Journal of Food Engineering 169 (2016) 38–43

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Removal of *Opuntia* thorns by pulsed laser ablation: Bromatological and microbiological analysis

L. Ponce Cabrera [a,*], T. Flores Reyes [a], A. Peña Delgado [a], R. Espinosa Ornela [b], D.A. Perez Caro [b], E. de Posada [c], M. Arronte [c]

[a] IPN CICATA ALTAMIRA, Km 14.5 Carretera Tampico Puerto Industrial, Altamira, 89600, Tam, Mexico
[b] Universidad del Noreste, Prolongación Avenida Hidalgo No. 6315, Colonia Nuevo Aeropuerto, Tampico, C.P. 89337, Tam, Mexico
[c] BRALAX S. de R.L. Mi., Ave. Las Torres, N220, Col. Chapultepec, Tampico, 89356, Tam, Mexico

A R T I C L E I N F O

Article history:
Received 19 June 2014
Received in revised form
4 August 2015
Accepted 12 August 2015
Available online 21 August 2015

Keywords:
Laser
Opuntia
Ablation
Bromatological analysis
Microbiological analysis

A B S T R A C T

The removal of thorns for human cactus consumption can be performed by applying laser pulses to the areolas. This technique has proven advantageous for increasing the shelf-life of the product and reducing losses of useful product volume. This work presents the bromatological and microbiological analysis of the nopal before and after de-thorning and an analysis of the morphology of the irradiated area by optical coherence tomography (OCT). The action of the laser produced a dehydrated layer 1 mm below the surface, which sealed the irradiated area after the removal of the thorn. A decrease in aerobic mesophiles, molds, yeasts, and total coliforms was observed, indicating that the laser process was favorable for the quality of this food product. No differences in mineral composition before and after laser irradiation were detected by bromatological analysis.

Published by Elsevier Ltd.

1. Introduction

One of the strongest food traditions in Mexico is the consumption of nopal, the common name for *Opuntia* cacti. This plant, is found in both the Mexican landscape and on the national flag, and is an essential part of the diet of the Mexican people as one of the most consumed vegetable foods in the country (Barbera, 1999). An important advantage is that it guarantees food security due to its extraordinary adaptation to extreme climates and lands where other crops cannot survive. In addition, it has unique nutritional and health properties (Pimienta, 1997) that explain its increasing demand on the international market (Yahia and Mondragon-Jacobo, 2011).

Of the approximately 104 species of *Opuntia* classified, 24 are used by humans for various applications (FND, 2011; Barbera, 1999). Of these, 15 are used as feed for cattle, 6 for the production of the fruit known as the prickly pear or tuna, and 3 for human consumption: *Opuntia ficus-indica*, *Opuntia robusta*, and *Nopalea cochenilshelf-lifera*. All varieties of the nopal cactus, including those for human consumption, are covered with thorns, as shown in Fig. 1. The nopal cactus leaf can contain dozens of thorns that are distributed relatively regularly on each face. The thorn is an important part of the plant and has biological functions, including the retention of water and its transmission to the interior.

The external market potential for nopal is large. There is growing demand in European countries, the United States, Japan, and China. The nopal is globally consumed for its advantages as a food that can be obtained in complex weather conditions and for its quality for human consumption (Flores Valdez). This is supported by the fact that China is becoming the largest nopal producer in the world.

De-thorning is likely the most significant issue limiting nopal consumption (Osorio-Cordoba et al., 2011). As part of the product preparation, the thorns must be removed, which is mostly performed by hand or by machines equipped with blades. During this process, up to 30% of the working volume is lost, and some of the cortex that protects the product is also removed (Corrales–Garcia and Flores–Valdez, 2003). The cortex removal drastically reduces product shelf-life due to increases in metabolic processes such as respiration, ethylene production, membrane lipid degradation, oxidative browning, loss of firmness and water, darkening of the de-thorned areas, unpleasant odors and flavors, and the

* Corresponding author.
E-mail address: lponce@ipn.mx (L.P. Cabrera).

http://dx.doi.org/10.1016/j.jfoodeng.2015.08.019
0260-8774/Published by Elsevier Ltd.

Fig. 1. Nopal plant with thorns.

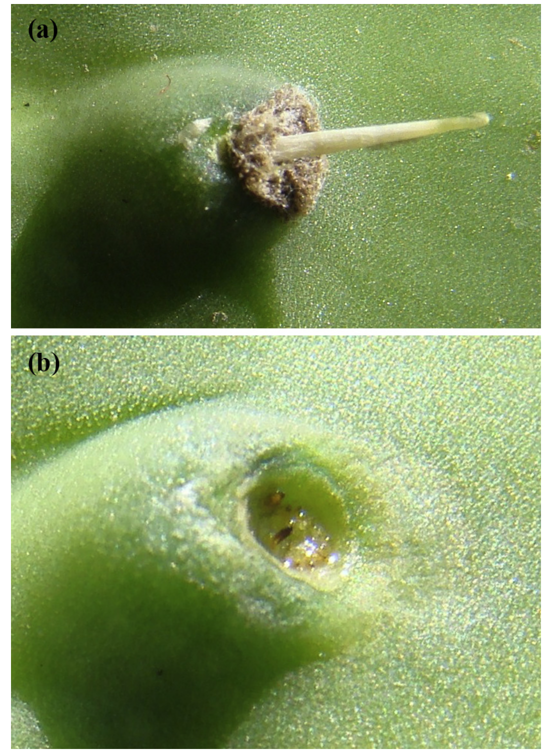

Fig. 2. Images of a thorn before (a) and after de-thorning (b).

accumulation of secondary metabolites (Osorio-Cordoba et al., 2011). These symptoms lead to the rejection of the product by the consumer.

Additionally, the activities of various metabolic pathways are altered because of the cortex removal under anaerobic conditions or the influence of abiotic stress factors such as injuries (Kozlowsky et al., 1997). Under these conditions, ethanolic fermentation can be induced in tissues, leading to the accumulation of alcohol and acetaldehyde (Kato-Noguchi, 2001; Kozlowsky et al., 1997) and contributing to the reduction of product shelf-life. For these reasons, it is necessary to consume the de-thorned cactus within six days after processing, even with refrigeration (Osorio-Cordoba et al., 2011). This prevents the development of an efficient export chain. A solution to this problem could be an important contribution to solving food problems in developing countries and improving global access to this food's beneficial properties.

In recent years, the use of laser technology has been proposed to remove thorns from food (Arronte et al., 2006; Ponce et al., 2009b). The advantages of this solution have been demonstrated, particularly for de-thorning nopal, eliminating losses of useful volume and lengthening the product shelf-life after de-thorning (Mejías Díaz et al., 2013). This new method removes thorns using laser pulses with appropriate parameters while avoiding damage to the cortex. The method is based on the selective absorption of laser light (Flores et al., 2006). This method can in principle remove thorns without affecting the substrate because the thorns preferentially absorb light of a different intensity and wavelength than the substrate. Fig. 2 shows a cactus thorn before (Fig. 2a) and after (Fig. 2b) processing with the laser. As shown in the figure, after removal of the thorn, only a crater is observed in the place where the thorn was, sealed and free of thorn fragments. No mucilage is released, and there is no impairment of the surrounding areas.

Naturally, the introduction of laser food processing at the industrial level requires detailed studies of the changes that may affect food quality. In one recent study (Mejías Díaz et al., 2013), the morphological and compositional changes that might be caused by laser de-thorning were evaluated by Fourier-transform infrared (FTIR) spectroscopy and differential-scanning calorimetry. No changes were observed in the consumable volume of the product. The present work contributes to the process evaluation through bromatological study and microbiological analysis of de-thorned nopal, which was compared to the unprocessed product.

2. Experimental

2.1. Nopal samples

Nopal leaves of the variety *Ficus-indica Opuntia* (6 months old, 17–20 cm long, and weighing 70–80 mg) were obtained from the same supplier to perform the analyses. Differences between one nopal and another may be associated with physiological factors; endogenous factors such as species, genotype, and variety; and environmental factors such as soil type, climate, and season. For these reasons, samples of the same variety (Jalpa) and area of culture were used.

The samples were de-thorned by both the laser method and the established method without any preparation. However, for characterization after de-thorning, samples were prepared according to the type of analysis performed. For bromatological analysis, the leaves were washed with abundant water, cut into small pieces of approximately 1 cm per side, and dried on a stove and ground. Physicochemical determinations were performed for both laser-processed and unprocessed nopal.

2.2. Experimental setup

The laser de-thorning method for the nopal cactus is described in detail in a previous work (Ponce et al., 2009a). The process is carried out by a machine that moves the laser beam sequentially