On the natural variability of kernel oil content in almond [Prunus dulcis Mill. DA Webb]: An Overview

El Hassan SAKARa,b,*, Mohamed EL YAMANIB, Abdelali BOUSSAKOURANb, Ahmed ZEROUALc, Saïd GHARBYd, Yahia RHARRABT Ib

a Department of Biology, Faculty of Sciences of Tetuan, Abdelmalek Essaâdi University, Mhannech II. 93002, Tetuan, Morocco.
b Laboratory of Natural Resources and Environment, Polydisciplinary Faculty of Taza, Sidi Mohamed Ben Abdellah University, Morocco.
c Laboratory of Material Engineering and Environment, Department of Chemistry, Faculty of Sciences Dhar El Mahraz Fez, Sidi Mohamed Ben Abdellah University, Morocco.
d Laboratory Biotechnology, Materials and Environment (LBME), Faculty Poly disciplinary of Taroudant, University Ibn Zohr, Taroudant, Morocco

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ABSTRACT
Sweet almonds are widely grown in both northern and southern hemispheres owing to their economic and nutritional values. Almonds consumption is linked to numerous health-promoting properties. From pomological and biochemical points of view, lipids are the major fraction in almond kernels. The majority of almond compositional research has been focused on chemical composition especially the lipidic fraction. Along with its nutritional value, almond fat has many cosmetic and medicinal uses, which arise from kernel lipids biochemical richness including several essential fatty acids and antioxidants such as tocopherols. The increase of almond production globally encourages almond oil production, which in turn push scientists and growers to select higher oil yielding genotypes and cultivars and to assess oil plasticity under various environments. Genotypic and environmental variations of almond oil have not been reviewed before, hence the originality of this review. Peer reviewed literature published in English for almond oil variability confirmed the genotypic dominance in the expression of this parameter with a heritability value of 0.57. Environmental conditions under which almonds are grown account for important variations in kernel oil content. The main environmental factors studied in the literature encompass climatic conditions along with soil moisture. It has been widely reported that moderate water deficit enhances oil accumulation for various commercial cultivars. An inverted effect is observed when soil water deficit become more pronounced. Almond oil content expression is the result of genotypic and environmental variations. Almond oil production must take into account these variations.

1. Introduction:
Almond [Prunus dulcis Mill. DA Webb] is the most important nut globally in terms of production. USA and some countries of the Mediterranean basin are the main producers. Following the latest FAOSTAT’s releases [1], the global production reached 3182902 tonnes of unshelled almond. The Moroccan production (being the 4th worldwide) reached 117270 tonnes.

(* )Corresponding author.
Tel.: +212667642912.
E-mail address: hassan.sc@gmail.com
This production comes from a harvested area of 186255 Ha with an important economic income since the production value exceeds 29 million USD according to FAOSTAT data. Besides, several investigations outcomes indicate that, almond growing, in Morocco as in many areas worldwide, is facing problem adaptations in the context of climate change in terms of dormancy release as outlined in El Yaacoubi et al. (2016) [2] and flowering as evidenced in El Yaacoubi et al. (2014) [3], and El Yaacoubi et al. (2019) [4]. Modern Moroccan orchards are organized in intensive or semi-intensive dominated by several cultivars such ‘Marcona’, ‘Fournat de Brézénaud’, ‘Ferraduel’, ‘Ferrangès’, and ‘Tuono’. These cultivars show a wide range of flowering times with some tolerance to frost, being one of limiting factors in almond growing as previously outlined in Sakar et al. (2017a) [5]. In addition, following Sakar et al. (2019a) [6], ripening time presents significant shift allowing almond growers to stagger harvesting in multi-varietal orchards. In contrast, traditional orchards are characterized by almond seedlings grown on poor and marginal soils with one or several limiting factors as reported in Kodad et al. (2015) [7]. Flowering earliness in these almond seedlings previously studied by Sakar et al. (2019b) [8] subject them to frost risks resulting in poor fruiting. Almond is deemed to be an important fruit tree and cultivated for its kernel, which is the edible part of the nut. Almond kernel is known to be of higher nutritional and economic values (Kodad et al., 2014a; Kodad et al., 2014b; Yada et al., 2013) [9–11]. Almonds can be consumed under various forms: raw, roasted, unblanched, blanched, and incorporated into other products after processing (mostly sliced and slivered almonds). The important nutritive value of almond kernel comes from its high lipid content, which constitutes an important caloric energy source as pointed out in Alasalvar et al. (2020) [12]. A literature review shows that the majority of works on almond composition was devoted to the lipid fraction and its composition, mainly fatty acids as reviewed in several reports (Čolić et al., 2019; Maestri et al., 2020) [13, 14]. In almonds, fats are mainly storage lipids, which are found as intracellular oil droplets (Figure 1). These droplets account for about 1-3 μm of diameter in the cotyledon tissues within kernels [15, 16]. Wide ranges of variability in oil content have been reported for almond from various geographical origins [9, 11, 17–19]. Almond oils are a rich source of fatty acids with the predominance of monounsaturated, mainly oleic acid, polyphenols, vitamins, sterols, lipid-soluble bioactive compounds with large genotypic and environmental variations [9, 10, 19]. Almond oil biochemical richness is behind many nutraceutical and medicinal uses as reviewed in Čolić et al. (2019) [13] and Maestri et al. (2020) [14].

Figure 1. Confocal laser scanning microscopy two-dimensional images of almond oil bodies. The image includes a zoom (top left corner) on one almond oil body showing the protein layer covering the entire surface of the lipid core according to Gallier et al. (2012) [20].

The Codex Alimentarius Commission for Fats and Oils does not describe almond oils since they are produced at a small scale in some countries such as France, Spain, and USA. Besides, owing to numerous health benefits, almond oils have long been used mainly in complementary medicine circles but also as an edible oil mostly in vegetable dips and as a salad dressing as evidenced in reviews compiled by Čolić et al. (2019) [13] and Maestri et al. (2020) [14]. Almonds production is increasing worldwide with emergency of some new specialty oils encourages searching for almond cultivars and genotypes of higher oil content under different environments. The main common ways for obtaining almond oils are the following: extraction via solvents, extraction through supercritical fluids (CO2), and pressure systems, which consist of hydraulic and screw presses as discussed in Ronceró et al. (2016) [21]. When comparing these extraction systems, the worst oil quality but the higher industrial performance is achieved using solvents. In this case, the obtained oils are not virgin oils owing to the chemical solvents involved. Oils obtained via supercritical fluid extraction are of good quality, but at a very high cost. In this context, press extraction systems become the best alternative to achieve oils of higher quality with affordable costs as reviewed by Ronceró et al. (2016) [21]. To achieve a good oil recovery during extraction, a set of parameters must be controlled including kernel moisture content and temperature. These parameters impact also on both oil oxidative stability and its chemical composition as demonstrated by Martínez et al. (2013) [22]. A synthesis of peer reviewed works on extraction systems lets conclude that the technique used for extraction impact on the amount of oil recovered and related chemistry. Almond oil end-use requires a good quality without chemical residues.
The best one is that allowing better oil recovery while maintaining a good quality. Such inappropriate conditions during extraction could lead to active compound degradation or inactivation. To the best of our knowledge, there is no detailed information regarding genotypic and environmental variations of kernel oil content in almond. Therefore, the objectives of review article were: (i) to highlight oil content in the main almond cultivars commercially grown in the potential producers worldwide and (ii) to synthesize and compare the effects of both factors: genotype and environment in determining oil content using the peer reviewed literature.

2. Genotypic effects on almond oil content:
Several research works were devoted to assess oil content and its related physicochemical traits in wide range of cultivars and genotypes grown across various pedoclimatic conditions in both northern and southern hemispheres. As mentioned in Table 1, wide ranges of oil content are reported for the investigated genetic pool. Following data presented in this Table, oil content ranged from 20% in some Iranian genotypes to 79% in Turkish genotypes. Moroccan seedlings and cultivars show large variations from 48.6 to 67.5% expressed in dry basis as reported in evidenced in Table 1. Also, it has been demonstrated through statistical analyses that all factors (genotype, growing season, and growing area) and their interactions impact significantly oil content, at least, at 5% as probability level. However, the analysis of variance components in several reports such as Kodad et al. (2014a) [9] and Kodad & Socías i Company (2008) [17] shows that genotypic effect was the main variability source indicating that oil content is genetically dependent. These results are consistent with Font i Forcada et al. (2011) [23]. These authors investigated genetic variability of the chemical components including oil content in almond kernels harvested from 200 Spanish genotypes. By using variance components and heritability estimates, they found a higher heritability value (h² = 0.57) for oil content. Higher heritability as for oil content indicates an additive gene action as discussed in Yao and Mehlenbacher (2000) [24] and will be less impacted by the environment under which almonds are grown. From a breeding point of view, the selection in traits with higher heritability will be very effective, thus being easier to improve. Previous works have reported significant effects of genotype on oil content in genotypes and commercial cultivars released thanks to several international breeding programs. As evidenced in Table 1, oil content from European releases seems to be higher than that of American ones. In Morocco, which is ranked, as one of the potential almond producers, almond oil content values found in the main commercially grown cultivars as reported in Sakar et al. (2017b) [25] are comparable to oil content from seedling almonds as reported by Kodad et al. (2013) [26], but slightly higher than wild almond from Iran as highlighted by Kiani et al. (2015) [27] and Sorkheh et al. (2016) [18]. Kodad et al. (2014a) [9] investigated oil content and related fatty acids in 44 cultivars belonging to the Spanish genebank over three growing seasons, these authors found slightly higher values (50.58–64.95% DM) of oil content as compared to North American cultivars, which show a range of variability of 44.7–54.1% FM as pointed out by Yada et al. (2013) [11]. These results were confirmed by a recent investigation involving several Spanish cultivars by Rabadán et al. (2019) [28], who concluded the suitability of these cultivars for oil production thanks to their higher oil content. Almonds from the southern hemisphere especially in Australia and Argentina display higher oil content. Some areas in these regions seem to be under Mediterranean-like climate, which is more suitable for almond growing. Australian and Argentinean orchards are based mainly on commercial cultivars released thanks to European and North American breeding programs as discussed in Maestri et al. (2015) [29] and Zhu et al. (2015) [19]. It is worthy to highlight the fact that oil content changes as a function of developmental stage as observed by Zhu et al. (2017) [30] for cv ‘Nonpareil’ grown in Australia in such a way that the maximum of oil level was reached at 165 days after full blooming.

3. Environmental variations:
It is well documented that environments, under which almonds are grown, impact pomological traits as demonstrated in our previous works [74–76]. Indeed, despite the genetic control of oil content as discussed in the previous section, environmental factors (mainly soil and climate) account for a large extent in the variation of this parameter. Previously published findings report significant effects of these uncontrolled environmental conditions as reported in Yada et al. (2013) [11], Kodad et al. (2014a) [9], and Rabadán et al. (2019) [28]. From a statistical point of view, genotype by environment interactions show significant and higher extent as for genotype in determining oil content in almond [9, 17]. A biological explanation of this interaction is a given cultivar/genotype changes its behavior from an environment to another in terms of oil content.
Oil content varies significantly among growing seasons and growing areas. These outcomes are confirmed via research works in almonds and olives such as Zhu et al. (2015) [19], Sakar et al. (2017b) [25], and El Yamani et al. (2020) [77]. These differences could be assigned to pedoclimatic conditions varying from an environment to another as discussed in Yada et al. (2013) [11]. Furthermore, among the most important genotype by environment interactions: cultivar × growing area, cultivar × growing season, and cultivar × growing area × growing season. This indicates a difference in genotypic behavior towards various environments (growing areas and seasons).
There are several works, in the peer reviewed literature, devoted to assess almond oil under various environments. In this background, in a work involving three cultivars conducted under irrigated and drought conditions, Nanos et al. (2002) [37] reported that dry-grown almonds in Greece present higher values of oil content. Similar trends were observed in some commercial cultivars grown under various levels of water stress in Australia and Spain as reported in Zhu et al. (2015) [78], Lipan et al. (2019) [79], and Lipan et al. (2020) [80]. Based on these works, there is a consensus that a moderate water stress allows an increase of oil content, where as stress tends to be more severe, almond lipidic fraction tends to decrease. As discussed in Wijewardana et al. (2019) [81], an increase of oil content under moderate water deficit could be assigned to the overexpression, by twofold than that in control, of one of the genes encoding phospholipid diacylglycerol acyltransferase as a key enzyme in plant storage lipid accumulation. Besides, it is worthy to highlight that environmental factors along with genotype determine oil stability and its chemical composition via phenolics and pigments synthesis [82, 83].

Table 1: Range of variability of almond oil content as compiled by Kodad (2017) [31] with slight modifications. a = Fresh weight basis and b = Dry weight basis.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Range of variability (%)</th>
<th>References</th>
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<tbody>
<tr>
<td>Afghanistan</td>
<td>43–66.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>[32, 33]</td>
</tr>
<tr>
<td>Argentina</td>
<td>63–66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[34]</td>
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<tr>
<td></td>
<td>48–57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>[29]</td>
</tr>
<tr>
<td>Australia</td>
<td>53.1–63.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[19]</td>
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<tr>
<td>Bulgaria</td>
<td>63.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[35]</td>
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<tr>
<td>China</td>
<td>49.26–53.76</td>
<td>[36]</td>
</tr>
<tr>
<td>Greece</td>
<td>55.6–61.1</td>
<td>[37]</td>
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<tr>
<td>Iran</td>
<td>20.19–62&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[27, 38–40]</td>
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<tr>
<td>Italy</td>
<td>31.16–66.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[34, 41]</td>
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<td></td>
<td>42–47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>[42–44]</td>
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<tr>
<td>Morocco</td>
<td>48.6–67.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[25, 26, 45]</td>
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<td>Portugal</td>
<td>58.33–63.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>[34]</td>
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<td></td>
<td>44–59&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[46–48]</td>
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<td>36.30–62.86&lt;sup&gt;a&lt;/sup&gt;</td>
<td>[49–52]</td>
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<td>Spain</td>
<td>40–67&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[10, 17, 34, 53–60]</td>
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<td>56.1–59.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[61]</td>
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<td>46.2–63.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[62–67]</td>
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<tr>
<td></td>
<td>36.7–79&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[68]</td>
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<td>USA</td>
<td>35–66&lt;sup&gt;a&lt;/sup&gt;</td>
<td>[58, 69–73]</td>
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4. Conclusions:
In this review, we reported about almond oil content and its genotypic and environmental variations. The analyzed peer reviewed literature shows wide variations in terms of oil content in several commercial cultivars and genotypes grown worldwide. However, the main variability source was genotype with a higher heritability value, which makes the selection in this trait with higher heritability very effective, and therefore easier to improve from a breeding point of view. In contrast, oil production should take into account unpredictable environmental variations. In this regard, as discussed in above, some factor such as moderate water stress could improve kernel oil content. Other factors such as phenological stage at which almonds are harvested, fertilizers application, and others agronomic practices must be considered.

References


