins [32, 45, 52, 53]. Five different betaxanthins and six betacyanins structures have been identified in different *Opuntia*-colored fruits [32, 39, 54] being the ratio and concentration of betalains responsible for the yellow, orange, red, and purple colors. Cactus pear fruit have been suggested as a promising

source of red and yellow food colorants for use at neutral pH [45], being used in yoghurts and ice creams [55]. Purple fruits are a source of betalains, a potential antioxidant and colorant similar to the pigment obtained from red beet that is widely used in the food industry [56].

1.4. Harvest timing and equipment

The cactus pear is a nonclimacteric fruit, and once harvested null ripening takes place. At 20°C, it has low ethylene production ($0.2 \text{ nl g}^{-1} \text{ h}^{-1}$), a low respiration rate ($20 \text{ } \mu\text{L CO}_2 \text{ g}^{-1} \text{ h}^{-1}$), and it is not sensitive to ethylene [57]. It is important to collect the fruits at the optimal ripening stage for processing and consumption [36]. Fruit parameters such as size, peel color variation, firmness of the fruit, total suspended solids (TSS), and fall of the glochids determine optimal harvest period [6, 47]. Fruit harvest takes place after the soluble solids content exceeds 12°Brix.

When the peel coloration is halfway toward that of the fully ripened fruit, the TSS achieves 12–15%, depending on the cultivar. At this period, the fruit is at its best quality for consumption or for storage. The fully ripened fruit is not in the best condition for storage and is too soft for handling. It is best to begin harvesting early in the morning at the lowest possible air temperature to avoid glochids release. The fruits remain at low temperature, which reduces dehydration and infestation [6]. Fruit damage to the stem-end leads to attack by pathogens and fruit decay, so careful harvesting by twisting fruit from the stem or cutting fruit with a small piece of stem attached is required [58, 59]. However, during the postharvest period, the need to remove the attached pieces of cladode from the fruits will be required.

Fruits are collected in buckets or trays and left to cure in the sun, drying out any wounds and allowing the glochids to loosen. Fruit are laid-down in the field on beds of straw covered with plastic mesh. After removing the dry glochids with brooms, the fruit should be quickly packed and transported to a cool or refrigerated area. This is essential for long-term storage, avoiding dehydration and mold development on the fruit. Fruit packed in ventilated wooden or plastic crates, 4.5 kg cartons, or in single- or double-layer tray cartons [60] due to color, size, and quality condition [48]. Large fruits wrapped in tissue paper reduce scuffing and other physical injuries.

1.5. Postharvest of prickly pear fruit and shelf life

Cactus plantations in semiarid lands produce large quantities of cactus fruits with short shelf life where production rapidly surpasses demand. Improvements in shelf life will allow international refrigerated shipments of 3-weeks, withstanding 2°C fruit fly quarantine treatments and maintain its quality without the use of fungicides [61]. Extending shelf life opens up the possibility of supplying good-quality cactus pear fruit during periods of short supply in European markets [62].

Cactus pear fruits present a limited shelf life, even in cold storage, which has stimulated interest in obtaining processed items with increased shelf life [63]. High pH nonacid foods [64, 65] require of a sterilization treatment of 115.5°C or greater [66] to avoid pathogenic microorganisms growth such as *Fusarium* spp., *Alternaria* spp., and *Penicillium* spp. Stabilization procedures have detrimental effects on some sensory parameters of fresh fruits, such as color

and flavor. Green cactus pear juice treatment with ultrasound technology reduced total cell counts and enter-bacteria to levels of no detection [67]. Juices presented good quality parameters, and ultrasound contributed to the release of bioactive compounds.

Storage of this perishable fruit can withstand from 2 to 5 weeks at temperatures ranging between 5 and 8°C with very humid environments (90–95% RH). Several factors can limit storage life such as decay, dehydration, and chilling injury [63, 68]. Chilling injury (CI) symptoms include pitting, surface bronzing, dark spots on the peel, and increased susceptibility to decay. Summer-harvested fruit was more chilling sensitive than autumn-harvested fruit [43].

Hot water treatments by immersion for a short time reduced microbial load without damaging the fruit [69]. In Italy, immersing the fruit for 5 min in hot water at 55°C extended the shelf life of cactus pear fruit cv. *Gialla* by 4–6 weeks without any prior chemical treatment [62]. Firmness and external appearance remained for 31 days with green and red prickly pears immersed during 2 min in water at 55°C [70]. After fruit hot water immersion at 52°C for 3 min, a microscope viewed prickly pear wounds and cracks sealing [71]. This left a relatively homogeneous surface from the fusion of the layers of wax, which provided real protection from fungi attack. Similar results appeared with hot air treatments at 37°C for 12 and 24 h [71].

Controlled atmosphere storage of minimally processed cactus pear fruits at 2°C in 10% CO₂ preserved them up to 20 days, maintaining high visual appearance, reduced tendency toward browning, and sugar content [72]. Passive-modified atmosphere packaging limited decay and increased the marketability of peeled cactus pear, as long as fruits were stored at low temperature [73, 74]. Ready-to-eat fruit storage in 5% O₂ and 30% CO₂ caused a selective suppression of the growth of different microbial populations [75]. In another experiment with ready-to-eat peeled fruits, unpackaged samples reported a higher mean pH value than modified atmosphere samples. However, samples packed in modified atmospheres reached the limit of marketability after 9 days [76, 77].

2. Harvesting devices

There are different ways of harvesting prickly pears, giving glochids the hardest time to workers [36, 78]. A simple method to pick the fruit with gloves is to twist it slightly and detach it (**Figure 1a**). The gloves covered with hair thorns end up in the worker's skin the next time it is used. Kitchen tongs (**Figure 1b**) detach prickly pears easily and keep the worker at a safe distance. After washing the tongs, the glochids disappear without ever touching worker's skin. Knives or scissors (**Figure 1c**) can remove the fruit from the cladode without damaging either the fruit or the cladode. Motor-blade harvesters (**Figure 4b**) provide a simple detaching method without entering in contact with glochids [79].

During fruit picking, workers cyclically perform many repetitive activities with the muscles of the hands and arms, causing excessive strains that increase occupational illnesses and decrease work productivity [60, 80]. A pruning shear developed in Egypt showed a 7.2% increase in labor productivity (kg day⁻¹) in comparison with handpicking. Microbiological activity was similar for handpicking and by using the pruning equipment [81].



Figure 1. Harvesting methods using (a) gloves, (b) kitchen tongs, and (c) scissors.

2.1. Design of harvesting devices

The new harvesting tools should present high fruit detaching yield without producing hand pain. The light scissor device (**Figure 2a**) weighs only 412 g (**Table 1**), while the thimble cutter (**Figure 2b**) uses cast-iron covers to limit hand damage by thorns. The motorized equipment (**Figure 4b**) uses a light motor coupled to an abrasive disk being the distance between them adjusted for easy access to the prickle pear-cladode interface. At a speed of 1000 RPM, the device cuts the prickly pear in 1.1 s, consuming 1.36 A. A battery of 200 Ah would cut 147 prickly pears before discharging [79].

Ergonomic design criteria for pruning shears and harvesters should be included [81], considering a handle length longer than the widest part of hand (10–15 cm) and a strong spring, which stays set when pruning and reduces forceful exertions when opening. Another consideration includes grip span, wire cutting, and a rubber absorber to protect the wrist [81]. Grasping under internal forces, geometric and gravity sensors has been studied [82].

The third harvesting tool used a stainless steel wire to detach the prickly pear from the cladode (**Figure 3**). This light device contains a thimble for inserting the ring finger and another thimble-structure fixed to the glove within the palm of the hand. After moving the ring finger, both thimble-structures separate, stretching the wire and cutting the fruit that falls down into a storage pot. A spring between the thimbles (**Figure 3**) reduces the force exerted during the cut. A tactile sensor (mod HT201, TEKSCAN, USA) measured the force consisting

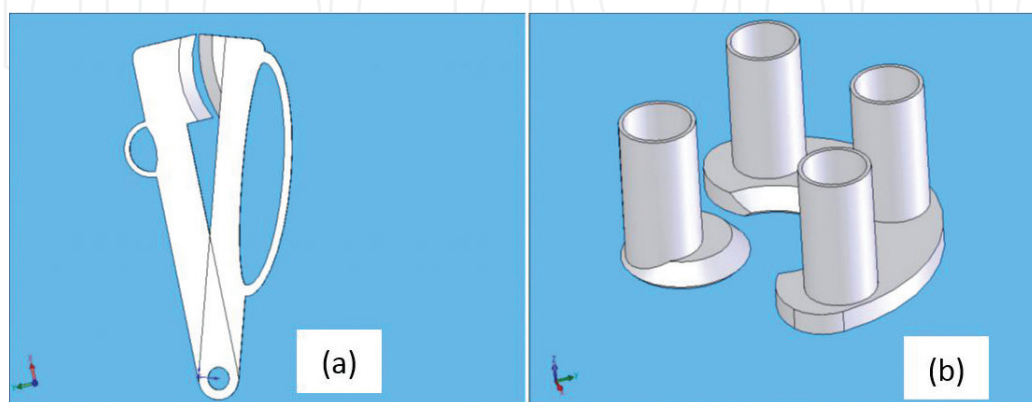


Figure 2. Proposed manual cutting (a) scissor tool and (b) thimble tool.

	Cutting tool				
	Disk	Scissor	Thimble	Motor	Wire
Weight, g	725	412	705	620	100
Diameter, mm	45	45	62	15	12
Length, mm	86	86	98	50	30
Pain	Small	Null	Regular	Vibration	Null
Yield, pears h ⁻¹	300	275	350	300	350
Straight cut, %	41	48	39	35	90
Large hand worker with glove cutting efficiency, %	81	79	91	94	90
Large hand worker without glove cutting efficiency, %	83	81	92		88
Small hand worker with glove cutting efficiency, %	60	69	59	94	83
Small hand worker without glove cutting efficiency, %	63	71	61		81

Table 1. Performance of the different harvesting devices.

of a piezo-resistive material sandwiched between two pieces of flexible polyester and only about eight mils thick. The contact area is 9.53 mm and can measure up to 130 N. The force measured during cutting varied between 90 and 120 N according to the prickly pear maturity.

2.2. Evaluation of harvesting devices

Table 1 compares the yield, cutting quality, and pain generated to the workers for each cutting device. The effect of workers’ hand size and glove use on cutting performance was studied.

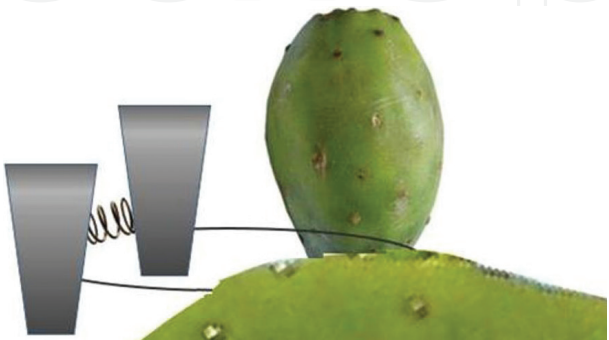


Figure 3. Stainless steel harvester tool to detach fruits.

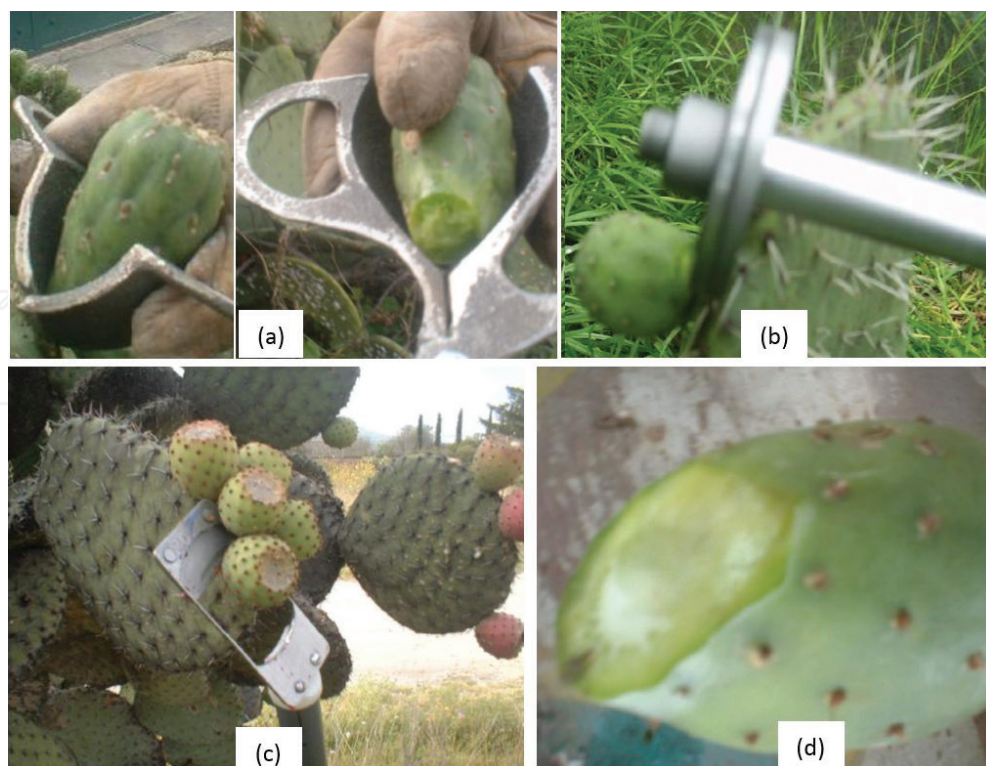


Figure 4. Device (a) slicing the pear straight, (b) electrically driven, (c) cutting with a simple knife, (d) slicing the fruit poorly.

Different workers performed daily during the autumn 2016 to obtain harvest data. **Table 1** compares the efficiency of the tools and although one device can provide a great yield if the cuts are not straight (**Figure 4d**), tool performance is poor. The stainless steel wire cutter cuts 350 pears h^{-1} , and 315 cuts were completely straight. Although the motorized device (**Figure 4b**) cuts 300 fruits in 1 h, it was harder to operate in cactus having pears lying close together (**Figure 4c**). As 35% of the fruit cuts were straight, only 105 were cauterized there. The prickly pear with the diagonal cut (**Figure 4d**) had to be sliced again, causing losses in the final harvest productivity. Productivity declined as day progressed for all harvesting devices.

Table 1 summarizes size (diameter and length) and weight of cast iron cutters. Reduction in weight to less than 750 g in the first three devices that resulted from 30% metal cover removal; the scissor device was the lightest. The thimble cutter was the shortest, but the worker's hand suffered pain, which remained for 2 months. In all cases, cutting efficiency decreased by using carnage gloves, which are clumsy and do not avoid the contact of glochids with the skin. The performance of the harvesting devices was compared (**Figure 4a**), showing the effect of the glove and the hand size. A reduction of 31% in fruits collected by small-hand workers that used gloves was noted when they employed the thimble-type tool, **Table 1**. Thimble-type tool size depends on worker's finger size; prickly pear size did not allow the cutter to operate easily.

The gripper hole of the disk-type prototype depends on worker's finger size; hand size affects cut quality and decreases productivity by 20%. The cutter moved by the thumb had no guide and was unable to enter between packed prickly pears on cactus plants (**Figure 4c**). Workers

having small fingers produced many poor cuts, as they were unable to press hard with the thumb (**Figure 4d**). The prickly pear cannot be picked-up easily, but this light prototype does not cause pain to the worker.

The cutting wire of the wire-cutting device (**Figure 3**) is changed every week. However, it is adjustable to the hand size and does not leave pain to the worker. Its productivity is almost 6 pears min⁻¹, and it is impossible to cut the fruits diagonally.

In the future, intensive productions in microtunnels will be common. The space between rows is shorter, requiring robotic systems, similar to fruit-collecting robots within greenhouses [83–85]. A new mechanism of four degrees of freedom positions the cutting tool over cactus plants. The tractor provides support and power to the arm for mechanical harvesting of prickly pears [86]. At the time, no reports on cutting speed and efficiency are available.

3. Cauterizing equipment

Cauterization is the process of destroying tissue with electricity and is widely used in modern surgery. The cauterization of this equipment uses a thermal source to create heat transfer between the source and the fruit cells. Cells heal creating a diaphragm-type surface, which reduces fruit water loss. The two developed cauterization processes increased prickly pear shelf life without requiring hot water tanks for fruit immersion in the field. The system patented by Hahn in 2016 [87] cauterizes the prickly pear with a flat hot metallic surface. After removing the peduncle, an electric resistance contacts the fresh pulp. The trimmed peduncle ensures a better heat transfer between the fruit and the electric heating resistance of 200°C. The cells of the viscous pulp expand forming a diaphragm-type cover 7 h after cauterization that prevents dehydration [88]. The other equipment works with ice, and heat transfer occurs from fruit to ice.

3.1. Hot cauterizer

The resistance-cauterizing machine (**Figure 5a**) uses two pneumatic pistons and its operation is explained in several paper [89, 90]. At the end of the top piston, a Celeron™ machined cylinder is fixed and encloses a circular heating resistance with a flat contact surface. The equipment works following three cycles (**Figure 5a–c**), starting and finishing when both the pistons remain retracted. Once the pear is detected, the piston moves downwards to exert pressure over the fruit fixed within the cup. An ATM 89C51 microcontroller board (**Figure 5e**) adjusts the heating period responsible for sealing the pear. The microcontroller board controls the two 3/2 way solenoid pneumatic valves (**Figure 5d**), which activate both pistons. A closed loop controller (mod E5CS-V, OMRON, Kyoto, Jap) maintains the heating resistance temperature constant by using a “J type” thermocouple. After 30 s, the embedded system interrupts the signal applied to the solenoid valve. The pneumatic pistons worked with a pressure varying between 100 and 200 kPa. A force of 20 N cm⁻² supported by the piston applies 200 kPa of pressure to the pear; a pressure of 275 kPa destroyed immature cactus pears, separating the peel from the pulp.

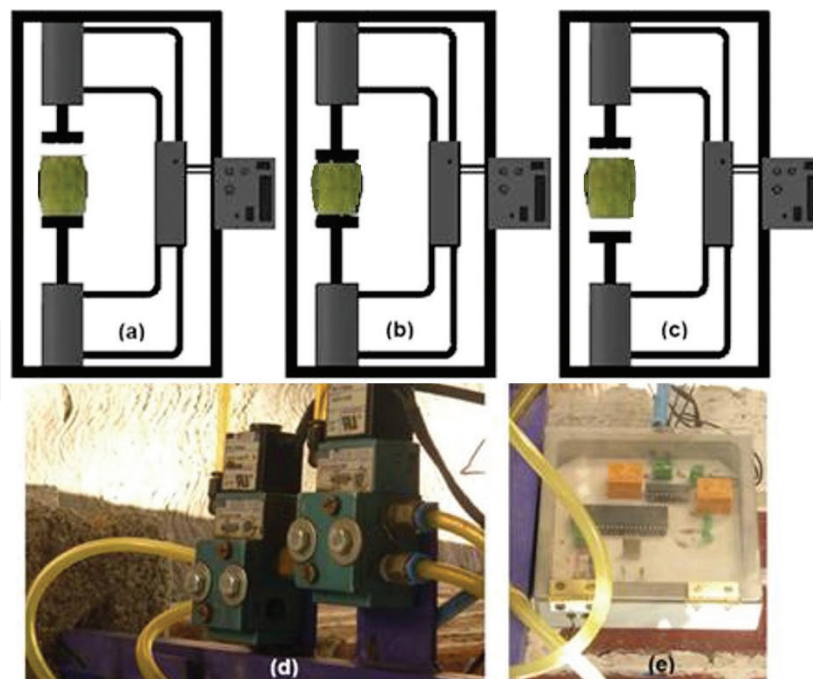


Figure 5. Heating cauterizer (a) lifts lower piston, (b) pressurizes the prickly pear, (c) finish treatment, (d) electro valves, and (e) microcontroller.

3.2. Experimental design and evaluation

The experimental design [89] consists of different treatments using four different pressures (50, 100, 150, and 200 kPa) and four different temperatures: 150, 180, 200, and 240°C. Each group consisted of 100 green sliced cactus pears numbered according to the applied pressure and temperature. After cauterization, the pears were stored at ambient temperature of $20 \pm 3^\circ\text{C}$ for 2 months. Visual observations rejected daily rotting fruit and shelf life for each group determined. Images of the cauterized area from five randomly selected pears were acquired with a digital camera (model WAT-250D, Watec, New York, USA) coupled to a stereoscopic microscope (model ZM160, ZEIGEN, D.F., Mexico) which magnified 40 \times . A nine W ring composed of 40 leds (model LED3000, LUXO CORP, New York, USA) provided 3600 foot-candles, which illuminated the sliced pear. Acquisition of images occurred after cauterization, 5 and 30 days after.

Measurements of pulp temperature during cauterization limited it to 70°C to avoid biochemical pulp changes [91]. A NTC thermistor (model STS-BTA, VERNIER, Beaverton, USA) with a resolution of 0.1°C and an accuracy of $\pm 0.5^\circ\text{C}$ was inserted in the fruit 0.5 cm beneath the cauterizing area. Pears were heated at 200°C using a pressure of 150 kPa, acquiring temperature measurements every second for a period of 45 s with a datalogger (VERNIER, Beaverton, USA).

Each pear was weighed every 5 days and the average water loss obtained. A machine texture analyzer (Zwicki Line Z0.5, ZWICK/ROELL, Germany) measured pulp firmness [90]. Measurements of firmness in the axial direction of the fruit used a 2.5 cm-diameter flat cylindrical probe. The force necessary to cause a deformation of 3 mm was determined to avoid fruit damage. Pulp firmness measurement happened 1 hour after cauterization, allowing time for the pulp to cool [90]. The value of pH was measured using a pH electrode and pH meter (HANNA, model HI

9021, USA), every 15 days after slicing ten prickly pears [92]. Every 15 days during the 60 days of storage, pulp firmness and pH of five fruits selected randomly were measured after slicing the pear just below the cauterized diaphragm.

3.3. Cold cauterizer

Freezing used for the long-term preservation, form ice crystals, and the final quality of the frozen product depends on the size and shape of these ice crystals [93]. Growth of ice crystals occurs after nucleation, after adding water molecules to the already formed nuclei. Slow freezing ($0.02\text{--}0.2^{\circ}\text{C min}^{-1}$) enhances the formation of large extracellular ice crystals [93], altering the cellular membrane transport properties and consequently losing its ability to act as a semi-permeable membrane; leeching of cellular substances and water loss is noted [94]. Growth of extracellular crystals caused tissue shrinkage and cell collapse [94].

The cold cauterizer is based on a pressure shift freezing system that will never arrive to zero degrees. Nucleation does not exist, as pressure release occurs very quickly [95]. Pressures of 200 and 150 kPa were applied to prickly pears, and the temperature within a pear was measured with a NTC thermistor inserted 0.5 cm from the sliced surface. Firmness, pH, and marketable fruit monitoring during storage provided results of the cauterization efficiency.

The device consists of a stainless steel vessel thermally insulated by a 5-cm thick glass fiber layer. A 3-cm thick ice bar introduced in the base of the equipment remains solid throughout 1 day. The fruit was manually placed within a hollow steel tube having a diameter of 7.5 cm so that two fingers can hold it (**Figure 6a**). A rack-and-pinion gear mechanism moved by a crank lowers the fruit held by a two finger-gripper (**Figure 6b**). These fingers have a spring that always press the fruit and do not drop it. Upon reaching the base, as the fruit touches the ice and cannot advance the fingers will open (**Figure 6c**).

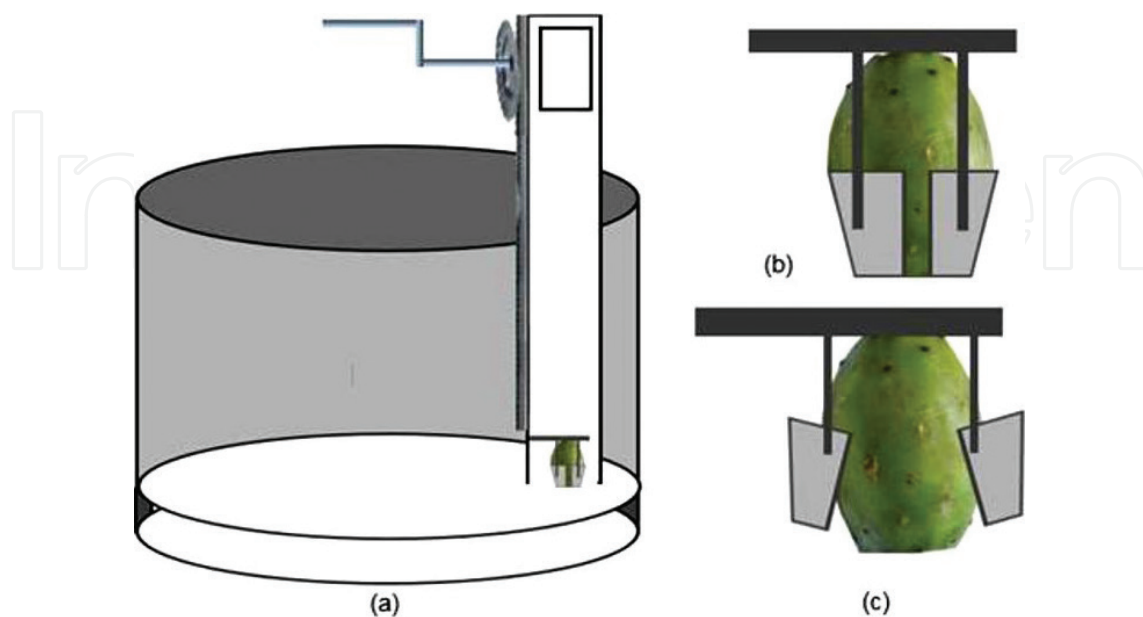


Figure 6. Cooling cauterizer (a) equipment, (b) during fruit transportation, and (c) during contact with ice.

3.4. Hot and cold cauterizer comparison

Surface pulp temperature increased to 56°C after applying a temperature of 200°C, while maintaining a pressure of 100 kPa (**Figure 7**). In the case of the cold cauterizer after 30 s, the temperature reached only 8°C, so no ice crystal building occurred. The temperature time constants were similar for hot and cold cauterization.

Cactus pears rotted after 15 days when not sliced and cauterized; slicing is an effective technique for getting a better contact area with the cauterizing surface. Fruits heated at 200°C using a pressure of 100 kPa began to rot after 37 days, but 50% of the fruit was still marketable after 63 days [90].

Quality parameters were measured on prickly pears during storage (**Table 2**) after hot cauterization (HT) treatment of 200°C@100 kPa and cold cauterization (CC) treatment of 100 kPa@0°C (ice). There were no significant differences encountered by ANOVA for both cauterizer treatments for fruit water loss during the first 45 days of storage. Hot and cold cauterizing processes presented average water loss after 2 months of storage of 0.9 and 4.5%, respectively. Significant differences appear after 60 storage days for hot treatments that applied pressures of 200 kPa [90]. The effect on Brix and pH on stored fruits after hot and cold cauterization was not significant, as shown by the ANOVA analysis. After 60 storage days, cold-cauterized pears increased its average soluble total solids by 7% over hot-processed fruits because of ripening, and decreased 8% its firmness (**Table 2**). Firmness showed significant differences in the cold treatment after 45 days of storage as longer fruits began to decay and mature. As the fruit gets soft with a firmness of 13 N cm⁻², it gets sweeter, giving values over 14.5°Brix. These firmness and Brix values occurred 45 days after CC processing, and 2 months after HC cauterizing. Cold cauterization processing extended fruit shelf life, but poor appearance was observed in 45% of the CC fruits after 2 months of storage.

Microscopic images show a great difference between HC and CC treatments being thickness of the healed tissue variable. **Figure 8d** shows the diaphragm formed as seal after 2 months of HC

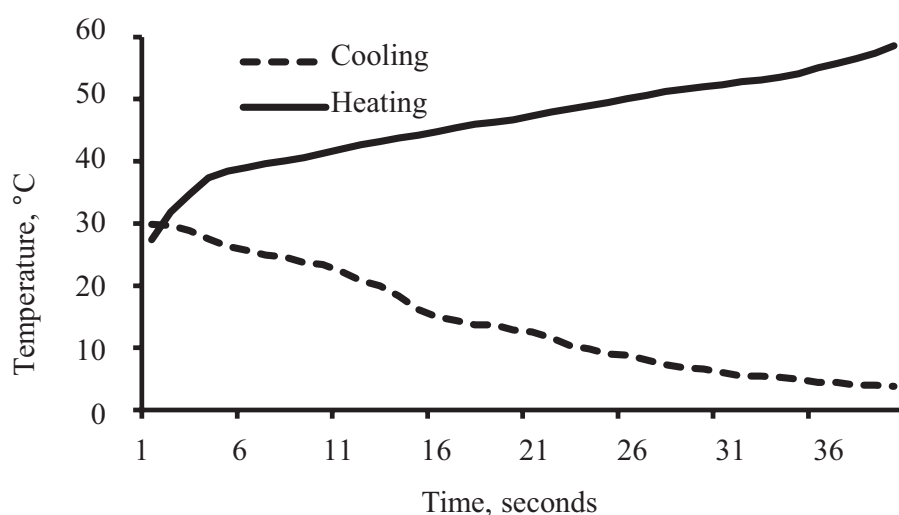


Figure 7. Effect of temperature inside the pear during hot and cold cauterization.

Variables	Cauterizer type	Measurement on:				
		Day 0	Day 15	Day 30	Day 45	Day 60
Water loss, %	H	0 ^a	0 ^a	0 ^a	0.5 ^a	0.9 ^b
	C	0 ^a	1.3 ^a	2.1 ^a	2.9 ^a	4.5 ^b
Firmness	H	16.4 ^a	16.2 ^a	15.7 ^a	14.8 ^a	13.1 ^b
N cm ⁻²	C	16.38 ^a	15.6 ^a	14.5 ^a	13.1 ^b	12.1 ^b
°Brix	H	13.05 ^a	13.1 ^a	13.15 ^a	13.5 ^a	14.19 ^a
	C	13.1 ^a	13.4 ^a	14 ^a	14.8 ^a	15.1 ^a
pH	H	5.32 ^a	5.32 ^a	5.39 ^a	5.66 ^a	5.79 ^a
	C	5.32 ^a	5.35 ^a	5.41 ^a	5.72 ^a	5.88 ^a
Fruits	H	0 ^a	0 ^a	0 ^a	4 ^a	15 ^b
Decay, %	C	0 ^a	0 ^a	2 ^a	16 ^b	45 ^c
Marketable	H	100 ^a	100 ^a	100 ^a	98 ^a	75 ^b
Fruit, %	C	100 ^a	100 ^a	96 ^a	82 ^b	50 ^c

^{a-c}Values sharing letters in the same row are not statistically significantly different from each other (based on least significant differences (lsd) from ANOVA, calculated standard error of 0.08).

Table 2. Compared variation of prickly pear stored after hot and cold cauterization every 15 days.



Figure 8. Microscopic image of (a) CC after 1 day, (b) CC shrinkage of cells, (c) HC seal after 1 month, and (d) HC seal after 2 months.

cauterization. One month before (**Figure 8c**), the seal was perfectly formed and did not allow any water loss. In **Figure 8a**, no seal appears and water movement appears after 1 month; temperature should be lower so that a thicker seal can appear and the cool-cauterizer process can be quicker.

4. Hot cauterizer line

The amount of prickly pears processed per hour is dependent on the time required for transferring heat from the resistance to the fruit in order to cauterize it. With a cauterization period of 30 s, only 120 fruits are cauterized per hour [90]. To increase the processing quantity, a packaging line was designed and implemented consisting of three sections. The first section removes the thorns, the second cauterizes the fruits, and the third packs them. The amount of cauterized pears per hour depends on the amount of cauterizing units operating in parallel, so if the line has 10 cauterizers, it will process 1200 fruits h^{-1} (approximately 250 kg h^{-1}). Several of these lines operating in parallel will increase even more the number of fruits processed.

Marquez and collaborators [25] found that 40% from the total prickly pear economical income was used for removing prickly pear glochids and packing; wooden boxes accounted for 35% of the crop revenue. Elimination of glochids in small processing plants takes place by running the fruits over rollers covered with hairs or nylon bristle brushes [6]. The first stage of the packaging line removes the glochids from the singulated prickly pears that advance slowly in-between two nylon brushes rotating in opposite directions. The brushes placed on each side of the V-type conveyor make the pears spin around removing the glochids without damaging the fruit.

Each prickly pear advances alone through the line and an articulated gate stops it; gates quantity depends on the number of cauterizer units. The controlled gate splits a pear from its neighbor by 15 cm, letting the fruit beneath the cauterizing piston (**Figure 9a**). A vision system analyzes the quality from each prickly pear as they advance through the line. After acquiring the image, an edge detection algorithm eliminates the contours (**Figure 10a**). The filtered image uses a mask to eliminate the glochids areas marked with green circles, making the rot in red detectable (**Figure 10b**). Once the high-quality fruit passes the vision system analysis, a signal turns on a cutter for removing the peduncle from the prickly pear. The fruit turned with the bare pulp upward, waits for the contact of the hot plate (**Figure 9b**). Each piston works independently since the displacement of each piston arm depends on fruit size. The process ends after 30 s of cauterization by lifting the top pistons (**Figure 9c**).

The third section of the line is the one that packs the fruits. Prickly pears move carefully through the conveyor belt, as fruits have no protection at the top side, after peduncle removal and fruit cauterization. Photodetector A (**Figure 11**) detects fruit movement over the conveyor. Once the conveyor rotates over the sprocket, the pear will fall unless a hard-plastic structure avoids it; the frame rotates the fruit by 90° maintaining the cauterized part looking up. Fruit turns around its center of gravity as shown in **Figure 11**, being the pear pulled downward by the band movement. The center of gravity causes fruit turning (**Figure 11**), and band movement pulls the pear downward.

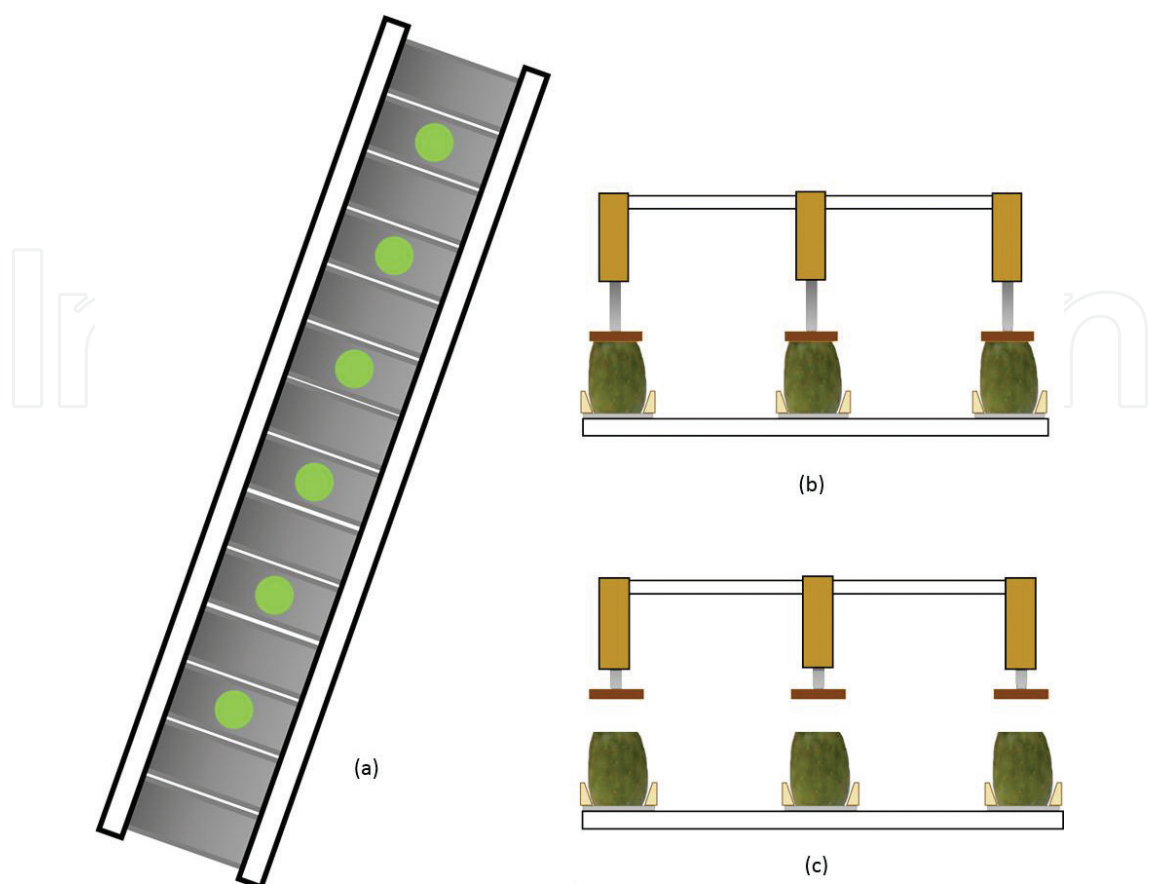


Figure 9. Packing line showing the (a) conveyor line, (b) cauterization units, and (c) end of process.

A camera or a capacitive sensor (B) transmits a signal to a movable gate to close. The gate stops the fruit falling by gravity, ensuring that the arm that is going to transport it to the packing boxes is in its right position. When sensor C perceives the pear standing over the gateway and sensor D detects the proper position of the gripper, the movable gate opens and the fruit will fall into the gripper fingers. The fingers move the fruit to the packing box.

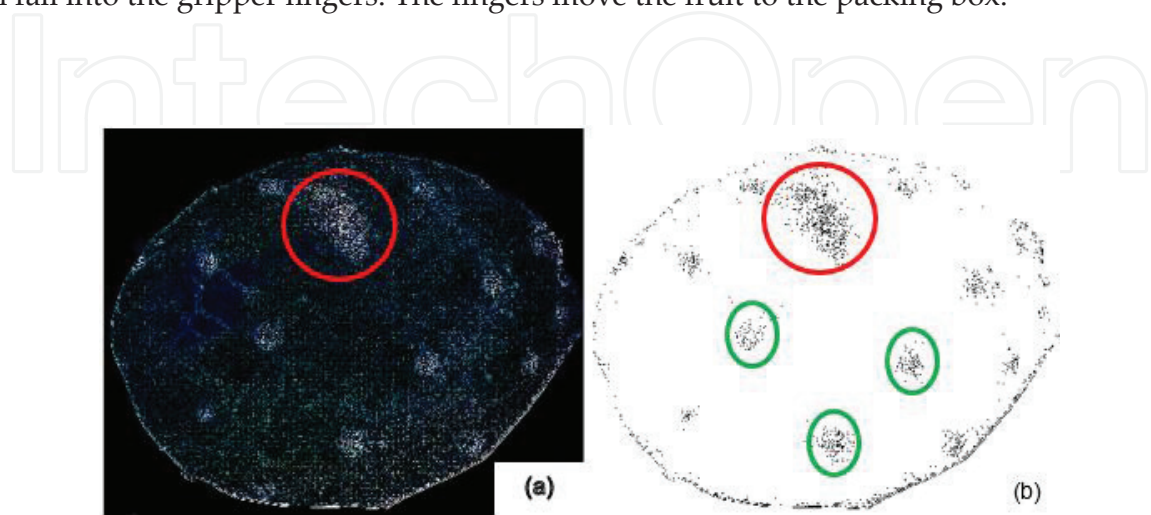


Figure 10. Image of a rot fruit after (a) edge detection and (b) filtering and noise removal.

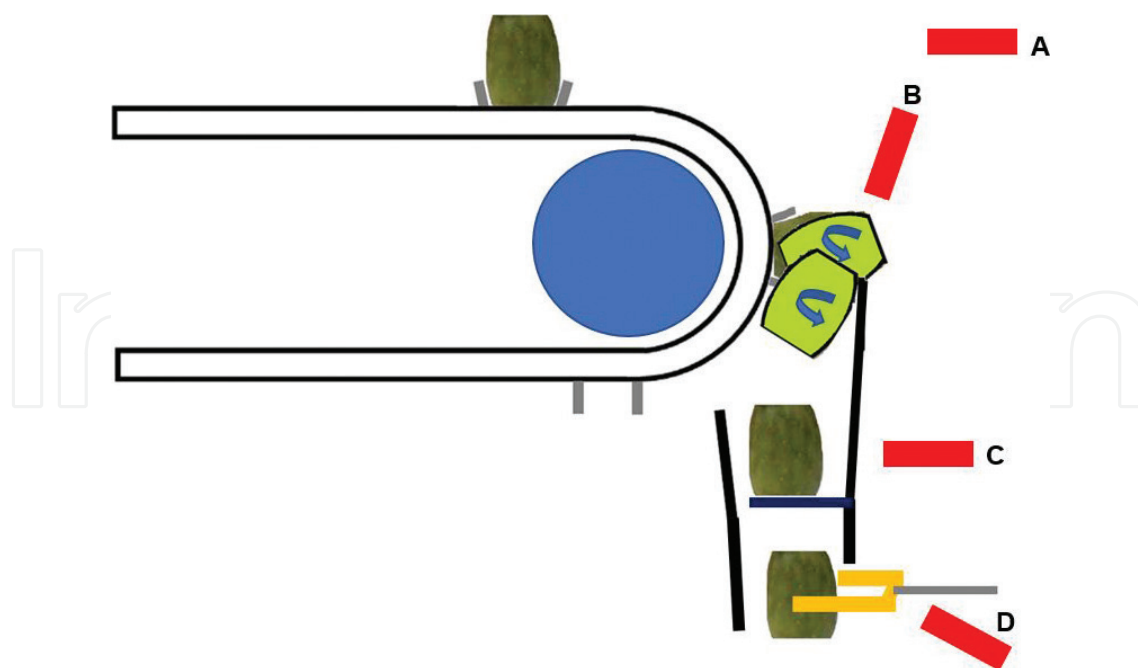


Figure 11. Packing mechanism for prickly pears.

5. Conclusion

An increase of the shelf life of prickly pear fruits can make them marketable in developed countries, considering the fruit nutraceutical and chemical functional properties. The first step to increase shelf life is to harvest fruits carefully as mechanical damage to the stem-end leads to attack by pathogens and fruit decay.

There are different ways of harvesting prickly pears, which include gloves, kitchen tongs, motor-blade tools, knives, and scissors. An important consideration when designing a tool for prickly pear fruit detaching is to avoid skin contact with glochids. Weight and another physical dimension of the tools, productivity, and quality of cuts were compared during harvesting trials using five tools. The stainless steel wire tool was the lighter and the more efficient; workers did not suffer any pain after using it. Ninety percent of the collected fruits had straight cuts, and 350 fruits were detached hourly. The motorized system was difficult to operate between fruits close together over the cladode.

Cauterization increased prickly pear fruits' shelf life over 2 months. Hot and cold cauterizer equipment extended shelf life without pathogen damage as the treatment seals the fruit and avoids dehydration. The hot cauterizer places a hot surface at 200°C in contact with the fresh prickly pear pulp. The trimmed peduncle allows a better heat transfer, enhanced further by a pressurized contact of 100 kPa. The cold cauterizer replaced the hot surface by ice to process the fruit. Pulp firmness, pH, water loss, Brix, and percentage of marketable fruit were compared using both cauterizers. The hot cauterizer working at 200°C and 100 kPa extended shelf life, being 85% of the fruit marketable after 2 months. Fruits were stored at ambient conditions. An automated cauterizer line was introduced for processing one quarter ton every hour.

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