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Optimal pressure and temperature parameters for prickly pear cauterization and infrared imaging detection for proper sealing

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ABSTRACT

Cactus pear (*Opuntia* sp.) is a highly perishable fruit that starts to deteriorate after several days of storage at room temperature. After two weeks at room temperature, 70% of the fruit shows signs of deterioration. Cactus pear quality for stored pears depends on harvest techniques and on practices for prolonging shelf life. A pneumatic cauterizing machine with a resistive heating element was used to seal cactus pears on their peduncle. More effective contact between the heater element and fruit was obtained after cutting the peduncle. Internal pulp temperature was measured with NTC thermistors and it was found that after heating at 200 °C for 30 s, pulp temperature increased to 60 °C. Surface temperature was measured with a thermal infrared camera. Cactus pear shelf life, water loss, firmness and ° Brix were evaluated using piston pressures of 50, 100, 150 and 200 kPa during 30 s at cauterizing temperatures of 150, 180, 200 and 240 °C. The best shelf life was obtained after pressing the fruit with 100 kPa during 30 s at a temperature of 200 °C. Thirty-seven days after being cauterized, fruits began to rot, and half of the fruit was not marketable after 63 days. Pulp firmness decreased by 81% after 60 storage days, and soluble solids increased by 105%. Pears that did not seal properly were detected using thermal imaging three days after cauterizing. Pears were sliced and cauterized again unless the rotting area was over 50% and firmness lower than 15 N cm^{-2}.

1. Introduction

Mexico is the world's largest producer of cactus pear with 79.4% of world production, and with 49,165 ha under cultivation. (Añorve Morga et al., 2006). This is followed by Italy and South Africa with 12.2% and 3.7% of world production, respectively. However, Italy is now the world's largest exporter of cactus pear to the European Union (EU), producing about 87 thousand tons annually in Sicily, which corresponds to 96% of the total Italian harvest (Timpanaro and Foti, 2014).

Cactus pear is highly perishable: fruit stored for over 9 days at room temperature exhibited a high incidence of spots and rotting; after 20 days almost 70% of the fruit was visibly damaged (Cervantes, 1998); while cooling the fruit to 10 °C increased its shelf life to 16 days. Fresh cactus pear shelf life can be increased to 32 days in modified atmosphere packaging with less than 20 kPa CO_2 (Guevara et al., 2003).

A cauterizer was developed to cut and seal 120 pieces of fruit per hour (Hahn, 2009). This process increased the shelf life of cactus pear (*Opuntia* sp.) without storage room ventilation or cooling. Cuts, made close to the cactus cladode at 150 °C during harvest, destroyed thorns and cauterized the fruit. After 2 months of storage, 78% of the pears were unspoiled. Maturation began after 45 days, when weight loss was 2%. Excessive heating duration or temperature may damage the treated fruit, while insufficient heating may leave non-sterilized surface segments (Lurie, 2006).

The use of uniformly applied heat treatments has been effective in controlling postharvest diseases, but can damage the treated fruit tissue if not applied carefully (Hansen et al., 2004). Thermal imaging has proved to be useful for measuring temperature changes over fruit surface and also for detecting internal heat intrusions and heterogeneity of the thermal properties within the product (Baranowski and Mazurek, 2009). Fruit surface-temperature distribution changes provide important information

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about the quality of the product at different stages during production. Apple fruit surface temperature and injury due to solar heat incidence have been measured using a thermal IR video imagery system (Glenn et al., 2002). Thermal imaging has also been used to identify single sprout-damaged barley kernels from healthy kernels based on the changes of the grain surface temperature distribution (Vadivambal et al., 2011).

This study aims to find the optimal operating parameters of a cactus pear cauterization machine; where the parameters are heater temperature and pressure on the fruit. Prickly pears were cauterized after cutting the top section of the fruit to obtain a better contact between the pulp and the heating surface. Fruit shelf life, firmness, °Brix and water loss were obtained for different pressures and heating temperatures for 30 s of cauterization. Infrared images helped to detect proper peduncle sealing three days after cauterization.

2. Materials and methods

Prickle pears were collected from an orchard situated in Axapusco, Estado de Mexico. The plantation located at 19° 43′ N and 98° 45′ W and at a height 2350 m above sea level has a density of 700 plants per hectare. The pear classified as *Opuntia albicarpa* var. Reyna (Márquez et al., 2012) has an elongated shape with a prickly surface and a green lemon color. The pears weigh between 160 and 200 g per fruit and contain sugars ranging from 13 to 16° Brix.

Three experiments were carried out, the first one studied pulp temperature, the second one analyzed proper cauterizing using thermal images and the third experiment analyzed shelf life, firmness and °Brix under different applied pressure and heater temperatures.

2.1. Cauterizing equipment operation

The industrial prickle pear cauterizing machine, designed and constructed by Hahn et al. (2012) was modified to operate more effectively, taking infrared images without imprecise manual movements. The new cauterizing machine (Fig. 1) moves the piston (A) vertically downwards to exert pressure over the prickle pear (I) fixed inside a cup (J). At the end of the piston a Celeron™ machined cylinder (C) is fixed, enclosing a circular heating resistance (O) with a flat contact surface. Celeron is a rigid material made of paper and fabric impregnated with phenolic resin and compressed under pressure. A linear guide (G) was added to align the Celeron cylinder during piston operation.

The single-acting cylinder with spring return (model NITRA-A, AUTOMATION DIRECT, USA) has one compressed air port to extend the rod in the "push" direction. The stroke moves 0.05 m to reach the pear and, after releasing the pressure, the internal spring retracts in the "pull" direction. An electro-pneumatic regulator (Model ITV-3031-01N4, SMC, USA) controlled the air pressure supplied to the piston (A). A DC voltage was supplied to the

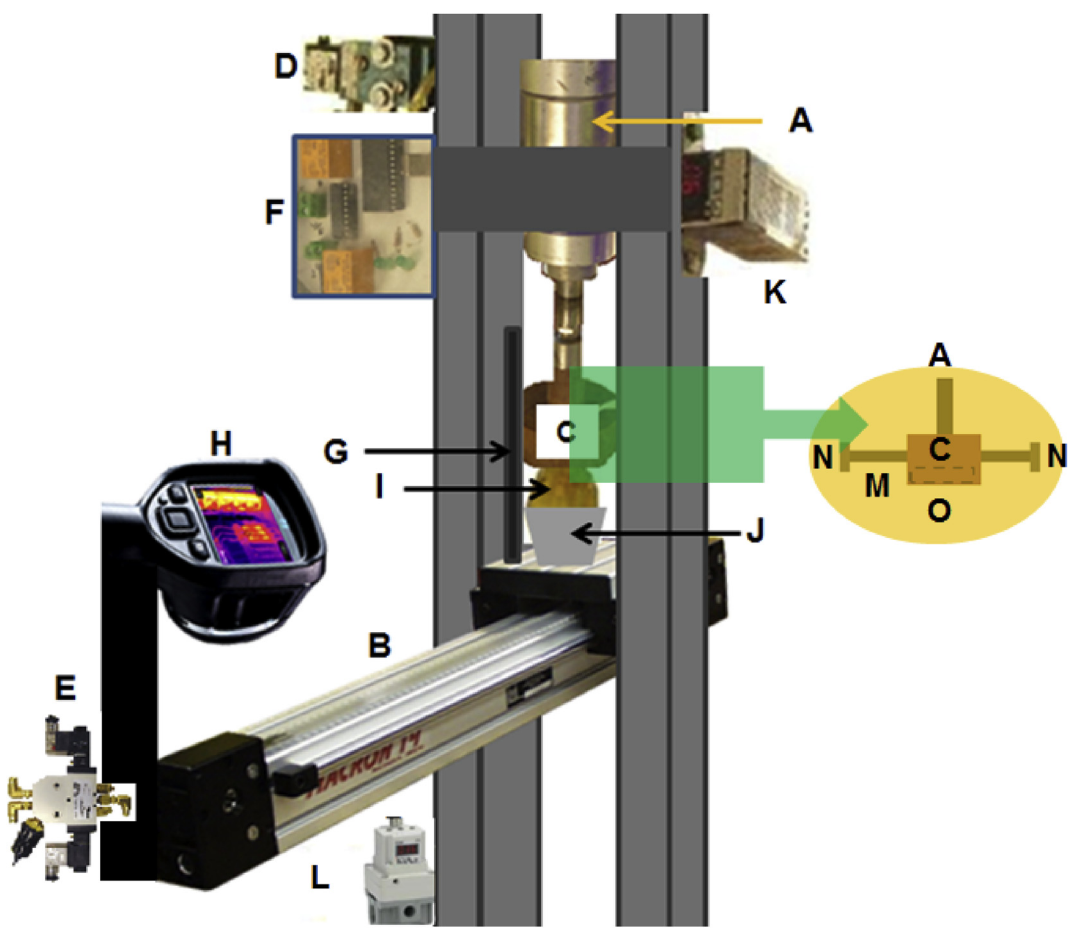

Fig. 1. The cauterization machine has a piston (A), a linear conveying device (B), a "celeron" cylinder with circular resistance (C), pneumatic solenoid valves (D), interference sensing module (E), an embedded system (F), a guide (G) a thermal imaging camera (H), a prickle pear (I) a handling cup (J), a closed loop temperature controller (K), electro-pneumatic regulator (L), stainless steel rod (M), bearings (N) and circular resistance (O).