1 INTRODUCTION

Cereals constitute the main source of food; they are also nutraceutical and therapeutical agents as they contain various types of beneficial elements such as starch, proteins, fiber, lipids and other medicinal compounds. Besides, they have also been found to contain a wide range of chemical substances with a high antioxidant activity. Among such cereals we can cite oats which belong to the Poaceae family (Table 1). Wild oats are diploid, but those cultivated are hexaploid with an estimated 1C genome size of 13.23 pg, corresponding to about 13000 Mbp. The common oat (Avena sativa L.) is an allohexaploid (2n = 6x = 42) crop species. Furthermore, Flander et al. showed that the whole oat grain contains many of these nutritional compounds, including minerals, proteins, fiber, lipids, unsaturated fatty acids, vitamins and phytochemicals. The common Avena sativa L. is the most important cultivated oat and it is also the most unusual compared with other cereal grains due to the storage of high amounts of oil in the endosperm which can be up to 90% of the total grain oil. Plants with oilseed represent many versatile commodities due to their use essentially in food, feed and medicine. The demand for these important agriculture crops is increasing since they constitute a renewable alternative to fossil oil. Unlike other cereals which accumulate oil in the embryo, scutellum, and aleurone layer, oat oil (Avena sativa L.) in kernels is deposited mostly in the same starch-accumulating endosperm cells. Therefore, several reports focused on oat endosperm as a desirable model tissue to study carbon allocation into oil, such as carbon partitioning between oil and carbohydrates or preferred carbon precursors for lipid labelling in the heterotrophic endosperm.

Oats (Avena sativa L.) are cultivated for grain, fodder, straw, and feed over more than 9 million hectares globally. This important multi-purpose cereal is widely grown compared with other cereal grains due to the storage of high amounts of oil in the endosperm which can be up to 90% of the total grain oil. Plants with oilseed represent many versatile commodities due to their use essentially in food, feed and medicine. The demand for these important agriculture crops is increasing since they constitute a renewable alternative to fossil oil. Unlike other cereals which accumulate oil in the embryo, scutellum, and aleurone layer, oat oil in kernels is deposited mostly in the same starch-accumulating endosperm cells. Therefore, several reports focused on oat endosperm as a desirable model tissue to study carbon allocation into oil, such as carbon partitioning between oil and carbohydrates or preferred carbon precursors for lipid labelling in the heterotrophic endosperm.

Abstract: Oat is a promising plant for the future. It is edible and beneficial thanks to its nutritional, medicinal and pharmaceutical uses and, hence, recognized to be useful for a healthier world. The assessment of the vital functions of oat components is important for industries requiring correct health labelling, valid during the shelf life of any product. Oil, enzymes and other biomolecules of nutraceutical or dietary usage from oats would be valorized for this purpose. Although oats have a unique and versatile composition including antioxidants and biomolecules indispensable for health, they are undervalued in comparison with other staple cereals such as wheat, barley and rice. Furthermore, oats, apart from maize, comprise a high oil content used for a wide range of beneficial purposes. In addition, they contain beta glucan that has proven to be very helpful in reducing blood cholesterol levels and other cardiovascular diseases risks. In fact, there is diversity in the composition and content of the beneficial oat components within their genotypes and the different environmental conditions and, thus, oats are amenable to be enhanced by agronomic practices and genetic approaches.

Key words: oat, lipids, antioxidant constitutes, biomolecules, industrial applications
as a spring crop mostly in cool moist climates. It can also be adapted to autumn sowings as mentioned by Sánchez-Martín et al.\textsuperscript{11} who assessed the adaptation of 32 modern oat cultivars from different origin and usage to the autumn sowings under Mediterranean agroecological conditions, including Tunisia, Spain, Egypt and Palestinian Territories characterized by hot and dry weather. Their study helped in the easy breeding of adaptive oat within the Mediterranean area.

Oats are nutritious palatable foodstuffs responsible for the supply of carbohydrates, mainly in the form of starch with a considerable amount of lipids as well as a reasonable level of much of our micronutrients intake (Table 2).

Oats are produced on a global scale. The Food and Agriculture Organization (FAO)\textsuperscript{10} indicated that the global oat production in 2012 was 19.6 megatons, while The US Department of Agriculture\textsuperscript{15} announced a preliminary figure of a global oat production in 2013/2014 of about 23.6 megatons, which means a 10.6\% increase compared with the 2012/2013 harvest. In Tunisia, oats are the most important livestock feed\textsuperscript{16}, and the indication of the FAO\textsuperscript{10} estimated an oat production of 1700 tons in Tunisia with more than 4000 hectares harvest area in 2013.

Oats have preferred regions for growth. They favour temperate regions, especially Russia, North America and Mid to North of Europe that comprise the major oat production regions (Fig. 1). Hence, moderate temperature and day length are the optimum growth conditions. Among cereals, oats have the advantage of tolerating acidic soils and wet weather more effectively; they are also relatively resistant to foliar diseases and require comparatively fewer fertilizer and pesticide inputs\textsuperscript{17}.

The impact of agronomic systems and environmental factors, including abiotic stressors such as temperature, fertilization and drought/flooding has been assessed on the health-beneficial and nutritive values of oat components\textsuperscript{18}.

Plant pathogens (viruses, fungal infections, etc.) constitute the major threat for oats. They affect negatively both the crop yield and the quality of oat. For example, the barley yellow dwarf virus can significantly reduce crop yield\textsuperscript{19}. Also, the powdery mildew (Blumeria graminis)\textsuperscript{20, 21} and the crown rust (Puccinia coronata)\textsuperscript{22} are the most widespread fungal diseases in the cool, humid regions of Europe and North America, respectively. But, the most fungal infections affecting cereals, in particular oats, are those caused by the Fusarium genus species which are known to produce hazardous mycotoxins such as nivalenol, deoxynivalenol, zearalenone and trichothecenes T-2 and HT-2. These toxins can be responsible for chronic toxicity which can induce apoptosis in the immune system and

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### Table 1  Taxonomic information\textsuperscript{12}.

<table>
<thead>
<tr>
<th>Kingdom</th>
<th>Plantae: plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superdivision</td>
<td>Spermatophyta: seed plants</td>
</tr>
<tr>
<td>Division</td>
<td>Magnoliophyta: flowering plants</td>
</tr>
<tr>
<td>Class</td>
<td>Liliopsida: monocotyledons</td>
</tr>
<tr>
<td>Order</td>
<td>Cyperales</td>
</tr>
<tr>
<td>Family</td>
<td>Poaceae: grass family</td>
</tr>
<tr>
<td>Genus</td>
<td>Avena: oat</td>
</tr>
<tr>
<td>Species</td>
<td>A. sativa: common oat, A. byzantina, A. fatua, A. diffusa, A. orientalis</td>
</tr>
</tbody>
</table>

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### Table 2  Oatmeal nutritional composition*.

<table>
<thead>
<tr>
<th>Component</th>
<th>Oatmeal (100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td>Kcal</td>
<td>401</td>
</tr>
<tr>
<td>KJ</td>
<td>1678</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>72.8</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>12.4</td>
</tr>
<tr>
<td>Oil (g)</td>
<td>8.7</td>
</tr>
<tr>
<td>Dietary fiber (g)</td>
<td>6.8</td>
</tr>
<tr>
<td>P (mg)</td>
<td>380</td>
</tr>
<tr>
<td>K (mg)</td>
<td>370</td>
</tr>
<tr>
<td>Mg (mg)</td>
<td>110</td>
</tr>
<tr>
<td>Ca (mg)</td>
<td>55</td>
</tr>
<tr>
<td>Se (µg)**</td>
<td>8.6</td>
</tr>
<tr>
<td>Fe (mg)</td>
<td>4.1</td>
</tr>
<tr>
<td>Zn (mg)</td>
<td>3.3</td>
</tr>
<tr>
<td>Niacin (mg)</td>
<td>3.8</td>
</tr>
<tr>
<td>Vitamin E (mg)</td>
<td>1.7</td>
</tr>
<tr>
<td>Thiamin (mg)</td>
<td>0.50</td>
</tr>
<tr>
<td>Cu (mg)</td>
<td>0.23</td>
</tr>
<tr>
<td>Vitamin B₆ (mg)</td>
<td>0.12</td>
</tr>
<tr>
<td>Riboflavin (mg)</td>
<td>0.10</td>
</tr>
<tr>
<td>Folic acid (µg)</td>
<td>60</td>
</tr>
</tbody>
</table>

* The data are taken from Welch\textsuperscript{13} and USDA Nutrient Database\textsuperscript{14}.

** 14.0 µg/100 g – Content is variable depending on soil and fertilizer regimen.
fetal tissues\textsuperscript{23}. In fact, the specific production of such toxins depends on oat growth localization\textsuperscript{24,25}. Therefore, implementing modern agricultural practices and/or developing new varieties of pathogen-resistant oats would be necessary to prevent pathogens attacks.

We can also note that different processing techniques on oats such as malting and roasting can help in keeping their high nutritive value and their resulting weaning mixes; it is also found that both oat roasted and malted weaning gruels are accepted by the panel members of sensory quality evaluation\textsuperscript{26}. Thus, child malnutrition, caused by the introduction of traditional weaning foods, would be improved by simple processing techniques on cereals such as oats whose formulated weaning mix is being increased in nutritional value\textsuperscript{26,27}.

Besides, oats have long been considered as a source of various characteristic constituents such as saponins, among which triterpenoid saponins are used as monocots biomolecules exerting dietary and nutraceutic potential\textsuperscript{28}. Thus, the common oat (\textit{Avena sativa L.}) is subject to many industrial applications.

2 DESCRIPTION OF OAT CONSTITUENTS

2.1 Proteins

Oat protein content varies between 15 and 20\%\textsuperscript{29}. Globulins which comprise 50–80\% and avenins 10–20\% of the seed proteins are therefore the two dominant classes\textsuperscript{30,31}. Globulins\textsuperscript{salt-soluble proteins} are abundant in oats compared with other cereals, thus conferring a higher nutritional value because of this class favorable composition in essential amino acids\textsuperscript{32}. Yet, it is worth noting that when oat globulins are present in aqueous salt solutions between pH 4-5, they are insoluble\textsuperscript{33}, thus limiting the use of oat in some products\textsuperscript{34}. Avenins or prolamins\textsuperscript{alcohol soluble proteins} are rich in proline and glutamine amino acids and are associated with celiac disease\textsuperscript{31}. Oat lipids are present in aqueous extracts and their proteins are poorly soluble, so emulsion, foam formation and stabilization are relatively not important. Konak \textit{et al.}\textsuperscript{34} reported that CO\textsubscript{2}-defatted oat flour improves foaming and emulsifying properties at basic pH values. In addition, the works of Sibakov \textit{et al.}\textsuperscript{35} are in agreement with the fact that the removal of oat lipids by supercritical carbon dioxide (SC-CO\textsubscript{2}) enhances the separation of grain cell wall material from starch and protein. Consequently, CO\textsubscript{2}-extracted oats can be useful raw materials in beverages and other aqueous applications, where protein functionality plays an important role\textsuperscript{34} in gelling, solubility and surface stabilization properties such as foaming and emulsifying\textsuperscript{36}. It is also important to focus on the better solubility of such proteins which play an evident role in the products texture, color, sensory and organoleptic characteristics\textsuperscript{37}.

2.2 Lipids

2.2.1 Oat lipids: generalities

Oats contain a wide range of active compounds, including avenanthramides, starches, hydrocolloid \B-glucan, vitamins, saponins and other antioxidants\textsuperscript{mostly phenolic esters} and a relatively high content of total lipids with a high unsaturated fatty acids percentage\textsuperscript{38,39}. Total lipids can reach 18\%\textsuperscript{40,41}, and about 41\% of the great lipids are tricylglycerols, while 5\% are free fatty acids\textsuperscript{42}. Thus, oats
grain has the highest capacity to accumulate an important amount of oil in the endosperm compared with other cereals; it is also important to note that maize is the only cereal having similar high grain oil content to that of oats, but it accumulates oil mostly in the embryo. In view of this fact, among all cereals, oat oil in the endosperm remains the only particular lipid to be studied.

Peterson and Wood described the composition and structure of oat (Avena sativa L.) selections with elevated oil concentrations ranging from 6.9 to 18.1%. These high-oil oats were obtained from recurrent selections breeding regime at Iowa State University. It was shown that, in these selections, tocotrienols concentration located predominantly in the endosperm was correlated with oil concentration unlike that of tocopherols which are concentrated in the germ. On the other hand, β-glucan and protein concentrations increased, whereas those of starch decreased with increasing oil concentrations.

White et al. suggested an intrinsic association between oat oil bodies and the E-vitamers. The latter, which are compounds metabolically and chemically related to vitamin E and with the same biological activity, are present in oats with significant levels. Therefore, these E-vitamers would be responsible for the oxidative stability of the membrane and/or oat oil bodies.

Martinez et al. evaluated different oat cultivars for grain yield, lipid profile and nutrient content during two years (2004 and 2005) in different climatic conditions. All variables tested seemed to be more influenced by environment than by genotype and, thus, Zhou et al. noted that it is possible to improve oat fatty acids composition through breeding procedures.

Banas et al. provided for the first time a characterization of lipid deposition and fatty acid composition in different parts of the oat grain tissues during grain development using two kinds of oat cultivars, one with medium oil (6%) (Cultivar Freja) and another with high oil (10%) (Matilda cultivar). Hence, the major part of the grain lipids (86–90%) was found and stored in the endosperm as shown by chemical and microscopical analyses. Up to 84% of the oat lipids were deposited in the endosperm during the first half of grain development when seeds were still green with a milky endosperm.

Microscopy studies revealed that oil bodies fused in the starchy endosperm with less associated proteins (oleosins) upon maturation and, thus, formed smears of oil, while they were intact in the embryo, scutellum and aleurone layer. Therefore, Heneen et al. showed that most stored oil areas were close to the enzymes production sites related to mobilization and germination. Yet, Leonova et al. who studied lipid reserves mobilization in different tissues during oat germination (Avena sativa L.) proved by transmission electron microscopy that the oil droplets which appeared in areas close to the scutellar epithelium and the aleurone of oat grain were oil bodies surrounded by oleosins. Oleosins stabilize and prevent oil bodies fusion and contribute to facilitate lipase activity to rapidly mobilize fatty acids during oil seeds germination. Oil seeds storage constitutes a form of energy (triacylglycerol (TAG)) which can be mobilized by the action of lipases which release free fatty acids (FFAs) from this oil and can be degraded under β-oxidation and glyoxylate cycles and which are subsequently converted into sugars. But the cereal endosperm is known to be a dead tissue in the mature grain, so this β-oxidation does not occur there. Leonova et al. tried to determine the fate of these endosperm lipids during germination in cereal grains with the use of oat as a model. Their results suggest that the TAG of oat endosperm oil is not a dead-end product because, microscopically, it was absorbed by the scutellum, either as a form of FFA released from TAG or as an intact TAG form immediately degraded to FFAs; these lipids may be transported from the scutellum into the embryo.

In fact, the large amount of lipids in many seed dicotyledonous plants accumulates in their endosperm, where they are broken down through β-oxidation for energy production during germination. When the endosperm reserves are exhausted, a programmed cell death takes place in this endosperm. However, this death is undergone in the endosperm of monocotyledons mature grains, thereby β-oxidation is not involved during germination. Banas et al. demonstrated that amylases and proteases, which are mainly secreted from the aleurone layer of monocotyledons grains, were involved in the mobilization of their endosperm reserves and that the produced sugars and amino acids were taken up by the growing embryo. Indeed, during germination, nutrients stored in the cereals endosperm are degraded by the corresponding enzymes which are synthesized and secreted from the scutellum and the aleurone tissues which transport the enzymatic products (nutrient molecules) from the absorptive scutellum to nourish the growing embryo. Moreover, reports have markedly studied starch and proteins degradation in the cereals endosperm during germination as it is implicated in malting and food industries. However, there have been few reports on cereal lipid degradation during germination, and some studies have been concerned with only how oat oil processing can interfere in food industry. Lehtinen et al. demonstrated that some oat lipid fractions were susceptible to be normally used at high temperature. Also, Kaukovirta-Norja et al. noted that oat lipids stability and their prevention of off-flavour formation are effective in oat processing industry due to the fact that oat has a high lipid content and a high native lipolytic activity. Therefore, the oil mobilization in the cereals endosperm has not been well investigated. Fortunately, Leonova et al. focused on this issue and described lipid mobilization during oat germina-
Nutritional value of oat (Avena sativa L.)

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about 90-95% of the total oat counting for approximately 40 and/or 36 effective dermatitis, protect the barrier and ensure a healthy skin, a patients. In order to limit further exacerbate the atopic skin care, moisturization and cleaning mandatory for these causing the water loss rate to increase, which makes daily novel 7-hydroxyhexadecanoic acid found in 1,2-diacylglyc-
dize the quality and content of oat oil (Avena sp.) in 33 accessions from 13 wild species and 10 accessions of cul-
tivated oat. They found that C18:1 FA content was higher in wild oat species. The cultivated oats and, interestingly, found unusual FAs. The latter consisted of minor amounts of several hydroxy and epoxy FAs trapped mainly in specific classes of lipids such as 15-hydroxy 18:2Δ9,12 (avenoic acid) which are mostly found among polar lipids, and a novel 7-hydroxyhexadecanoic acid found in 1,2-diacylglycerol.

Oats are particularly rich in monounsaturated oleic acid (18:1) and polyunsaturated linoleic acid (LA) (18:2) accounting for approximately 40 and/or 36% of the total oat oil, respectively.\(^{46, 64}\) It is worth noting that the percentage of oil oat reported in the literature varies according to the extraction method, variety or location\(^{46, 49}\). In addition, Leonova et al.\(^{65}\) analyzed the quality and content of oat oil (Avena sp.) in 33 accessions from 13 wild species and 10 accessions of cultivated oat. They found that C18:1 FA content was higher in wild oat species. The cultivated oats and, interestingly, found unusual FAs. The latter consisted of minor amounts of several hydroxy and epoxy FAs trapped mainly in specific classes of lipids such as 15-hydroxy 18:2Δ9,12 (avenoic acid) which are mostly found among polar lipids, and a novel 7-hydroxyhexadecanoic acid found in 1,2-diacylglycerol.

Patients with an atopic skin have a compromised skin barrier which allows entry of many pathogenic agents causing the water loss rate to increase, which makes daily skin care, moisturization and cleaning mandatory for these patients. In order to limit further exacerbate the atopic dermatitis, protect the barrier and ensure a healthy skin, a daily oat-based skin care regimen for an atopic skin is very effective. In fact, after two weeks treatment with a gentle oat-based daily skin care regimen, significant improvements were observed by an independent dermatologist. Thus, patients perceived skin benefits such as a better skin texture and an overall improved look and feeling. In addition, Southall et al.\(^{67}\) demonstrated that oat oil improves the skin barrier as it is rich in LA which is an essential polyunsaturated fatty acid critical for the maintenance of the skin permeability barrier. Therefore, oat lotion proved to be highly useful in alleviating itch, ameliorating the skin barrier and effectively improving dryness and roughness associated with moderate to severe dry skin.\(^{67}\)

Finally, it can be noted that recently Feng et al.\(^{75}\) demonstrated for the first time the protective effect of oat at the cellular level due to the antioxidant properties of oat bran extract by enzymatic hydrolysates which prevents human dermal fibroblast injury induced by hydrogen peroxide (H\(_2\)O\(_2\)). Yet, precautions should be taken as regards for long time cream based Avena sativa application or intolerance of this plant.\(^{73}\)

In conclusion, oat can be a promising agent in preventing and improving dermal injuries; hence, further research is required to probe into the benefits and efficiency of oats as a protective and preventive factor.

2.2.3 Oat lipids: protective effect on reprotoxicity

Ben Halima et al.\(^{64}\) showed the positive effect of oat oil as a preventive agent on reprotoxicity in male mice induced by deltamethrin which is a pyrethroid pesticide exerting a wide range of effects on non-targeted organisms. Other reports demonstrated that pesticides could induce damage to reprotoxicity in vivo such as testicular injury or decrease testicular steroidogenesis in rats/mice.\(^{72-74}\)

Moreover, it is recognized that tocopherols (vitamin E) deficiency impairs mammalian fertility.\(^{75, 76}\)

It was proven that reprotoxicity caused to mice by orally administered deltamethrin (DEL) can be effectively antagonized by the beneficial effects of oats oil as a potential antioxidant including a considerable amount of tocopherols to alleviate testis oxidative damage induced by this pesticide. In fact, what Ben Halima et al.\(^{64}\) reported consisted in an in vivo study in which thirty-two male albino mice were divided into four equal groups: group 1 served as a control group; group 2 received deltamethrin (5 mg per kg b.w.); group 3 was administered deltamethrin after receiving oats oil (6 g per kg b.w.) and group 4 received only oats oil. Results showed that exposure to deltamethrin at a dose of 5 mg per kg b.w. per day caused oxidative stress in testis, evidenced by a decrease in the epididymal sperm count and motility, an increase in the number of abnormal morphologies in spermatozoa and a significant increase in lipid peroxidation compared with control animals. Co-administration of oats oil to the DEL-treated mice, however, ameliorated the testicular biochemical parameters as well as the histological impairments in tests. Thus, oats oil can be an efficient alternative to prevent testis deltamethrin toxic effects. 2.2.4 Oat lipids: polar lipids

Lipids from oats are a heterogeneous mixture of acyl lipids and unsaponifiable components. Neutral lipids are mainly made up of triglycerides and account for 50-60% of total oat lipids.\(^{77}\) Kaimainen et al.\(^{78}\) indicated that Avena sativa seeds oil is also rich in polar lipids (glycolipids and phospholipids) which can amount to 34%. This polar lipid fraction is characterized and proven to be useful.
as a potential oil/water emulsifier because of its amphiphilic structure. Moreover, phospholipids are known to be essential to the establishment of body cells and considered as antioxidants. Oat phospholipids fraction is estimated to be 5-26% of total lipids. Regarding the composition of this lipid class, for example, Price and Parsons found that L-α-phosphatidylethanolamine (PE), L-α-phosphatidylcholine (PC), and L-α-lyso phosphatidylcholine (lyso-PC) were the most abundant of all tested cereal grains. On the other hand, Sahasrabudhe determined some phospholipids proportion in six oat cultivars with 29.9% PC (the most abundant), 20.4% L-α-lyso phosphatidylethanolamine (lysoPE), 14.8% PE, 9.5% L-α-phosphatidylglycerol (PG), 3.9% L-α-phosphatidylinositol (PI), and 3.2% L-α-phosphatidylserine (PS). In fact, using high-performance scattering detector (HPLC-ELSD), found the same PC content. Also, Doehlert et al. characterized the polar lipids fraction from oat kernels by HPLC-ELSD.

Montealegre et al. determined different phospholipids in Romanian oat samples using high-performance liquid chromatography combined with an evaporative light scattering detector which led to establish that PE was the most representative phospholipid in the entire analyzed oat samples. Montealegre et al. also used high-performance liquid chromatography combined with electrospray ionization mass spectrometry analysis, and results showed that C16:0, C16:1, C18:0, C18:1, C18:2, C18:3, C20:0 and C20:1 were the fatty acids bound to the glycerol backbone. Finally, they used also first-preparative TLC and gas chromatography to demonstrate that LA (C18:2) was the main fatty acid of the phospholipid fraction in all the tested samples.

The molecular species of membrane phospholipids of spring oat (Avena sativa L cv Ogle) was described by Uemura and Stepontcus. These authors found that the plasma membrane lipid composition which was isolated from oat leaves contained predominately phospholipids (28.8 mol% of the total lipids). They noted also that after 4 weeks of cold acclimation, the proportion of phospholipids increased significantly in oat (from 28.8 to 36.8 mol%) as a result of increases in the proportions of PC and PE as well as the relative proportions of di-unsaturated species increased after the cold acclimation.

2.2.5 Oat lipids: lipolytic enzymes

Oat lipolytic enzymes were identified and measured by several authors. Widne and Onselius recognized that Avena sativa L. lipase is potentially more active than other cereal grains such as barley, wheat, and rye. Oats also contain promising types of phospholipases such as phospholipase D or phospholipases C. Several reports highlighted the importance of such enzymes.

2.3 Carbohydrates: fiber and starch

The dietary fibers in general are well documented and recognized to be proponents for commercial applications. Several studies identified that oat β-glucan content falls roughly within 2.5-8.3% of dry grain. In addition, β-glucan polydispersity such as polymer molar masses distribution and polymerization degrees were interesting because the higher-molecular-weight components were highlighted to be biologically beneficial and effective. Report of Lazaridou and Biliaderis proved the significance of the molecular weight of β-glucan polydispersity covering the range of 65-3100 kDa. Oat β-D-glucans are extracted and characterized for industrial utilization.

Wang and Ellis illustrated the physico-chemical characteristics of oat β-glucan and its effect on blood-glucose and cholesterol-lowering properties. In fact, the potent factor that lowers human cholesterol and postprandial glycaemia is mainly β-glucan which is a soluble dietary fiber. This bioactive component exists in oats and it is responsible for oat beneficial metabolic effects. To this end, Zhang provided an insight into oat β-glucan which is beneficial to the digestive system by increasing ATPases activity and the energy charge in the rats’ small intestine. The properties and structure of oat β-glucan vary among oat varieties and are influenced by environmental conditions. Moreover, analysis and extraction methods would also affect oat β-glucan variation.

Obviously, the most abundant grain component is starch in most oat cultivars (55-60% of starch in the oat grain). Starch is known as a storage polysaccharide present in the tubers, seeds, etc. of various plants, and consists of two components, amylose and amylopectin (Fig. 2). Amylose is a linear glucose polymer with α-1,4 linkages, whereas amylopectin is a branched polymer in which linear chains of α-1,4 glucose residues are interlinked by α-1,6 linkages (Fig. 2).

Oat starch has typical gelatinization characteristics and, when cooling, develops unusually high viscosity. Compared with the other cereal starches, the cooled oat starch is less firm, easily more digestible, more elastic, more adhesive, clearer and also less susceptible to retrogradation. Oat starch can contain about 25-30% amylase. Amylases are a class of hydrolyses that can specifically cleave the O-glycosidic bonds in starch. In fact, they are widely distributed in animals, microbes and plafiplants, they play a significant role in seed germination and maturation and would be promising catalysts in many potential applications compared with those from animal or microbe sources.

The use of starch-converting enzymes (Fig. 3) is the basis of several industrial processes such as maltodextrin and modified starch production, or glucose and fructose syrups preparation; they are also used as laundry and porcelain detergents or as anti-staling agents in baking, bread making.
and brewing\textsuperscript{109, 113}. Currently, these enzymes account for about 30\% of the world’s enzyme production\textsuperscript{113}.

Recently, Ben Halima et al.\textsuperscript{114} showed the beneficial impact of oat amylase on bread properties. In fact, in their report, statistical approaches were employed for the extraction optimization of amylolytic activity from oat (\textit{Avena sativa}) seeds. The application of the response surface methodology allows determining a set of optimal conditions for this enzyme extraction. Its maximum activity is at pH 5.6 and at 55°C. Besides, they studied the incorporation of the optimised oat extract into bread formulation which revealed an improvement in the sensory quality and textural properties of fresh and stored bread. Three-dimensional elaborations of confocal laser scanning microscopy (CLSM) images were performed on the crumb of different breads to evaluate the influence of oat amylase activity on microstructure. Results showed improved baking characteristics as well as an overall microscopic and macroscopic appearance\textsuperscript{114}.

Moreover, the aqueous oat extract is a mixture of a multitude of biomolecules exhibiting either amylolytic activity\textsuperscript{115} or other types of enzymes, in particular chitinase.

\textbf{Fig. 2} The structure of the two starch polymers: A: Amylose and B: Amylopectin\textsuperscript{109}.

\textbf{Fig. 3} The different enzymes involved in the degradation of starch. The open ring structure symbolizes the reducing end of a polyglucose molecule\textsuperscript{113}. 
Indeed, Sørensen et al.\textsuperscript{116} showed that oat seed extract is enriched in class I chitinase which acts as an antifungal, especially against \textit{Penicillium roqueforti}, a major contaminating species in industrial food processing and, hence, oat extract could be used directly on rye bread to prevent \textit{P. roqueforti} colonies formation\textsuperscript{116}. They also found that, compared with wheat, barley and rye seed extracts, class 1 chitinase in oat seed extract is at least ten times more abundant and highly more antifungal toward \textit{P. roqueforti} than the other cereal seed extracts tested.

2.4 Oat: antioxidant components

Oats are a source of natural antioxidants\textsuperscript{117–120}, the most abundant of which in \textit{Avena sativa} L. are tocols (vitamin E), phenolic compounds, phytic acid, avenanthramides as well as sterols and flavonoids\textsuperscript{121}.

2.4.1 Tocols

Tocols (tocopherols, tocotrienols, vitamin E, etc.) are lipid-soluble compounds and represent the natural antioxidants in grains\textsuperscript{122}. In fact, tocols are composed of four homologues of tocotrienol and tocopherol (Fig. 4) which differ in position and number of methyl groups on the chroman ring structure\textsuperscript{121}. Thus, they are distinctive in their biological activities particularly their antioxidant activity\textsuperscript{123, 124}. The major tocols in oats are \(\alpha\)-tocotrienol followed by \(\alpha\)-tocopherol\textsuperscript{125} which, combined, account for 86 to 91\% of total tocols\textsuperscript{121}. Tocotrienols have more ability as free radical scavengers than tocopherols\textsuperscript{126}. Vitamin E is a lipophilic antioxidant present in oats. It is a generic term for entities displaying tocopherol biological activity. Indeed, there are eight tocols with vitamin E activity in plants\textsuperscript{121}.

In general, these compounds exhibit a biological activity from their ability to donate phenolic hydrogen atoms to free radicals, which allows the breaking of destructive chain reactions\textsuperscript{127}. Intrinsically, tocols could reduce the serum cholesterol concentration and also have the ability to inhibit the growth of cancer cells\textsuperscript{128}. Tocols concentration in oats is significantly affected by location and genotype\textsuperscript{128}. For example, total tocol concentrations in the study of 12 oat genotypes grown at three locations in the U.S.A. ranged from 19.0 to 30.3 mg/kg\textsuperscript{128}. However, in another survey of 13 oat genotypes mostly European and grown in Hungary, total tocol concentrations ranged from 15 to 48 mg/kg\textsuperscript{129}

2.4.2 Avenanthramides

Avenanthramides are phenolic compounds consisting of

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\[\text{Fig. 4 Structures of tocols: (a) Tocopherols; (b) Tocotrienols}^{121}\].

\[\text{\begin{tabular}{c|c|c}
\hline
R& R & \\
\hline
\(\alpha\) & CH\(_3\) & CH\(_3\) \\
\(\beta\) & CH\(_3\) & H \\
\(\gamma\) & H & CH\(_3\) \\
\(\delta\) & H & H \\
\hline
\end{tabular}}\]
hydroxycinnamic acid amides and hydroxyanthranilic acids (Fig. 5). They are secondary metabolites found in oat \textit{(Avena sativa)} groats and hulls\textsuperscript{130}. There are at least 20 different phenolic conjugates with anthranilic acid derivatives which are present in oats, but their chemical structures have not been fully identified\textsuperscript{133}. Pihlava \textit{et al.}\textsuperscript{130} estimated that the amount of avenanthramides in grains ranges from 2 mg/kg to 53 mg/kg. Ishihara \textit{et al.}\textsuperscript{132} identified new series of avenanthramides in the methanol extract of oat seeds. By chromatographic tools, they detected and purified three compounds, 1, 2, and 3, which are eluted at the retention times similarly to avenanthramides. In fact, these three compounds are suggested to be amides of 4,5-dihydroxyanthranilic acid with caffeic, \(p\)-coumaric, and ferulic acids, amounting to 16.5–26.9\% of corresponding avenanthamides with 5-hydroxyanthranilic acid, respectively, as shown by LC-MS/MS analysis with multiple reaction monitoring.

Avenanthramides play a major role as potential antioxidants\textsuperscript{133}. Peterson \textit{et al.}\textsuperscript{134} investigated their anti-oxidant

\begin{table}[h]
\centering
\begin{tabular}{llllll}
\hline
\textbf{Compound} & \textbf{Groats, free acid} & \textbf{Hulls, free acid} \\

\hline
Caffeic acid & 1.0 & 16.8 & 2.2 & 2.4 & 0.9 \\
p-Coumaric acid & 0.7 & 44.9 & 1.6 & 0.9 & 59.7 & 9.7 \\
Gallic acid & & & & 1.3 & 0.6 \\
Ferulic acid & 2.4 & 147.2 & 2.3 & 1.2 & 142.3 & 1.7 \\
p-Hydroxybenzoic acid & 0.7 & 3.5 & & 50.0 & \\
p-Hydroxybenzaldehyde & & & 0.9 & 0.3 & 7.7 \\
p-Hydroxyphenylacetic acid & 0.4 & 0.6 & & & 4.6 \\
Protocatechuic acid & 0.5 & & & 0.7 & 2.1 \\
Sinapic acid & & & tr & 0.5 & 5.6 & 0.6 \\
Vanillic acid & 0.7 & 16.1 & 1.2 & 1.6 & 24.3 & 4.0 \\
Vanillin & 3.4 & 2.3 & 1.0 & & 54.2 & 6.3 \\
\hline
\end{tabular}
\caption{Concentrations of some organic compounds (Phenolic acids and aldehydes) present in oat groats and hulls, mg/kg\textsuperscript{121}.}
\end{table}
activity using in vitro systems such as the reaction with the free radical 2,2-diphenyl-1-picrylhydrazyl (DPPH) or the inhibition of β-carotene bleaching. Avenanthramides are also considered to be phytoalexins in oat leaves as they display an anti-fungal activity and their synthesis can be induced by various factors such as either pathogen-related infection or elicitors treatment. On the other hand, avenanthramides exhibit an anti-atherogenic, anti-inflammatory and anti-itching activity of the skin. They have been shown to inhibit the production of pro-inflammatory cytokines, the adhesion of monocyte cells to aortic endothelial cell monolayers, and the expression of adhesion molecules.

2.4.3 Other antioxidants: organic acids, sterols, flavonoids

2.4.3.1 Organic acids

A number of organic acids such as p-coumaric acid, caffeic acid, ferulic acid, p-hydroxybenzoic acid, vanillic acid, etc. have been reported in oat groats and hulls, as shown in Table 3. Previous studies indicated differences in these compounds content very likely due to the extraction methods.

Oats also contain significant amounts of phytic acid which exhibits antioxidant functions. Several works reported that oat phytic acid concentration averaged 5.6 to 8.7 mg/g in five cultivars grown at four locations for 2 years in Finland, whereas, a groat phytic acid concentration from four oat cultivars grown at three locations in Wisconsin, U.S.A. for 4 years averaged 12.7 mg/g. Besides, phytic acid concentration in a whole oat grain was about 11.4 mg/g according to a study of Larsson and Sandberg. In fact, phytic acid concentration is affected by environmental factors such as available soil p

2.4.3.2 Sterols

Oats also comprise a number of sterols some of which can exhibit an antioxidant activity. Singh et al. indicated that acylated steryl glycosides, steryl glycosides and steroidal saponins can be found in oat leaves. The major sterol in oat is β-sitosterol with Δ^5-avenasterol and Δ^7-avenasterol also present in significant quantities.

2.4.3.3 Flavonoids

Oats also contain flavonoids (Fig. 7). Recently, Zhang et al. isolated fifteen chemical constituents identified as flavonoids from Avena sativa bran, nine of which were isolated from Avena sativa Linn. for the first time and identified as kaempferol 3-O-(2',3'-di-E-p-coumaroyl)-α-L-rhamnopyranoside (1), kaempferol 3-O-(3'-E-p-coumaroyl)-α-L-rhamnopyranoside (2), kaempferol 3-O-(2''-E-p-coumaroyl)-β-D-glucopyranoside (3), kaempferol 3-O-β-D-glucopyranoside (4), kaempferol 7-O-α-L-rhamnopyranoside (5), linarin (6), tilianin (7), myricitrin (8) and quercitrin (9).

3 Oats: prevention of disease

Antioxidants have a high potential to prevent diseases. Tocotrienols are among antioxidants having cholesterol-lowering properties in humans and experimental animals. Moreover, oat oil was recently proven to promote the excretion of faecal lipids in hypercholesterolemic rats and, thus, lower plasma and liver cholesterol concentrations.

Several studies focused on oats as a therapeutical agent as well as its instrumental antioxidant system to heal such acute diseases as colon tumor and hepatic steatosis.

Oats consumption is associated with a reduced risk of chronic ailments such as type 2 diabetes and cardiovascular diseases (CVD). In fact, Thies et al. described these effects through long-term intervention studies revealing a reduction in CVD risk markers.

Thongoun et al. confirmed that oat β-glucan considerably reduced blood cholesterol levels in Thai hypercholesterolemic adults. Thus, following daily oatmeal consumption (3 g of soluble fiber beta glucan), reduced total...
cholesterol and LDL-cholesterol levels by 5 and 10%, respectively. Furthermore, these levels were significantly lower than those observed with rice consumption. Oats are unique in providing vital nutrients (unsaturated TAG, complex lipids, resistant starch, phenolic compounds, etc.) for the gut microbiota. Therefore, they contribute to a healthy human gut microbiome which plays a fundamental role in ensuring intestinal functions and preventing bowel diseases.

A systematic literature review describing intervention studies investigated oats effects on bowel disease. Results showed that the consumption of uncontaminated oats up to 100 g/d could be tolerated by most patients with coeliac disease, an autoimmune disorder of the gastrointestinal tract and, thus, oats can be added to a gluten-free diet for these patients.

Several recent reports suggested that the consumption of oats attenuated hyperglycemia and diabetes, prevented obesity, abdominal fat and improved liver function by inhibiting lipogenesis in animal models as well as in a clinical trials. Consequently, a daily oat supplement can act as an effective adjuvant for the treatment of metabolic disorders in humans.

In a recent experiment, Boffetta et al. focused on the effectiveness of oats consumption on epidemiological studies including cancer risk and overall mortality. Results provided weak evidence of oats protective effect on cancer risk and overall mortality; however, further experiments should be conducted in the future.

4 Conclusion and open directives

Oats (Avena sativa L.) are unique compared with other cereals thanks to the high quality of their composition, especially lipids, bioactive components and antioxidant systems. They have been globally recognized as relevant for a wide range of applications namely in pharmacology, medicine and food industries, which explains their inclusion in the British Herbal Pharmacopoeia. Therefore, they constitute useful plants for a healthier world, and future investigations on their organism are required for a better and deeper understanding of their genome.

Huang et al. dealt with the utility of genomic approaches, especially genotyping-by-sequencing (GBS) to provide additional information on oat breeding. In addition, the development of single nucleotide polymorphism (SNP) on hexaploid oats using high-throughput 454 sequencing technology favours the understanding of complex genomes. Moreover, ESTs (expressed sequence tags) are useful tools contributing to the identification of genes from oats thus improving knowledge of the full oat genome.

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