Postharvest Biology and Technology 147 (2019) 132–138

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Robotic cactus pear cryocauterization increases storage life

Federico Hahn-Schlam[a,*], Salvador Valle-Guadarrama[b], Tim Jenkins[c]

[a] Departamento de Irrigación, Universidad Autónoma Chapingo, Km 38.5 Carretera Mexico-Texcoco, Chapingo, 56230, Texcoco de Mora, Mexico
[b] Departamento de Ingeniería Agroindustrial, Universidad Autónoma Chapingo, Km 38.5 Carretera Mexico-Texcoco, Chapingo, 56230, Texcoco de Mora, Mexico
[c] Centre for Sustainable Agricultural Technologies, P.O. Box 29683, Riccarton, Christchurch 8440, New Zealand

ARTICLE INFO

Keywords:
Opuntia spp.
Cryocauterization
Dry ice
Robotic pneumatic machine
Shelf life

ABSTRACT

Cactus pear (*Opuntia* spp.) is a highly perishable fruit that starts to deteriorate after several days of storage at room temperature. After two weeks, 70% of the fruit show signs of deterioration. A cauterization process used a pneumatic robotic gripper to press a cactus pear against a dry-ice wall inserted inside a thermally isolated chamber. Batches of 1800 cactus pears were processed daily under different environmental conditions (sun, cloud, and rain). The best cryocauterizing treatment for fruit was 150 kPa for 15 s, which on sunny, cloudy, and rainy days resulted in marketable fruit index of 0.86, 0.84, and 0.82, respectively, after 90 d (where 1.0 = 100% marketable fruit). Cryocauterization is a good alternative to increase storage life of cactus pear, but it should be applied early in the working day and without rainy conditions.

1. Introduction

Cactus pear (*Opuntia* spp.) is a fruit that is produced in arid and semi-arid regions of several countries around the world (Márquez-Berber et al., 2012), mainly in Mexico and other countries of Latin America, Mediterranean countries, and South Africa (Shedbalkar et al., 2010). Cactus pear is generally consumed fresh, but is highly perishable. Fruit stored at room temperature can exhibit high incidence of spots and rotting after 9 d due to decay (Granata and Sidoti, 2002; Varvaro et al., 1993). Almost 70% of fruit can be damaged after 20 d at ambient conditions and with refrigeration shelf life can be increased to four to six weeks (Schirra et al., 1999). Storage under modified atmosphere delayed microbial development to 10 d at 27 °C and 20 d at 10 °C (Ochoa-Velasco and Guerrero-Beltrán, 2016).

Cauterization of wounds that occur during harvest can increase storage life and 78% of fruit remained unspoiled after two months (Hahn, 2009). The treatment used a cauterizer at a temperature of 150 °C, after harvesting the cactus pear on the nopal pad corner. The procedure was improved after designing a device that applied constant pressure of 100 kPa to ensure a uniform treatment at 200 °C during 30 s. This system effectively controlled postharvest diseases (Hahn et al., 2016), but depends on a strategy to apply heat, which is expensive when the number of fruit to be treated is high.

The hypothesis considered a new method of cold cauterization capable of transferring heat rapidly from the cactus pear sliced area to a dry ice surface to ensure a long shelf life without applying heat energy for cauterization. A first experiment had the objective of evaluating the effect of pressing a cactus pear against a surface at temperatures below the freezing point to cause a local burn that generates a protective film, in a similar way to what happens with foods handled under freezing conditions (Schmidt and Lee, 2009). Dry ice (CO_2 in solid state), due to its availability at low cost and its thermodynamic properties (Mazzoldi et al., 2008), was considered an alternative to apply this treatment. A robotic gripper capable of pressing a cactus pear against a dry ice for a given period was designed for cauterizing the fruit to increase its storage life.

2. Materials and methods

2.1. Plant material

Cactus pears (*Opuntia albicarpa* var. Cristalina) were harvested at San Martín de las Pirámides, Mexico (19°46″20′ N, 98°38″48′ W; 2300 m above sea level). Fruit were green lemon and had an elongated shape. Weight varied between 90 and 200 g. Fruit were harvested manually in the morning, between 8:00 and 10:00 AM, with leather gloves and using scissors. Fruit were placed over paper bags and plastic containers to prevent the contact with glochids and wounds that could be generated. No additional procedure was used to remove glochids.

* Corresponding author.
E-mail address: fhahn@correo.chapingo.mx (F. Hahn-Schlam).

https://doi.org/10.1016/j.postharvbio.2018.09.014
Received 3 May 2018; Received in revised form 17 September 2018; Accepted 17 September 2018
0925-5214/

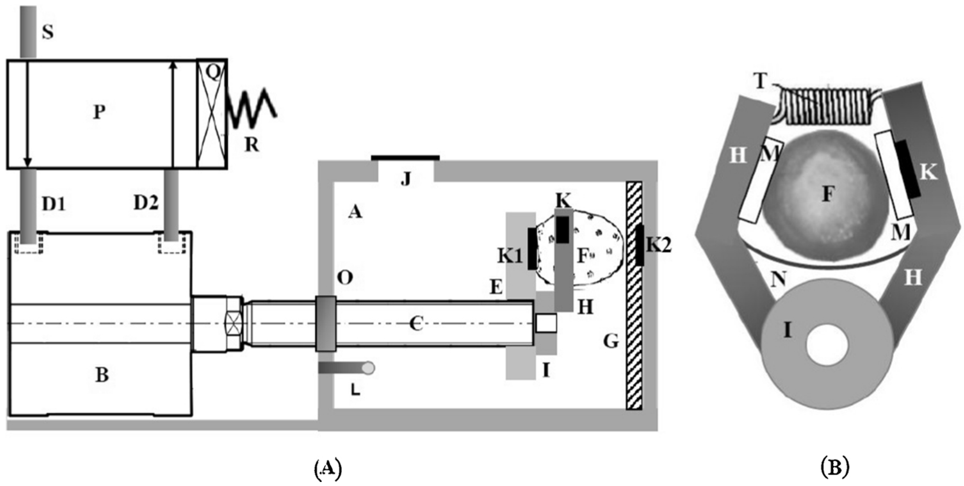

Fig. 1. Lateral view (a) and frontal view (b) of the cauterization machine that comprises a chamber (A), a linear piston (B), a piston rod (C), hoses for air transport (D1 & D2), a flat steel plate (E), a prickly pear (F), a dry ice wall (G) gripper fingers (H), a gripper cylinder handler (I), an opening gate (J), force sensors (K, K1, & K2), a limit contact (L), cushions (M), a support base (N), a linear bearing (O), an air solenoid valve (P), a solenoid coil (Q), a spring (R), a hose to the air regulator (S) and gripper compression spring (T).

2.2. Cauterizing equipment

The cauterizing machine (Fig. 1A) worked inside a thermal isolated chamber (A) having dry ice on one wall (G). The stainless-steel chamber was isolated with fiberglass 5-cm thick and a sliding gate (J) that allowed fruit insertion. A linear pneumatic piston (B) drove the rod (C) horizontally guided by a linear bearing (O) to minimize friction. Each fruit (F) grabbed by the gripper (H) was pushed by a stainless steel plate (E) fixed to the piston rod. A piezo resistive detector (K1) was placed in the stainless steel plate to quantify the applied force during cauterization. Cushions (M) within the two-finger gripper (H) avoided fruit skin damage (Fig. 1B). An elliptic support (N) maintained fruit perpendicular to the dry ice wall. The bottom of the gripper-fingers was held by a stainless-steel cylinder (I) screwed to the piston shaft end. The double-acting cylinder (A24060DN, Automation Direct, USA) provided a maximum pressure of 200 kPa to the fruit. The cylinder moved the fruit linearly (0.15 m) until it touched the dry ice surface, exerting pressure during a programmed time, before returning to the starting position. An electro-pneumatic regulator (Model ITV-3031, SMC, USA), controlled the air pressure supplied to the piston (B). Air fed to the piston (B) was controlled by a normally closed 3/2-way single solenoid valve (P2LBZ, Parker, Michigan, USA); the solenoid (Q) was activated with a 24 V signal. Once the solenoid valve (P) was activated, compressed air (S) entered the push port (D1) through a hose and moved the piston towards the dry ice surface. A spring (R) on the solenoid valve controlled its initial position. During this period, the pull port (D2) remained blocked. After turning-off the valve, the push port (D1) released the compressed air within the cylinder to the atmosphere and the rod returned the fruit to the initial position. A limit switch (L) provided a signal to stop precisely the piston rod, the gripper, and the fruit (Hahn, 2018).

An embedded board, based on an ATM 89C51 microcontroller (ATMEL Corp., San Jose, CA, USA), controlled the horizontal pneumatic guide position and used three force sensor resistors (FSR). These sensors (mod A401, Tekscan, USA) measured forces up to 40 N within a 5 cm^2 sampling area. For each sensor (Ashruf, 2002), a constant current source converted the resistance output value into voltage, in a way that a pressure of 200 kPa provided an output of 3 V, while the corresponding value for a pressure of 100 kPa was 1.5 V. The gripper measured the grasping force and detected fruit removal with a piezo resistive force detector (K = FSR1). A second force sensor (K1 = FSR2) fixed in the stainless steel plate measured the horizontal force applied to the fruit. The third sensor (K2 = FSR3) evaluated the force on the dry ice surface.

The routine of the embedded system started by programming the air regulator pressure (Fig. 2) using a direct voltage signal. A voltage of 0.75 V regulated the air pressure to 150 kPa, meanwhile a voltage of 1 V maintained the air pressure at 200 kPa. With the piston at its starting position, the limit-switch turns-on a LED indicating that the fruit can be loaded to the gripper. Once inserting the fruit within the fingers, FSR1 (K) provides an output of 2 V that activates the valve and moves the piston rod (Fig. 2). Cauterization is initiated as fruit applies pressure to the dry-ice wall. During this period, the force of each FSR sensor is acquired and stored. If FSR2 < < FSR3 the pressure of the fruit against the dry-ice surface is considered poor. Therefore, the air pressure applied to the cylinder should be increased. After ending the cauterization period, the solenoid valve closes. The piston returns to its initial position, triggering the limit switch and turning-on the LED.

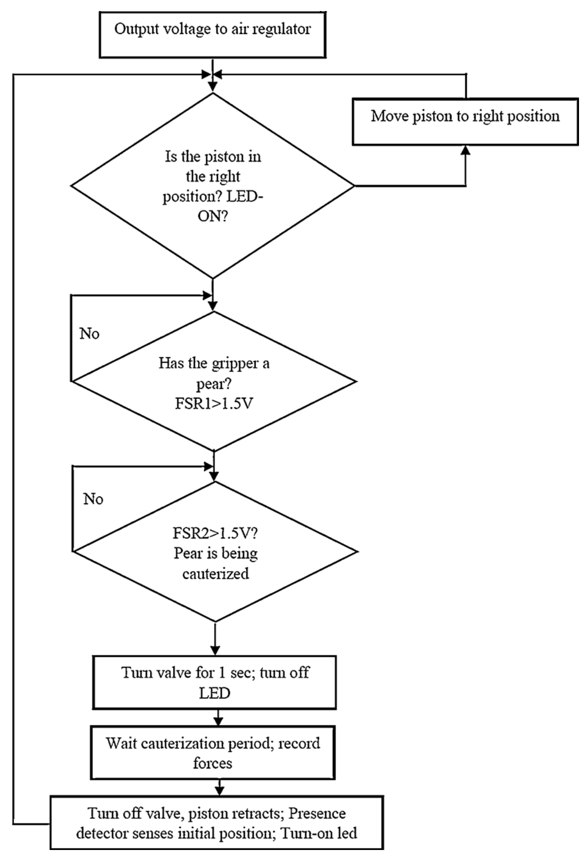

Fig. 2. Flowchart of the embedded system program.