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Antioxidant properties of fresh and processed cactus pear cladodes from selected *Opuntia ficus-indica* and *O. robusta* cultivars

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ABSTRACT

If the cactus plant could find applications in the food industry, other than that of fresh fruit, by means of preserving the cladodes, a larger market may emerge, thus making it an economically more viable crop. The aim of this study was therefore to explore the processing of cladodes into different preserved food products and to study the processed products' antioxidant content and -capacity compared to the fresh cladodes. All cultivars demonstrated high antioxidant capacities and consequently, the cladodes of any cultivar could be considered as suitable for processing or preserved to produce healthy products. Processing had a greater influence on the antioxidant content of cactus cladode products than the cultivar. Dried products were the best in terms of antioxidant content and -capacity.
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1. Introduction

Twenty-two spineless Burbank *Opuntia ficus-indica* and *O. robusta* cultivars, developed by Luther Burbank (California, USA) were imported into South Africa in 1914 and established at Grootfontein research station (Middelburg, Cape Province). This collection is unique and South Africa is the only country where these cultivars are still available. These were evaluated and propagated mainly for cladode use in animal fodder (Potgieter and Mashope, 2009). A few cultivars are nowadays cultivated and evaluated for commercial production of the fruit destined for the local and European markets (Joubert, 1993; Coetzer and Fouché, 2015). There is currently a small but well developed commercial sector in South-Africa, but the plant as a whole is mainly under-utilized and under-valued (de Wit and Fouché, 2015). This under-utilization may be, in part, a consequence of the uncertainty that exist regarding the invasive nature of the cactus pear (Shackleton et al., 2011). According to the Conservation of Agricultural Resources Act (1983) (Act No. 43 of 1983), *Opuntia ficus-indica* (L.) Mill. is categorized as a Category 1 weed, meaning that no plants should be planted, established, maintained, propagated, imported or sold (Beinart and Wotshela, 2013). According to the latest list of invasive plant species, *Opuntia ficus-indica* (Species No. 218) is a category 1b invasive (DEAT, 2009; Shackleton et al., 2011). The spineless cultivars and selections are however excluded from the Act and invasive species list.

The stems or pads (cladodes) of the cactus pear plant (*Opuntia ficus-indica* and *Opuntia robusta*) are safe for human consumption; they have always been considered an important food and nutritional food source in Latin America (Rodríguez-Felix and Villegas-Ochoa, 1998). In Mexico, the whole cactus stems or pads used for food are known as nopal or pencas, while the young and tender cladodes cut into bite sized pieces is called nopales or nopalitos (Sáenz-Hernández et al., 2002). It is sold in open informal markets or packaged by using modified atmosphere packaging (Guevara et al., 2001). It is prepared and used either raw in dishes such as salads and salsas or cooked by means of boiling or frying (Saenz, 2000). It is used with other ingredients in a variety of traditional culinary dishes including desserts, beverages, snacks, soups, stews, sauces and salads (Saenz, 2000). Nopalitos are also preserved in brine or pickled (Rodriguez-Felix and Cantwell, 1988). There has been increased interest for products derived from the cactus pear plant due to their potential nutraceutical effects (Ruiz Pérez-Cacho et al., 2006). Compounds found in these products are known to combat oxidative stress and chronic diseases (Chavez-Santoscoy et al., 2009). The medicinal uses of the cladodes (Feugang et al., 2006) include possible anti-cancer effects and proven anti-oxidant properties, anti-viral-, anti-inflammatory-, anti-diabetic (type II) effects as well as anti-hyperlipidemia and hypercholesterolemia.

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The mucilage found in cladodes is a very important source of soluble fiber and products using the whole cladode contain large amounts of both insoluble and soluble fiber that are not absorbed by the human digestive system (Sáenz-Hernández et al., 2002). The cactus cladodes are used to regulate weight, increase fiber intake or manage diabetes mellitus and as a natural source of potassium (Sáenz, 1997). Hfaiedh et al. (2008) found that cladode juice provided highly effective radical scavenger effects.

Fresh fruit and cladodes are only ready to be harvested for a few months of the year and storage time is limited (Joubert, 1993). Food technologists are challenged to develop procedures to lengthen the storage life of the cactus pear fruit and cladodes and to diversify the plant by producing different types of preserved products (Joubert, 1993; Piga et al., 2003; Sáenz et al., 2004). Several products could be obtained from processing the fruit and cladodes. Some of the traditional and known products are juices, marmalades, jellies, jams, dried sheets, pickles, candy and alcoholic drinks. Recently developed products include liquid sweeteners, frozen fruit, cladode flour (Sáenz-Hernández et al., 2002; de Wit et al., 2015), oil (from the seeds) (de Wit et al., 2016, 2017, 2018a, 2018b), mucilage (from cladodes) (du Toit, 2016; de Wit et al., 2018a; du Toit et al., 2018a, 2018b), pigments and dietary fiber (from the cladodes) (Saenz, 2000).

It is possible that processing could damage and therefore decrease antioxidant content (Tesoriere et al., 2005), however this seems not to be the case. When Jaramillo-Flores et al. (2003) investigated the cladodes for carotene content after thermal treatment, it was found that the carotenoid extractability increased after thermal treatment. It was demonstrated that higher processing temperature caused more carotene to be released from the cell matrix because of thermal denaturation of carotenoid-proteins, softening of tissue and therefore allowing higher penetration of organic solvents into the cells. Rickman et al. (2007b) confirmed that thermal processing methods such as canning improved the extraction of carotene from the cell matrix of cladodes. This effect might be as a result of complexes formed with mucilage because of the high degree of pectin esterification that cannot be detected at pre-gelling temperatures. Medina-Torres et al. (2011) found that bioactive compounds are preserved in cladodes during the dehydration process as 25% of flavonoids, 20% of ascorbic acid and 50% carotene remained intact. Stintzing et al. (2005) demonstrated that betalains maintain their appearance as well as their antioxidant capacity over a large pH spectrum from pH 3 to 7.

Rickman et al. (2007b) studied the alleged increase in carotenoids after cooking and found that several authors reported such an increase during cooking of other fresh and frozen vegetables (carrots, broccoli, green beans, spinach and peas) on a wet basis. They also observed that frozen and cooked canned products contained antioxidant values similar to fresh products, regardless of the length of storage time (Rickman et al., 2007a). Rickman et al. (2007b) concluded that vegetables that were initially good sources of carotene remained good sources after processing. The same phenomenon was found by Howard et al. (1999) where microwave cooking resulted in greater solvent extraction of β-carotene in broccoli and carrots. Ryan and Prescott (2010) found that many other authors have reported the same phenomenon and possible explanations were reported as: antioxidant capacity increased because the heat disrupts the cell walls allowing more antioxidant components to be released; heat treatments deactivate oxidative enzymes that would normally destroy antioxidants; as well as heat treatments cause the formation of new structural groups which enhance antioxidant activity.

The last explanation was seen by Ryan and Prescott (2010) as the most correct one, as it was found before that antioxidant capacity of gallic acid increased after heat treatment because of the formation of new hydroxyl groups and that structure changes in polyphenols increases antioxidant activity. Therefore Ryan and Prescott (2010) theorized that heat treatment can possibly increase antioxidant capacity by causing slight changes to take place in the structure of the compounds. These changes render the antioxidant more stable to pH, allowing it to continue its activity throughout the digestive tract. If the cactus plant could find applications in the food industry, other than that of fresh fruit, by means of preserving the cladodes, a larger market may emerge, thus making it an economically more viable crop. In a previous study (du Toit, 2013; du Toit et al., 2015) different colors of fruit from different cultivars were processed into different food products and evaluated in terms of antioxidant content and -capacity. The highest antioxidant content and -capacity were found in purple (*O. robusta* Robusta) fruit products, attributed to the high levels of betalains. Orange fruit (*O. ficus-indica*) products had the second highest levels attributed to ascorbic acid and phenolic compound contents. Betalains were highly retained in processed products; ascorbic acid was mostly preserved in the processed products that involved minimal heat treatments, while carotene and phenolics increased after processing. The aim of this study was to explore the processing of cladodes into different preserved food products, to study the processed products' antioxidant content and -capacity compared to the fresh cladodes as well as to distinguish if fruit color is an indication of antioxidant content and -capacity of cladodes.

2. Materials and methods

2.1. Sample collection and preparation

Six-month-old cladodes from the same cultivars used in the study of du Toit et al. (2015) were chosen and collected to represent the four colors of fruit available namely green, orange, pink-red and purple. Cladodes of good quality, without any blemishes, which had not bear any fruit, from four cultivars of *O. ficus-indica* [Gymno-Carpo (orange), Meyers (red-pink), Nepgen (green), Ofer (orange)] and one from *O. robusta* [Robusta (purple)] were collected from Waterkloof, an eight year old cactus pear orchard located in the Bloemfontein district of the Free State Province in South Africa. It is 1348 m above sea level and receives 556 mm rainfall on average annually. The GPS coordinates are 29°10′53″ S, 25°58′38″ E. It hosts 40 *Opuntia ficus-indica* cultivars and two *O. robusta* cultivars, laid out in a fully randomized design with two replications of each cultivar (de Wit et al., 2010). Each replication consists of five plants. Two cladodes from the first, third and fifth plant of each replication were harvested. Cladodes were all selected to be at the same height of the plant and of equal size. Three cladodes were randomly selected per each replication (thus 6 cladodes per cultivar).

For the fresh cladode samples, the cladodes were weighed, cut into pieces and liquidized. Equal weights of water (100%) were added, homogenized and centrifuged at 8000 rpm for 10 min at 4 °C and the supernatant was frozen in aliquots.

Cladode juice was prepared by peeling the cladodes, liquidizing the inner soft part, strained (0.5 mm mesh size) and the filtered juice was then pasteurized in a water-bath for 10 min until the internal temperature reached 72 °C, immediately shocked in cold water and then frozen (not longer than one month). For dried cladodes, the cladodes were washed, cut in thin strips and blanched at 80 °C for 5 min. It was dried in a convection oven set at 90 °C for 18 h (Voedselpreservering, 1986), vacuum packed and frozen.

Cladodes were also preserved (jarred) in brine according to the steam pressure method (Van Zyl et al., 1987), whereby the cladodes were washed and cut into thin strips of approximately 20 mm × 150 mm, blanched, packed into sterilized hot jars and filled with hot brine solution consisting of 2.5 g salt, 3 g vinegar and 2 g sugar and 500 ml water and sealed. It was pressure cooked for 25 min (Bennion, 1985).

For chutney preparation, the cladodes were washed and the pulp was obtained by feeding cladodes through a juicer. The total weight of cladode pulp was obtained and the chutney was further formulated as follows: cladode pulp 65%, sugar 10%, cayenne pepper 0.01%, minced onion 4%, salt 0.2%, powdered ginger 0.2%, powdered mustard 0.06%,

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