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CACTUSNET NEWSLETTER

CACTI FOR THE FOOD INDUSTRY

Editors: Carmen Sáenz & Maryna de Wit

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FOREWORD

It is with gratitude that we can present this newsletter to our CactusNet community. Gratitude for this humble crop that present so many opportunities to all involved with it. Gratitude for this global community bound together because of this amazing plant with its immense potential.

This potential will be elaborated on in the contributions from authors in this issue.

With the whole world experiencing very trying times currently, this issue will hopefully shed insight on cactus pears' contribution to agro-industries and how it contributes to livelihoods on all levels.

A very encouraging aspect is the growth of this crop with anewed interest from many areas in the world. One example is the report, in this issue, on the founding of the International Cactus Pear Association – CactisMundis. Members represent more than 56 nationalities – indicating the need for knowledge and applications of cactus pear. It is with collaborations like these, where experience and knowledge are being shared – that the CactusNet can be strengthened, and sustained to serve the global cactus network.

This CacusNet issue is dedicated to the Food industries, focusing on many food-related topics and applications of cactus pear. We are presenting exciting novel innovations and interesting agro-industrial contributions of the nopal cactus.

To Professor Carmen Saénz, the General Coordinator of the International Steering Committee of the FAO-ICARDA CactusNet, thank you for your constant and persistent assistance and dedication, not only for this issue, but to the Network.

Prof Maryna de Wit

Thematic coordinator for Post-harvest and Agro-industries of the International Steering Committee of the FAO-ICARDA CactusNet

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HEAT TREATMENTS

TO IMPROVE CACTUS PEAR STORABILITY: AN OVERVIEW

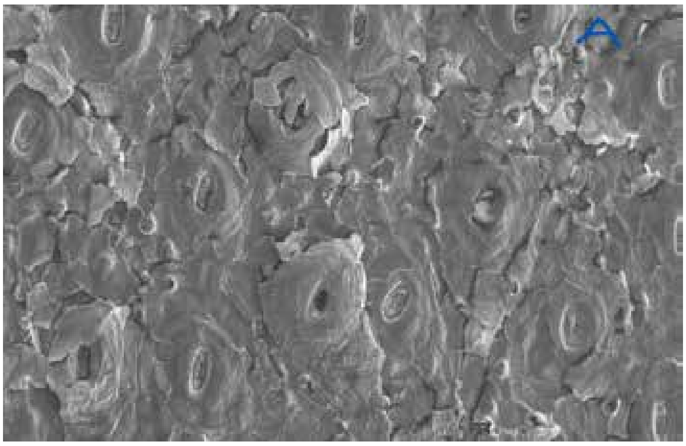
INTRODUCTION

Cactus pear fruit are very perishable, due to the high susceptibility to decay and chilling injury (CI) when exposed for long times to low temperatures (Potgieter and D'Aquino, 2017). The primary cause of microbiological spoilage is due to wounds that occur when fruit are harvested and separated from the mother cladode and to punctures caused by spines and glochids when they are placed in baskets or boxes and transported to the packinghouse. Spines and glochids continue to damage the fruit when they are removed; it doesn't matter whether despination is carried out with brooms or in processing lines, in both cases the countless micro-wounds inflicted by the tiny thorns will increase the "load of mechanical injuries" (abrasion, scratches, impacts) that represent entry sites for bacteria or decay-causing fungi. Cold storage can delay microorganisms' growth, and the lower the storage temperature the lower the decay will be at the end of storage, but prolonged exposure to low temperatures also induces metabolic imbalances that reduce natural tissue resistance. Eventually, physiological disorders develop in the form of lenticel spotting, stain dots, peel scald and discolorations, but by the time these damages will appear the tissues would have lost their natural resistance and become more susceptible to decay. Thus, low temperature storage, if on the one hand delays microorganisms' growth, and on the other hand, if metabolic imbalances would occur (CI), may alter fruit appearance, and stimulate microbiological spoilage, especially when fruit from cold storage are transferred to warm temperatures.

This article aims to give an up-dated look to the heat treatments to improve cactus pear storability.

HEAT TREATMENTS

Synthetic fungicides could be a good solution to face CI as well as decay: they would allow to store the fruit at higher temperatures that do not cause CI. Indeed, several studies have shown their efficacy to prevent decay and mitigate CI in cactus pear. Nevertheless, despite that there is interest in some producing countries to register some fungicides, consumers prefer fruit free from chemical residues, thus it is unlikely that in the next future synthetic fungicides will be authorized. CI remain an important issue to overcome when fruit are exported in countries which require cold quarantine treatments to prevent the introduction of un-wanted pests. In that case, fruit must be stored for several days at temperatures near to 0 °C to comply with specific protocols (Potgieter and D'Aquino, 2017). Environment-friendly technologies and in particular heat treatments have widely been studied on several species to solve specific postharvest issues and considerable efforts have been done in the last decades to optimize and transfer their use on a commercial scale (Ben-Yeoshua and Porat, 2005). Before the advent of synthetic fungicides and insecticides, heat treatments had been largely used to control fungal diseases and insect infestations. The main constrain to the widespread use of heat is the sensitivity of many fruits to the temperatures required for effective treatments to kill pests and microorganisms. Any heat treatment can potentially be feasible only if the temperature threshold to kill insects or fungi is lower than that injurious for fruit tissues. Heat tolerance in plants can be increased by exposure to a mild heat conditioning period (35-40 °C); but the same conditions will eventually induce heat-tolerance in insects and pathogens (Lurie, 1998). Injury mitigation by low temperature in heat-treated fruits and vegetables could be attributed to (1) enhancement of membrane integrity; (2) enhancement of heat shock protein (HSP) gene expression and accumulation; (3) enhancement of antioxidant system activity; (4) enhancement of the arginine pathways which lead to the accumulation of signaling molecules with pivotal roles in improving chilling tolerance such as polyamines, nitric oxide, and proline; (5) alteration in phenylalanine ammonia-lyase (PAL) and polyphenol oxidase (PPO) enzyme activities; and (6) enhancement of sugar metabolism (Aghdam and Bodbodak, 2014). Similarly, heat treatments can act in several ways to control decay. The first mode is through a direct inhibition of spores' germination and mycelia growth. Heat may also change the structure of fruit epicuticular waxes. Epicuticular waxes are normally characterized by fractures and micro-cracks inside which conidia can lodge. Heat treatments may eliminate these cracks and occlude in part the stomata openings by a partial melting of the natural wax of the cuticle, thus providing a mechanical barrier at these sites against the ingress of wound pathogens (Figure 1). Heat treatments may further strengthen the barrier to pathogens invasion by stimulating the lignification process of the cell walls (Figure 2), especially of those surrounding the wounds (Ben-Yeoshua and Porat, 2005; Lurie 2008).



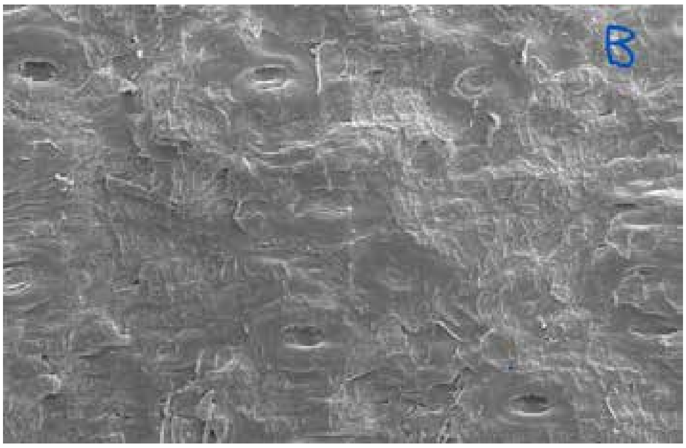


Figure 1 - Scanning electron microscopy in fruit immersed for 2 minutes in water at 20 °C (A) or in water heated at 50 °C.

METHODS TO APPLY HEAT TREATMENTS

Hot water dips - Hot water dips initially were developed to control fungal decay, but its use has been extended to insect control and to reduce CI in sensitive species (Lu et al., 2007). When aimed at fungal control the treatment duration lasts from a few to several minutes at temperature of 40-55 °C. Fungicides or other compounds with fungicidal activity applied as heated water emulsions/solutions can markedly enhance their activity (D'Aquino and Palma, 2020; Schirra et al., 2008; Lurie, 1998). When hot water dips are integrated in a packing line, the produce is usually conveyed through a tank containing hot water, with the belt speed set in order to let fruits and vegetables

Figure 2 - Healed (lignified) wound in artificially wounded fruit dipped for 2 minutes in water at 50 °C and stored for 4 weeks at 6 °C and 7 days at 20 °C.

be submerged for the planned length of time. In case the devise is not integrated with the packing line, it may consist of a large-volume tank within which fruits or vegetables, placed in bins or plastic crates, are immersed for the desired time (Fallik and Ilic', 2020).

Hot water brushing - Hot water brushing can be considered as an evolution of in-line water dip systems. The produce along the packing line enters a section with a series of brush rollers, at the same time pressurized hot water is continually sprayed on produce while the rollers move the produce forward. Generally, the treatment lasts several seconds, but less than one minute, whereas the water temperature is 45-63 °C (Fallick and Ilic', 2020). This treatment can be easily applied at commercial level as any existing packing line can be re-adapted. It offers the advantage of being rapid and requires much less energy than other heat treatments. Hot water brushing has shown to improve the cleaning process of produce, reduce decay and enhance tissues tolerance to low temperature.

Vapor heat - Vapor heat is a method of heating the fruit in air saturated with water vapor at temperatures of 40–50°C. It was developed mainly to kill insects' eggs and larvae and works well as a quarantine treatment to apply before fresh market shipment for pests like the Mediterranean (*Ceratitis capitata* Wiedemann) and the Mexican (*Anastrepha ludens*) fruit flies. Heat is transferred by condensation of water vapor on the cooler fruit surface (Lurie, 1998).

Hot air conditioning - Hot air conditioning has been used to control both decay and insects. In the treating room or chamber, the air can be static or forced. Heat transfer to the fruit occurs at a much slower rate than in water dips or vapor heat treatments, thus the treatments normally require more time. Initially, hot air treatments were tested by Klein and Lurie (1991) for physiological studies but were also tested to control the Mediterranean fruit fly and the oriental fruit fly (Armstong et al., 1989).

POSTHARVEST HEAT TREATMENTS ON CACTUS PEAR

Hot water dips **-** Cactus pears have shown to tolerate water dips at a temperature as high as 55 °C for 5 minutes quite well without showing phytotoxic symptoms. Schirra et al.(1996) studied the response of late-crop cactus pear (*Opuntia ficus-indica* Mill.) to individual or combined treatments of hot water dip treatments (5 minutes at 55°C), or high-temperature conditioning (24 h at 38°C), with or without thiabendazole fungicide (1000 mg/L) over a 4-week storage time at 6°C plus one additional week at 20°C (simulated shelf-life conditions). All treatments reduced CI and decay without causing heat injury or detrimental effects to fruit firmness, flavor, taste, or freshness. The combined treatments neither increase tolerance to CI nor reduced decay compared to individual treatments. Fruit respiration and ethylene production were minimally affected by both treatments while slight changes occurred in juice pH, total soluble solids, acetaldehyde, ethanol, and ascorbic acid levels. In a subsequent experiment, Schirra et al. (2002) showed that the same results could be achieved with lower temperatures and reduced immersion time. The fruit were dipped for 3 minutes in water heated at 52 °C and the combined treatment of hot water dips with thiabendazole was tested. Despite that the applied concentration of thiabendazole at 52 °C was almost 7-fold lower than that at 20 °C, after 6 weeks of storage at 6 °C plus 1 week at 17 °C, decay incidence was only 2 % in the treatment were thiabendazole (150 mg/L) was heated at 52 °C, compared to 10 % of the treatment with 1000 mg/L thiabendazole at 20 °C. Yet, the percentage of fruit with slight to moderate symptoms of CI and with severe symptoms in heated thiabendazole treatment were 15.1 % and 1.9 %, respectively, whereas in fruit treated with thiabendazole at 20 °C it was 23.2 % and 10.7 %, respectively. A significant reduction of decay and CI were also achieved by immersing the fruit only in water at 52 °C compared to fruit dipped in water at 20 °C. However, even briefer immersion times at 50 °C can improve peel disorders in cold stored fruit (Figure 3).

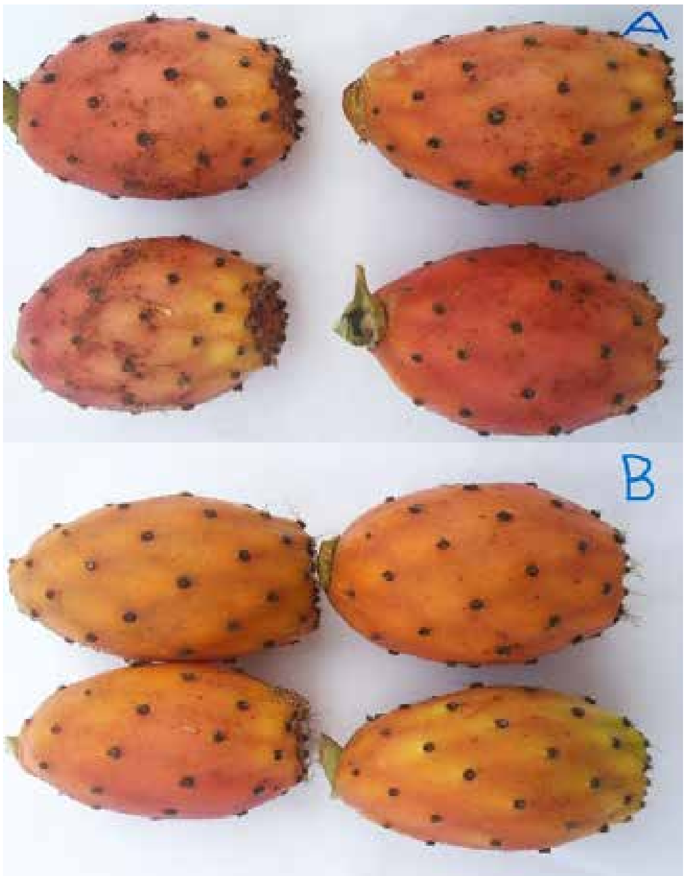


Figure 3 - Fruit immersed for 2 minutes at 20 °C (A) or at 50 °C (B) after 3 weeks at 6°C plus one week at 20 °C.

When fruit are cold stored, disorders that develops not always are a direct consequence of CI; some alterations elicited by other environmental factors or tissues senescence, would develop anyway, even if fruit were stored at warm temperatures. In cold stored fruit, these disorders can be exacerbated by metabolic imbalances by low temperature and can overlap to specific CI symptoms, thus giving rise to a very complex syndrome. For example, pitting or micro-wounds caused by spines or glochids can evolve in peel alterations as dermatosis after harvest. In these cases, a rapid curing process would not occur at low temperatures and the sound cells around the injuries might not die and allow the formation of a thin layer of suberized/lignified coating around the wounds. These cells close to the wounds will lose water for transpiration at a high rate and involve the surrounding cells in this process. Eventually, the excessive water loss leads to a wide layer of dead cells around the micro-wounds giving rise to superficial brown spots of variable size. Hot water treatments, as well other heat treatments, have shown to be beneficial in mitigating the severity of these disorders (dermatosis or pitting) through remodeling the epicuticular waxes and forming an even wax coating on fruit surface that drastically reduce punctiform transpiration (Figure 3).

D'hallewin et al. (1999) exposed cactus pear fruit cv Gialla to water saturated air at 37 °C for 12, 24 and 72 hours or dipped fruit of the same cultivar for 3 minutes in water heated at 52 °C. Scanning electron microscopy revealed that both treatments sealed the micro-wounds and the cracks that are normally present in untreated fruit, resulting in the disappearance of platelets and to a more even fruit surface. Schirra et al. (1999) underlined the possible relationship existing between epicuticular remodeling and reduction of CI. Yet, they also suggested that the reduction of decay following hot treatments could not be only due to a direct effect on spores, but also to a delay in fungal germination which is sufficient to let the tissue build up a resistance barrier at the wound site.

A El-Saedy and El-Naggar (2009), compared the effect of a water steam treatment with a water dip treatment on CI and other parameters on (of) cactus pears harvested at three different maturity stages: light green (G), yellowish green (YG) and yellow (Y). The fruit were exposed to water steam at approximately 78 °C for one minute or dipped into hot water (HW) at 55 °C for two minutes or washed with regular tap water (control). The fruit were then stored at 5 °C or 10 °C. Both heat treatments prolonged the storage period of all ripening stages, delayed decay development and CI in fruit stored at 5 °C. They also detected a maturity stage response, with the highest beneficial effects occurring in more mature (yellow) fruit. Differences between heat treated fruit and control fruit were negligible at 10 °C, as symptoms of CI appeared only sporadically. Yet, while water steam reduced weight loss, hot water dips increased the weight loss of all maturity stages. Both treatments generally did not affect the juice chemical parameters.

Naglaa and Enas (2010) found that immersing cactus pear fruit in water at 55 °C for 2 minutes and storing them at 10 °C and 85-90 % RH, increased vitamin C and carotenoids content and reduced weight loss, but found any improvement of appearance, as CI did not develop in any treatments. Similar results were reported by Ben-Abda et al. (2010) in Tunisian ‘Gialla’ cactus pears dipped at 53 °C for 1 minutes and stored for 30 days at 5 °C or 9 °C plus 4 additional days at 20 °C. Hot water treatment significantly reduced CI symptoms and decay in fruit stored at 5 °C but showed no beneficial effect at 9 °C.

D’Aquino et al. (2015), tested the effect of a pre-storage 2-minute-long dip treatment in water at 20 °C or heated at 50 °C. The treatments were given as stand-alone or in combination with fludioxonil (FDL) (600 mg/L at 50 °C or 300 mg/L at 20 °C) or with sodium bicarbonate (SBC) at 2 % at both temperatures. Although FDL is not approved for cactus pear, it is a reduced risk fungicide according to the US-EPA agency, and it is approved for postharvest use in many countries, thus potentially could be registered also for cactus pears. At the end of 4 weeks storage at 5 °C and 95 % RH, fruit were checked and those free of decay and still saleable of each of the six pre-storage treatments were subjected to one of the following post-storage 2-minute-dip-long treatments: water at 20 °C, 300 mg/L FDL at 20 °C; 2 % SBC at 20 °C; water 50 °C; 150 mg/L FDL at 50 °C; 2 % SBC at 50 °C. Results showed that water dips at 50 °C caused higher weight loss than water dips at 20 °C but reduced both CI and decay incidence. When water dip at 50 °C was repeated at the end of storage at 5 °C, decay incidence control improved slightly in fruit immersed in water at 50 °C pre-storage but improved greatly when compared to decay occurring in fruit which did not receive any heat treatment (neither pre- nor post-storage). SBC did not reduce decay when applied at 20 °C but was effective at 50 °C. FDL was the best treatment to control decay and even CI and its efficacy increased when applied in water heated at 50 °C, despite that the used concentration was half of that applied at 20 °C. Differences in weight loss among treatment were negligible, however SBC at 50 °C led to higher losses.

In another study D’Aquino et al. (2012) tested the effect of water dips for 2 minutes at 20 °C or 50 °C as stand-alone treatments or in combination with soy lecithin (0.1 %), sodium carbonate (2 %), or soy lecithin+ sodium carbonate. In preliminary tests sodium carbonate showed the potential to reduce decay, but it resulted in phytotoxicity and led to higher weight loss, whereas treatments with lecithin ameliorated fruit appearance, but increased decay.

After 3 weeks of storage at 2 °C plus 1 week at 20 °C the highest weight loss was detected in fruit dipped in water at 50 °C and in sodium carbonate at 50 °C, whereas the lowest percentage of weight loss occurred in all treatments where lecithin was used. Peel disorders were higher in treatments done at 20 °C and, at both temperatures, sodium carbonate increased their severity. However, when lecithin and sodium carbonate were combined, the phytotoxicity of sodium carbonate was mitigated but its capacity to prevent decay persisted. In contrast, when lecithin was applied alone (not in combination with sodium carbonate) decay incidence was higher, even when heated at 50 °C. The results confirmed the effectiveness of hot water dips to reduce peel disorders, CI and decay, but the very remarkable achievement of this study was the positive interactions of soy lecithin with sodium carbonate and hot water: when the three treatments, lecithin, sodium carbonate and hot water, were combined, the best results of all assessed parameters were achieved.

Figure 4 - Larvae of Ceratitis capitata developed from pre-harvested infested fruit after 4 weeks of storage at 6 °C and 7 d at 20 °C.

Cactus pear are subjected to fruit flies' attacks, particularly the Mediterranean fruit fly (*Ceratitis capitata*), which is a quarantine pest. Fruit infested shortly before harvest cannot be distinguished from not infested fruit, but larvae can grow during storage and lead fruit to decay (Figure 4). The only quarantine treatments approved by countries where Mediterranean fruit fly is considered as a quarantine pest is the USDA treatment T 107 A (USDA, 2002) which requires a storage temperature of 2.2 °C for 16-18 days. Although sensitivity to CI varies greatly with cultivars, environmental conditions and maturity stage, fruit of no specific cultivar can be stored for such a long time to a temperature regime of 2 °C, without reporting severe damages from CI. Rodriguez-Verastegui et al. (2005) evaluated the potential of a treatment with hot water to mitigate CI induced by a standard cold quarantine treatment. They used fruit of a local cultivar, 'Santiagueña', and fruit from the Texas A&M University—Kingsville (TAMUK) clone '1287'. Fruit of both cultivars were dipped for 3 minutes in water heated at 52 °C and then stored at 2 °C or 8 °C. The sensitivity to CI was affected by the maturity stage [fruit more mature were more susceptible in contrast with results by El-Saedy and El-Naggar (2009)] and the variety. In all cases, heat treated fruit showed less CI compared to control fruit, especially when stored at 2 °C. In both cultivars a significant reduction of decay also occurred.

D'hallewin et al. (2005) inoculated fruit cv Gialla with Mediterranean fruit fly eggs and tested the effect of hot water dips on CI and larval vitality. Pre-inoculated fruit were dipped for 2 minutes at 20, 50, 54, 58 or 60 °C and then stored at 1 °C for 3, 6 or 10 days. At each established time, fruit were picked and checked for vital larvae and degree of CI. Probit-9 (a larval mortality of 99.9968 %) requirement for fruit flies by the United States Department of Agriculture was achieved in all cases when fruit were cold stored for 10 days, but only immersion at 50 and 54 °C did not cause heat phytotoxicity.

More recently, Figueroa-Novella et al. (2016), evaluated the effectiveness of hot water heated by electrical resistance or by microwaves to clean cactus pear fruit from infestation of pests, such as *Dactylopius indicus* and *Aceria cactorum*. Microwaves offer the advantage of volumetric and fast heating. They analyzed the effect of hot water (HW) or microwave-assisted hot water treatment (MWHW) on the postharvest quality of cactus pears. Fruit (*Opuntia ficus-indica*, cv. White or *Opuntia streptacantha* cv. Red) were heated until 49 °C, held for 4 minutes at this temperature (holding time is enough to kill these pests) and then cooled in water at 11 °C for 21 minutes. In both treatments weight loss was lower than in untreated fruit, whereas pH and total soluble solids were not affected. The authors concluded that the microwave-assisted hot water treatment at low power (350 W) has potential commercial application to control superficial insects of cactus pears without negatively affecting the quality.

Hot water dips have also been tested to improve storability of cactus stems. In a first experiment, Rodríguez-Verástegui et al. (2019), evaluated the best temperature (45, 50 or 52 °C) x immersion-time (40, 45 or 50 seconds) combination and found that the immersion of stem in water at 48 °C for 42 seconds gave the best results in terms of preservation of the initial green color of 'Atlixco' stems. They also tested different modified atmosphere packaging solutions. In a second experiment they laid out a 2 x 2 factorial design, where the levels of the first factor were: 1) non heated stems (NoHT) and 2) stems dipped in water at 48 °C for 42 seconds (HT). The levels of the second factor were: 1) stems packaged inside ventilated clamshell containers (NoMAP), and 2) stems packaged inside bags with a modified atmosphere of 10 % CO_2 and 90 % N_2(MAP). In both experiments the stems were stored at 4 °C and 85-95 % RH for 20-28 days with inspections at 2- or 7-day intervals depending on the checked parameters. The HT-NoMAP treatment significantly reduced weight loss compared to NoHT-NoMAP treatment but had no effect on CI (Bronzing Pitting Index), which increased at the same rate in NoHT-NoMAP as in HT-NoMAP. In contrast MAP, either combined or not combined with HT, markedly inhibited both CI and weight loss.

Hot air conditioning -Differently than hot water dips, hot air conditioning needs more time to get a physiological effect, but rather than acting on fruit surface or in the first layers of skin cells, it involve the whole fruit. Schirra et al. (1997), tested the effect of heat conditioning at 38 °C and RH higher than 90 % for 24, 48 or 72 hours prior to transfer to 6 °C and 90-95 % RH for 21 days plus 7 days at 20 °C to simulated marketing conditions. All treatments reduced weight loss compared to untreated fruit, but the best results were achieved in fruit exposed for 48 and 72 hours. All treatments equally reduced decay incidence and CI, delayed the decline of visual quality, suppressed ethylene production, particularly in fruit conditioned for 48 and 72 hours, but did not affect respiration. Juice ethanol content of 24- and 48-hour conditioned fruit did not differ from control fruit but was about 5-fold higher in 72-hour conditioned fruit. However, despite the high level of ethanol, the sensory quality of 72-hour conditioned fruit was still good.

López–Castañeda studied the effect of different vapor heat treatments (35, 38 and 42 °C for 12 or 24 hours) after storage for 15 days at 20°C and 75% RH or 30 days at 10 °C and 95% RH on weight loss, respiration rate, cuticle thickness, and epicuticular microstructure of six cultivars of cactus pear. Vapor heat treatment reduced weight loss in fruit stored at 20 °C as well as in those stored at 10 °C. Optimal combination temperature/treatment-duration varied with cultivar and storage duration. Although treatments significantly affected cuticle thickness, either increasing or reducing its values, the reduction of weight loss seemed to be affected by the rearrangement of the epicuticular wax layer and the degree at which cracks were reduced.

In another experiment, D'Aquino et al. (2014) evaluated the impact of the relative humidity (RH) during curing treatment. 'Gialla' cactus pear fruit were conditioned within 200 L plexiglass boxes at 38 °C for 36 hours at 75 % or 100 % RH. After curing the fruit were stored at 5 °C for 4 weeks plus one week at 20 °C to simulate marketing conditions, or 5 weeks at 20 °C. Control fruit were directly stored at 5 or 20 °C. At the end of the week of simulated marketing conditioned (SMC) fruit conditioned at 75 or 100 % were equally effective in reducing CI, weight loss and in improving other physiological and qualitative parameters compared to control fruit. Decay was not affected in fruit stored from the beginning at 20 °C, as its incidence was very low in all treatments. However, in cold stored fruit, decay incidence was significantly reduced by both heat treatments, but results of the curing treatment done at 75 % RH were superior to that of done at 100 %.

Previous studies have shown that film wrapping is more efficient that heat treatments to reduce weight loss and CI, but the water saturated in-package atmosphere favoring microorganisms' growth can cause high losses because of decay. To overcome this problem, D'Aquino et al. (2017) tested a pre-storage high temperature conditioning treatment (HTC, 38 °C and 95% RH for 24 h) or an individual film wrapping (IFW) treatment with a perforated polyolefin heat-shrinkable film either as individual treatments or in combination on first crop cactus pear cv Gialla. The fruit were stored for 21 days at either 2 or 8 °C (CS) plus 1 week of simulated marketing conditions (SMC) at 20 °C. The results showed a higher efficiency of IFW in reducing peel disorders, weight loss, fresh maintenance than HTC, but as expected, decay was very high in IFW than in HTC. However, in the conditioning of individual film wrapped fruit at 38 °C (IFW + HTC) CI and weight loss was prevented as in the individual treatment of IFW, but decay incidences were negligible. Thus, IFW with a perforated film in combination with HTC could be is a good means to overcome the stringent conditions of cold quarantine treatments, while maintaining fruit freshness and reducing decay in cold stored cactus pears. A reduction of decay was also achieved when several conditioned fruit were packaged together (Figure 5).

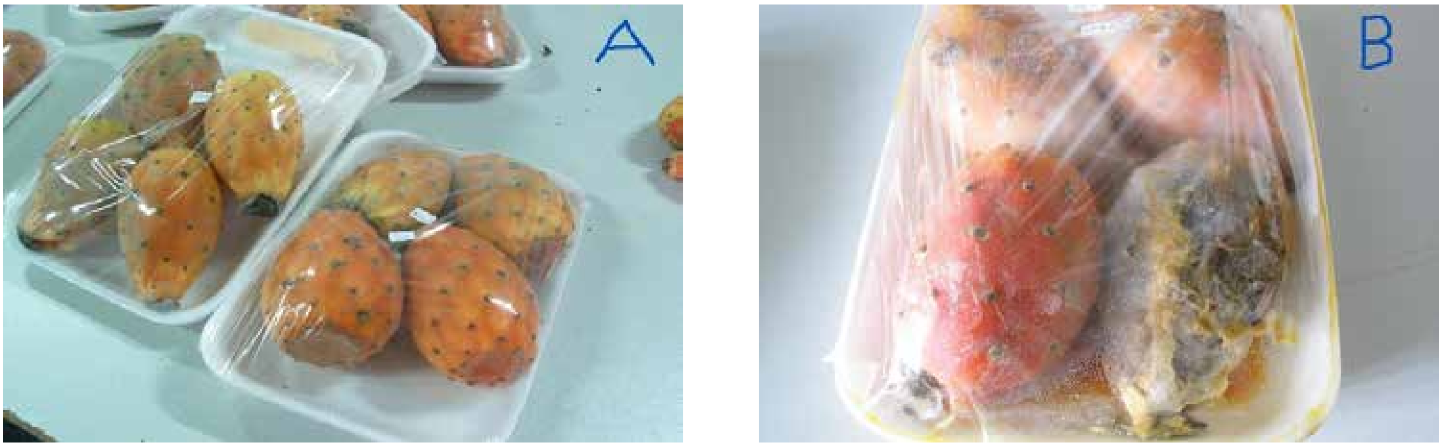


Figure 5 – Packaged fruit air conditioned at 36 °C and 100 % RH for 36 h (A) or not conditioned (B) and then stored for 3 weeks at 2 °C plus 3 d at 20 °C.

A very interesting study was carried out by Dimitris et al. (2005) who tested the effect of hot water brushing on fruit stored at 6 °C for 4 weeks followed by an additional week at 20 °C to simulate marketing conditions. Fruit was simultaneously brushed to remove the spines and sprayed with water at 20, 60, 65 and 70 °C for 10, 20 and 30 seconds. All treatment combinations reduced water loss, chilling injury and decay, however when the temperature was raised to 70 °C some phytotoxic effects were detected, whereas the combination 60 °C and 30 seconds or 65 °C 20 seconds improved all detected parameters. Differently than the other heat treatments, hot water brushing has the potential of being easily transferred to commercial practice as only minor modifications of the despining facilities are required.

CONCLUSION

Heat treatments had been exploited to control decay and pests until the first half of last century. The advent of synthetic pesticides to control decay and quarantine insects reduced their popularity until the end of the century. The growing concern about the risks that the use of synthetic molecules may have on consumer health and the environment are giving new interest to environment friendly technologies, included heat treatments. Nowadays that new technologies based on renewable energy (solar radiation) can significantly reduce the energy cost, thermal treatments can represent a key technology to support the management of important post-harvest issues of cactus pears.

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BIOGAS PRODUCTION
IN THE CACTUS AGROINDUSTRY

INTRODUCTION

Agro-industrial production is usually associated with two major problems, in one hand, its high energy consumption, and on the other hand, the amount of waste it can generate. Although today, agribusiness has been looking for more sustainable ways to manage their waste, through practices of recycling, composting and reuse to minimize the environmental impact. In this way, responsible practices of agro-industrial waste management have been promoted to reduce the environmental impact and promote the circular economy. Organic matter has traditional forms such as composting, or cladodes and animal waste is directly incorporated into the soil, but the efficiency of dry matter mineralization under natural conditions in arid zones is low, mainly due to low water availability. It is important to mention that many of these wastes can also be used for other purposes, either as feed for livestock, to produce organic fertilizer (already mentioned), or even to obtain extracts or additional products.

Today agriculture faces cost increases. There is also a need for greater management efficiency to reduce pollution and ensure the sustainability of agricultural systems. For this reason, the introduction of waste fermentation processes can serve not only to obtain cheap fuel but also to recycle expensive elements, such as fertilizers.

The fermentation of residues in closed compartments makes very efficient use of available water and not only produces biogas but also solid waste with high nutritional content that becomes available more quickly to plants than untreated waste.

In addition, within the parameters of the circular economy, for these two factors, energy and waste, the production of biogas (production from anaerobic biodigestion) can be a good alternative, since it would combine the use of these residues and the production of biogas as an energy source.

BIOGAS

Biogas production occurs in many natural ecosystems such as lakes, swamps, flooded soils, as well as within the digestive systems of animals. It can be synthesized artificially by anaerobic treatment of various raw materials such as animal and human excreta, and agricultural and industrial waste. Commercially or artificially, biogas is a viable energy source in agricultural and rural areas, obtained from processing organic waste through anaerobic digestion. This process produces a gaseous compound of high-value fuel, namely biogas, consisting mainly of methane and carbon dioxide, plus other gases in trace amounts. It also produces a stabilized organic waste, digestate (also known as biol or biofertilizer), which can be used as a soil conditioner and/or biofertilizer (Varnero, 1991; Varnero, 2001).

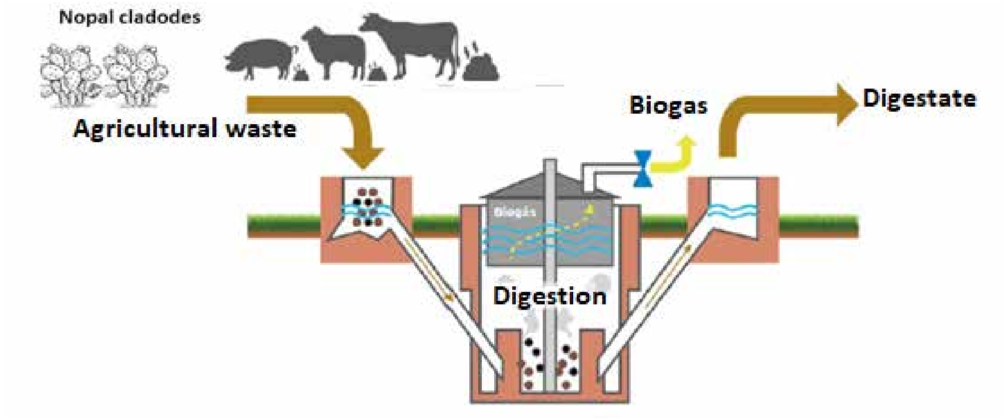

Figure 1. Family size biogas system (Modified from Varnero et al., 2015)

The biodegradation rate of organic residues is related to the microbial activity of the anaerobic system. The parameters that determine the digestion period to produce biogas and biofertilizer depend on the characteristics of the raw materials such as the pH of the medium, the total level of solids and the temperature of the process.

Opuntia cladodes have a high potential for producing methane (327 m^3 CH_4 Mg^{-1} volatile solid) which is in the biomethane potential range of traditional energy crops, because their carbohydrates have a low fiber content and are easily degraded. However, Varnero and García de Cortázar (2006) indicated that the cladodes are not by themselves a good methanogenic material. The incorporation of cladodes in the anaerobic digestion of other raw materials (e.g. manure, plant residues, microalgae) and C/N ratio (16–30) favors the development of microorganisms in the digestate. Animal manure would encourage methanogenic fermentation, provided that the pH of mixtures of these raw materials ranges from neutral or slightly acidic (the cladodes have a pH between 3.5 and 5.5). The inclusion of an appropriate percentage of cladodes in animal manure positively influences the start time of the vegetable fermentation process (Homer and Varnero, 2017), which is attributed to the energy and carbonated source, which the cactus pear provides, favoring the development of acidogenic bacteria, which generate the substrate that requires the methanogenic bacteria (accelerating the methanogenic process and concentrating this activity in less time (FAO, 2011). Different studies showed a certain similarity, in that the highest production was in the ratio 3:1 of nopal/manure at a temperature of 30 ° C, maintaining a pH of neutral to slightly acidic.

Contreras and Toha (1984) studies indicated that three kg of dried cactus pear can produce 1 m^3 of biogas, at the same time, implying production of 10 kW-h. Homer and Varnero (2017) indicated that the calorific value of the cactus pear was 7,058 Kcal m^{-3}, with a range of error ranging from 6,800 to 7,200Kcal m^{-3}. The same authors indicated that the potential of biogas for *Opuntia ficus-indica* cladodes can be expressed as 0.360 m^3 kg^{-1} dry matter and a little more from the fruits. But, in agro-industrial processes, you can have different wastes. At laboratory level, Contreras and Tohá (1984) found that in samples of cactus pear cladodes elaborated only with mucilage, a greater volume of gas was produced during the first 70 h of incubation at 35 °C (220 mL g^{-1}), than in those constituted only by cladode bark (outermost section of the cladode) (58.8 mL g^{-1}) and cladodes (167.2 mL g^{-1}), which is in agreement with the composition of mucilage reported in several studies. Those residues that contain a higher proportion of fractions with high resistance to degradation (hemicellulose, cellulose, lignin), such as cladode bark, have proven to produce less methane than raw materials containing a higher proportion of fractions susceptible to degradation, such as cladode mucilage (Quiroz et al., 2021).

On the other hand, the production of biogas described above establishes that 0.45 m^3 of gas is obtained per m^3 of the digester.

The initial cost of biogas production in rural households is variable according to the technology and the area, with references of around USD 50 per biodigester (Bui Xuan An et al., 1999). In cold climates, the cost of materials is around USD 250, while in tropical climates it drops to USD 150, which is recovered in two to three years due to the savings obtained in fuel expenditure, time, and improvement of production (RedBioLAC, 2023). This cost is recovered within 9–18 months through savings in fuel costs. In gas economy, it is assumed that 1 m^3 of biogas is equivalent to 453 grams of Liquefied petroleum gas (LPG).

The liquid biofertilizer residues obtained from digestion processes also contain nutrients that can make it a valuable fertilizer, apart from its contribution in microorganisms and organic material, as well as the possibility of obtaining solid materials when emptying the digester. Thus, reducing expenditure on commercial fertilizers. According to Varnero (1991), one ton of solid biofertilizer is equivalent to 40 kg of urea, 50 kg of potassium nitrate and 94 kg of triple superphosphate. International fertilizer prices of these three fertilizers vary on average from USD 255 to USD 380 ton^{-1} (Reaching values of USD 850) in 2022 (Indexmundi, 2023). Assuming an average price of USD 0.32 kg^{-1} of fertilizer, each ton of biofertilizer would save USD 58.8 on fertilizer costs. But, the composition of the digestate is closely related to the type of raw materials used and the duration of the hydraulic retention time (Arthurson, 2009)

BIODIGESTERS DESIGN AND OPERATION

The selection of the right biodigester will depend on the use and associated costs. An appropriate digester design must meet certain criteria such as being airtight, essential to prevent undesirable gas output and the incorporation of unwanted air. It must be thermally insulated to avoid large temperature changes and must incorporate a safety valve.

There are basically two types of digesters, continuous or batch type (discontinuous). In the continuous type, material loading is done frequently (daily or weekly) where each load replaces approximately 5 to 15% of the total volume. The solids concentration is low (6-8% of the volume). Although they need to add water to it, this is not the case with the cladodes load, since the main component of *Opuntia's* cladodes is water (88–92%) (Quiroz et al., 2021), and once the digestion process starts, the biogas production rate is relatively constant (this is mainly dependent on the temperature). Continuous digesters are best suited to situations where there is a constant production of material for biodigestion and is feasible to use if a continuous collection of the cladodes is done during the year. They are also suited to small properties where household waste can be added as raw material, for example, using the feces produced by the farm animals or through a connection between the bathroom and digester (Varnero and García de Cortázar, 2006; FAO, 2011). For these types of digesters, different models are available. The Taiwan type, which is made of plastic sleeves (polyethylene), pools with covers, Indian type, and Chinese type (Figures 2a and 2b). They differ in that the Chinese type is a closed one, with gas accumulation at the top, while the Indian digester gasometer is included in the digester in the form of a floating bell.

Batch-type digesters (Figure 2c) consist of a sealed battery of tanks or deposits, with a gas outlet connected to a floating gasometer, where the biogas is stored. The aim of having more than one digester is to always have one loading or unloading, while the rest is in biogas production. Feeding or charging the digester with the raw material which has a higher concentration of solids (40 - 60%) is done only once and there is no recharging during the fermentation process.

The discharge of the stabilized organic material is performed once the production of biogas has ended. The biogas production rate has an initial waiting period, where the steps of fermentative hydrolysis and the formation of organic acids is followed by the step of methane formation. From this point, most of the biogas production occurs. It then slows down and finally decreases to almost zero, as built-load materials run out. The complete duration of the process depends on the temperature.

The discontinuous system is applicable in different situations, such as: where raw materials exhibit handling problems in continuous systems; where materials are difficult to digest by methanogenic fermentation, and when processing of raw materials are available intermittently. In the case of the cladode harvest, this is carried out once or twice a year, or when labor or availability is limited. (Varnero and Garcia de Cortázar, 2006; FAO, 2011).

Under optimal conditions and for the same load of dry matter, both types of digesters produce the same amount of biogas; therefore, the choice should be based on the frequency of waste production (in this case, cladodes) and the availability of water.

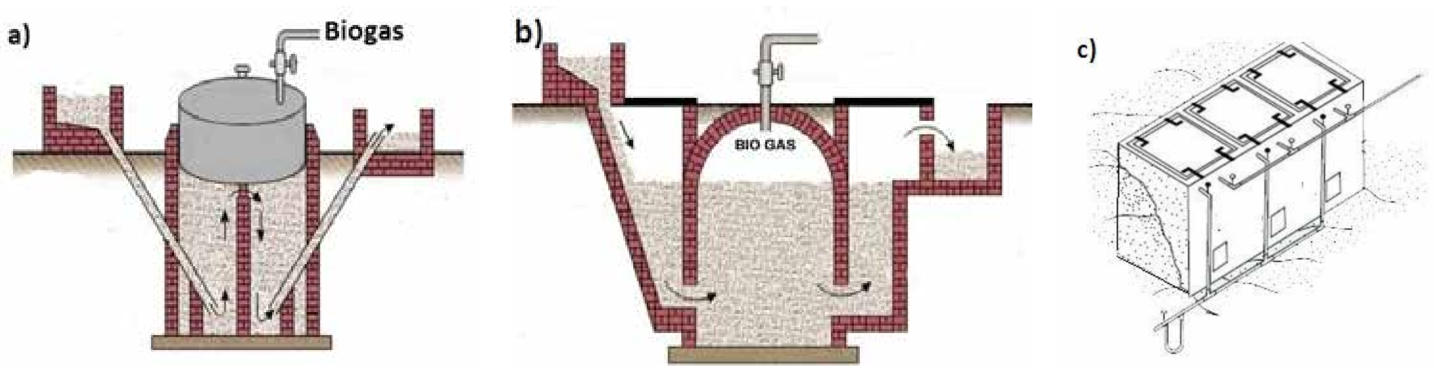

Figure 2. a) Indian continuous digester; b) Chinese continuous digester; c) Batch digester.

For small and medium producers, there is a wide range of materials suitable to construct a biogas digester, ranging from the most economic continuous types, made of low-cost polyethylene tube (or from EPDM, PVC, HDPE).

OTHER BIOENERGY USES

Referring to others bioenergy issues, cactus cladodes production can also be used for other purposes such as direct burning, or biodiesel or ethanol production. In direct burning, it is interesting if a production of 40 ton is assumed ha $^{-1}$ year $^{-1}$ in specific crops for energy use, or 10-ton ha $^{-1}$ year $^{-1}$ in traditional pruning fruit plantations. In this case, the cladodes are harvested, dried and then crushed, and used in direct burning or cogeneration mix coal-fired because it has a calorific value of 3,850 - 4,200 Kcal kg-^{1} (Homer and Varnero, 2019).

The ethanol production technology is more complex than the production of biogas, adapting better on a larger scale, especially by high investment costs and technology, for concentrations above 98 % ethanol. At the stage of fermentation, it is required to have specific yeast to maximize the production of alcohol. The ethanol concentration in the fermentation is 8-12% (García de Cortázar and Varnero, 1995); therefore, it must be followed by distillation to achieve the required concentration of ethanol as fuel.

Some estimates with cactus mucilage to produce ethanol in small amounts indicated that about 20 milliliters per kilogram of mucilage was obtained; 8.6 L were produced by 100 kg of dried cladodes and 24.7 L to 100 kg of dried fruits, so is not considered competitive in relation to fermented fruits. With a density of 635-5,000 plants per hectare, in the case of using only the cladodes (Retamal et al., 1987), you could get an average of 300 and 3,000 L of ethanol from plantations irrigated and non-irrigated, respectively.

From agribusiness residues, one could extract fatty acids for the transformation into biodiesel, the most efficient being obtained from fruit seed residue. However, values are reduced as each fruit has between 150 and 300 seeds, to obtain oil contents ranging between 98 and 139 g kg^{-1} of seed (Moßhammer et al*.,* 2006), therefore it is only profitable when it was associated with the fruit processing industry (Sáenz and Sepúlveda, 2006), in products such as pulps, juices and other products, in which the seed was a waste product from which a valuable oil can be extracted (on average, 9.8 g 100 g^{-1} of seed) (Ramadan and Morsel, 2003)).

CONCLUSIONS

Waste from the nopal industry can include various by-products resulting from the production and processing of this plant, such as discarded spines and leaves, pulp, waste (skin, seeds), and water. It is important to mention that many of these wastes can be used for other purposes, either as livestock feed, the production of organic fertilizer or even to obtain extracts or additional products.

For more sustainable ways to manage its waste, through recycling techniques, the management of industrial waste to reduce environmental impact and promote the circular economy, anaerobic biodigestion (Biogas) allows for the reduction of waste, energy generation (0.360 m^3biogas kg^{-1} dry matter), and also produces a stabilized organic waste, digestate (also known as biol or biofertilizer), which can be used as a soil conditioner and/or biofertilizer

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APPLICATION OF *OPUNTIA FICUS-INDICA* MUCILAGE AS EDIBLE COATING FOR FRUIT QUALITY PRESERVATION DURING STORAGE

INTRODUCTION

Opuntia ficus-indica (L.) Mill. is a drought-tolerant species belonging to the *Cactaceae* family and cultivated in semi-arid and arid regions worldwide (D'Aquino et al., 2017). Its fruit and cladodes are a source of nutrients and phytochemicals used in the food and pharmaceutical industries (Nazareno, 2017).

The significant changes in people's lifestyles in recent years have led to an increase in the popularity of fresh-cut, ready-to-eat foods. Among them, the consumption of minimally processed fruit and vegetables has seen a sharp increase, and the industry's interest in producing fresh-cut fruits has significantly increased per capita consumption. Among new postharvest management strategies of environment-friendly fresh fruit handling, the application of edible coatings has been reported to be very effective (Liguori et al., 2021a). Edible coatings can act as a semipermeable barrier against gases and water vapor; can modify fruit tissue metabolism by affecting respiration rate, decrease moisture and firmness loss, preserving the color, transporting antimicrobial, antioxidant, and other preservatives, controlling microbial growth, and maintaining fruit quality for a longer period (Liguori et al., 2021a; Pushpendra & Shruti, 2018).

O. ficus-indica fruit and cladodes contain mucilage, a complex carbohydrate that is composed of variable amounts of L-arabinose, D-galactose, L-rhamnose, and D-xylose, as well as galacturonic acid, which is a potential ingredient for the food industry, due to its nutritional and technological properties, such as viscosity (Sàenz et al., 2004). Mucilage is, in fact, a hydrocolloid with a great water retention capacity that, together with Crassulacean Acid Metabolism (CAM) allows *O. ficus-indica* to thrive in semi-arid and arid conditions (Liguori et al., 2013). Moreover, mucilages' rheological characteristics make it interesting to produce natural edible coatings with a high nutraceutical value, useful for fruit and food preservation. Its concentrations depend on genotype, cladode age and environmental conditions (Allegra et al., 2016). Several studies reported that *O. ficus-indica* edible coatings positively affected fruit quality, reducing water transpiration and browning, maintaining fruit fresh weight, visual score values, fruit firmness, nutraceutical attributes, and controlling microbial growth, resulting in a longer storage period.

The aim of our study was to assess the effects of *O. ficus-indica* mucilage-based coating on quality, nutraceutical value, microbiological growth, and sensorial parameters of minimally processed fruits during cold storage.

MATERIALS AND METHODS

Cactus pear fruits were collected from 10-year-old *Opuntia ficus-indica* plants, cv. Gialla, spaced 6 x 5 m apart and trained to a globe shape. The commercial orchard was in Roccapalumba, Palermo, Italy (37°48’ N, 13°38’ E, 350 m a.s.l) on sandy-loam Mediterranean red-soils, plants were subjected to ordinary horticultural care and the orchard was drip-irrigated. Loquat, *Eriobotrya japonica Lindl,* white-flesh fruits, cv. Martorana—MRT were harvested from commercial orchards located in Palermo (38°04’ N, 13°23’ E, 99–104 m a.s.l.).

Fresh O. ficus-indica mucilage extraction and application

One-year-old cladodes were collected from *O. ficus-indica* plants of the cultivar “Gialla”, located at the Department of Agricultural, Food and Forest Sciences, University of Palermo (38° 7’ 4.0800” N 13° 22’ 11.2800” E, 29 m a.s.l). Harvested cladodes were quickly transported to the laboratory where they were measured, weighed, and processed for mucilage extraction, using a modified patented method of Du Toit & De Wit (2011) developed in South Africa.

Cladodes were washed with chlorinated water to to remove impurities and spines improve mucilage shelf life. Cladodes chlorenchyma was then removed with a peeler to obtain high pure quality mucilage (Figure 1). Cladodes were then sliced into squares and cooked in a microwave oven (900 W) for 3-5 min, until soft. The cooked, soft cladode pieces were then mixed using an Omni Mixer Homogenizer (mod. Omni-Mixer. 17107, Dupont Instruments Sorvall, USA) to aid the mucilage extraction. The obtained pulp was then centrifuged using a Sigma centrifuge (mod. 6K15, Sigma Laborzentrifugen GmbH, Germany) at 8,117 x g for 15 min at 4 °C, to separate the liquid mucilage from the solids. The mucilage was then decanted and weighed while the solid material left in the falcon tubes were discarded (Figure 1). No chemicals have been used during this extraction process and as such, the extracted mucilage obtained is natural and unadulterated by chemicals.

After peeling, fruits (cactus pear and loquat fruits) (Liguori et al., 2021a, 2022) were divided into two treatment groups (control uncoated fruit and coated fruit). Coated fruits samples were treated with *O. ficus-indica* mucilage, and uncoated fruit samples were treated with distilled water and used as control. Mucilage edible coating and distilled water were applied by using an atomizing spray system (flow rate: 1 L h^{-1}; air pressure: 50 kPa) (Figure 1). Soon after coating, all fruits were air-dried at room temperature for 15’, then, coated, and uncoated samples, were placed in rigid polypropylene retail boxes sealed with microperforated polypropylene film and stored at 5 ± 0.5 °C and 95% RH (cactus pear cold storage period: 9 days; loquat fruits cold storage period: 13 days).

Figure 1 O. ficus indica mucilage extraction and application

Fruit quality analysis: firmness, soluble solid content, titratable acidity, color, weight loss, sensorial analysis, and visual score

The quality of minimally processed fruits was assessed soon after coating and during the cold storage period (5 °C) (cactus pear cold storage period: 9 days; loquat fruits cold storage period: 13 days)). Fruit firmness was measured using a texture analyzer (Mod. Z0.5 TS, Zwick Roell, Ulm, Germany). After firmness determinations, the pulp of the fruit was cut into pieces to obtain a uniform sample of each replicate. A part was homogenized and used to measure total soluble solids (TSS) content and titratable acidity (TA) and a part was immediately frozen at −80 °C for the nutraceutical analysis. Total soluble solids content (TSS) was determined by a digital refractometer (Palette PR-32, Atago Co., Ltd, Tokyo, Japan); titratable acidity (TA) was measured by titration of 10 mL homogenized fruit flesh juice with 0.1 N NaOH to an endpoint of pH 8.1 and expressed as the percentage of citric acid for cactus pear and malic acid for loquat fruit (mod. S compact titrator, Crison Instruments, Barcelona, Spain). Minimally processed cactus pear and loquat fruits external color was measured at two opposite points on each fruit using a colorimeter (Chroma Meter CR-400C, Minolta, Osaka, Japan). CIE L*a*b* coordinates were recorded as L* (lightness), a* (positive values for reddish colors and negative values for greenish colors), and b* (positive values for yellowish colors and negative values for bluish colors). From these components Chroma (C*) and Hue angle (h°) were calculated as C* = (a*2 + b*2)1/2 and h° = arctan (b*/a*) (Liguori et al., 2021a, 2022).

Fruits weight loss was calculated on 5 packages for each treatment (5 boxes × 2 treatments) and expressed as the percentage reduction with respect to the initial time, using a two-decimal precision digital balance (Mod. CENT-2 10000, Gibertini, Milan, Italy).

% Weight loss = $[(W_i – W_s)]/W_i \times 100$

where W_i is the initial weight, and W_s is the weight measured during storage.

At each sampling date, fruit samples for each treatment (coated and uncoated) were subjected to sensory evaluation and visual score. The sensory profile was constructed by a panel made up of 10 judges trained in a few preliminary meetings: by using commercial fruit, the judges generated a list of descriptors. Sensory analysis was focused on firmness, sweetness, acidity, aroma, off-flavor development, and overall acceptance. The different descriptors were quantified using a ten-point intensity scale where the digit 1 indicates the descriptor absence while digit 10, the full intensity (Liguori et al., 2021a). Visual appearance score resulted from the medium value of color, visible structural integrity, and visual appearance (Allegra et al., 2016). The different descriptors were quantified using a subjective 5–1 rating scale with 5 = very good, 4 = good, 3 = sufficient, 2 = poor (limit of edibility) and 1 = very poor (inedible). A score of 3 was the limit of marketability. The order of presentation was randomized between judges. Water was provided for rinsing between samples.

RESULTS AND DISCUSSION

Cactus pear fresh-cut

Fruit texture is a critical quality attribute in cactus pears as tissue softening occurs at a very high rate with fruit ripening. The enzymatic reactions, due to fruit processing operations (peeling, slicing etc.), lead to rapid losses in firmness (Palma et al., 2018). In our study, the highest fruit firmness values were measured on coated fresh-cut cactus pear (OFI M) samples during the cold storage period, showing the ability of mucilage to preserve fruit structure (Table 1). This effect on fruit firmness could be attributed to calcium content in *Opuntia ficus-indica* (OFI) mucilage that preserves fruit integrity cell wall and middle lamella, by interacting with the pectic acid in the cell walls to form calcium pectate (Allegra et al., 2017). Our study showed the positive effect of polysaccharidic coatings, such as cactus pear mucilage, that act as a barrier reducing losses on firmness, as reported in previous studies (Palma et al., 2018; Liguori et al., 2022) indeed, OFI M samples reported firmness values 1.7 times higher than uncoated fresh-cut cactus pear (OFI CTR) samples at the end of the cold storage period, enhancing their resistance to mechanical damage during storage and, thereby, reducing economic losses throughout the value chain. Results of our study indicated that the weight loss of minimally processed cactus pear fruit, was strongly influenced by OFI mucilage coating, indeed, OFI CTR samples showed weight loss values 2.5 times higher than OFI M (data not shown). Concerning chemical parameters there was evidence of slight changes in terms of TSS and TA during storage in both OFI CTR and OFI M samples (Table 1). TSS showed a slight increase in OFI CTR samples, while TA values remained stables in both samples during cold storage, no significant differences between OFI CTR and OFI M occurred for TSS and TA (Table 1.).

Betalains and ascorbic acid are important nutraceutical components of cactus pears that give the fruit a peculiar antioxidant capacity (Palma et al., 2018). Storage temperature, in-package atmosphere composition, antioxidant compounds and fruit maturity stage could all stimulate synthesis and affect losses in contents of betacyanins and betaxanthins during storage (Palma et al., 2018). Low temperature combined with reduced levels of O_2 stimulated the synthesis of both pigments. In our study, betanin and indicaxanthin did not increase during storage, it was probably due to the O_2 in-package partial pressure that was not low enough to stimulate new pigment synthesis, as reported by Palma et al. (2018). Betalain content is also reported to increase with fruit maturity, reaching the maximum concentration at full maturity, but before full skin coloration. Indicaxanthin and betanin content was significantly higher in OFI M samples than in OFI CTR samples, showing a positive effect of mucilage coating on the nutraceutical fruit value during cold storage (Table 1). The antioxidant capacity after processing operations could be increased by some factors (i.e. phenols, betalains, vitamin C) and decreased by others. Its trend would reflect the contribution given by each individual factor (Palma et al., 2018). In our study, mucilage coating showed a positive effect on minimally processed cactus pear fruits' radical scavenging activity (DPPH) after 6 days of cold storage, indeed, OFI CTR samples showed a sharp decrease from the day 6th until the end of the cold storage, while DPPH was almost stable in OFI M samples during storage (Table 1). The sensory analysis showed that the judges preferred mucilage coated samples at the end of the cold storage period as reported by previous studies in strawberry (Liguori et al., 2021b) and kiwifruit (Allegra et al., 2016). Furthermore, the mucilage coating did not negatively affect the natural taste of minimally processed cactus pear fruits. None of the panelists could discern any "off□flavor" in OFI M samples, which is an important aspect regarding the use of edible coatings when taste modification is undesirable. OFI mucilage coating has exalted some important parameters, as well as firmness, aroma, sweetness, and taste that are particularly appreciated by consumers (Figure 2). OFI M fruits had the highest visual quality scores until the end of the cold storage period, and they were still above the marketability and edibility threshold during the storage, while OFI CTR fruits were marketable and edible during the first 6 days of storage (Figure 2). In all microbial groups investigated, OFI M fruit showed a lower concentration of about 1 Log cycle than OFI CTR fruit during the entire period of observation (data not shown). Fruit flesh brightness (L*) was similar in OFI CTR and OFI M fruit at the time of treatment. OFI CTR fruit showed a continuous decrease of flesh brightness, with lower values than OFI M fruit during the entire cold storage period (from 0 to 9 days of storage at 5°C) (data not shown). OFI M showed a slight decrease during storage, with a loss of 9% of flesh brightness from T0 to 9 days of cold storage, while OFI CTR showed a sharply decrease with a loss of 25% of flesh brightness from the beginning to the end of the cold storage period (data not shown). The mucilage coating positively affected fruit quality parameters, reduced weight loss, and improved fruit brightness. In our study OFI CTR samples brightness decreased significantly during cold storage, while OFI M did not show significant change in brightness during cold storage with 1.2 times than OFI CTR at end of the cold storage period (data not shown), OFI CTR samples showed the same behaviour reported by Palma et al., (2018). Fruit color decrease is probably correlated to betalains content changes, indeed, in our study the decrease in terms of betalains content was strictly correlated to the loss in brightness in uncoated cactus pears samples during storage. Our data showed a significant effect of mucilage coating on preserving quality, nutritional value, sensorial parameters, and improving postharvest life of minimally processed cactus pear fruits. *O. ficus-indica* mucilage had a barrier effect on cactus pear minimally processed fruit during cold storage, reflected by the lower weight loss and the higher firmness than uncoated ones, after 9 days of storage at 5°C.

Loquat fruits fresh-cut

Loquat fruit are easily bruised and scratched, and the damaged areas usually later turn brown or black in air. In addition, low temperature injury is one of the major limitations for long-term cold storage of loquat fruit. Fruit processing, as well as peeling, could allow producers to sell loquat fruits that present large purple spotted areas in the epicarp to the market, which are usually considered unmarketable. Fruit texture is an important quality attribute in minimally processed fruits, as the enzymatic reactions due to fruit processing operations (peeling, slicing, etc.) lead to rapid losses in firmness. In our study, the highest fruit firmness values were measured in coated fresh-cut loquat fruits (LOQ M) samples during the cold storage period (13 days at 5°C), showing the ability of mucilage to preserve fruit structure (Table 1). TSS, TA, extractable juice, and ascorbic acid content are important indicators to measure the quality of loquat fruit. The changes in composition and content affect the fruit's taste and acceptance. In terms of chemical parameters, there was evidence of slight changes in terms of TSS and TA during storage in both uncoated samples (LOQ CTR) and coated samples (LOQ M) samples (Table 1) although mucilage-based edible coatings inhibited the decrease of TSS, TA, extractable juice, and ascorbic acid content in LOQ M samples (Table 1). Furthermore, our study showed that the weight loss of minimally processed loquat fruit was positively affected by the mucilage-based coating; indeed, LOQ M coated samples showed weight loss values 1.5 times higher than LOQ CTR uncoated ones (data not shown). The sensory analysis showed that judges preferred mucilage coated samples at each sampling date of the cold storage period, as reported by previous studies on other fruits (Liguori et al., 2021a-b, 2022). LOQ M samples were preferred by the panelist in all the descriptors that gave mean scores of 7.4 to overall acceptance at the end of the cold storage period (13 days at 5 °C), while LOQ CTR had mean scores of 6.2 in overall acceptance at the end of the cold storage period (5 °C) (Figure 3). LOQ M samples had the highest visual quality scores until the end of the cold storage period, while LOQ M samples were above the limit of marketability until 10 days of cold storage and edibility until the end of the cold storage period, while LOQ CTR samples were marketable until 3 days of cold storage and edible until the first 6 days of storage (Figures 3). Although bacteria and fungi increased during storage in coated loquat fruits, cell densities observed in uncoated loquat fruits were 1 log cycle higher. This trend is mainly due to the ability of *O. ficus-indica* mucilage edible coatings to reduce the microbial growth in fresh-cut fruits (Liguori et al., 2021a-b, 2022) (data not shown). LOQ CTR and LOQ M showed a slight decrease in terms of flesh brightness during storage, with a loss of 10% and 13% respectively, from T0 to 13 days of cold storage (data not shown). Fruit color decrease and browning are mainly caused by enzymatic oxidation of endogenous polyphenols into quinones, which are then polymerized with other quinones and amines to form brown pigments (Liguori et al., 2022). Our data showed a significant effect of mucilage coating on preserving quality, nutraceutical value, sensorial parameters, and improving postharvest life of minimally processed loquat fruits. *O. ficus-indica* mucilage had a barrier effect on loquat minimally processed fruit during cold storage, reflected by coated samples having lower weight loss and higher firmness than uncoated ones, after 13 days of cold storage at 5 °C. This factor could reduce economic losses; loquat fruit are easily bruised and scratched, and the damaged areas usually later turn brown or black in air.

Table 1 Evolution of quality parameters in fresh-cut cactus pear fruits (uncoated: OFI CTR and coated with mucilage: OFI M) and loquat fruits (uncoated: LOQ CTR and coated with mucilage: LOQ M) during cold storage at 5 °C. Data regarding cactus pear fruits are reported in the top part and data related to loquat fruits are reported in the bottom part of the table.

STORAGE TIME *(Days)*	FIRMNESS *(N)*		TSS *(°Brix)*		TA *(g citric acid 100 g-1 FW)*		INDICAXANTIN *(mg 100 g-1 FW)*		BETANIN *(mg 100 g-1 FW)*	
	OFI CTR	OFI M	OFI CTR	OFI M	OFI CTR	OFI M	OFI CTR	OFI M	OFI CTR	OFI M
0	18.50 ± 0.71	18.50 ± 0.71	13.95 ± 0.42	13.95 ± 0.42	0.058 ± 0.002	0.058 ± 0.002	8.12 ± 0.32	8.93 ± 0.33	0.45 ± 0.02	0.49 ± 0.02
3	15.41 ± 0.89	17.97 ± 0.92	14.75 ± 0.35	14.11 ± 0.41	0.053 ± 0.003	0.054 ± 0.001	6.86 ± 0.28	8.29 ± 0.32	0.38 ± 0.04	0.46 ± 0.03
6	13.62 ± 0.84	16.32 ± 0.91	14.91 ± 0.59	14.32 ± 0.51	0.052 ± 0.002	0.053 ± 0.003	6.91 ± 0.17	8.27 ± 0.23	0.38 ± 0.05	0.45 ± 0.03
9	9.11 ± 0.97	15.93 ± 0.88	14.95 ± 0.47	14.42 ± 0.41	0.051 ± 0.002	0.053 ± 0.001	6.89 ± 0.21	8.89 ± 0.51	0.37 ± 0.02	0.49 ± 0.01
STORAGE TIME *(Days)*	FIRMNESS *(N)*		TSS *(°Brix)*		TA *(% malic acid)*		EXTRACTABLE JUICE *(%)*		ASCORBIC ACID *(mg 100 g-1 FW)*	
	LOQ CTR	LOQ M	LOQ CTR	LOQ M	LOQ CTR	LOQ M	LOQ CTR	LOQ M	LOQ CTR	LOQ M
0	8.49 ± 0.12	8.49 ± 0.12	10.15 ± 0.34	10.15 ± 0.34	0.69 ± 0.02	0.69 ± 0.02	56.30 ± 1.17	56.30 ± 1.17	6.14 ± 0.03	6.14 ± 0.03
3	7.75 ± 0.09	8.25 ± 0.08	10.01 ± 0.23	10.05 ± 0.29	0.57 ± 0.01	0.62 ± 0.01				
5	7.35 ± 0.08	7.81 ± 0.09	9.51 ± 0.41	9.58 ± 0.32	0.52 ± 0.02	0.58 ± 0.02	48.01 ± 0.50	51.47 ± 0.49	5.05 ± 0.05	5.15 ± 0.01
7	6.72 ± 0.14	7.19 ± 0.11	9.37 ± 0.21	9.48 ± 0.29	0.51 ± 0.01	0.53 ± 0.01				
10	6.10 ± 0.02	6.91 ± 0.03	9.22 ± 0.29	9.17 ± 0.14	0.44 ± 0.02	0.51 ± 0.01				
13	5.03 ± 0.14	5.72 ± 0.12	8.08 ± 0.12	9.15 ± 0.19	0.35 ± 0.01	0.48 ± 0.01	45.36 ± 0.68	50.14 ± 1.44	3.38 ± 0.03	4.81 ± 0.06

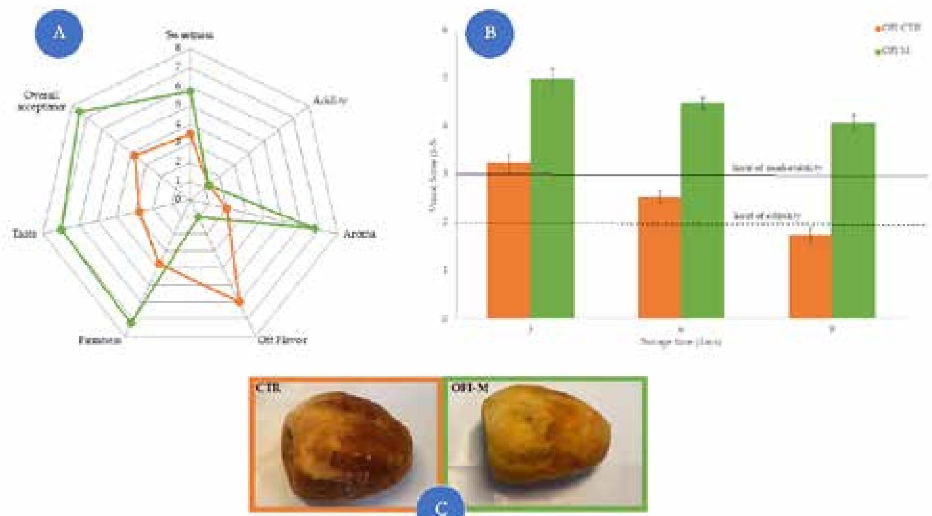

Figure 2 Sensorial analysis of fresh-cut uncoated (OFI CTR) and coated with mucilage cactus pear fruits (OFIM) at end of the cold storage period (A). Visual score of fresh-cut uncoated (OFI CTR) and coated with mucilage cactus pear fruits (OFI M) during the cold storage period at 5 °C (9 days at 5 °C) (B). Fresh-cut uncoated (CTR) and coated with mucilage cactus pear fruits (OFI M) at end of the cold storage period (C).

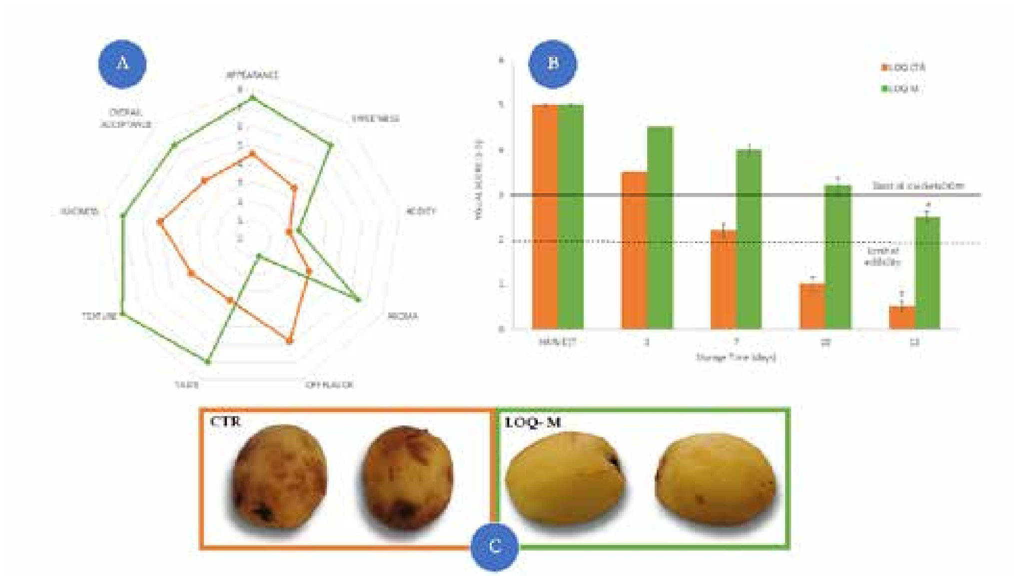

Figure 3 Sensorial analysis of fresh-cut uncoated (LOQ CTR) and coated with mucilage loquat fruits (LOQ M) at end of the cold storage period (A). Visual score of fresh-cut uncoated (LOQ CTR) and coated with mucilage loquat fruits (LOQ M) during the cold storage period (10 days at 5 °C) (B). Fresh-cut uncoated (CTR) and coated with mucilage loquat fruits (LOQ M) at end of the cold storage period [(5 = very good, 4 = good, 3 = fair (limit of marketability), 2 = poor (limit of edibility) and 1 = very poor (inedible)] (C).

CONCLUSIONS

In conclusion, our data suggest that *O. ficus-indica* mucilage could be a useful environment-friendly way of maintaining minimally processed fruits quality, nutraceutical value, visual quality, sensorial traits and extending its postharvest life. Our research also indicated that minimal fruit processing and coating with *O. ficus-indica* mucilage could extend the shelf life of peeled loquat fruits and enable producers to sell loquat fruits with large spots on the epicarp, which are typically regarded as unmarketable, to consumers.

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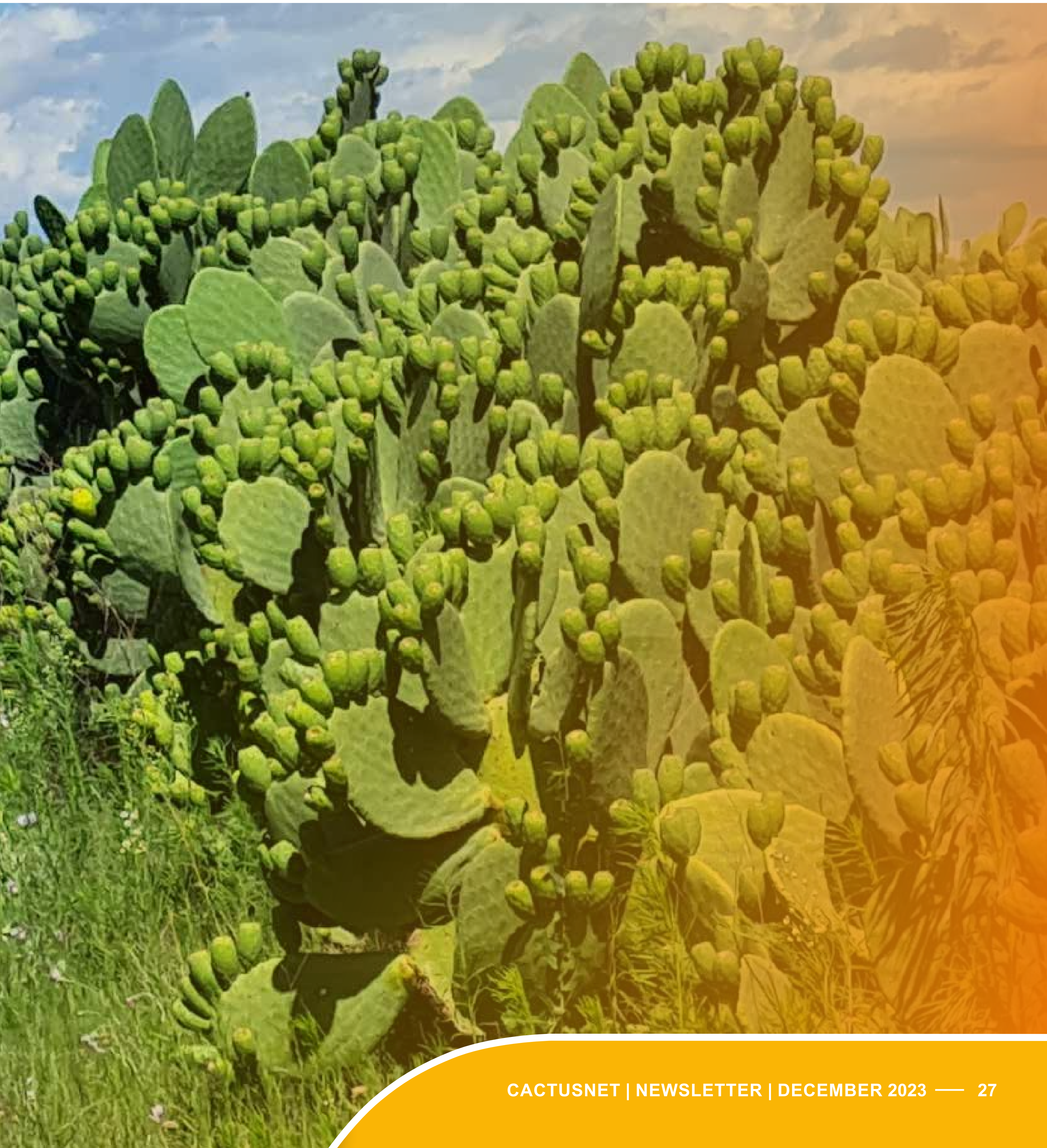

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EFFECTS OF UV EXPOSURE ON THE PHYSICAL-MECHANICAL PROPERTIES OF CACTUS BASED BIOPOLYMER

INTRODUCTION

Plastic usage has grown exponentially since its emergence as a mass-produced material in the early 1900s. Over the last decade alone, plastic production worldwide has increased by an estimated 130 million ton (Shen et al., 2020). Considering the impact of such production has become pertinent in recent years.

To reduce the negative effects associated with plastic production, there are a few viable options, the most drastic being an immediate halt in production and use. This option is not feasible as long as there is a consumer market for this material. Option two is implementing a reduction in plastic use. This is also unlikely, especially in capitalist countries that are set to gain income in this market. Reusability is frequently brought up in an effort to improve the environmental impact of products, however many plastics currently in production are single use plastics that cannot, or currently are not, reformed and reused. The most obvious answer is recycling; however, many countries are notoriously known for their poor recycling conditions. This leads to the two-common end of life stages for plastics: landfill accumulation or incineration. This ultimately leads to an increase in CO_2 emissions each year per ton of plastic incinerated. Due to the negative environmental impacts associated with CO_2 emissions, countries with enough available land dispose of their plastic waste in landfills.

If proper plastic disposal is not an option, changing the way plastic is made may be the solution to minimizing environmental impact. As such, research has been performed in the area of biopolymers to incorporate sustainability practices into multiple parts of the life cycle.

Biopolymers are polymers that are produced from living organisms. Polymers are sequences of repeating monomers. Polymers can be developed from synthetic materials, like PET, or organic materials like biopolymers. There are three main ingredients found in cells that can be extracted to produce biopolymers: proteins, carbohydrates, and lipids.

Biopolymers void of synthetic additives are biodegradable. Biodegradation details the chemical degradation caused by environmental factors, such as UV radiation, that leads to the breakage of bonds and change in atomic structure. A material's affinity for biodegradation therefore lessens the environmental footprint for the end-of-life stage of plastics due to a decrease in landfill reliance and ocean accumulation. While the switch to biopolymers is better in relation to environmental impact, a detailed analysis of stress-strain curves and other thermomechanical properties can highlight where biopolymers must improve to become viable contenders in the world market.

The two main categories of biopolymers are defined by their structural foundations, where animal-based polymers typically focus on proteins and plant-based polymers focus on saccharides. In addition, plant-based polymers tend to require less energy and fewer resources for extraction than animal-based polymers. This makes plant-based polymers more attractive for research and long-term implementation.

When producing a biopolymer, factoring in the production location is vital. Arid countries do not have as much available water for crops, so a plant that requires minimal water is the optimal solution. This geographical condition shines light on cacti as a viable biopolymer resource. Cacti thrive in dry environments with warmer climates and don't require as much water compared to other plants. The ease with which cacti grow in the Americas makes them a readily available natural resource for polymer production (Esquivel, 2004).

The aim of this work is to study the effects of UV exposure on the physical-mechanical properties of cactus based biopolymer.

MATERIALS AND METHODS

Sample Preparation

Material was prepared using the following formulation: 60 % nopal juice, 20 % animal protein, 10 % natural wax and 10 % glycerin. With the material still in liquid form, eight (8) films of 12 in x 15 in were obtained with the gel casting technique, which were cut into strips for the tests.

These samples were intended for mass loss, thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR), dynamic mechanical analysis (DMA) testing in tension and Scanning Electron Microscopy. For each series of tests, specimens were cut from the same sheet to limit variability in composition and thicknesses. In addition, all specimens were cut from the first batch.

Q-UV Accelerated Weathering Tests

The degradation of the biopolymers was tested in a UV weathering chamber. UV irradiance was measured using an irradiance sensor at an irradiance of 0.89 W / (m^2 nm), according to ASTM D5208-14. Three 3 in x 1 in biopolymer strips were placed horizontally across the 2.5 in x 3.5 in openings. The samples were then placed in the UV aging machine and the lights were turned on. The specimens were rotated horizontally twice a week and vertically once a week to ensure even light distribution throughout the experiment. The specimens were exposed to UV irradiations and samples were obtained every week, with the last exposure lasting a total of four weeks.

RESULTS AND DISCUSSION

Mass Loss

The mass loss values after UV exposure indicated most of the mass loss occurred during the first week of exposure. The material experienced a mass loss of approximately 9 %. This mass loss is hypothesized to be water evaporation and is discussed in more detail when analyzing the TGA data.

A similar method of validation was reported by Quispe et al. (2019) for thermoplastic starch exposed to UV-A for a total of 264 h under experimental conditions similar to those discussed in this report. The study identified residual water content by performing thermogravimetric analysis. Like the trend observed for the cactus-based biopolymer, most of the mass loss observed pertaining to the thermoplastic starch specimens occurred during initial exposure. They recorded approximately 5 % mass loss during the first 48 h of exposure, with an approximate net change of 1 % from hour 48 to hour 264. The mass loss was validated by identifying initial degradation in the thermogravimetric data. Similarly, the mass loss observed for the cactus-based biopolymer was consistent with the initial degradation in the thermogravimetric data.

Thermogravimetric Analysis (TGA)

Thermogravimetric analysis was performed before and after UV exposure. Table 1 shows the data collected before and after UV exposure. The bulk of the mass loss occurred around 128 °C and 223 °C. The mass loss at 128 °C is most likely water evaporation, meaning that the degradation of the biopolymer itself occurs around 223 °C. The mass loss associated with water evaporation has changed by about ten percent, which is the same amount of mass loss recorded when looking at the UV data. When comparing pre and post UV degradation, the material stayed mostly consistent after UV exposure, only changing by a few degrees.

Table 1. TGA data.

WEEKS OF UV EXPOSURE	ONSET (°C)	2nd ONSET (°C)	% WEIGHT LOSS	RESIDUE (mg)
0	136.01	229.12	79 %	1.32
4	135.58	226.43	84 %	1.2

Differential Scanning Calorimetry

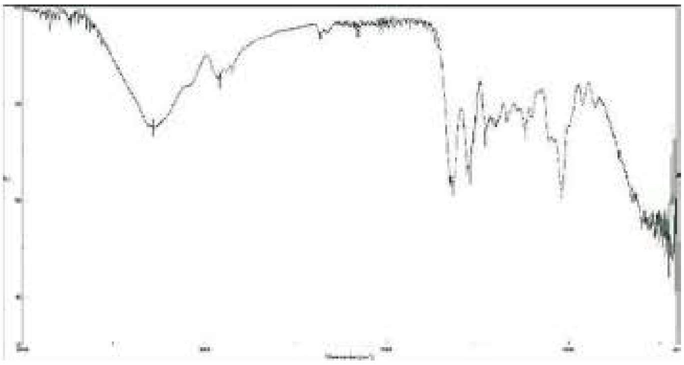
Once the degradation temperature was discovered through TGA, differential scanning calorimetry was performed to find the glass transition and melting temperature of the biopolymer. Table 2 shows the glass transition temperatures and melting points for each week of UV exposure. After four weeks of UV exposure, there was no noticeable change in the glass transition or melting point. This suggests that four weeks of UV light was not enough molecular agitation to change the Tg or glass transition.

Table 2. T_g and T_m at differing lengths of UV exposure.

WEEKS OF UV EXPOSURE	GLASS TRANSITION TEMPERATURE (°C)	2nd GLASS TRANSITION ONSET(°C)	MELTING ONSET (°C)	2nd MELT ONSET (°C)
0	43.42		56.31	
1	42.95		49.36	60.63
2	37.68		57.58	
3	38.05		51.39	62.5
4	43.61	45.2	50.62	62.18

Fourier Transform Infrared Spectroscopy

FTIR results revealed the presence of each component of the biopolymer. Figure 1 shows the FTIR spectra before UV exposure and after 4 weeks of UV exposure. By interpreting the wavenumbers at the peaks of the spectra it was possible to determine their content. Cactus juice is recognizable by the presence of OH bonds, which could be observed around 3280 cm^{-1}. The presence of amides could be observed around 1641 cm^{-1} and 1552 cm^{-1}, which are unique to animal protein. Natural waxes, which are composed of long fatty acids formed by hydrocarbons, are observed around 2900 cm^{-1}. These wavenumbers did not change even after four weeks of UV exposure. This suggests that the biopolymer did not degrade during the time in the accelerated UV aging machine.



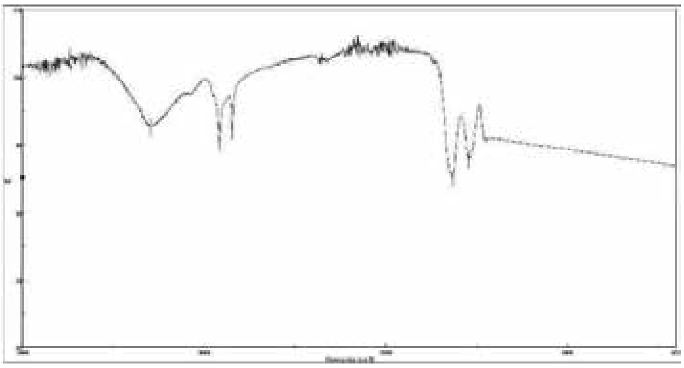


Figure 1. (a) FTIR Spectra pre-UV exposure and (b) FTIR Spectra post UV exposure.

The FTIR data shows a high number of hydrogen bonds. In that case, UV exposure would not provide enough molecular agitation to remove the water.

Dynamic Mechanical Analysis (DMA)

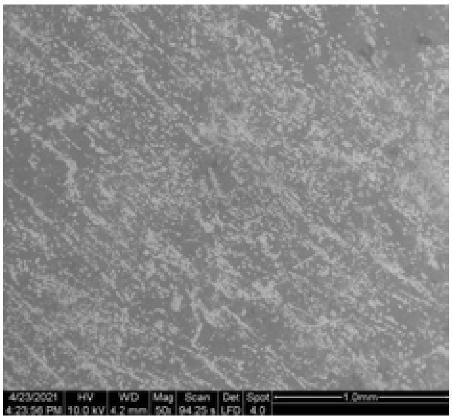
The DMA data is depicted in Table 3. The modulus values were taken after four weeks of UV exposure. It depicted an upward trend in the elastic modulus, which could be due to increased crosslinking between polymer chains, more specifically crosslinking or increased interactions between proteins due to the heat generated from the UV exposure (Mihalca et al., 2021). However, it is unreasonable to form any conclusions based off the DMA data alone since there were not enough data points collected.

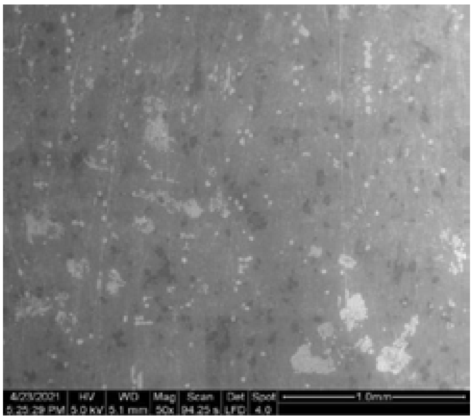
Table 3. DMA mechanical data before and after UV exposure.

WEEKS OF UV EXPOSURE	YOUNG'S MODULUS (MPA)	SECANT MODULUS (MPA)	TANGENT MODULUS (MPA)
0	0.296	0.087	0.033
4	0.519	0.185	0.092

Scanning Electron Microscopy

(a)





(b)

Figure 2. (a) Pre U.V. Exposure and (b) after four weeks of U.V. exposure.

Figure 2 shows the micrographs of the material before and after being exposed for four weeks to UV radiation. There are certain changes in the appearance of the material after being subjected to radiation, in this case it may be due to the loss of moisture in the material, since it cannot be assured that there was a certain degree of degradation in the short period of time according to the properties evaluated.

CONCLUSIONS

While a low percentage of mass loss was attributed to polymer degradation during testing, the thermo-mechanical properties didn't showcase the loss in terms of different thermo-mechanical properties. The mass loss may be too small for the equipment to detect any change in properties. Minimal degradation of the biopolymer was observed, save the water weight discussed. This indicates degradation of the polymer itself was minimal after approximately 672 h of UV exposure.

Based on the time constraints of this study, the main recommendation would be to increase the UV exposure period and collect more data within the first week of exposure. Additionally, it would be beneficial to see more standardization of the processing of the material to limit variability between sheets and the number of voids contained within it. If possible, testing other routes of degradation and comparing them in their rates and general effects on the properties would be beneficial.

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NOPAL POWDER

A FUNCTIONAL INGREDIENT FOR FOOD FORMULATIONS

INTRODUCTION

Young cladodes *(nopalitos)*, commonly consumed in countries such as Mexico, contribute to a healthy diet with dietary fiber, phenolic compounds, and minerals such as Ca, K, Mg among other nutrients (Hernández-Becerra et al., 2022; Perez Méndez et al., 2015; Hernández-Urbiola et al., 2010).

Dietary fiber intake is generally recommended to be close to 25 g/day, i.e., the US Department of Agriculture recommends 14 g per 1000 calories of food, that being 28 g for a 2000-calorie intake (U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2020). Many people in many countries do not eat enough fiber, therefore food enriched with fiber could improve these indices. Dietary fiber is known for several health benefits, such as weight control because it makes one feel full faster, it also helps digestion, and prevents constipation.

Natural ingredients with high fiber content are increasingly being sought to enrich food formulations. Therefore, an interesting alternative is *Opuntia* cladode powder, -a dry and concentrated ingredient, with low aw and good shelf-life- as an option for its addition in foods with the aim of increasing the intake of dietary fiber and minerals.

Some studies about the changes of bioactive compounds with the cladode's maturity stage help to select the best stage to have a more functional and nutritive powder to be included in food formulations (Beyá-Marshall et al., 2022; Rodríguez-García et al., 2007). Another important factor to preserve the functional characteristics of the powders is the drying conditions of the cladodes (temperature and time). Several authors had studied the process' conditions (Beyá-Marshall et al., 2022; Rodriguez-García et al., 2007; Di Bella et al., 2022; Boukid et al., 2015).

The *nopalitos* powder has been studied as a food ingredient in different foods, with good options for use by the food industry. Its nutritional and functional characteristics make it a sought-after ingredient for food fortification. In Mexico there are different brands and types of the typical *tortillas* and crunchy *tortillas* called *tostadas*, but most of them are made with fresh nopalitos: (i.e. https://www.senorcactus.com.mx/en/tortillas_nopal_320g/; https://tmnopal.com.mx/tortillas-de-nopal/) (Fig. 1) However, there are also a lot of recipes to prepare *tortillas* with *nopal* (mature cladodes) powder and all those products are gluten-free.

Figure 1. Some commercial products from the Mexican market made with fresh nopalitos.

The addition of cladode (young or mature) powder to different food formulations must pass some barriers to be used successfully. For example, the green color the powder adds when it is not expected, the negative change in viscosity in the case of liquid foods, and the herbaceous aftertaste in the aroma and flavor when high proportions are used, are some of the barriers.

CHEMICAL AND FUNCTIONAL CHARACTERISTICS OF NOPAL POWDERS

The dietary fiber content and the functional properties of cactus cladode powder has been reported and discussed by several authors, most of them used cladodes of one or more years old to add value to the waste of cactus pruning (Beyá-Marshall et al., 2022; Sáenz et al., 2012; Hernández-Urbiola et al., 2011; Rodríguez-García et al., 2007; Sepúlveda et al., 2013). One of the firsts papers published about dietary fiber content in cladode powder was that of Rosado and Díaz (1995) who reported a total dietary fiber (TDF) of 50.4 g 100 g^{-1}. Later, other authors, such as Sáenz et al. (2010) in cactus powder from mature cladodes (1-2 years-old), reported a TDF content of 42.99 g 100g^{-1}, and a ratio of insoluble fiber (IF) (28.45%) to soluble fiber (SF) (14.54%) of 2:1. *Nopalitos* powder is richest in soluble fiber (SF) compared with the oldest cladodes (Beyá-Marshall et al., 2022; Rodríguez-García et al., 2007), a valuable fiber, scarce in vegetables. Another important factor in preserving the functional characteristics of the powder is the drying conditions of the cladodes (temperature and time). Beyá-Marshall et al. (2022) selected a drying process at 40 °C in a forced air dehydrator until constant weight and the reported amounts of fiber are shown below. Rodriguez-García et al. (2007) used 40 °C in a vacuum oven and reported 55.09 g 100g^{-1} of total dietary fiber (TDF). Di Bella et al. (2022) in Sicilian fresh *nopalitos* of 30-50 cm length, dried used a solar drier for 5 days at 55 °C, reported a total dietary fiber content of 44.11–49.55 %, no details are shown about the soluble and insoluble fiber content. Boukid et al. (2015) also studied the drying temperature of cladodes in a convection oven, and they selected 60° C as the best temperature for drying.

Although cactus cladode powder (*Opuntia ficus-indica*) appears to be a good source of dietary fiber, the sensory characteristics of the powder, and its mucilage content, limit the addition of this ingredient to formulated foods. To reduce these negative characteristics, mainly the herbal flavor and the mucilaginous texture, other studies have been done. Sáenz et al. (2012) assayed different methods to purify dietary fiber from cactus pear cladodes, obtaining a product high in dietary fiber (IF=58.4–62.6 g 100g^{-1} and SF=18.7–24.7 g 100g^{-1}), with a color that was less green, but lower in total phenolic compounds compared with the powder without purification treatments, mainly because the purification methods apply water at higher temperatures. These results suggested that studies on this fiber concentrate should be continued with the aim of retaining the phenolic compounds present in the raw material. Chaloulos et al. (2023) dried 4-month-old cladodes without epidermis in an electric oven at 40 °C for 48 h, the dried cladodes were then ground. The dietary fiber of these powders was TDF (% d.b.) 51.02 ± 0.94, IDF (% d.b.) 42.08 ± 0.68, SDF (% d.b.) 8.94 ± 0.66, Insoluble: soluble dietary fiber ratio=1:4.7.

Other authors, continuing the search for natural ingredients especially high in soluble fiber, studied the effect of the maturity stages of cladodes in the chemical and functional composition of nopal powders, and some of them also studied different drying temperatures. Rodríguez-García et al. (2007) prepared cladode powders by drying the nopal slices of different maturity stages (60, 100, 150 and 200 g) in a vacuum oven (102 Torr, 40°C, 12 h). The authors reported that the soluble fiber (SF) decreased from 25.22 for nopalitos (60 g) to 14.91 g 100g^{-1} for nopal pads (200 g) while insoluble fiber (IF) increased from 29.87 to 41.65 g 100g^{-1}. The ash content increased from 18.41 to 23.24 g 100g^{-1}; calcium content increased from 1.52 to 3.72 g 100g^{-1}, while phosphorous exhibited an opposite trend: 0.43 to 0.27 g 100g^{-1}, respectively. Calcium oxalate decreased from 7.95 to 3.47 mg/g and the Ca/P ratio varied from 3.6 to 11. Beyá-Marshall et al. (2022) studied the effect of drying temperature (40 and 60 °C) on cactus cladodes of different stages of development (30, 60, 90, and 365 days) and reported that moisture, water activity and TDF did not show great difference between the drying temperatures or the age of the cladodes, with an average of IF=50 g 100g^{-1}, SF=10 g 100g^{-1} and TDF=60 g 100g^{-1}). However, when comparing the 30, 60 and 90 days with 365-day old cladodes (Table 1), there are differences among them in total dietary fiber content, the TDF being higher in the old cladodes (365 days) due to the increase of IF. The results showed that as harvest days increase there is a marked drop in total phenols and antioxidant capacity. The selection of temperature (40°C) and harvest age (30 days old) of the cladodes was proposed based on costs, greener color and increase in the number of harvests (new sprouting), as well as obtaining a powder with good antioxidant content (42,124 µmol Eq. Trolox 100 g^{-1}) and phenolic content (1,408 EAG/100 g^{-1}) characteristics. The powder from older cladodes (365 days) showed a phenolic content close to 500 EAG/100 g^{-1} and an antioxidant content close to 10,000 µmol Eq. Trolox 100 g^{-1}.

Table 1. Fiber content and bioactive properties of cladode powder

CLADODE AGE (DAYS)	DRYING TEMPERATURE (°C)	DIETARY FIBER (G/100 G)			POLYPHENOLS AND BIOACTIVE PROPERTIES	
		IF	SF	TDF	TOTAL PHENOLIC (MG EAG/100 G)	ANTIOXIDANT CAPACITY (MMOL EQ. TROLOX/100G)
IF	40	51±6c	10±1ab	61±6bc	1408±36b	42124±2276a
	60	53±3bc	8±3b	62±4b	1629±9a	33838±2112b
IF	40	43±1d	12±2a	55±2bc	785±9d	24524±973c
	60	32±2e	12±2a	44±3d	816±5c	24205±1697c
IF	40	43±3d	12±3a	55±0bc	622±2ef	18366±1315d
	60	42±3d	11±1ab	54±5c	630±7e	17602±397d
IF	40	59±2ab	11±1ab	71±0a	596±35f	11308±208e
	60	62±3a	10±1ab	71±4a	472±27g	9903±230e

Source: Beyá-Marshall et al. (2022). IF= Insoluble fiber; S.F.= Soluble fiber; TDF=Total dietary fiber

The difference in the results reported by the different authors in the dietary fiber content and the functional properties can be associated with the *Opuntia* species, climatic conditions, cladode age, crop management or type of cladode processing.

Studies on functional properties, such as water absorption capacity, oil absorption capacity, swelling, solubility, all useful in food formulation, mainly baked products, are less common. However, some authors have referred to them (Harrak, 2021; Boukid et al., 2015; López-Cervantes et al., 2011; El-Safy, 2013; Sepúlveda et al., 2013). The drying of young cladodes (*nopalitos*) at high temperatures affects the water absorption capacity and the green color negatively, the best temperature recommended to dry at is 60 °C (López-Cervantes et al., 2011). Then, temperatures between 40 and 60 °C are therefore recommended as the most suitable for drying cladodes and having a good fiber content in the powder.

With this data, the contribution of *nopalitos* and *nopales* (young and mature cladodes, respectively) as a source of dietary fiber is clear, but the interest in finding the most suitable and attractive way to use these powders in food formulations persists. Some examples are discussed below.

FOOD FORMULATIONS WITH CLADODE POWDER

A few commercial products made with cactus cladode powder have been available for some years now on the Mexican market, i.e., one of them is a breakfast product ("CactuFibra") which is prepared with wheat bran, nopal powder, milled flaxseed and sweetened with Splenda®. It contains no preservatives or artificial colorants and provides 46.5% of total dietary fiber, with a high content of calcium and β-carotene (Sáenz et al., 2006). Another product with nopal powder also available on the Mexican market is baked toast with nixtamalized corn flour, dehydrated nopal powder (2%), salt, guar gum, xanthan gum (Fig. 2).

As far as we know, commercial products incorporating nopal powder are not very abundant, which is why studies continue to gather data and information that can be used by small farmers, small entrepreneurs, or other actors to launch new products with this valuable natural ingredient on the market.

Among the studies about the addition of nopal powder in foods are those with biscuits, sponge cake, gluten-free crackers, rolled cakes, oat biscuits, gelled dessert, and extruded products (Sáenz et al., 2006; Boukid et al. (2015); Dick et al., 2020; Achondo-Trejo et al., 2020). In general, the proportion of nopal powder included in the formulations is limited by the effect of its sensory characteristics; any addition greater than 20-25% affects the texture, taste and aroma of the foods and its acceptance rate due to its herbaceous flavor (de Wit et al., 2015; Sepúlveda et al., 2013).

One exception to this is that reported by Boukid et al. (2015) who prepared a butter cream rolled cake with cladode powder (dried at 60 °C). The formulation included flour, sugar, eggs, and butter cream (butter+sugar). The cake was prepared by including cladode powders in wheat flour (0, 10, 20 and 30 %). Sensory analyses showed that the 30% rolled cake had significantly higher scores for all attributes than the other formulations including the control cake. The addition of cladode powder in rolled cake significantly influenced the taste, flavor, color and overall acceptability results, an addition of 30% being the most preferred. Dick et al. (2020) reported a formulation of gluten-free crackers with different additions of cladode mucilage and cladode powder from *Opuntia monocantha*. They tested 5, 10 and 15% addition of cladode powder. All the formulations showed higher total phenolic content and antioxidant activity compared with a control with commercial gum, 5% of cactus powder addition being the most preferred cracker. In this respect, they confirmed that reported by Sepúlveda et al. (2013) that taste, and aroma of foods formulated with cladode flour can be negatively impacted by its higher proportion of addition, due to its herbaceous flavor.

Figure 2. Some commercial products from the Mexican market made with nopal powder. https://www.missionfoods.com.mx/productos/tostadas/tostadas-horneadas/mission-tostadas-nopal-224g/

El-Safy (2015) prepared sponge cakes with 5, 10, 15 and 20 % addition of cladode powder, the other ingredients were flour, eggs, sugar, salt, baking powder, vanilla, and some lemon juice. The acceptability rate decreased when the addition of the cladode powder increases (taste, texture, and color) close to 10-15 % addition being acceptable; but the best formulation was with 5% cladode powder. Moreover, also in baked products, Ayadi et al. (2009) and Kim et al. (2012) reported that cladode powder could not be added in at more than 5% and 9% levels, in sponge cakes and cakes, respectively. De Wit et al (2015) reported that in a carrot cake up to 25% cladodes powder can be included, and in seed bread up to 17%, could be carrot and seed mask the herbaceous taste in both products. De Wit et al. (2015) in crunchy oats biscuits reported that the most liked was that with 10 % cladodes powder inclusion. Sáenz et al. (2002) tested 15%, 20% and 25% nopal powder addition in oatmeal cookies, where those with an addition of 15% was the most sensorially accepted. The main limitations were the herbaceous taste as well as the mucilaginous sensation when tasted. However, this biscuit showed an increase of dietary fiber close to 43% more compared with a control. A daily intake of 3 cookies would be enough to cover 6% of the recommended daily intake of dietary fiber. Nabil et al. (2020) reported in a study about whole-wheat flour biscuits with an addition at different proportions of cladode powder 25%, 50%, 75%, and 100%, where acceptability (5-point hedonic scale) was 2.7 for biscuits at 25% level not differing from the control. However, for a greater addition of powder (75% and 100%), the acceptability was low, due to the strong taste and aroma of cladode powder. Taste and color are the most recommended attributes to be improved according to panelists' suggestions. Msaddak et al. (2017) prepared bread with different proportions of cladode powder: 2.5, 5.0, 7.5 and 10.0 g per 100 g wheat flour. The results showed, as in other foods, that the increase of cladode powder addition decreased the sensory attributes. At 10% addition the bread texture, and taste were not acceptable. Another parameter that changes is color, being acceptable at 5% addition, while it decreased at the highest addition. Likewise, the results showed that replacing at 5% improved the total phenolics content and the bread's antioxidant activity compared with a control. Recently, Angor et al. (2023) reported the addition of cladode powder (3, 5 and 7 %) in plain chocolates observing a decrease of the fat content and oxidative degradation, there being no differences among the treatments in the overall acceptability; however, the texture and appearance with the higher addition (7%) showed the lowest scores. Chaloulos et al. (2023) studied the cladode powder incorporation in a soup model, to partially substitute the corn starch, including as other ingredients (% w/w): skim milk powder 2.5, sunflower oil 2, vinegar 2, salt 0.9, onion powder 0.1, garlic powder 0.1, sugar 0.1, pepper 0.1, water 89.2. They tested addition of cladode powder between 1-10 % w/w and observed that full substitution of corn starch by the same amount of cladode powder would result in an inferior final product in terms of texture. It is not easy to adjust these replacements mainly in liquid formulations, as the mucilage present in the powder at higher concentrations gives it a viscosity that is not accepted (Sáenz et al., 2006).

Extrusion technology is another process that has been tested in foods containing cladode powder. Extrusion has been widely used in the production of cereal-based snacks with a variety of textures and shapes, and some authors have explored this versatile but expensive technology that not everyone has access to. For this purpose, they have suggested concentrations of 4 to 15 % nopal powder for this kind of product. Martínez (2011) used nopal powder in different amounts, for the development of an extruded cereal with corn flour and malt extract, obtaining the best sensory results with a concentration of 10.5%. Likewise, Achondo-Trejo et al. (2020) studied the development of a snack using nopal powder, native Mexican rice starch, extrusion-modified rice starch and xanthan gum. Results indicated that the greatest expansion occurred with intermediate concentrations of nopal powder (5%) and without xanthan gum.

CONCLUSIONS

In conclusion, the use of *nopalitos* or *nopal* powder as a natural ingredient in foods leads us to be optimistic about its future use. As the number of studies has been increasing over the years, efforts to achieve results that offer attractive foods to consumers will undoubtedly bear fruit. Foods with a good balance between nutritional value and sensory quality is the goal to reach.

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INTERVENTIONS

IN THE VISCOSITY OF *OPUNTIA* MUCILAGE BY MEANS OF THE ALTERATION OF ITS IONIC ENVIRONMENT

INTRODUCTION

Mucilage from *Opuntia* spp. has been reported to have the potential for use as a functional ingredient in the food industry (Medina-Torres et al., 2000; Sáenz et al., 2004). This reported potential is inferred from the physical characteristics of mucilage in solution, which is a result of its chemical properties. These properties arise from mucilage being a negatively charged polysaccharide that interacts strongly with calcium ions (Trachtenberg and Mayer, 1980, 1981; Medina-Torres et al., 2000).

It has been established that the functional, rheological properties of charged molecules such as mucilage are highly dependent on the ionic strength of a solution. It has also been demonstrated that when the ion concentration of a mucilage solution is decreased, an increase can be observed in viscosity, and when the concentration of ions is increased, the viscosity is reduced (Medina-Torres et al., 2000). This effect is ascribed to the expansion of the molecule due to intermolecular repulsion from exposed charges where the ion concentration is low, and the reduction of this expansion by the addition of calcium molecules (Medina-Torres et al., 2000).

It is also known that low-methoxylated pectin, which contains the same charged sugar that is present in *Opuntia* mucilage, galacturonic acid, is known to form gels (Fraeye et al., 2010). This process relies on a complicated mechanism which is not induced by electrostatic interaction alone (Fraeye et al., 2010). The strength of the gel is influenced by the availability of calcium (Fraeye et al., 2010). Mucilage does not have a demonstrated ability to form gels like pectin does (Medina-Torres et al., 2000). However, it has structural similarities to pectin, and it is possible that similar effects might occur in mucilage, which might also affect its viscosity, should the potential to form such interactions arise.

Understanding the way in which ions affect mucilage viscosity and finding ways to regulate and control it would provide greater insight into the roles in which mucilage can function in the food industry, and how it can be optimised in those roles. This would also provide manufacturers who want to use mucilage with a greater understanding of how the texture and viscosity will change in different food formulations. To explore this, an investigation into how the regulation of the concentration of calcium ions present in solutions of reconstituted freeze-dried mucilage from *Opuntia robusta* cultivar Robusta and *Opuntia ficus-indica* (L) Mill. cultivars Algerian and Morado was undertaken.

It examined how the addition of different chelating agents, which lowers the available ion concentration of the solution, affected the physical properties of the mucilage, specifically its impact on viscosity, providing more information which can assist in the industrial use of mucilage.

MATERIALS AND METHODS

Mucilage from *Opuntia robusta* cultivar Robusta, and *Opuntia ficus-indica* (L.) Mill. cultivars Morado and Algerian was extracted as per a patented extraction method (Du Toit and De Wit, 2011). The extracted mucilage was then freeze-dried and powdered, before being reconstituted in 5% w/w solutions. The reconstituted mucilage solutions then had 1% of the mass of the mucilage in chelating agents added and allowed to stand for 30 minutes at room temperature, after which the viscosity was measured. Five agents with chelating effects were used, namely creatine, sodium hexametaphosphate, citric acid monohydrate, EDTA (Ethylenediaminetetraacetic acid), and tartaric acid. Next, calcium was added (as calcium chloride) at 30% w/w of the freeze-dried mucilage, and these samples were then allowed to stand a further 30 minutes at room temperature before undergoing rheological testing. Rheology was measured using a Brookfield DV3T extra rheometer, with an AMETEK SC4-21 spindle, and the associated Rheocalc software. An abbreviated version of this method is presented in Figure 1.

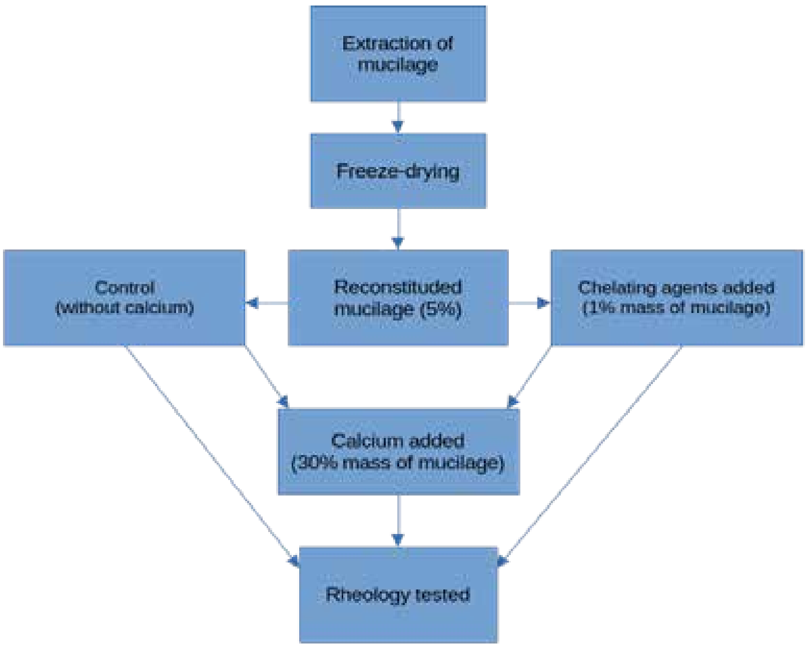

Figure 1. The abbreviated methodology of the experiment.

RESULTS AND DISCUSSION

The results are presented in Figures 2-4 and Table 1. Different chelating agents had different effects in altering the rheology of mucilage and did so to different degrees. In the case of the *Opuntia ficus-indica* cultivars, the least effective chelating agent was citric acid in both cases, and the most effective was sodium hexametaphosphate and EDTA in Algerian and Morado, respectively. However, the apparent viscosity in Morado was below the control viscosity in all cases except for the sample containing EDTA, and all were within one standard deviation of the control regardless. In Algerian, the rheology of the test samples was above that of the control and all but one, citric acid, outside of one standard deviation.

In *Opuntia robusta* cultivar Robusta, the effect was akin to that of the Algerian cultivar of *Opuntia ficus-indica*, but more pronounced.

As shown in Table 1, in all tested cultivars the apparent viscosity decreased when calcium was added to the control sample, which is behaviour expected from negatively charged polyelectrolytes (Medina-Torres et al., 2000). However, in several samples that had chelating agents added, the average values of the viscosity increased. The addition of chelating agents leading to a viscosity increase matches the expectations set out in the principles as stated by Medina-Torres et al. (2000), as the chelating agents are expected to have decreased the availability of ions in solution. However, when the calcium was added in the second step, the viscosity did not decrease in certain samples where chelating agents were added, especially in *Opuntia robusta* cultivar Robusta and *Opuntia ficus-indica* cultivar Algerian, where the opposite occurs in some samples. Figure 5 lists the chelating agents which affected samples to create the highest and lowest viscosity, respectively.

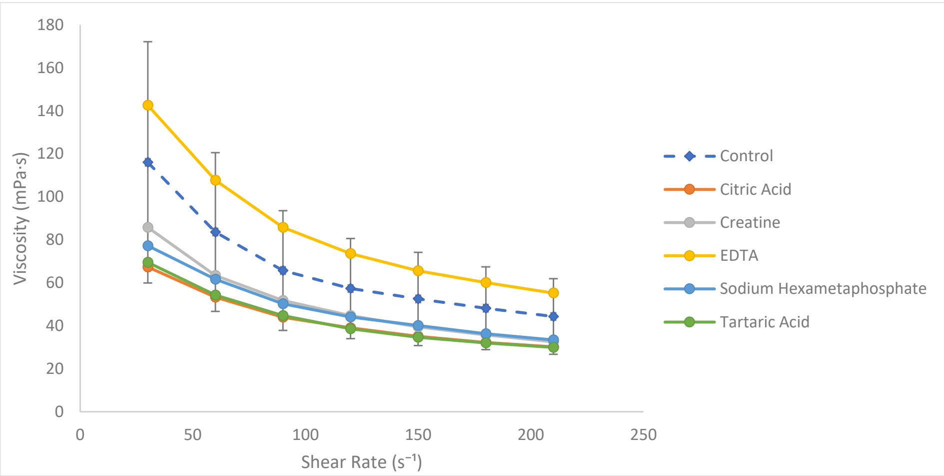

Figure 2. The apparent viscosity of Opuntia ficus-indica (L.) Mill. Cultivar Morado, Reconstituted freeze-dried mucilage, under effect of different chelating agents and with added calcium

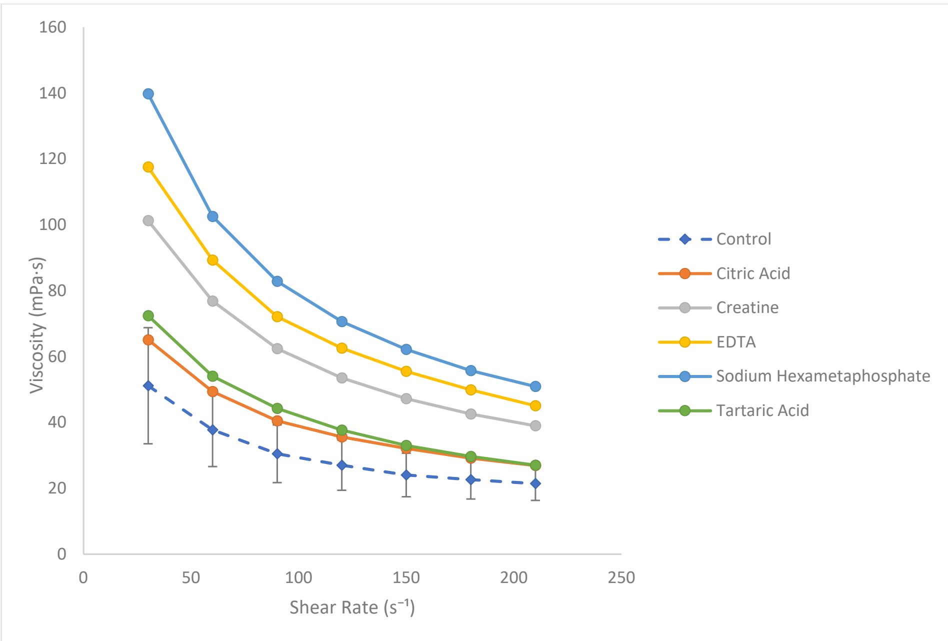

Figure 3. The apparent viscosity of Opuntia ficus-indica (L.) Mill. Cultivar Algerian, Reconstituted freeze-dried mucilage, under effect of different chelating agents and with added calcium

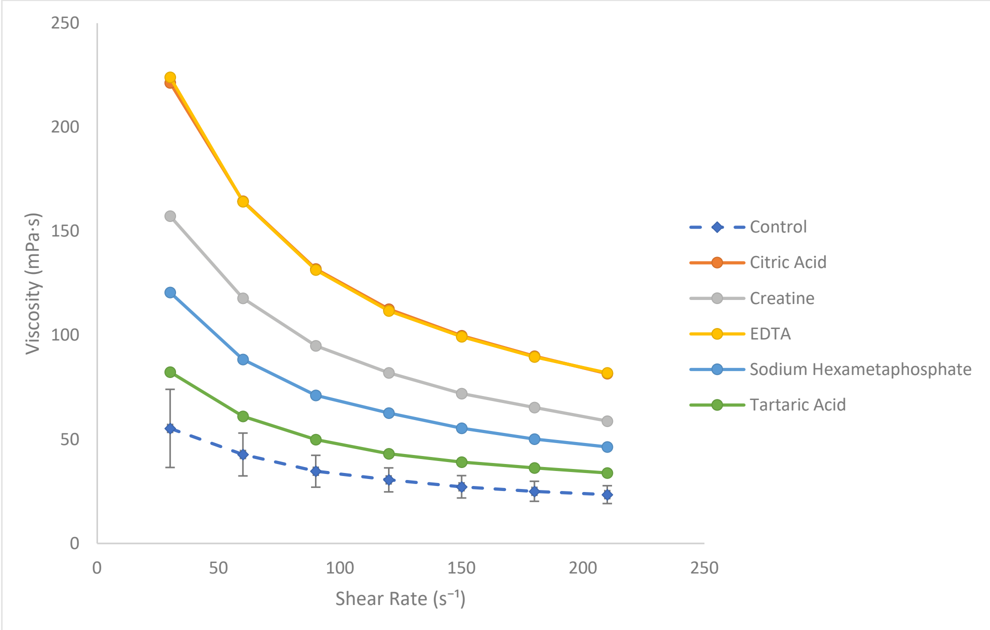

Figure 4. The apparent viscosity of Opuntia robusta cultivar Robusta reconstituted freeze-dried mucilage, under effect of different chelating agents and with added calcium

These results suggest that a more complex mechanism might be present than the simple reduction of available calcium but the chelating agents. The addition of calcium resulting in an increase in viscosity in some samples, suggests that there is a change in the interactions between molecules after the chelating agent was added, which might be in line with the effect seen in pectin, explaining the increase in viscosity. Further research may also be needed to find optimal chelating agent levels for this effect. The composition of the mucilage extracted from different cultivars may also further affect the outcomes.

Table 1. The rheological parameters at first measured value of reconstituted freeze-dried mucilage across all samples

	APPARENT VISCOSITY WITHOUT CALCIUM (MPA·S) (MORADO)	APPARENT VISCOSITY WITH CALCIUM (MPA·S) (MORADO)	APPARENT VISCOSITY WITHOUT CALCIUM (MPA·S) (ALGERIAN)	APPARENT VISCOSITY WITH CALCIUM (MPA·S) (ALGERIAN)	APPARENT VISCOSITY WITHOUT CALCIUM (MPA·S) (ROBUSTA)	APPARENT VISCOSITY WITH CALCIUM (MPA·S) (ROBUSTA)
CONTROL	194.85 ± 53.03	116.02 ± 56.12	79.22 ± 12.26	51.15 ± 17.63	71.56 ± 22.93	55.28 ± 18.77
CITRIC ACID	178.27 ± 52.22	67.33 ± 26.01	98.95 ±20.89	65.1 ± 24.74	165.58 ± 23.26	221.4 ± 73.11
CREATINE	83.44 ± 36.42	85.77 ± 13.43	94.79 ± 15.50	101.28 ± 30.68	52.44 ± 4.94	157.33 ± 29.94
EDTA	104.11 ± 26.38	142.59 ± 36.43	70.53 ± 3.89	117.53 ± 44.68	184.73 ± 35.81	224.02 ± 80.24
SODIUM HEXAMETA-PHOSPHATE	94.55 ± 15.81	77.24 ± 20.87	139.26 ± 46.43	139.78 ± 41.31	122.47 ± 6.77	120.64 ± 28.98
TARTARIC ACID	86.03 ± 28.03	69.49 ± 14.58	89.63 ± 54.09	72.41 ± 32.84	186.27 ± 19	82.4 ± 76.23

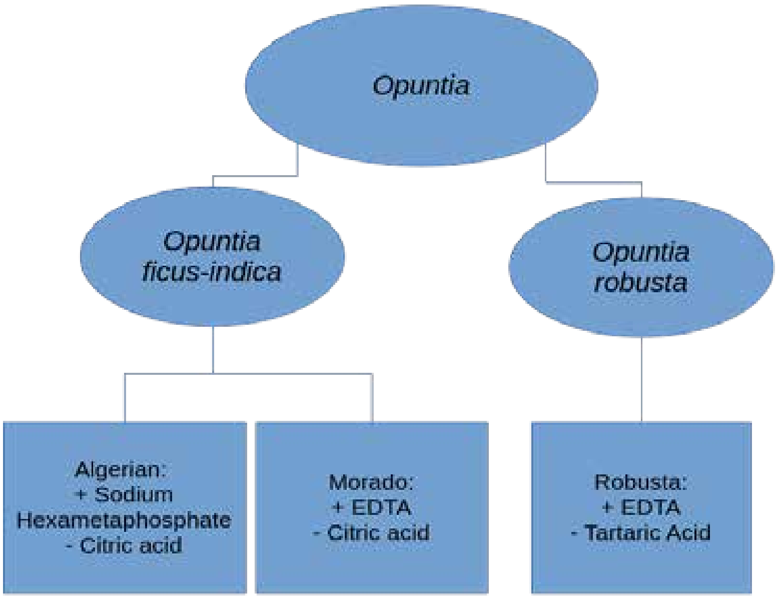

Figure 5. The different cultivars of Opuntia with the chelating agents resulting in the highest and lowest viscosity indicated. "+": Highest viscosity; "-": Lowest viscosity

CONCLUSION

The results from this experiment demonstrate that there is potential for the examined process to alter mucilage rheology in a way which might have beneficial applications. This demonstrates that the regulation of calcium and the changing in the ionic environment of mucilage can affect the properties thereof, and suggests that this can be controlled, which may be useful in industrial processes.

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MEXICO'S SUSTAINABLE MIRACLE:
UNVEILING THE WONDERS OF NOPALES

INTRODUCTION

Nopales have been in Mexico since before the country was called Mexico. The importance of *Opuntia ficus-indica* in our home country can't be understated. The Aztecs received a message from the gods that they should build their city wherever they saw an Eagle devouring a serpent over a nopal plant. They found the spot and started to build what would later become the epicenter of the powerful Aztec empire. This place is now known as Mexico City. This scene is so symbolic that it secured a privileged spot as the coat of arms in the Mexican flag (Picture 1).

Covarrubias A., (2006) Based on the arms by Juan Manuel Gabino Villascán. - Mexican Government, Public Domain, https://commons.wikimedia.org/w/index.php?curid=374591

Opuntia ficus-indica can be seen almost anywhere in their native country. They are a notorious part of the nation's culture, cuisine, and history. *Nopales* have been used in Mexican folk medicine for centuries. Today, treating type 2 diabetes with *nopales* is a traditional Mexican remedy. *Nopales*, or prickly pear cactus, help reduce blood sugar levels (Lopez-Romero et al., 2014) and soften insulin peaks, making them an essential part of a diabetic patient's life.

Nopalitos, the young tender pads, are celebrated for their unique texture and flavor profile, making them a versatile addition to a variety of dishes. They can be incorporated into salads, soups, stews, and even grilled as a side dish. In Mexico, it is not uncommon to eat *nopalitos* tacos in a street cart or in a high-end award-winning restaurant. This teaches us something: *nopales* are for everyone.

Although widely popular in their country of origin, they are still relatively unheard-of in the mainstream market in most parts of the world. Whenever we travel to international trade shows and events and talk about our *nopales* business, the inevitable question we always get at least twice a day is "You mean you can actually eat cactus?"

Not only *can* you eat cactus; but you *should*.

It is estimated that per capita consumption in Mexico of fresh nopalitos is only around 6.4 kg per year (SADER, 2020). Eating *nopales* as a fresh vegetable is the standard practice in the country. It is the easiest and most popular way to try it. However, its thorns, a short shelf-life, a costly cold chain, and limited market awareness may confine the crop's international growth and expansion potential.

As climate change starts to present its effects in everyday life, finding sustainable crops and foods has become nothing short of urgent. *Nopales*' adaptation to arid environments, efficient water use, and carbon-sequestering abilities (Hailu, 2020) make them a viable option for environmentally-friendly food around the world. Aside from providing food security, they have been gaining popularity as a sustainable and green resource. Over the years, the market for cactus products has expanded, showcasing a wide array of applications ranging from culinary delights to skincare essentials.

CACTUS PRODUCTS

The diverse range of cactus products available in the market today reflects the remarkable versatility and sustainability of these desert plants. From *nopales* snacks to cactus seed oil, each product undergoes unique processing techniques to harness the natural goodness of cacti. Moreover, scientific studies continue to shed light on the numerous health benefits and applications of cactus-derived products, further solidifying their place for the modern consumer.

Dehydrated cactus strips

Health-conscious individuals are drawn to dehydrated cactus pear pad snacks because they offer a long lasting alternative to unhealthy munching while also providing essential nutrients. These dried *nopales* can be seasoned according to consumers' wants and preferences. For instance, adding chili and lime, something quite common for Mexican products, can appeal to individuals who already enjoy exotic fruit jerky (Picture 2).

Photo: Courtesy of Grupo Nopalero Mexicano XO, S.A. de C.V., by Martínez M. (2017)

With their high dietary fiber content, dehydrated *nopales* promote a healthy regular digestion. Consumers are left feeling full, making *nopales* a guilt-free choice for those watching their weight. Moreover these snacks are naturally low in calories and fat, making them ideal for individuals who want to maintain a diet without sacrificing taste. The popularity of *nopales* in the health snack market is further enhanced by the clean label trend. Their unique flavor coupled with their nourishing benefits, positions dehydrated *nopales* as an appealing and innovative option for healthy snack enthusiasts seeking a flavorful treat without any regrets.

Cactus Water

Cactus water is a relatively new trend in the beverage industry. It is derived from the cactus pear fruit and its hydrating properties are highly marketed. The processing technique involves harvesting fruits and extracting their juice. Cactus water is low in calories, contains essential vitamins and minerals, and scientific research has shown that it contains potent antioxidants and anti-inflammatory benefits (Shoemaker, 2020).

Cactus Seed Oil

Cactus seed oil, also known as prickly pear seed oil, is extracted from the seeds of the *tuna* (cactus pear fruit), or *nopales* fruit. The processing method involves carefully collecting and drying the seeds before cold-pressing them to obtain the precious oil. The oil is praised for its exceptional skin-nourishing properties. It is rich in essential fatty acids, including linoleic acid, which has anti-inflammatory properties. (Boelsma et al., 2001) The high concentration of this compound in the oil helps quickly permeate the different layers of the skin, provoking cell renewal. Oleic and stearic acid moisturize the dermis and promote collagen production while the palmitic acid prevents wrinkles. Once the oil is absorbed, it helps trap free radicals and reduces redness, putting into action its potent anti-aging properties. (Ciriminna et al., 2017).

From a marketing standpoint, cactus seed oil is an excellent choice for products targeting dry and sensitive skin. Cactus pear's natural ability to thrive in arid environments can equal to effective hydration, making *nopales* an optimal ingredient choice for cosmetic and skin care products.

Cactus Powder

Nopal cactus powder is a fine pulverized version of cactus pads. It can be used as a functional ingredient in food and beverages. Nopal-based juices and smoothies have gained popularity as they are refreshing, packed with antioxidants, and keep consumers feeling full as they bring in much-needed fiber. This product is especially useful for diabetics, because of the blood sugar-controlling properties *Opuntias* possess.

Nopal powder can be used as a raw material in bakery and snack goods as well. Partially substituting corn, wheat, almond or any other flour with cactus powder is the most common way to add *nopales* into everyday products. Bread, cookies, tortillas, tortilla chips and pasta are only some of the many products that can be enhanced with this pulverized goodness. For *nopal* cactus powders that claim to be 100% purely made of *nopales*, calories should be minimal and fiber content should be high. (Picture 3)

Nutrition Facts

About 10 servings per container
Serving Size 1Tbsp (10g)

Amount per serving	
Calories	**4**
	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 0mg	0%
Total Carbohydrate 6g	2%
Dietary Fiber 5g	20%
Total Sugars 1g	
Includes 0g Added Sugars	0%
Protein 1g	
Vitamin D 0g	0%
Calcium 830mg	83%
Iron 1mg	3%
Potassium 210mg	6%

The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Photo: Courtesy of LGI Foods Inc (2023)

As consumer preferences continue their rapid shift toward natural, healthy, and Earth-friendly options, *nopales* will likely become a prominent and sought-after ingredient across food, beverage and many other industries.

CHOOSING CACTUS CONSCIOUSLY

As more companies jump on the *nopales* trend, there is a risk of some merely capitalizing on the cactus's up-and-coming name and reputation to boost sales, without truly incorporating the plant or its health benefits into their final goods. Consumers should be wary of products that only feature the name "*nopales*" on their packaging without providing substantial evidence of the cactus's presence inside.

Consumers should pay attention to the order when reading the ingredient list. If *nopales* are one of the first components listed, the product can most certainly guarantee a genuine presence of *nopales* inside.

Some food companies use minimal amounts of *nopales* or rely on processed extracts, starches or additives that dilute the wholesome properties of the mighty cactus in order to lower the price and thus the quality. In such cases, the actual fiber content and other nutritional benefits of *nopales* might not be as significant as expected, potentially leading to deceptive marketing practices and disappointing results for *nopales* aficionados or health-conscious buyers.

When reviewing food and beverage products that claim cactus pear as one of their ingredients, the fiber content should have a notorious presence since this is *nopales*' staple nutrient. The calcium, potassium and magnesium contents should also be significant.
Therefore, consumers must be vigilant and discerning, ensuring that they choose products from reputable companies committed to transparency and genuinely harnessing the health benefits of *nopales* in their offerings. This scrutiny will enable consumers to make informed choices and fully enjoy the nutritional advantages that *nopales* have to offer.

NOPALES' POTENTIAL

The *nopales* industry holds immense potential for the next 20 years as the demand for sustainable and health-oriented products continues to grow. This surge can be attributed to the increasing awareness of the cactus's nutritional benefits, coupled with the rising popularity of plant-based diets and natural ingredients in various industries.

For companies looking to expand their product portfolio and tap into the healthy, clean-label market, shifting into *nopales* as an ingredient presents a promising opportunity. Food manufacturers can explore incorporating dehydrated *nopales* into their snack lines, cereal bars, and even plant-based munchies and bakery goods, offering customers a nutritious twist to their favorite treats. Beauty brands can venture into *nopales*-infused skincare products, capitalizing on the cactus's hydrating and antioxidant properties to appeal to eco-conscious consumers seeking natural and sustainable beauty solutions.

By embracing *nopales* as a valuable ingredient, companies can position themselves as pioneers in the health and wellness industry, aligning with current consumer trends and securing a competitive edge in the market.

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Photo: Courtesy of Grupo Nopalero Mexicano XO, SA de CV, by Martínez M. (2017)

Photo: Courtesy of LGI Foods Inc (2023)

Eng. Abderrahmane AIT HAMOU
Cactus Premium sarl
Morocco

THE INTERNATIONAL
ITINERANT UNIVERSITY OF CACTUS PEAR (IIUCP)

INTRODUCTION

Background : Idea and objectives

The IIUCP was initiated on November 5th , 2006 between Argentinian researchers from the National University of Santiago del Estero and several cooperative presidents, university researchers, and farmers from Marocco. Visits to some universities, research centers, women's cooperatives, and orchards lead to the idea of the International Itinerant University of Cactus Pear (IIUCP).

The following objectives had been defined for the IIUCP:

- Exchange of knowledge between participating universities, producers, and processors of the cactus pear
- Identify and meet the needs of farmers in terms of new technologies
- Raising consumer awareness of the nutraceutical virtues of cactus pear with the aim of contributing to the improvement of public health
- Raise public awareness on the environmental interest of cactus pear
- Transfer knowledge and new ideas for good management of good agricultural practices in cactus plantations.
- Promote technical cooperation between participating universities and research centers
- Tourist and cultural visits to explore the cultural peculiarities of the organizing country

THE FIRST EDITION:

Morocco from 06 to 11 November 2006
Participating countries: Morocco, Argentina, and Tunisia

During this first edition, more than 1200 km were traveled (Map 1). The participating countries were Argentina, Morocco and partly Tunisia. The edition program was marked by:

- The study day organized at the Hassan I University of Settat in collaboration with the Regional Center for Agronomic Research. The theme chosen for this day was the role of cacti in human development.
- In a semi-arid region (center of Morocco), visits to some farms revealed the importance of the cactus pear as animal fodder, especially during the dry seasons.
- Around Marrakech, the visit of a forest estate aimed to observe the role of the cactus pear in the preservation of biodiversity. This plant provides the necessary fodder for the herds of the Dorcas gazelle, recently introduced to the region.
- In Marrakech, Cadi Ayad University organized a round table discussion during which Moroccan experts discussed with their Argentinian

counterparts the state of cactus research in their respective universities. The round table ended with a visit to research laboratories and an agreement to strengthen scientific cooperation between Cadi Ayad University and the National University of Santiago del Estero.

- In Agadir, the participants were received by the Regional Center for Agronomic Research. Conferences and field visits were organized.

Map 1. Itinerary of the First UNIC

This first edition was also marked by:

- The official dinner offered on the evening of November 6th by His Excellency the Governor of the Province of Kelaa Sraghna in honor of the Guests. During this dinner, the Governor underlined the interest of the authorities to the cultivation of cactus.
- The sightseeing tour of the cities of Marrakech, Agadir, Essaouira, Safi, Oualidia and El-Jadida.

From left to right: Dra J.Ochoa , Eng. A. Aithamou , Late Dr S. Uhart , Dra M. Nazareno

Dra M. Nazareno and Dra J. Ochoa visiting a pilot farm where cactus pear is integrated with sheep farming

THE SECOND EDITION:

Morocco 03 to 06 October 2011 Participating countries: Morocco, Mexico, and Algeria

The second edition was organized in the cities of Casablanca, Skhours Rehamna, Marrakech and Kelaa-Sraghna (Map 2)

In addition to Moroccan researchers, the experts who facilitated the activities were:

- Dr. Liberato Portillo, from the University of Guadalajara, Professor-researcher who was then Group coordinator of the FAO-ICARDA-CactusNet Network,
- Dr. Ana Lilia Vigueras from the University of Guadalajara, expert researcher in the valorization of cactus products (carmine),

- Dr. Ana Núñez Carrasco from the Center for Research and Assistance in Technology and Design of the State of Jalisco,
- Dr Gabriela Arroyo, biotechnologist at the University of Guadalajara,
- Pr Brahim Kamal Louacini (University of Tiaret, Algeria).

Map 2. Second IICP Itinerary

The program for this second edition was very informative and diversified:

- Casablanca: In this largest Moroccan metropolis, the activities planned have targeted consumers to raise awareness of the nutritional and cosmetic benefits of the cactus.
- After a conference (Dr. L. Portillo), a practical workshop (Dr. A.L. Vigueras) allowed participants to get to know the different uses of cacti (figs and rackets) in gastronomy.
- In a cosmetic workshop, Dr. G. Arroyo gave a hands-on demonstration of making natural cochineal lipstick.
- Skhours des Rehamna: After visiting the orchards of the region, a soap-making workshop was organized for the benefit of 20 women members of a cactus pear cooperative.
- Marrakech: Likewise, to the first edition, Cadi Ayad University organized a study day. Several conferences were given by Mexican and Moroccan experts.
- Kelaa Sraghna: the IIUCP Second Edition had been closed, at the *Environmental Education Club*, after a special workshop for the benefit of schoolchildren. The latter have been sensitized to the environmental interests of cactus pear.

THE THIRD EDITION:

Mexico September 13 to 23, 2019 Participating countries: Mexico, Morocco, Argentina, USA, Algeria, Peru, Ethiopia

During this third and big Edition, more than 2000 km were covered across the states of Jalisco, Guanajuato, San Luis Potosi, Michoacán, Puebla and Hidalgo (Map 3). In each of the states many activities were held: official receptions, conferences, round table discussions, exhibitions, field visits, tastings of cactus products, tourist tours and artistic evenings. For more detail on the program of this edition see the useful link n°1.

Map 3. Itinerary of the Third IIUCP - Mexico

One of the highlights of this edition was the proclamation, proposed by Engineer A. AIT HAMOU (Morocco), of the World Cactus Day. The proposed date was September 18th , which coincides with the National Nopal Day in Mexico - the country where the cactus is emblematic!

September 18, as World Cactus Day, was one of the important recommendations of the Third Edition of the IIUNC

Mobile round table inside Rancho Las Papas

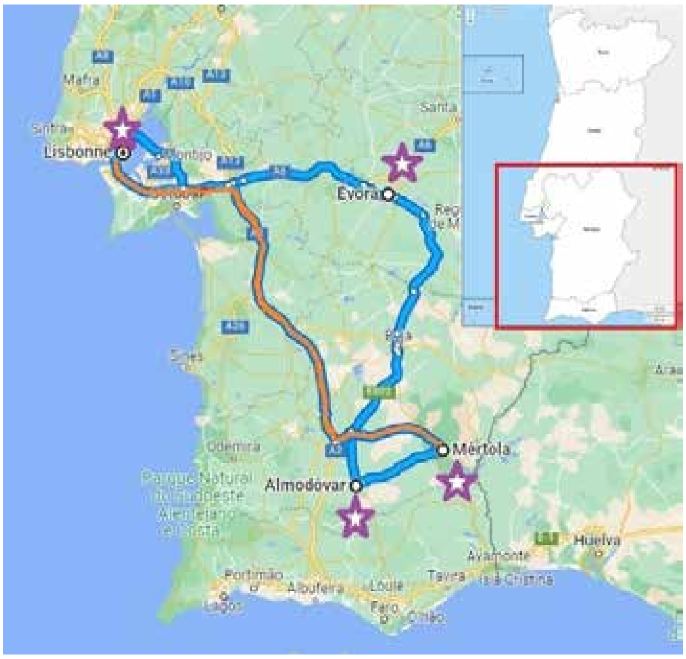
Delivery of Certificates to Participants

THE FOURTH EDITION:

Portugal 14 to 18 September 2022 Participating countries: Argentina, Chile, Egypt, France, Mexico, Morocco, Portugal, Spain, Turkey, UK, and USA

Eleven countries were represented in this Edition. Although the duration of the event was limited to 5 days, the activities carried out were numerous, rich and diversified. Main visited cities were Lisbon, Évora, Almodôvar and Mértola (Map 4). The detailed program of this edition is summarized in Table 1.

According to official data, released by the Ministry of Agriculture, the area occupied by cactus pear in Portugal exceeds 1000 hectares.



Map 4. Itinerary of the Fourth IIUCP - Portugal

Other sources suggest that this figure is estimated to be more than 2000 hectares because the areas are constantly expanding due to the attention paid by Portuguese farmers to this crop. This interest explains why more than 90% of the farms are certified organic. The *Confraria do Figo da Índia* (a national Association) has published an excellent map representing Portuguese producers and processors (see the useful link n° 2).

The valorization of cactus pear is noticeably developed in Portugal. Several companies have invested in the transformation of cactus: fruit and cladodes.

Participants visiting "Pepe Aromas" one of the companies processing cactus pear

Portugal: Remarkable participation of women experts

Among these companies we can mention: Pepe Aromas, SP Essentials, Biopuntia, Dialogos do Bosque, Doçuras do Vale, Doces Candeias and others. Various brands are created, most of which are certified organic: juice, vinegar, jam, nectar, and cosmetic derivatives.

Examples of Portuguese organic products: fresh figs, honey, jelly, and cosmetic derivatives

The Fourth edition was completed on September 18th with two major events:

- Celebrating World Cactus Day through a party (dance of flags)
- The Decision to create CactisMundis, the name given to the International Cactus Association, which will certainly play a major role in the development of this culture

The Logo designed by Eng. Djamal Chaib (Algeria)

Table 1. Program of the fourth International Itinerant University of Cactus Pear (2022)

Date	City and organizer		Activities	Speakers	Theme
14/11	Evora	Opening ceremony: A. Ait Hamou MOR L. Portillo MEX N. Ventura POR			
15/11		Field visit : Pepe Aromas			
		University of Évora	Conferences	Filipe Themudo. B	Historical contextualization of nopal in the world
				Dr. Mustapha Ait Chitt	Large-scale micropropagation of *O. ficu-indica* in Morocco.
				Pr. Ana Luisa Fernando	Increasing the shelf life of cactus pear by natural coatings application
				Carlos Gaspar Reis	Morphological characterization, genetics, and physical-chemical analysis of fruits
				Dr. Monica Nazareno	Cosmetic and nutritional aspects of *O.ficus-indica*
				Nourhaal Nasser	Cactus Pear Cosmetics: its seed oil
				A. Cristina A. Santos	Improving the use of cactus pear products
			Presentation Posters		
16/11	Almodôvar	Municipality	Round	all	Tourist visit (Santa Clara-a-Nova)
			Opening ceremony: Antonio Bota: Welcome / Presentation EEC PROVERE		
			Conferences	Lina Torres	Experience of "El Rancho Las Papas"
				Dr. Jihane Oumatou	Characteristics of some fruit varieties in Morocco
				Abderrahmane Aithamou	*Opuntia ficus-indica*: A Strategic Plant for Arid Areas: case of Morocco
				Fernando Torres	Nopal as a barrier against the advance of the desert
				Antonio Rodrigues	Use of cladodes in animal feed
			Round	All	Touristic visit of Almodôvar
17/11	Mertola	Municipality	Opening ceremony		
			Conferences	A.Méry, N.Saber J.Ochoa, P.Fanucchi, J.Tomas, A.Tasyurek	Location of cactus pear in Chile, Egypt, Argentina, France, Spain, Turkey
				Cesar Castro Carrasco	Use of two predators to control *Dactylopius opuntiae* pest of *Opuntia ficus-indica* in two seasons of the year
				A.Aithamou _	Impact of cochineal on cactus production Case of Morocco
18/11			Field Visit " Herdade Vale do Guadiana" Practical conference		
			Touristic visit to Mértola		
			World Cactus Day Celebration (Pavilhão Multipurpose)		
			Creation of CactisMundis: The Cactus Pear International Association/Federation		
			Closing event		

USEFUL LINKS

1. https://www.researchgate.net/publication/348481581_COMPENDIO_DE_PRESENTACIONES_DE_PONENCIAS_EN_LA_TERCERA_UNIVERSIDAD_ITINERANTE_DEL_NOPAL
2. Video 1: The Second IIUC: https://youtu.be/1M44HTHhKwM
3. Video 2: The Third IIUC: https://www.youtube.com/watch?v=5do5NLUU0bc
4. https://sites.google.com/prod/view/confrariadofigodaindia/mapa-produtores
5. Video 3 : The Fourth IIUC: https://youtu.be/5do5NLUU0bc

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