LWT - Food Science and Technology 80 (2017) 470–478

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Carotenoid stability and lipid oxidation during storage of low-fat carrot and tomato based systems

Leonard Mutsokoti, Agnese Panozzo, Jeritah Tongonya, Biniam T. Kebede, Ann Van Loey, Marc Hendrickx*

[a] Laboratory of Food Technology and Leuven Food Science and Nutrition Research Centre (LFoRCe), Department of Microbial and Molecular Systems (M^2S), KU Leuven, Kasteelpark Arenberg 22, 3001 Heverlee, Belgium

ARTICLE INFO

Article history:
Received 14 July 2016
Received in revised form
3 February 2017
Accepted 11 March 2017
Available online 16 March 2017

Keywords:
Carotenoids
Thermal processing
Storage
Lipid oxidation
Bioaccessibility

ABSTRACT

Thermally processed (F_0 = 5min, process temperature 117 °C) tomato and carrot purees containing 5% olive oil were stored in the dark at 20, 30 and 40 °C for 6 months and investigated for carotenoids and lipid stability. Lipid oxidation (peroxide value and hexanal) and carotenoids (lycopene, α- and β-carotene) were analyzed and monitored during storage. Carotenoid bioaccessibility of the samples during storage was also studied. Under the storage conditions studied, the samples did not undergo significant lipid oxidation. Moreover, carotenoid bioaccessibility remained ($P > 0.05$) unaffected by storage. Regardless of storage temperature, carotenoids were stable with a retention of ≥98% and color (L^*, a^*, b^* and ΔE) changes were imperceptible after 6 months. The results suggests that through formulation and careful selection of processing and storage conditions, carotenoid stability in lipid-containing fruit- and vegetable-based foods can potentially be guaranteed. This can be important to define optimal control measures to favor carotenoid stability and acceptable organoleptic properties during the storage of similar foods.

1. Introduction

Carotenoids are fat soluble phytochemicals largely responsible for the red, orange and yellow color of fruits and vegetables. Interest in these compounds arises from their purported health benefits. The increased awareness of the health benefits associated with carotenoids has brought a surge of interest in identifying specific food formulations and processing conditions so as to maximize the potential of carotenoid-rich foods to confer the health benefits (Liu, 2003; Van Duyn & Pivonka, 2000; Astorg, 1997; Hornero-Méndez & Mínguez-Mosquera 2007). To this regard, the inclusion of lipids into food formulations during processing (high pressure homogenization and/or thermal processing) can be a strategy to potentially enhance the nutritional quality of carrot and tomato based products (Colle et al., 2013; Mutsokoti, Panozzo, Musabe, Van Loey, & Hendrickx, 2015). In fact, processing can be used to favor the mass transfer of lycopene, β-carotene and α-carotene from the matrix to the oil phase, thus obtaining a carotenoid-rich lipid phase prior to digestion. This allows circumventing matrix-related factors and the low acidity gastric conditions that hinders the transfer of carotenoids into the oil phase during digestion (Rich, Fillery-Travis, & Parker, 1998). The transfer of carotenoids to oil is crucial for their bioaccessibility, i.e. the fraction of the nutrient that is released from the food matrix and subsequently incorporated into micelles during digestion before being absorbed by the enterocytes (Hedrén, Diaz, & Svanberg, 2002). To consider the effectiveness of the aforementioned strategy for food applications, it is necessary for the carotenoid enriched lipid phase in the food system to maintain its stability and functionality during storage. Therefore, investigation of the effects of storage conditions on the quality of lipid-containing fruit and vegetable based systems is needed.

Lipids can undergo peroxidation, during processing and storage (Bonnie & Choo, 1999). Lipid oxidation is a complex process where unsaturated fatty acids react with molecular oxygen via a free radical mechanism or in a photosensitized or enzyme-catalyzed oxidation process (Christensen, Edelenbos, & Kreutzmann, 2007). Consequently, nonvolatile hydroperoxides are formed (primary oxidation) that further decompose to volatile compounds

* Corresponding author. KU Leuven, Department of Microbial and Molecular Systems, Laboratory of Food Technology, Kasteelpark Arenberg 22 postbox 2457, B-3001 Leuven, Belgium.
E-mail address: marceg.hendrickx@kuleuven.be (M. Hendrickx).

http://dx.doi.org/10.1016/j.lwt.2017.03.021
0023-6438/

(secondary oxidation) which are responsible for quality changes in foods (Decker & McClements, 2000; Jeleń, Majcher, & Dziadas, 2012). Important to note is that the radical species that can be produced during the peroxidation process not only degrade fatty acids, but also other components of the lipid fraction, such as carotenoids, resulting in reduced nutritional quality (Hornero-Mendez, Pérez-Gálvez, & Mínguez-Mosquera, 2001). In fresh and processed lipid-containing foods, lipid oxidation is one of the main causes of deterioration and reduced stability and quality and is often a determining factor in their shelf-life (van Ruth, Roozen, Posthumus, & Jansen, 1999). Therefore, the control of lipid oxidation is a major issue.

The type of lipid can influence not only carotenoid bioaccessibility (Colle, Van Buggenhout, Lemmens, Loey, & Hendrickx, 2012; Huo, Ferruzzi, Schwartz, & Failla, 2007) but also carotenoid stability during storage. Specifically, the oxidative stability of lipids depends on a number of factors such as the degree of unsaturation of fatty acids and presence of other naturally occurring compounds that may inhibit lipid peroxidation during storage (Parker, Adams, Zhou, Harris, & Yu, 2003). Therefore, careful selection of the lipid substrate, as an ingredient, and food formulation design can be a strategy to control lipid oxidation, and as a consequence maintain carotenoid stability in carotenoid-rich food systems. In the Mediterranean diet, extra virgin olive oil (EVOO) represents the major edible vegetable oil and is becoming increasingly popular in other parts of the world due to its unique health benefits (Lamy, Ouanouki, Béliveau, & Desrosiers, 2014; Saleh & Saleh, 2011; Tuck & Hayball, 2002). In the food industry, EVOO is not only used as a filling medium of canned products, but also represents the lipid phase of a number of food formulations such as salad dressings, sauces and chilled and frozen ready-to-eat products (Calligaris, Sovrano, Manzocco, & Nicoli, 2006).

To date, carotenoid stability studies during storage have been conducted in both model and real food systems. It is known that carotenoid degradation reactions during storage are accelerated at high temperature, oxygen and light exposure, and very low moisture content (Xianquan, Shi, Kakuda, & Yueming, 2005). In the case of fruit and vegetable based food systems (e.g. purees, juices, dehydrated carrots and tomatoes pieces), the general conclusion from shelf-life studies is that significant carotenoid degradation can occur during storage (Giovanelli & Paradiso, 2002) implying that storage conditions play a crucial role in impacting the final nutritional quality.

Therefore, the aim of this study was to evaluate carotenoid stability during the storage of thermally processed lipid-containing fruit and vegetable based matrices. To this purpose, lycopene and β-carotene in tomato and α- and β-carotene in carrot purees containing 5% (w/w) olive oil were considered. Aiming at shelf-stable food systems, industrially relevant thermal processing conditions were selected ($F^{10\,^{\circ}C}_{121.1\,^{\circ}c}(F_0)$ = 5min, holding temperature = 117 °C). These processing conditions will transfer a large portion of carotenoids to the oil fraction (Mutsokoti, Panozzo, Van Loey, & Hendrickx, 2016). The thermally processed purees were stored at 20, 30 and 40 °C for 6 months and the stability of the samples monitored by measuring carotenoid content (all-*trans* and the *cis* isomers) and lipid oxidation (both primary and secondary) products. The effect of storage on the bioaccessibility of carotenoids was also investigated. This work is important for the design of effective control measures to promote carotenoid stability and acceptable organoleptic properties during the storage of shelf-stable lipid-containing fruit and vegetable based formulations. Ultimately, this research has broad implications on the development and elaboration of carotenoid-containing functional foods.

2. Materials and methods

2.1. Materials

All chemicals and reagents used were of analytical or HPLC-grade. L-α-phosphatidylcholine and carotenoid standards (all-*trans* lycopene, all-*trans* β-carotene and all-*trans* α-carotene) were purchased from Sigma-Aldrich (Borne, Belgium). 5-*cis* lycopene, 9-*cis*, 13-*cis* and 15-*cis* β-carotene were purchased from CaroteNature (Lupsingen, Switzerland). Olive oil (extra virgin) was kindly donated by Vandemoortele (Ghent, Belgium). Red ripe tomatoes (*Lycopersicon esculentum* cv Prunus) and orange carrots (*Daucus carota cv* Nerac) were obtained from a local shop in Belgium and stored at 4 °C for 1 day prior to use.

2.2. Sample pre-treatments

Tomatoes and carrots were sorted and washed under running deionized water. Carrots were peeled, cut into cylinders, while tomatoes were cut into thirds. The pieces were vacuum-packed in low density polythene bags. To prevent enzymatic reactions during processing and storage, tomatoes were blanched at 95 °C for 8 min (Kebede et al., 2014). Carrots were pre-treated at 95 °C for 20 min in a water bath (Haak W15 DC-10, Germany) in order to facilitate the softening of the cell wall as a result of β-eliminative depolymerisation of pectin (Sila, Smout, Elliot, Loey, & Hendrickx, 2006). The blanched plastic bags were immediately cooled in ice water, frozen in liquid nitrogen and stored for 3 days at −40 °C until puree preparation.

2.3. Low fat puree preparation

The pre-treated tomato and carrot samples were thawed overnight at 4 °C. The pre-treated tomato pieces were blended (Waring Commercial, Torrington, CT, USA) for 1 min and then sieved (pore size 1.0 mm) to remove the seeds and the excess skin while the pre-treated carrot pieces were mixed with deionized water in a 1:1 ratio and then blended using the same conditions previously described. On the one hand, to the carrot puree, extra virgin olive oil (EVOO) (5%, w/w) was added and the mixtures blended (Waring Commercial, Torrington, CT, USA) further for 10 s. The carrot puree/oil mixture was then high pressure homogenized (Panda 2K, Gea Niro Soavi, Parma, Italy) at 100 MPa over one cycle for matrix disruption to aid carotenoid release and stabilize the puree/oil mixture. On the other hand, the tomato puree was first high pressure homogenized at 100 MPa during one cycle followed by the addition of EVOO (5%, w/w). The tomato puree/oil mixture was blended for 10 s and then further high pressure homogenized using the same conditions previously described.

2.4. Thermal processing

The thermal treatment was carried out in a static steriflow pilot retort (Barriquand, Paris, France). The thermal treatment was done simultaneously for both low fat tomato and carrot purees. Glass jars, (100 mL volume, 95 mm height, and 45 mm diameter) were filled with 90 ± 0.5 g of the homogenized puree/oil mixtures, from here on referred to as simply puree, and closed with metal lids. The glass jars were loaded into the retort and sterilized at a process temperature of 117 °C to achieve an F_0 value of 5 min, with a holding time of 29.9 min. Temperature profiles in the retort and at the coldest point within the product were recorded using type T thermocouples (Ellab, Hillerod, Denmark). Following the thermal treatment, glass jars were immediately cooled in an ice bath.