Passive and Semi-Active Modified Atmosphere Packaging of Prickly Pear Cactus Stems (Opuntia spp.)

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Abstract
Prickly pear cactus stems (nopal or nopalito) are consumed in Mexico for their nutritional and health benefits. The effect of passive or semi-active modified atmosphere packaging (MAP) on the physico-chemical and microbiological characteristics of prickly pear cactus stems was determined during storage at 5°C and 85% RH for up to 35 days. In semi-active MAP we have injected elevated concentrations of CO₂ (20, 40 or 80 kPa) to the packages immediately after sealing. Passive atmospheres (where no CO₂ was added) were created because of respiration gases and film permeability. Semi-active MAP with elevated initial concentrations of 40 or 80 kPa CO₂ increased the losses in texture, weight, chlorophyll content, dietary fiber content and color. Passive MAP, which developed an atmosphere of up to 8.9 kPa O₂ and up to 7 kPa CO₂, and semi-active MAP with an initial CO₂ concentration of 20 kPa significantly decreased losses in all the quality parameters analyzed and in microbial population, but slightly increased the total anaerobic mesophilic counts. The microorganisms identified were not pathogenic. Therefore, fresh prickly pear cactus stems can be stored for up to 32 days in MAP with CO₂ concentration of ≤ 20 kPa without significant losses in quality, nor any significant increase in microbial population.

INTRODUCTION
Nopalitos, the young cladodes of prickly pear cactus stems (Opuntia spp.) are low in calories, high in fibers and traditionally consumed as vegetable in Mexico. They are used in various pharmaceutical applications for their therapeutic, dermatological and medical properties (Frati, 1992). The stems are very perishable, being very sensitive to water loss, darkening and decay, and their storage life was reported to be one day at room temperature, and 6 days at 5°C (Rodríguez-Felix and Soto-Valdez, 1992). Modified atmospheres (MA) which involves the decrease of O₂ concentration and/or the increase of CO₂ levels, reduce respiration rate, ethylene production and sensitivity, chlorophyll degradation, texture losses, and delay ripening and senescence of several horticultural products (Yahia, 1998). Modified atmosphere packaging (MAP) utilizes polymeric films with selective permeability for O₂, CO₂, C₂H₄, N₂, and H₂O vapor to create a MA around the packaged product. Passive MAP creates a MA due to the respiration of the product and the selective permeability of the packaging material. Semi-active MAP is created by the addition or the removal of a gas mixture immediately after sealing of the package. The objective of this work was to determine the effects of passive and semi-active MAP and holding at 5°C for up to 35 days, on the storage life and quality of prickly pear cactus stems.

MATERIALS AND METHODS
Young cladodes (Opuntia ficus-indica, Milpa Alta) were obtained from a commercial plantation in Milpa Alta, Mexico, D.F. (Guevara et al., 2001; 2003). One lot was left without packaging in polymeric bags, packed in a carton box in the same way that cladodes are commonly marketed and was considered as control. Other cladodes were loosely packed in Cryovac RS425 bags (2 stems of about 200 g/bag). One lot was packed in these bags, sealed and considered as the passive MAP (without adding CO₂).
The third, fourth and fifth lots were placed in the same bags and different concentrations of CO₂ (20 kPa, 40 kPa and 80 kPa, respectively) were added in each bag immediately after sealing. These were considered as the semi-active MAP treatments. Packaged and non-packaged clades were placed at 5°C and 80% R.H. for up to 35 days in the dark (Guevara et al., 2001; 2003).

Evaluation consisted in the analysis of the concentration of O₂ and CO₂ in the MAP bags, weight loss, overall quality scores, color, texture, dietary fiber content, chlorophyll content (total, a and b), chlorophyllase activity and microbial counts (Guevara et al., 2001; 2003).

RESULTS AND DISCUSSION

The in-package atmosphere changed rapidly (Fig. 1), probably as a result of the high respiration rate of the cactus stems. Oxygen concentration in the passive MA decreased and reached about 8 kPa after 35 days in storage (Fig. 1a), while the CO₂ concentration (Fig. 1a) increased to about 7.5 kPa in the same period of time. In the semi-active MA, where 20 kPa CO₂ was added to the package (Fig. 1b), the oxygen concentration decreased to about 13 kPa and the carbon dioxide concentration decreased to about 13.5 kPa after 35 days in storage. On the other hand, the CO₂ concentration in semi-active MAP with an initial CO₂ concentration of 40 kPa and 80 kPa (Fig. 1c, 1d), decreased to about 15 kPa and 25 kPa, respectively, and the oxygen concentration slightly increased to about 15 kPa at the end of the storage period. The CO₂ concentrations created in the semi-active MAP with initial concentrations of 40 and 80 kPa were higher than the minimum tolerated levels for many fresh horticultural crops (Yahia, 1998). However, it decreased very sharply in the package, which was the reason for not causing major negative effects.

Texture decreased in all clades, but the decrease was faster in those that were kept in semi-active MAP with initial concentrations of 40 and 80 kPa CO₂, and clades that were maintained without packaging, and the least texture loss was observed in the passive MAP and in semi-active MAP with an initial 20 kPa CO₂ (Fig. 2a). A relation similar to texture was found in the changes of dietary fiber content (Fig. 2b). The highest loss in dietary fibers was observed in clades maintained in semi-active MAP with initial concentrations of 40 and 80 kPa CO₂, and in clades that were maintained without packaging, and the lowest loss was observed in the clades kept in clades maintained in passive MAP and in semi-active MAP with an initial concentration of 20 kPa CO₂ (Fig. 2b). It is possible that the loss in texture is caused by losses in fibers resulting in the softening of the clades. The retention in texture of clades maintained in passive MAP or in semi-active MAP with an initial concentration of 20 kPa CO₂ might be due to the positive effects of MA with intermediate CO₂ concentrations.

Weight loss was least in clades that were packaged in passive MAP and in semi-active MAP with an initial concentration of 20 kPa CO₂, and the rest of the conditions showed a high weight loss of more than 25% (data not shown). There was a close relation between weight loss and the overall quality. Clades that were not packaged lost their brilliant green color appearance and became dull as the storage period increased.

Quality was highest in clades that were packaged in semi-active MAP with an initial concentration of 20 kPa CO₂, followed by those packaged in passive MAP. Concentrations ≤ 20 kPa CO₂ can decrease the rates of respiration and transpiration, resulting in low weight loss. The L* value slightly increased in clades maintained in semi-active MAP with initial concentrations of 40 and 80 kPa CO₂, and in those maintained without packaging, for up to 25 days in storage. The lowest L* values were observed in clades packages in passive MAP and in semi-active MAP with an initial concentration of 20 kPa CO₂. The a* value slightly increased in all conditions as a result of the loss in green color, however, the increase was slower in clades packaged in semi-active MAP with initial concentrations of 40 and 80 kPa, and in clades that were not packaged. The b* value increased, and the highest increase was observed in clades packaged in semi-active MAP with an initial concentration of 80 kPa CO₂, followed by those maintained in semi-active MAP with an initial 40 kPa CO₂, and by those kept without packaging until 25 days in storage, after which a decrease was observed. Darkening was present in clades packaged in semi-MAP with an initial of 40 and 80 kPa CO₂, especially during the last period of the study, which might be due to enzymatic oxidation. External color of clades that were not held in MAP changed from brilliant green to opaque green.

The decrease in chlorophyll content (total, a and b) (data not shown) was the least in clades that were maintained in passive MAP and in semi-active MAP with an initial of 20 kPa CO₂, followed by those packaged in semi-active MAP with initial concentrations of 40 and 80 kPa CO₂, and in those kept without packaging. Total chlorophyll and chlorophyll a of clades kept in passive MAP and in semi-active MAP with 20 kPa CO₂ decreased about 33% and 35%, respectively, while elevated CO₂ concentrations (40 and 80 kPa) caused a decrease of about 53% and 63%, respectively. Chlorophyll b content decreased about 57%, 38%, 37%, 80% and 99% for in clades that were not packaged, packaged in passive MAP, or packaged in semi-active MAP with initial 20, 40 or 80 kPa CO₂ respectively after 35 days in storage. Chlorophyll a was higher than chlorophyll b at all stages, however, their degradation velocity was similar. Chlorophyllase activity increased in all clades as the storage period increased. The decrease in chlorophyllase activity was present in clades packaged in passive MAP and in semi-active MAP with 20 kPa CO₂, and the highest activity was found in clades packaged in semi-active MAP with an initial concentration of 40 and 80 kPa CO₂ in clades kept without packaging. The highest chlorophyllase activity present in treatments with elevated CO₂ concentrations (semi-active MAP with initial 40 and 80 kPa CO₂) is probably due to the stress caused by CO₂ injury. There is a clear relation between chlorophyll degradation and chlorophyllase activity. Conditions that showed the highest chlorophyll degradation also had the highest chlorophyllase activity. It seems likely that chlorophyllase is important for chlorophyll degradation in prickly pear cactus stems.

Microbial population started to increase after 15-20 days of storage (Fig. 3). The least increase in aerobic mesophiles (AEM) population was in clades that were kept in semi-active MAP with an initial of 20 kPa CO₂, followed by those maintained in semi-active MAP with an initial concentration of 40 kPa CO₂, and the highest increase was in clades maintained in semi-active MAP with an initial of 80 kPa CO₂, and in those maintained without packaging (Fig. 3a). AEM population reached up to 2.2 x 10⁶ CFU g⁻¹ after 35 days in storage. AnM (Fig. 3b) were highest in clades that were held in semi-active MAP with an initial of 80 kPa CO₂ and least in those held without packaging and in those held in semi-active MAP with an initial of 20 kPa CO₂. The highest anamorphic mesophiles (AnM) count was 2.1 x 10⁷ CFU g⁻¹. The highest increase in MY (Fig. 3e) was found in clades that were held in semi-active MAP with an initial of 40 kPa CO₂, followed by those maintained without packaging, while the least MY population was in clades maintained in semi-active MAP with initial concentrations of 20 and 80 kPa CO₂. The highest MY population reached up to 5 x 10⁶ CFU g⁻¹.

It is possible to extend the shelf life of prickly pear cactus stems. This can be achieved by generating an atmosphere with O₂ levels of up to 8 kPa and CO₂ levels of up to 7 kPa in passive MAP, or up to 20 kPa in semi-active MAP. Carbon dioxide concentrations between 7 and 20 kPa decreased the loss in color, texture, and fiber content, and decreased the chlorophyllase activity, and the use of MAP decreased the microbial flora on the stems. These benefits are due to atmosphere modifications and not to increased humidity in the atmosphere (Guevara et al., 2001). On the other hand, elevated CO₂ concentrations (≥ 40 kPa) caused injury in clades in comparison with non-packaged cactus stems. There were no significant differences between prickly pear cactus stems packaged in passive MAP or in semi-active MAP with an initial CO₂ concentration of 20 kPa. The relative limit of tolerance of prickly pear cactus stems to CO₂ was 20 kPa. The storage life of the cactus stems can be up to 32 days in passive MAP or in semi-active MAP with an initial CO₂ concentration of 20 kPa. Bacteria of the genus...
Leuconostoc, Bacillus, Pseudomonas, Micrococcus and Ruminococcus were identified in the microflora of Opuntia ficus-indica cactus in MAP. The moulds isolated were of the genus Absidia, Cladosporium, Penicillium, in addition to the yeast Pichia. No pathogenic micro-organisms were identified in the cactus stems.

Literature Cited

Figures

![Fig. 1. Changes in in-package O₂ and CO₂ in passive MAP (a), 20 (b), 40 (c) and 80 (d) kPa CO₂.](image1)

![Fig. 2. Changes in texture and fiber content.](image2)

![Fig. 3. Changes in aerobic mesophiles, anaerobic mesophiles, and yeast and moulds.](image3)