Food Research International 99 (2017) 917–927

Contents lists available at ScienceDirect

Food Research International

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

Effects of pectin on lipid digestion and possible implications for carotenoid bioavailability during pre-absorptive stages: A review

Braulio Cervantes-Paz [a], José de Jesús Ornelas-Paz [a,*], Saul Ruiz-Cruz [b], Claudio Rios-Velasco [a], Vrani Ibarra-Junquera [c], Elhadi M. Yahia [d], Alfonso A. Gardea-Béjar [e]

[a] Centro de Investigación en Alimentación y Desarrollo, A.C.-Unidad Cuauhtémoc, Av. Río Conchos S/N, Parque Industrial, C.P. 31570, Cd. Cuauhtémoc, Chihuahua, Mexico
[b] Instituto Tecnológico de Sonora, Departamento de Biotecnología y Ciencias Alimentarias, 5 de Febrero 818 Sur, C.P. 85000 Cd. Obregón, Sonora, Mexico
[c] Universidad de Colima, Bioengineering Laboratory, Km. 9 carretera Coquimatlán-Colima, C.P. 28400 Coquimatlán, Colima, Mexico
[d] Universidad Autónoma de Querétaro, Facultad de Ciencias Naturales. Avenida de las Ciencias S/N, C.P. 76230 Juriquilla, Querétaro, Mexico
[e] Centro de Investigación en Alimentación y Desarrollo, A.C.-Unidad Guaymas, Carretera al Varadero Nacional km. 6.6, Col. Las Playitas, C.P. 85480 Guaymas, Sonora, Mexico

ARTICLE INFO

Article history:
Received 2 November 2016
Received in revised form 3 February 2017
Accepted 17 February 2017
Available online 21 February 2017

Keywords:
Polysaccharides
Fiber
Lipid-soluble pigments
Bioactive compounds
Bioavailability

ABSTRACT

Pectin, an abundant polysaccharide in the human diet, has structural characteristics and functional properties that are strongly dependent on the food matrix (*e.g.*, origin, type, cultivar/variety, ripening stage, style and intensity of processing). These polysaccharides have a strong effect on lipid digestion, which is required for the liberation of carotenoids from emulsified lipid droplets in the gastrointestinal content and for the formation of micelles, in which the carotenoids must be incorporated before absorption. Only micellarized carotenoids can be absorbed and subsequently exert protective effects on human health. The alteration of lipolysis by pectin can occur through several mechanisms; however, they have not been linked directly to carotenoid micellarization. This paper provides an overview of the effects of the properties of pectin on the ion concentration in the digestive content, the viscosity of the digestive medium, the properties of the lipid droplet surfaces and lipase activity and analyzes the impact of these events on lipid digestion and subsequent carotenoid micellarization.

1. Introduction

Carotenoids are lipid-soluble pigments that can be found at high concentrations in many fruits and vegetables (Victoria-Campos et al., 2013). They confer yellow, red or orange pigmentation to many vegetables (Cervantes-Paz et al., 2012). Several protective effects on human health have been attributed to these pigments, including anti-obesity effects, strengthening of the immune system, and a reduction of the risk of suffering several forms of cancer and cardiovascular diseases (Yahia & Ornelas-Paz, 2010). The mechanisms involved in these effects are not clear, but they are believed to be a consequence of the antioxidant activity of carotenoids and their capacity to favor cell-to-cell communication and influence gene expression (Cervantes-Paz, Victoria-Campos, & Ornelas-Paz, 2016a). However, the biological activity of carotenoids is highly dependent on their intestinal absorption. One of the most relevant factors limiting the bioavailability of carotenoids at the pre-absorptive stages is the food matrix. This effect refers to the combined effects of all factors inherent to a food that simultaneously promotes or reduces the bioavailability of carotenoids (Ornelas-Paz, Failla, Yahia, & Gardea-Bejar, 2008). Fiber is a food-matrix–related factor, and pectin is a component of fiber (Ramos-Aguilar et al., 2015). Some *in vivo* studies have found a negative effect of pectin on carotenoid bioavailability. Riedl, Linseisen, Hoffman, and Wolfram (1999) demonstrated that citrus pectin reduced the bioavailability of β-carotene by 42% and found that soluble fiber, like pectin, has a stronger effect than insoluble fiber. Horvitz, Simon, and Tanumihardjo (2004) attributed the low bioavailability of carrot carotenoids to the high fiber content in the vegetable. Many other similar studies demonstrated the negative effect of pectin on carotenoid bioavailability; however, the mechanisms involved have only recently been investigated (Verrijssen, Verkempinck, Christiaens, Van Loey, & Hendrickx, 2015; Verrijssen et al., 2014). The amount and properties of pectin in foods are highly dependent on the characteristics of the vegetable matrix, including the food type, cultivar/variety, ripening stage, and processing style/intensity (Ornelas-Paz et al., 2008; Victoria-Campos et al., 2013; Ramos-Aguilar et al., 2015). These variations have different physicochemical effects on lipid digestion, including alterations in the interaction between pectin and essential components for lipid digestion (bile salts and calcium), digestive medium viscosity, properties of lipid droplet surfaces, and lipase activity (Espinal-Ruiz, Restrepo-Sánchez, Narváez-Cuenca, &

* Corresponding author.
E-mail addresses: braulio.cervantes@estudiantes.ciad.mx (B. Cervantes-Paz), jornelas@ciad.mx (J.J. Ornelas-Paz), saul.ruiz.cruz@itson.edu.mx (S. Ruiz-Cruz), claudio.rios@ciad.mx (C. Rios-Velasco), vij@ucol.mx (V. Ibarra-Junquera), yahia@uaq.mx (E.M. Yahia), gardea@ciad.mx (A.A. Gardea-Béjar).

http://dx.doi.org/10.1016/j.foodres.2017.02.012
0963-9969/

McClements, 2016; Espinal-Ruiz, Parada-Alfonso, Restrepo-Sánchez, Narváez-Cuenca, & McClements, 2014a). Thus, these variations might also explain the high variability in the micellarization and bioavailability of the same carotenoid in different foods or even in the same food type (Table 1) (Cervantes-Paz et al., 2016a). This hypothesis is reinforced by a limited number of studies demonstrating that the characteristics of pectin modulate carotenoid micellarization and by many studies demonstrating that the amount and characteristics/properties of pectin alter the digestion of lipids, a key determinant of carotenoid transport and absorption (Cervantes-Paz et al., 2016b; Verrijssen et al., 2015; Yonekura & Nagao, 2007, 2009). Elucidation of the mechanisms involved in this phenomenon is challenging because the main structural characteristics of pectin are related to each other and studying the effect of individual characteristics of pectin requires modification of a single property without altering the others, which represents a major technical challenge (Aschoff et al., 2015; Espinal-Ruiz et al., 2016; Galisteo, Duarte, & Zarzuelo, 2008). The purpose of this paper is to provide a systematic analysis of the existing evidence of the effects of pectin on lipid digestion and to link these effects with the alteration of the micellarization and bioavailability of dietary carotenoids.

2. The carotenoid absorption process

Carotenoid absorption involves the release of pigment from the food matrix, its incorporation into lipid droplets and then to micelles before to be up taken by the enterocytes. The chewing of food during the oral phase and the transportation of food to the stomach by peristalsis have an important effect on lipid digestion and carotenoid bioavailability because they contribute to the mechanical disruption of food and the liberation of food components and the contact with digestive enzymes (Low, D'Arcy, & Gidley, 2015). These effects of mechanical disruption of food are enhanced by the chemical and enzymatic digestion of food in the oral and gastric phases, making more efficient the digestion of lipids and increasing carotenoid bioavailability (Guerra et al., 2012). The oral phase highly contributes to the hydrolysis of food starch while the acid and pepsin of the gastric juice mainly favor the protein

Table 1
Micellarization of carotenoids from different sources.

Food matrix	Micellarization (%)				
	β-Carotene	Lycopene	Lutein	Zeaxanthin	β-Cryptoxanthin
Pure carotenoids	13–84[e,g]	3–25[c,g]	46–65[c,g]		
Carotenoid + pectin					
Pepper	0–18[b]			0–13[b]	0–22[b]
Citrus	33–61[h]				
Butternut squash	16.5[j]		15.9[j]		
Grapefruit	7.9[j]	4.5[j]	7.9[j]		
Mandarin	25–32[r]				15–18[r]
Melon	7.1[j]		33.7[j]	50.2[m]	
Watermelon	<1–30[j,k]	<1–2.7[j,k]	48.6[k]		
Broccoli	21–54[m,p]		7.38[m,p]	6.0[p]	
Sweet potato	3–45[m,n]		97[m]	92[m]	
Kiwi	47–57[m,p]		62[p]		77[m]
Mango	4–32[d,j]		14[j]		
Papaya	5–49[f,j]	<1[f]	37.3[j]		
Raw carrots	<1–75[k,p]	38.9[j]	35–44[k,p]		
Processed carrots					
Boiled	6–45[s]				
Canned	2.7[k]		53.8[k]		
Juice	2–14[k,q]		14–22[q]		
Puree	4.4[k]				
Raw tomato	<1–16[j,k]	<1–5[j,o]	57–83[k,o]		96.8[o]
Processed tomato					
Sauce	5.9[k]	1.6[k]	57.4[k]		
Boiled	47.2[o]	4.9[o]	84.7[o]		90.4[o]
Grilled	45.8[o]	7.6[o]	61.5[o]		
Microwave cooked	39.7[o]	5.0[o]	37.0[o]		
Steamed	29.2[o]	1.7[o]	51.3[o]		106.2[o]
Raw spinach	2–30[k,m]		6–48[k-p]	7.0[p]	
Processed spinach					
Boiled	17.5[k]		47.8[k]		
Minced	5.2[k]		48.1[k]		
Raw courgette	18.0[o]	17.6[o]	45.9[o]		95.4[o]
Processed courgette					
Boiled	79.4[o]				84.1[o]
Grilled	67.6[o]	50.4[o]			
Microwave cooked	56.6[o]	49.9[o]			
Steamed	56.9[o]	3.9[o]			77.0[o]
Orange fruit	6–34[a,m]	1[l]	9–25[a,p]	40[p]	5–98[a,m]
Orange juice	20–30[a,l]	3[l]			26–70[a,l]
Raw hot peppers	20–30[i-p]	18.6[o]	55–98[m,p]	48–91[i,p]	30–98[m,p]
Processed hot peppers					
Boiled	11–77[i,o]	15.2[o]	22–109[i,o]	66–78[i]	36–73[i,o]
Grilled	17–51[i,o]	12.5[o]		70–82[o]	42–66[i]
Microwave cooked	40.9[o]	13.0[o]	39.2[o]		
Steamed	59.2[o]	8.2[o]			50.0[o]

[a]Aschoff et al. (2015); [b]Cervantes-Paz et al. (2016b); [c]Corte-Real et al. (2016); [d]Ornelas-Paz et al. (2008); [e]Salvia-Trujillo et al. (2013); [f]Schweiggert et al. (2012); [g]Sy et al. (2012); [h]Verrijssen et al. (2015); [i]Victoria-Campos et al. (2013); [j]Jeffery, Turner, and King (2012); [k]Reboul et al. (2006); [l]Rodrigo, Cilla, Barberá, and Zacarías (2015); [m]O'Connell, Ryan, and O'Brien (2007); [n]Failla et al. (2009); [o]Ryan, O'Connell, O'Sullivan, Aherne, and O'Brien (2008); [p]Granado-Lorencio et al. (2007); [q]Courraud, Berger, Cristol, and Avallone (2013); [r]Dhuique-Mayer et al. (2007); [s]Hedrén et al. (2002).