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The influence of pre-harvest factors on the quality of globe artichoke

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ABSTRACT

The globe artichoke, a species native to the Mediterranean Basin, makes a significant contribution to the region's agricultural economy. Its increasing popularity has extended into northern Europe, the Americas and parts of Asia. To an extent, the increased interest in the crop reflects the perceived beneficial health effects of its inclusion in the human diet, flowing mainly from its high content of polyphenols and inulin in the immature inflorescence (also called head or *capitulum*). The accumulation of these compounds, together with the head's appearance and size, is an important determinant of quality at harvest and hence, of consumer preference. The purpose of this review is to collate the state of current knowledge regarding the major pre-harvest factors which affect globe artichoke at harvest quality, including aspects of genotype, the growing environment and crop management. The literature suggests that the at harvest quality of globe artichoke depends on a complex of interactions between this group of factors. In conclusion, this review establishes a departure point for manipulating some of these factors to maximize globe artichoke at harvest quality.

1. Introduction

The globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori = *C. scolymus* L.] is an economically important herbaceous perennial C3 plant species native to the Mediterranean Basin (Mauro et al., 2009). It belongs to the family Asteraceae (ex Compositae). Its production, long limited to its native region, has in the last decades become globally quite widely dispersed, although the bulk of its production remains in the Mediterranean region, which harvests 1.26 Mt of edible product (the immature inflorescence, which is composed of a receptacle surrounded by thickened bracts, and is generally referred to as the *capitulum* or head) per year from some 98 Kha of land. The main producer countries are Italy (43 Kha), Spain (16 Kha) and Egypt (15 Kha) (FAOSTAT, 2012–2014). The crop is currently also grown in the Americas and Asia (Portis et al., 2014).

Globe artichoke plant produces heads with different size: the largest (called as primary head) is formed at the apex of the central stem, while the smaller heads (secondary) develop on the central branches. Depending on cultivar and harvest time, single head range in weight from 120 g to 600 g, and the ratio of edible fraction to the total head weight is 10–18% for the lower part (only receptacle) and about 40% for the internal parts (including receptacle and inner bracts).

The heads were manually harvested when they reached commercial maturity (at this stage the length of the central global flower buds is ≤2 mm) (Mauromicale and Ierna, 2000). They are destined to the fresh consumption or are industrially processed as frozen, cooked and canned product (Ciancolini, 2012). Currently, consumer's needs for added-value fresh products, in terms of quality, convenience, nutritional value and ease of preparation (Colelli and Calabrese, 2009), have increased the industrial production of fresh-cut globe artichoke heads. The heads, as fresh or processed form, are used as ingredient in many typical recipes in the Mediterranean countries.While largely appreciated for its culinary value, due to a balance between bitterness and sweetness, and between fleshiness and tenderness (Di Salvo et al., 2014), its therapeutic properties have also been recognized for many centuries (Coinu et al., 2007; Fantini et al., 2011).

Globe artichoke cultivation and industrial processing also generate a high proportion (nearly 80% of the total biomass) of by-products, among which the stems if properly prepared could be eaten. Such by-products may be used: (i) for the industrial extraction of food additives and bioactive compounds, such as polyphenols and inulin (Ceccarelli et al., 2010a; Christaki et al., 2012; Lattanzio et al., 2009); (ii) as raw material in the green chemal industry for paper-pulp production, biofuels or plant dyes (De Falco and di Novella, 2011); (iii) as a forage (particularly stems and leaves) (Christaki et al., 2012). In addition, flowers contain some proteolytic enzymes that could be used as natural coagulants for cheese making (Amato et al., 2011).

As for many vegetable species, globe artichoke at harvest quality has both a product- and a consumer-dependent dimension (Huyskens-Keil and Schreiner, 2003), in which the interaction between many

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aspects contributes to the overall acceptance of the product (Schreiner et al., 2013). While the intrinsic aspects can be objectively quantified, reflecting its sensory, nutritional and safety properties, the extrinsic ones are less quantifiable, since they are governed by issues of distribution, pricing, communication policies and advertising (Scharf et al., 2009). In the present review, the focus is limited to intrinsic at harvest quality traits.

Some objective criteria applied to quantify the quality at harvest of fresh heads have been established in Europe under regulation EC 1466/2003. The EU marketing standards classify heads into three commercial categories (extra, first and second classes) on the basis of some qualitative traits (*e.g.* calibre, homogeneity) and the presence of any defects or damages. In addition, the heads must be sold entire, hygienically packaged and labelled with information on the cultivation origin (Piazza and Caccioni, 2009). However, these standards ignore other qualitative traits such as flavour and the content of any bioactive compounds. Given the growing consumer-led demand for food providing both nutritional and health benefits, these aspects of quality should not be neglected for heads destined for fresh market. The quality of processed globe artichoke heads depends on several quality indices, among which processing yield, product visual appearance, weight loss, pH, browning proneness and microbiological stability are the most important for this specific crop (Del Nobile et al., 2009).

The nutritional value of globe artichoke is attributable to its low fat content and its high content of minerals, fibre, vitamins and bioactive compounds (Lattanzio et al., 2009; Lutz et al., 2011; Pandino et al., 2011a,b; Petropoulos et al., 2017). The literature suggests that heads are composed on average of 132 g kg^{-1} of dry matter (DM), 760 g kg^{-1} DM carbohydrate, 196 g kg^{-1} DM protein, 20.3 g kg^{-1} DM crude fat and 8.6 g kg^{-1} DM ash (Table 1); they also provide a dietary source of vitamin C, the minerals potassium (K), calcium (Ca), iron (Fe) and zinc (Zn), inulin and various polyphenols (Gil-Izquierdo et al., 2001; Lombardo et al., 2012a; Pandino et al., 2011a,b). It is the inulin (a fructan polysaccharide) and polyphenols which are thought to contribute most to the hepatoprotective, anticarcinogenic, prebiotic and antioxidant activities of globe artichoke extracts (De Falco et al., 2015; Gebhardt and Fausel, 1997; Jimènez-Escrig et al., 2003). The biological role of polyphenols is largely to defend against biotic (bacterial, fungal and viral pathogens) and abiotic (extreme temperature, UV radiation, moisture deficit) stresses, but some of these compounds also contribute to the plant's growth and reproduction (Bravo, 1998). Although not classed as essential in the diet, it is known that a sufficient intake is beneficial to human health and well-being, specifically reducing the incidence of cardiovascular disease and certain forms of cancer (Holst and Williamson, 2008; Martínez-Ballesta et al., 2008). The potential contribution of globe artichoke to dietary polyphenol is significant since the head harbours more polyphenols than do other vegetables (Brat et al., 2006). The predominant class of polyphenol compounds in the head are the mono- and di-caffeoylquinic acids (among which chlorogenic acid and cynarin), along with a range of flavonoids derived from apigenin and luteolin. Abu-Reidah et al. have identified the presence in globe artichoke of over 60 different polyphenols.

Table 1
The proximate composition of globe artichoke head.

	Range	Mean	Reference
Dry matter (DM) (g kg^{-1})	107–169	132	Lombardo et al. (2012a)
Ash (g kg^{-1} DM)	74–105	86	Pandino et al. (2011a)
Crude fat (g kg^{-1} DM)[a]	14.2–25.7	20.3	Petropoulos et al. (2017)
Protein (g kg^{-1} DM)	189–260	196	Pandino et al. (2011b)
Total carbohydrates (g kg^{-1} DM)[a]	725–832	760	Petropoulos et al. (2017)

[a] The values were calculated from those on a fresh matter basis reported by the literature reference.

Inulin represents 18.9–36.2% of head DM (Lattanzio et al., 2009). Variation in its polymerization status influences its water-solubility, thermal stability and prebiotic activity (De Falco et al., 2015). In addition the inulin contributes to the sweetness of the product, while the bitterness of globe artichoke derives from a set of sesquiterpene lactones, dominated by cynaropicrin with a contribution, at lower concentrations, of grosheimin and its derivatives (Cravotto et al., 2005; Fritsche et al., 2002). From a microbiological point of view, the product is considered as a safe food (Lombardo et al., 2015b; Restuccia et al., 2014), because its major post-harvest pathogens [primarily *Sclerotinia sclerotiorum* (white mould) (Marcucci et al., 2010), *Botrytis cinerea* (grey mould) (Larran et al., 2004), and *Verticillium dahliae* (Amenduni et al., 2005)], could be reduced by sanitizing treatments (*e.g.* ozonisation). Moreover due to its morphology, the edible fraction of the head, being internally situated, is protected by several pests.

This review focuses on the effect on quality at harvest of the most important pre-harvest factors, which comprise genotype, the climatic and edaphic environment and the management of the crop. Global aspects of quality at harvest are addressed with a view to bringing together the available literature covering individual and/or specific qualitative traits (Ceccarelli et al., 2010a; Lattanzio et al., 2009; Pandino et al., 2012a).

2. Pre-harvest factors that affect at harvest quality

2.1. Genetic factors

The crop is typically propagated vegetatively (by offshoots, stumps, or dried shoots harvested from commercial fields at the end of the growing cycle), and a substantial level of genetic diversity has been retained both within and between commercial and landrace varieties cultivated in the Mediterranean basin (Mauro et al., 2009) (Fig. 1). The 100–120 known cultivated types have been grouped on the basis of their harvest time ('early' or 'late') and head morphology (shape, colour of the external bracts and presence/absence of spines) (Mauro et al., 2009; Mauromicale, 1987; Rottemberg and Zohary, 1996). Early cultivars are typically autumn-winter crops and continue to produce until around spring, while late ones produce in spring. Porceddu et al. (1976) have suggested four distinct germplasm groups, namely: 1) the 'Spinosi' (for example 'Spinoso di Palermo' and 'Spinoso Sardo'), containing cultivars with long sharp spines on bracts and leaves; 2) the 'Violetti' (for example 'Violetto di Toscana' and 'Nostrano'), with medium-sized violet-coloured heads; 3) the 'Romaneschi' (for example 'Castellamare' and 'Tondo di Paestum'), to which belongs cultivars with spherical or sub-spherical shape; 4) the 'Catanesi' (for example 'Violetto di Sicilia' and 'Violet de Provence'), with relatively small and elongated heads. Another classification is adopted in France, and includes two groups: Breton (with large green heads) and Midi (with smaller pigmented heads) (De Falco et al., 2015). However, the number of commercially important varieties is only twelve (*i.e.* 'Green globe', 'Blanca de Espãna', 'Opera', 'Violetto di Sicilia', 'Violet de Provence', 'Camus de Bretagne', 'Tema', 'Spinoso sardo', 'Opal', Madrigal', 'Romanesco', 'Madrigal'). Apart from these major groupings, many traditional landraces were cultivated in small holdings. They typically yield less than the commercial varieties, but are well suited for specific final uses, tolerant of environmental stress and adapted to a low input farming system (Mauro et al., 2009).

As abovementioned, globe artichoke cultivation is traditionally based on vegetatively propagated cultivars, but the effectiveness of asexual reproduction is limited due to the low rate of multiplication and the build-up of pathogens. For these reasons, during the last decades seed-propagated cultivars were increasingly introduced in the globe artichoke cultivation. Gamic propagation can be performed using open pollinated genotypes, inbreed lines, F1 hybrids and synthetic varieties (Ciancolini, 2012). Among the inbred and open pollinated seed propagated cultivars there are 'Imperial Star', 'Green Globe' and 'Colorado'.