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Review

Quality and shelf life of tree nuts: A review

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ABSTRACT

The global market for tree nuts is growing rapidly with trade in excess of $US32 billion annually. Tree nuts have a high oil content and fatty acid composition that can render them susceptible to oxidative rancidity and rapid deterioration. In spite of their global importance, there is limited information on optimal storage conditions and shelf lives of many species of tree nut. This review explores current knowledge of the major factors that influence the shelf life of tree nuts. Storage conditions greatly influence the quality and shelf life of tree nuts. Tree nut species differ in their storage requirements because of their varying oil and fatty acid compositions. In general, nuts with high levels of monounsaturated fatty acids are more stable and less susceptible to oxidative rancidity than nuts containing high levels of polyunsaturated fatty acids. Temperatures ranging from 4 to 15 °C, kernel moisture content around 2.5%, relative humidity of about 40–60%, oxygen concentration less than 2.5%, and dark conditions are ideal storage conditions for most tree nuts. Harvesting time, cultivar and storage of nuts either as nut-in shell or as kernel also affect the quality and shelf life of nuts. There is a need for tree-nut industries to derive universal rancidity indicators for quality control. Optimised storage conditions will provide the best nutritional quality and health benefits of tree nuts for consumers.

1. Introduction

Tree nuts are an economically important food product with an annual global trade in excess of $US32 billion (INC, 2017). Tree nuts have a range of benefits in human health (Brufau et al., 2006; Bolling et al., 2011; Vadivel et al., 2012; Moreda-Piñeiro et al., 2016). They are rich sources of macronutrients such as proteins, carbohydrates and fats, and micronutrients such as potassium, copper, calcium, magnesium, phosphorus, iron and sodium (Nanos et al., 2002; Ayadi et al., 2006; Venkatachalam and Sathe, 2006; King et al., 2008; Bai et al., 2018; Gama et al., 2018a, b). They also contain significant amounts of fibre and vitamins such as vitamins C and E (Savage, 2001; Kornsteiner et al., 2006; Yang et al., 2009). In addition, tree nuts contain antioxidants such as flavonoids, tocopherols, polyphenols and squalene (Maguire et al., 2004; Ryan et al., 2006; Chen and Blumberg, 2008; King et al., 2008; Yang et al., 2009). The popularity of nuts as healthy snack foods is growing and nuts can also be incorporated as baking and cooking ingredients (Curb et al., 2000; Brufau et al., 2006; Griel et al., 2008). The most popular tree nuts globally include almond, Brazil nut, cashew, hazelnut, macadamia, pecan, pine nut, pistachio and walnut (Sabaté et al., 2006; Alasalvar and Shahidi, 2009).

The chemical composition of tree nuts, and differences in the concentrations of individual chemical compounds, determine their shelf life (Venkatachalam and Sathe, 2006; Bakkalbaşı et al., 2012). Shelf life is the length of time that a food, drink or medicine remains fit for sale or consumption (Irtwange and Oshodi, 2009). Shelf lives of products in the food industry are provided as `use by` or `best before` dates to ensure food safety and eating quality. Shelf life of nuts is particularly important because nuts are highly susceptible to deterioration (Kashani Nejad et al., 2003; Christopoulos and Tsantili, 2015; Walton et al., 2017). Quality and shelf life are linked inextricably as shelf life is determined by changes in quality (Mexis et al., 2009a, b; Bakkalbaşı et al., 2012). Conditions to which the nuts are exposed before and after harvest can affect their physicochemical composition, leading to quality loss and reduced shelf life (Kazantzis et al., 2003; Walton and Wallace, 2009, 2010; Raei et al., 2010; Ghirardello et al., 2013). Shelf life is determined mainly by oxidative changes and, to a lesser extent, by hydrolytic reactions that occur within the nut during storage (Zajdenwerg et al., 2011). Shelf life studies are very important in the food industry because reduced shelf life has direct impacts on financial returns and human health (Venkatachalam and Sathe, 2006; Gerez et al., 2010; Zajdenwerg et al., 2011). Acceptable limits for food quality parameters are used to define the shelf life of nuts, typically based on values beyond which the kernels are perceived as inedible by

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consumers (Mexis and Kontominas, 2009b; Mexis et al., 2009b; Bakkalbaşı et al., 2012). Previous research on nut quality has focused mainly on setting acceptable quality standards for edible oils while there has been relatively little synthesis of research on the shelf lives of tree nuts. The aim of this paper is to review factors that affect the shelf life of nuts, as measured by changes in kernel quality parameters.

1.1. Kernel oil composition

Tree nuts have a high oil content but they contain healthy compounds such as beneficial fatty acids and phytosterols (Kaijser et al., 2000; Miraliakbari and Shahidi, 2008a; Robbins et al., 2011; Christopoulos and Tsantili, 2015; Yildirim et al., 2016). Macadamia kernels have the highest oil content of about 77% whilst chestnut kernels have the lowest oil content of 3% (Ebrahem et al., 1993). Polyunsaturated fatty acids such as linoleic acid and α-linolenic acid are essential fatty acids that reduce the incidence of diabetes and coronary heart disease (Virtanen et al., 2014). The unsaturated fatty acid content of tree nuts makes them a suitable substitute for many high-fat foods because of these heart-related health benefits (Curb et al., 2000; Garg et al., 2003; Ros and Mataix, 2006; Griel et al., 2008). For example, groups of people subjected to a macadamia diet high in monounsaturated fat or a moderately low-fat diet for 30 days both had lower cholesterol and low-density lipoprotein cholesterol (LDP-C) than another group consuming a typical American diet (Curb et al., 2000). The antioxidants in tree nuts are also beneficial in the human diet (Blomhoff et al., 2006; Yang, 2009; Yang et al., 2009; Vinson and Cai, 2012). Pistachios, walnuts and chestnuts have particularly high levels of antioxidants (Blomhoff et al., 2006), which help reduce cholesterol levels and the likelihood of cardiovascular diseases (Yang et al., 2009; Tsantili et al., 2011).

The unsaturated fatty acids in tree nuts make them nutritionally valuable but they also make them prone to autoxidation and reduced shelf life (Koyuncu, 2004; Ghirardello et al., 2013; Nkwonta et al., 2016). However, their high levels of antioxidants and tocopherols may help in preventing oxidation of nut oil lipids, delaying oxidative rancidity and increasing their shelf life (Zacheo et al., 2000; Alasalvar et al., 2003; Martínez et al., 2013). Antioxidant levels can therefore be used to determine the oxidative stability and shelf life of edible oils (Kamal-Eldin, 2006; Maestri et al., 2015).

1.2. Lipid oxidation and oxidative rancidity in nuts

The storage conditions of nuts greatly affect their chemistry, composition and eating quality (Mexis et al., 2009b; Bakkalbaşı et al., 2012; Phatanayindee et al., 2012). Changes in quality during the storage of kernels are generally caused by lipid oxidation, and the initial stages of lipid oxidation are characterised by the production of hydrogen peroxides (Kashani Nejad et al., 2003; Raisi et al., 2015). Concentrations of hydrogen peroxides determine the storage stability of edible oils and are quantified as peroxide values (Kashani Nejad et al., 2003; Ajith et al., 2015; Tavakolipour, 2015). Peroxide values are used as a classic indicator of oxidative rancidity of fats and oils (Severini et al., 2000; Ozkan et al., 2007; Bakkalbaşı et al., 2012; Ajith et al., 2015; Raisi et al., 2015). Acceptable peroxide values vary widely in the literature despite being considered an important indicator of tree nut quality (Table 1). Peroxide values depend on cultivar, harvest time, delaying of storage after harvest, ecological conditions, cultural management during the growing season, and handling procedures after harvest.

Free fatty acid levels are another major quality parameter of edible nuts and oils. Enzymatic lipid hydrolysis produces free fatty acids and is driven by a reaction between moisture and oil (Phatanayindee et al., 2012; Ling et al., 2014). Free fatty acids in edible oils, therefore, indicate lipid hydrolysis whilst peroxide values indicate lipid oxidation (Maskan and Karataş, 1998; Buransompob et al., 2003; Gecgel et al., 2011). However, there is often a strong positive correlation between free fatty acids and peroxide values (Christopoulos and Tsantili, 2015). Levels of free fatty acids of tree nuts need to be monitored carefully prior to and during storage because a change in the levels of free fatty acids is an indication of diminishing nutritional quality and shelf life of nuts (Arena et al., 2013; Christopoulos and Tsantili, 2015).

Lipid oxidation also produces secondary products, such as carbonyl compounds, malonaldehyde, other aldehydes, hydrocarbons, ketones and furans, that are indicators of food quality deterioration (Gray, 1978; Frankel, 1987; Mexis and Kontominas, 2009b, 2010; Phatanayindee et al., 2012). Hexanal and nonanal are the predominant volatile aldehydes produced by many nuts as secondary products of lipid oxidation (Miraliakbari and Shahidi, 2008b). Hexanal and nonanal are products of oxidation of linoleic acid and oleic acid, respectively (Shahidi and Pegg, 1994; Ramírez et al., 2004). Propanal is another volatile compound produced by nuts and oils during lipid oxidation (Miraliakbari and Shahidi, 2008b; Van Ruth et al., 2000). Hexanal is the most-commonly used volatile secondary product of lipid oxidation to determine deterioration of food products and estimate their shelf life (Mexis et al., 2009a; Leufven et al., 2010; Aceña et al., 2011; Bakkalbaşı et al., 2012; Ghirardello et al., 2016). Hexanal content of walnuts, for example, increases with oxidative rancidity and is therefore used as an important measure of nut quality (Jensen et al., 2001; Mexis et al., 2009a). Oxidation of edible oils reduces oil quality and human health benefits and so it is important to minimise lipid oxidation (Shahidi and Zhong, 2010). Sensory panels dislike or reject nuts that have high hexanal levels and high peroxide values, with the high values typically indicating lipid oxidation and rancidity (Mexis and Kontominas, 2009a; Mexis et al., 2009a; Mexis and Kontominas, 2010; Bakkalbaşı et al., 2012).

Standard acceptable limits for peroxide values, free fatty acids, hexanal content, and other quality parameters have been determined for most edible tree nuts (Table 1). However, large differences exist in maximum acceptable limits of some quality parameters within a nut species; e.g. for macadamia and walnuts (Table 1). These variations are probably due to the differences in cultivars used in the studies (Table 1). More-universal standard values would be useful for quality control throughout the global nut industry.

2. Factors affecting the shelf life of tree nuts

The quality and thus shelf life of tree nuts is affected by both preharvest and postharvest factors. Preharvest factors include inherent nut characteristics, events and cultural management that occur in the orchard during the growing season before harvest. These can include the nut cultivar, orchard practices during production, ecological factors during the growing season and the time of harvest (Trueman et al., 2000, 2002; Koaze et al., 2002; Kazantzis et al., 2003; Walton and Wallace, 2009; Piscopo et al., 2010). Cultural practices such as type of fertiliser and time of fertiliser application are known to affect the quality of nuts (Stephenson and Gallagher, 1989; Stephenson et al., 2002; Paula Silva et al., 2003). Agronomic practices are, however, beyond the scope of this review. Postharvest factors include all operations performed after the nuts have been removed from the tree or the orchard floor, including dehusking, drying, cracking, packaging, storage and transport. Proper postharvest procedures are essential to prevent physical and chemical damage that reduces the quality of the nuts (Walton and Wallace, 2004, 2008, 2010, 2011, 2012; Ghirardello et al., 2013; Ajith et al., 2015; Raisi et al., 2015; Srichamnong and Srzednicki, 2015). Harvesting and postharvest handling techniques can both greatly influence product quality and profitability in the marketplace (Kashani Nejad et al., 2003). One of the most critical postharvest factors that affects shelf life of nuts is storage conditions (Kazantzis et al., 2003; Arena et al., 2013; Walton et al., 2013; Christopoulos and Tsantili, 2015; Raisi et al., 2015; Walton et al., 2017) hence storage conditions will be a major focus of this review.

Quality parameters of pistachios used to determine shelf life include

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