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Home cooking and ingredient synergism improve lycopene isomer production in *Sofrito*

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ABSTRACT

There has been increasing interest in tomato products rich in lycopene *Z*-isomers since these carotenoids present greater bioavailability and antioxidant capacity than the all-*E* lycopene form. Intrinsic food properties as well as processing and the interaction between dietary components can all influence the content, type and bioavailability of carotenoids. The aim of this study was to evaluate whether carotenoid content and isomerization in tomato-based Mediterranean *sofrito* is affected by the process of home cooking and the presence of other ingredients such as extra virgin olive oil, onion and garlic. We used a full factorial design to clarify the contribution of each ingredient to the carotenoid composition of *sofrito* and to determine whether this can be improved by the cooking time and ingredient synergism. Cooking time and onion content were associated with a higher production of 5-*Z*-lycopene, 9-*Z*-lycopene and 13-*Z*-lycopene in *sofrito*. Onion proved to be the most interesting ingredient in the *sofrito* formulation due to their enhancing effect on lycopene isomerization. The use of onion combined with an adequate processing time may improve the bioavailability of lycopene in tomato products.

1. Introduction

The PREDIMED (PREvención con Dieta MEDiterranea) study confirmed the health benefits of the vegetable-based Mediterranean diet, which are attributed to a high ingestion of phytochemicals (Estruch et al., 2013). Adherence to this diet has become popular in non-Mediterranean countries and assessment of its effects must take into account different ways of food preparation. Home cooking of typical Mediterranean dishes is interesting from the nutritional point of view, since this process can increase, decrease or change phytochemical content and bioavailability in food, thereby determining the intake and beneficial effects of bioactive compounds (Hoffman & Gerber, 2015). *Sofrito* is a typical home-made tomato-based Mediterranean sauce which also contains onion, garlic and olive oil (Vallverdú-Queralt, de Alvarenga, Estruch, & Lamuela-Raventos, 2013). Tomato is a principal dietary source of carotenoids and is associated with a regulation of the lipid profile and inflammatory biomarkers (Burton-Freeman, Talbot, Park, Krishnankutty, & Edirisinghe, 2012; Cuevas-Ramos et al., 2013; Sesso, Wang, Ridker, & Buring, 2012; Valderas-Martinez et al., 2016). Onion and garlic are widely used as gastronomic ingredients and present beneficial effects against cardiovascular diseases, hypertension, diabetes and cancer attributed to their content of organosulfur compounds and polyphenols (Corzo-Martínez, Corzo, & Villamiel, 2007).

Lycopene is the major carotenoid found in tomato and tomato products and has antioxidant capacity, affects the expression of genes and regulatory proteins, and has shown beneficial effects against cancer, cardiovascular diseases and type II diabetes (Burton-Freeman et al., 2012; Cervantes-paz, Victoria-campos, & Ornelas-paz, 2016; Cuevas-Ramos et al., 2013; Jacques, Lyass, Massaro, Vasan, & D'Agostino, 2013; Sesso et al., 2012). *Z*-lycopene isomers are currently gaining interest due to their higher bioavailability and antioxidant capacity compared to other carotenoids (Arranz et al., 2015; Bohm, Puspitasari-Nienaber, Ferruzzi, & Schwartz, 2002). Recent studies have focused on producing ingredients and products with a high content of *Z*-lycopene isomers, using organic solvents and vegetable oils as mediators (Honda et al., 2016; Lambelet, Richelle, Bortlik, Franceschi, & Giori, 2009). The presence of lipids during food preparation increases the solubility of carotenoids by favoring their incorporation in small micelles, which do not readily occur in the gastrointestinal tract (Palmero, Panozzo, Simatupang, Hendrickx, & Van Loey, 2014). Processing tomato sauce with oil increases the extractability of carotenoids from the food matrix (Colle et al., 2010a; Colle, Lemmens, Van Buggenhout, Van Loey, & Hendrickx, 2013; Vallverdú-Queralt, Regueiro, de Alvarenga, Torrado, & Lamuela-Raventos, 2015) and improves their bioavailability

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in humans (Arranz et al., 2015; Valderas-Martinez et al., 2016). The bioavailability of carotenoids is affected by intrinsic food properties, processing and the presence of other dietary components, and the complexity of these interacting factors is a challenging subject for research (Cervantes-Paz et al., 2016). The individual ingredients of *sofrito*, tomato sauce, and tomato sauce emulsified with oil have been extensively studied, but to our knowledge, a possible synergistic effect of the ingredients of home-made *sofrito* has not been studied.

The aim of this study was to evaluate how the home cooking process and the additional ingredients such as extra virgin olive oil, onion and garlic used to prepare tomato-based Mediterranean *sofrito* may interact and improve carotenoid content and isomerization.

2. Material and methods

2.1. Chemicals and standards

The standards of carotenoids all-*E*-α-carotene, all-*E*-β-carotene and all-*E*-lycopene were purchased from Sigma-Aldrich (St. Louis, MO, USA). Ethanol and methanol were purchased from AppliChem, Panreac Quimica SA (Barcelona, Spain). Methyl tert-butyl ether (MTBE) and hexane were purchased from Sigma-Aldrich (St. Louis, MO, USA). Ultrapure water (Milli-Q) was produced by a Millipore system (Millipore, Bedford, MA, USA).

2.2. Material

The tomatoes used (*Lycopersicon esculentum* Mill, c. v. Pera) were bought from Grupo Almería (La Cañada, Almería, Spain) and were all from the same batch and had a diameter of 57–67 mm. Extra virgin olive oil (EVOO) was provided by Manuel Heredia Halcón (Cortijo De Suerte Alta, Albedin-Baena-Córdoba). Onions and garlic were bought from Casa Ametller (Barcelona, Spain).

2.3. Factorial design

We used a full factorial design (FFD) in the present study in order to clarify the effect of individual ingredients, different cooking times and possible ingredient synergism on the carotenoid composition of *sofrito*. The factors EVOO, onion, garlic and cooking time were analyzed in a two-level FFD. Each factor had a high (+1) and low (−1) level, producing a 2^4 FFD, with 16 different experiments. The levels for each factor were: 5% (−1) and 10% (+1) for oil; 20% (−1) and 40% (+1) for onion; 2% (−1) and 4% (+1) for garlic, and 30 min (−1) and 60 min (+1) for time. The FFD experiments were performed independently in triplicate and randomized for better reproducibility, and the pure error and lack of fit were estimated in a total of 48 experiments. The level of each ingredient and cooking time were defined by consulting the literature (Colle et al., 2010a; Vallverdú-Queralt et al., 2015). Table 1 shows the variables and levels of ingredients and cooking time for each experiment. Data obtained in the FFD experiments were analyzed by analysis of variance (ANOVA) using STATISTICA 10 software (StatSoft, USA) and a regression equation of a first order model with four parameters and their interaction terms was applied for modeling (Eq. 1):

$$Y = b_0 + b_1E + b_2O + b_3G + b_4t + b_{12}EO + b_{13}EG + b_{14}Et + b_{23}OG + b_{24}Ot + b_{34}Gt + b_{123}EOG + b_{124}EOt + b_{134}EGt + b_{234}OGt + b_{1234}EOGt$$

where Y is the predicted response variable, b_0 the average value, b_1 b_2, b_3 and b_4 the linear coefficients and b_{12}, b_{13}, b_{14}, b_{23}, b_{24}, b_{34}, b_{123}, b_{124}, b_{134} and b_{234} the interaction coefficients. The independent variables are E (EVOO), O (onion), G (garlic) and t (time).

2.4. Sofrito preparation

The *sofrito* was prepared at Torribera Campus, University of Barcelona (Santa Coloma de Gramenet, Spain), following a home cooking method. The tomatoes, garlic and onions were washed, cut into small pieces, mixed with a blender (model R5 Plus, Robot Coupe®) and weighed according to the FFD. The cooking process was based on the traditional Mediterranean diet: in an uncovered pan (24 cm diameter, 15 cm height, 6.3 L volume, thickness 1.59 mm, made of inox 18/10). The EVOO was heated on an electrical cooking plate (180 mm diameter, 1500 W, model Encimera EM/30 2P, Teka®) at potency 4 (ranging from 1 to 6) for 1 min. The onion and garlic were then added and fried for 1 min, before adding the tomato, at which point the cooking process was timed, and the temperature was reduced to potency 2 to provide constant heat throughout the process (100 ± 1 °C). After preparation, the 16 *sofritos* were weighed to quantify weight loss, frozen in plastic vacuum bags, and stored at −25 °C (Table 1).

2.5. Extraction and analysis of carotenoids

The carotenoid extraction was performed under light with UV filters and ice to minimize the oxidation and isomerization of the compounds. All the samples were extracted in triplicate.

2.5.1. Extraction of carotenoids from tomato, onion, garlic and sofrito

The *sofrito* (0.5 g) was weighed and homogenized with ethanol: *n*-hexane (4:3, v/v), after which it was sonicated for 10 min and then centrifuged at 2486*g*, for 20 min at 4 °C. The apolar phase was separated into a flask and the extraction was repeated until colorless. The supernatants were combined and evaporated until dry using a vacuum concentrator (miVac DNA concentrator, Genevac LTD, England). The residue was reconstituted with 1 mL of MTBE, filtered using a 25 mm, 0.22 μm PTFE filter (Teknokroma, Spain) into an amber vial for HPLC analysis, and stored at −80 °C until analysis (Vallverdú-Queralt et al., 2013).

2.5.2. Extraction of carotenoids from EVOO

EVOO (1 g) was weighed and diluted with 1 mL of n-hexane. Thereafter, 2 mL of methanol was added, homogenized and centrifuged at 1399*g* for 3 min at 4 °C. The apolar phase and polar phase were separated and again extracted with 1 mL of *n*-hexane and 2 mL of methanol, respectively. The apolar phases were combined and evaporated until

Table 1
Experimental level of the factors used in the full factorial design (FDD).

	EVOO (%)	Onion (%)	Garlic (%)	Time (min)	Tomato (%)	Initial weight (g)	Final weight (g)		
							a	b	c
1	5	20	2	30	73	1000	497	492	515
2	10	20	2	30	68	1000	523	485	500
3	5	40	2	30	53	1000	347	390	401
4	10	40	2	30	48	1000	465	436	430
5	5	20	4	30	71	1000	486	545	491
6	10	20	4	30	66	1000	535	628	621
7	5	40	4	30	51	1000	453	454	433
8	10	40	4	30	46	1000	407	385	380
9	5	20	2	60	73	1000	446	486	423
10	10	20	2	60	68	1000	455	497	478
11	5	40	2	60	53	1000	461	466	464
12	10	40	2	60	48	1000	422	420	421
13	5	20	4	60	71	1000	398	472	513
14	10	20	4	60	66	1000	503	547	531
15	5	40	4	60	51	1000	379	500	480
16	10	40	4	60	46	1000	401	361	362

n = 3 (represent as a, b and c). EVOO = Extra Virgin Olive Oil. Initial weight (before cooking) and Final weight (after cooking process).