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Application of wounding stress to produce a nutraceutical-rich carrot powder ingredient and its incorporation to nixtamalized corn flour tortillas

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Wounding stress was applied to carrot to obtain a nutraceutical-rich carrot powder (stressed-carrot powder, SCP) that contained 522, 225, and 23% more chlorogenic acid, total phenolics, and dietary fiber, respectively, compared to regular carrot powder. Tortillas were produced by substituting nixtamalized corn flour with 10% w/w dry weight (DW) of SCP, showing considerable sensory acceptability, and causing an increase in masa elasticity and deformation resistance. Furthermore, SCP substitution induced a change in color of tortillas to yellow, but did not affect cohesiveness and adhesiveness of masa, neither the dimensions, rollability, texture, nor shelf-life of tortillas. Unlike regular tortillas, 10% SCP tortillas had chlorogenic acid, β-carotene, α-carotene, and lutein (270, 39, 36, and 15 μg/g DW, respectively), 155% more total phenolics, and 35% more dietary fiber. SCP is a suitable ingredient for nutraceutical enhancement of foods, which could greatly aid in the prevention of chronic and degenerative diseases.

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Abbreviations: 3,5-diCQA, 3,5-dicaffeoylquinic acid; CCP, control-carrot powder; CHA, chlorogenic acid; CP(s), carrot powder(s); DW, dry weight; FA, ferulic acid; FADA, ferulic acid derivative A; FADB, ferulic acid derivative B; FW, fresh weight; IC, isocoumarin; IDF, insoluble dietary fiber; MED, maximum extensibility distance; MEF, maximum extensibility force; NCF, nixtamalized corn flour; *p*-CA, *p*-coumaric acid; *p*-CADA, *p*-coumaric acid derivative A; *p*-CADB, *p*-coumaric acid derivative B; SCP, stressed-carrot powder; SDF, soluble dietary fiber; TDF, total dietary fiber; TP, total phenolics; TC, total carotenoids; TPA, texture profile analysis; WAI, water absorption index; WRC, water retention capacity; WS, wounding stress; WSI, water solubility index

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1. Introduction

The main causes of death worldwide are chronic and degenerative diseases, such as cancer, diabetes, and cardiovascular diseases (WHO, 2014). A strategy to prevent such diseases is through the consumption of foods fortified with nutraceuticals.

Carrot (*Daucus carota*) is an important vegetable in countries such as Mexico, and a significant source of nutraceuticals, including phenolics, carotenoids, and dietary fiber. Carrot production in Mexico from 2010 to 2013 was between 300 and 400 thousand tons per year (FAOSTAT, 2013), with a commercial value of ~175 USD per ton. Furthermore, chlorogenic acid (CHA) is the most abundant phenolic compound in carrot, representing 42.2–61.8% of total phenolics (Zhang & Hamauzu, 2004). Clinical studies have found that CHA alone, or in combination with other bioactive molecules, has antioxidant (Hoelzl et al., 2010), anti-diabetic (Ahrens & Thompson, 2013; Johnston, Clifford, & Morgan, 2003; Van Dijk et al., 2009), anti-obesity (Thom, 2007), and anti-hypertension properties (Kozuma, Tsuchiya, Kohori, Hase, & Tokimitsu, 2005; Watanabe et al., 2006). In addition, the carotenoid composition of carrot is β-carotene (60–80%), α-carotene (10–40%), lutein (1–5 %), and other minor carotenoids (0.1–1.0%) (Chen, Peng, & Chen, 1995). β-carotene and α-carotene possess provitamin A activity (Jaswir, Noviendri, Hasrini, & Octavianti, 2011). Likewise, β-carotene plays a role in the prevention of some diseases such as atherosclerosis (D'Odorico et al., 2000), UV-induced erythema (Heinrich et al., 2003), cancer (Mayne, 1996), and may exert long-term cognitive benefits (Grodstein, Kang, Glynn, Cook, & Gaziano, 2007). Moreover, α-carotene and lutein have preventive properties against atherosclerosis (D'Odorico et al., 2000), and age-related macular degeneration (Hammond et al., 1997), respectively. Finally, health benefits of dietary fiber include laxation, and protective properties against coronary heart disease, diabetes, obesity, and some forms of cancer, such as colon cancer (Yangilar, 2013). Therefore, carrot is an excellent alternative to be processed into a powder to be used as an ingredient to enhance the nutraceutical content of foods.

A potential food to incorporate carrot powder (CP) is the nixtamalized corn flour tortilla, which is the staple food of Mexicans. Mexico is ranked among the top places in obesity (OECD, 2014), and most causes of death in this country are obesity-related diseases, including diabetes, cardiovascular and cerebrovascular diseases (INEGI, 2013). Thus, enhancing the nutraceutical content of corn tortillas could have a huge impact in the prevention of such diseases in the Mexican population.

However, during the production of CP and corn tortillas, thermal degradation of bioactive compounds can be encountered. Freeze drying has been acknowledged as the best method to obtain powders with the highest quality (Pandey, Harilal, Srihari, Jayathilakan, & Radhakrishna, 2013), but it is too expensive for industrial applications. A more economical option is convection drying. Nonetheless, convection drying can decrease the nutraceutical content of carrot due to thermal degradation (Chantaro, Devahastin, & Chiewchan, 2008; Mayer-Miebach, Behsnilian, Regier, & Schuchmann, 2005). Furthermore, in some cases attempts to increase the nutraceutical content of tortillas have been frustrated due to thermal degradation during masa cooking (Vázquez-Rodríguez, 2013). Hence, increasing the amount of nutraceuticals in carrot before its conversion to CP could compensate the thermal degradation.

A strategy to increase nutraceuticals in horticultural crops is the application of postharvest abiotic stresses (Cisneros-Zevallos, 2003; Jacobo-Velázquez & Cisneros-Zevallos, 2012). Carrots accumulate phenolics in response to wounding stress alone and in combination with other abiotic stresses, such as UV-light, hyperoxia, and phytohormones (Becerra-Moreno, Benavides, Cisneros-Zevallos, & Jacobo-Velázquez, 2012; Becerra-Moreno et al., 2015; Jacobo-Velázquez & Cisneros-Zevallos, 2012; Jacobo-Velázquez, González-Agüero, & Cisneros-Zevallos, 2015; Jacobo-Velázquez, Martínez-Hernández, Del C. Rodríguez, Cao, & Cisneros-Zevallos, 2011; Surjadinata & Cisneros-Zevallos, 2012). The phenolic that accumulates the most as a response to wounding stress is CHA, where increases up to 2000% have been reported (Jacobo-Velázquez et al., 2011).

The application of wounding stress to carrots offers the possibility to increase their phenolic content high enough to overcome the aforementioned thermal degradation. To the best of our knowledge, there are no previous reports in literature regarding the production of a powder from carrots with increased levels of antioxidants. In this study, carrots were treated with wounding stress to produce a CP richer in phenolics (stressed-carrot powder, SCP) than regular CP (control-carrot powder, CCP). Detailed characterization of the nutraceutical and proximate compositions of SCP was done and compared to CCP, and the effects of substitution of both CPs on corn masa and tortilla physicochemical properties were also studied.

2. Materials and methods

2.1. Reagents and plant material

Acetone (HPLC grade), ethanol, and orthophosphoric acid were purchased from Desarrollo de Especialidades Químicas S.A. de C.V. (San Nicolás de los Garza, NL, México). Methanol (HPLC grade), butylated hydroxytoluene (BHT), CHA, 3,5-dicaffeoylquinic acid (3,5-diCQA), ferulic acid (FA), *p*-coumaric acid (*p*-CA), and β-carotene were obtained from Sigma Chemical Co. (St. Louis, MO, USA). Finally, chlorine (Cloralex®, 6% sodium hypochlorite), carrots, and white nixtamalized corn flour (NCF) (MASECA®) were purchased from a local supermarket (HEB, Monterrey, NL, México).

2.2. Carrot powder production

Fresh carrots with no fungi development or significant damage were selected. Then carrots were washed with tap water, disinfected in a 200 ppm chlorine solution (pH 6.5–7.0) for 5 min, and dried with paper towel. Both ends of carrots were cut with a knife, and wounding stress was applied by shredding them using a food processor (Waring Commercial, WFP11, Torrington, CT, USA). Shredded carrots (12 kg) were placed in 19-L plastic containers (3 kg/container) with 4 holes (0.8 cm diameter) evenly distributed on their lids to allow respiration. Paper towel was set at the bottom of the containers to absorb excess moisture, and stored in a Symphony incubator (VWR, Radnor, PA, USA) for 48 h at 15 °C.