Food Research International xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Food Research International

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

Review

Effect of cooking on olive oil quality attributes

Carla S.P. Santos, Rebeca Cruz, Sara C. Cunha, Susana Casal *

REQUIMTE, Serviço de Bromatologia e Hidrologia, Faculdade de Farmácia, Universidade do Porto, Rua de Jorge Viterbo Ferreira, 228, 4050-313 Porto, Portugal

ARTICLE INFO

Article history:
Received 1 March 2013
Received in revised form 15 April 2013
Accepted 19 April 2013
Available online xxxx

Keywords:
Olive oil
Thermal processing
Lipid degradation
Antioxidants
Domestic cooking

ABSTRACT

Virgin olive oil consumption, as final seasoning or within cooked foods, is increasing worldwide, mainly due to its recognized nutritional benefits. However, the maintenance of its quality and health attributes after thermal processing is frequently questioned. The aim of this article was to provide a careful review of published studies on the assessment of olive oil thermal processing, in order to ascertain the optimal settings for maximization of olive oil quality, while delaying the onset of oxidation products with detrimental health impacts.

Through the selection of a particular olive grade, such as extra-virgin, virgin or refined olive oil, distinct starting compositions may be achieved, particularly regarding bioactive and antioxidant compounds, with a direct effect on thermal performance and nutritional value of cooked foods. Furthermore, different cooking practices, from common frying to boiling and including microwave cooking, along with operating conditions, as time, temperature and food amounts, undoubtedly modify the olive oil chemical profile.

According to the compiled studies, in order to preserve virgin olive oil bioactive components heating time should be reduced to the minimum. Nevertheless, olive oil performance under prolonged thermal processing is usually equal or superior to other refined vegetable oils, due to its balanced composition regarding both major and minor components. However, as most of its bioactive components, including phenolic compounds, are gradually loss, it is economically advantageous to use lower olive oil grades and frequent replenishment under prolonged thermal processing. Future studies dealing with thermal degradation paths of minor olive oil components and their implication in human health will be of particular value to further clarify this issue.

Contents

1. Introduction

Originally limited to the Mediterranean regions, where olive oil still remains as the main source of external fat, *Olea europaea* L. tree cultivation and olive oil consumption are expanding to other countries in Northern Europe, as well as United States, Argentina, Chile, Mexico and Australia, mainly as a result of its sensorial attributes and potential health benefits (Boskou, 2009; García-González, Aparicio-Ruiz, & Aparicio, 2008; Gustone, 2002).

Abbreviations: CFAM, cyclic fatty acid monomers; EVOO, extra-virgin olive oil; FFA, free fatty acids; HOSO, high-oleic sunflower oil; IOC, International Olive Oil Council; MUFA, monounsaturated fatty acids; OO, olive oil; PAV, *p*-anisidine value; PUFA, polyunsaturated fatty acids; PV, peroxide values; ROO, refined olive oil; TAG, triacylglycerols; TPC, total polar compounds; VOO, virgin olive oil.

* Corresponding author. Tel.: +351 220428638; fax: +351 226093390.
E-mail address: sucasal@ff.up.pt (S. Casal).

0963-9969/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.foodres.2013.04.014

Table 1
Commercial olive oil categories classified according to their free fatty acid percentage (adapted from Commission Regulation (EU) no. 2568/91; Codex *Alimentarius*, 1981 and IOC, 2013).

Category	Free fatty acids (% of oleic acid)		
	Commission Regulation (EU) no. 2568/91[a]	Codex *Alimentarius*	IOC
Extra virgin olive oil	≤0.8	≤0.8	≤0.8
Virgin olive oil	≤2.0	≤2.0	≤2.0
Refined olive oil	≤0.3	≤0.3	≤0.3
Olive oil	≤1.0	≤1.0	≤1.0

IOC — International Olive Oil Council.
[a] Including amendments.

Olive oil is usually obtained by cold-pressing of olive fruits, followed eventually by washing with water, filtering and centrifugation. In comparison with other common vegetable oils, obtained by solvent extraction and further submitted to diverse refining processes, this virgin olive oil (VOO) retains much of the original fruit components. Therefore, while most marketed vegetable oils are mainly triacylglycerol (TAG) mixtures, olive oil presents other natural fruit components, as pigments, phenolic compounds and volatile compounds. In addition to the health benefits of a rich monounsaturated fat, increasingly documented in the literature, the presence of these minor compounds enforces an added value to olive oil, increasing its potential bioactivity (Stark & Madar, 2002; Waterman & Lockwood, 2007).

Several olive oil grades are commercially available. Its classification is usually based on sensorial attributes and chemical parameters that give a general overview on its quality and authenticity. These characteristics, namely the free fatty acids (FFA) as described in Table 1, are regulated by several organizations, including the European Commission itself, the International Olive Oil Council (IOC), or the Codex *Alimentarius* established by the Food and Agriculture Organization of the United Nations and the World Health Organization.

Extra-virgin olive oil (EVOO) and VOO are the most prized olive oil grades, being consensual that their quality attributes are maximized when consumed without being previously subjected to any thermal treatment. Therefore olive oil should be preferably added as final seasoning in fresh salads, soups, or more elaborated dishes. Still, when olive oil is used as the cooking base, as in roasting, sautéing (pan-frying), stir-frying, or even deep-frying, thermal effects occur (Boskou, 2009; Waterman & Lockwood, 2007). Besides, in opposition to other refined vegetable oils, these effects will also disturb the minor olive compounds. Several authors have addressed this issue, in particular the heating effect on olive oil nutritional and biological properties. Such knowledge is essential if one intends to know the adequate temperatures for each olive oil category and processing method, the interaction with the food under cooking, the adequate rejection time or the shelf-life of the processed food, aiming the maintenance of the original nutritional features of crude olive oil.

The present review focuses on the most important studies dealing with olive oil heating, under laboratorial simulation or, preferably, under real cooking conditions, while attempting to understand adequate processing conditions to preserve its quality and to reduce hazard formation. Moreover, the current work identifies those issues that require further research to reinforce olive oil correct use and to potentiate its health benefits.

2. Olive oil composition

In order to understand olive oil behavior under thermal processing conditions, it is fundamental to address some considerations into its chemical composition. In a brief way, as this is not the subject of the present review, some key points must be mentioned. First, olive oil is among the vegetable oils with higher monounsaturated fatty acids (MUFA) in its composition, being therefore less prone to oxidation than those with higher polyunsaturated fatty acid (PUFA) content. Second, VOO are not subjected to any refining process, keeping important olive fruit components, namely phenolic compounds (e.g. hydroxytyrosol, tyrosol and oleuropein), pigments (e.g. chlorophylls), hydrocarbons (e.g. carotenes and squalene), sterols, phospholipids, mono- and diglycerides, fatty alcohols, waxes, and diverse aroma compounds, all with relevant functions in olive oil stability and flavor. Third, olive oil composition is dependent on several parameters including olive variety, edaphoclimatic conditions, harvesting period and technique, fruit ripening degree, leaf removal, extraction system, etc. (Firestone, 2005; Frankel, 2011; Gustone, 2002; Pellegrini & Battino, 2006), making each olive oil batch unique, and increasing the difficulties when attempting to standardize experimental conditions.

Compositional changes in the olive oil after thermal processing are expected. The most common degradations include TAG hydrolysis and polymerization, fatty acid and sterol oxidation, *Maillard* reactions with food components, among others. These reactions are common to all vegetable oils, each one with particular rates and susceptibilities, and are generally used to predict fat degradation (Warner, 2002). Therefore, the most usual parameters when testing vegetable oil thermal behavior include physical measurements (color, foam, density, etc.) and several chemical indicators such as FFA, polymerization degree, saturated/unsaturated fatty acid ratios, tocopherol and phenolic degradation.

Apart from the loss of beneficial substances during thermal treatment, a great concern regarding new formed compounds under thermal stress, including oxidized fatty acids and sterols or TAG polymers, and their possible impact on human health is rising. Nevertheless, due to its richness in other components than fatty acids, VOO represent a complex pool of possible thermal reactions, including degradation and interactions of those aforementioned substances.

The present review will focus on the behavior of the most important olive oil components under thermal processing, including fatty acids and several vital minor compounds. When available, comparisons with other vegetable oils will be established.

3. Cooking with olive oil

Olive oil, similar to other vegetable oils, is used in deep-frying, pan-frying, roasting, microwave cooking, etc. (Boskou, 2009; Waterman & Lockwood, 2007). Each thermal processing type has particular characteristics, namely regarding temperature and confection time. Tables 2 and 3 compile several studies with olive oil cooking, grouped by processing method. Within each group, real and simulated cooking are included and compared, being supported by the analytical parameters chosen by the authors to evaluate olive oil performance.

3.1. Frying

Frying is one of the oldest methods of food preparation. It improves the sensory quality of food by formation of aroma compounds, attractive color, crust and texture, all highly appreciated by the consumers. However, the high level of incorporated fat is an undesirable outcome, increasing caloric intake (Echarte, Ansorena, & Astiasaraän, 2003; Pedreschi, 2012).

Due to the high temperature and prolonged timed used on repeated frying, the oils are progressively degraded by a complex series of chemical reactions including oxidation, hydrolysis, and polymerization. These reactions, however, are not equivalent for all the vegetable oils, and there is a particular concern regarding olive oil since its bioactive attributes might be lost during this process, despite being highly resistant to thermal oxidation.

The most common frying methods are deep-frying, being the food totally immersed in hot oil, and pan-frying, when the food is cooked in a pan with little amounts of oil (Bognár, 1998; Boskou, Salta, Chiou, Troullidou, & Andrikopoulos, 2006; Sioen et al., 2006). Following consumer's awareness to reduce fat intake, several electrical cooking systems are being developed, aiming to achieve products similar to the