Review
Oat and Oat Processed Products—Technology, Composition, Nutritional Value, and Health

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Abstract: Oat has been known in food technology and human nutrition for a very long time. Its rich chemical composition and high nutritional value make it of interest to scientists in the field of food processing technology as well as nutritionists. Low-processed, whole-grain oat products rich in biologically active substances with well-proven preventive and therapeutic effects include not only dehulled oat grains and groats but also a wide range of breakfast cereals. These products fit into the definition of functional foods and are considered excellent prebiotics. The continuous development of cereal processing technologies can improve existing cereal products and help to create new ones; however, it also increases the possibility of raw material over-processing, thus decreasing its functional properties. Therefore, monitoring technological progress and the quality of the products obtained is of great value and interest for nutritionists and consumers. The work presented here aims at systematizing existing knowledge on oat products, their impact on human health, and progress in oat processing technology. It also brings insight into various new avenues for the utilization of oat products in food technology.

Keywords: oat grain; oat products; health-promoting properties; β-glucan

1. Introduction

Analysis of nutritional, chemical, and physical properties of oat grain, with emphasis on β-glucans, has led to its appreciation in human nutrition, mainly due to its health-promoting properties, including cholesterol-lowering, blood glucose-stabilizing, anti-cancer, and anti-inflammatory effects [1–4].

The oat (Avena L.) genus is represented by 25 annual plant species, including field crops, wild species, and weeds. Avena sativa is the main cultivated oat species, comprising about 90% of the world’s oat production. Other cultivated oat species, with minor importance, include black oats (Avena strigosa) and red oats (Avena byzantina). At the same time, common wild oat (Avena fatua) is a weed of cereal crops, especially oats.

Oat appeared in cultivation several thousand years later than wheat and barley, so it was unknown to ancient agricultural cultures. It was considered a secondary crop, as it initially accompanied the cultivation of other crops, mainly emmer wheat (Triticum dicoccum Schübl.), as a segetal weed.
Nowadays, globally, oat is grown on approximately 10 million hectares, accounting for only 1.5% of the acreage occupied by cereals. Oat grain is mainly used for animal feeds and human consumption but is also gaining importance in the pharmaceutical and beauty industries.

Both the hulled (more widely grown) and the naked (unhulled) forms of oat are known. The naked form is characterized by the lack of glumellae in the grain. A high proportion of glumellae in the grain of the hulled form reduces its nutritional value and limits its usefulness for feeding monogastric animals (such as poultry). However, it is an excellent component of the feed for horses, cattle, and sheep.

Oat grain is a raw material valued in cereal processing due to its nutritional and health-promoting qualities. Products of oat grain processing can be divided into three major categories, including (I) products obtained by milling: flakes (instant, mountain, ordinary), pearl barley, bran, flour, and groats; (II) products with the addition of oat grain or substances derived from oat grain: confectionery, special breads (wheat-oat bread, fine bakery products), cereal/fruit mixes (muesli), oat preparations; and (III) products derived from oat grain (e.g., β-glucan) used in pharmacology, cosmetics, brewing, and chemical industries [5–8].

Oat grains, apart from highly valuable nutritional compounds, contain substances with anti-nutritional and toxic effects, i.e., saponins (avenacosides), which can irreversibly connect to the cell membrane, thus increasing its permeability [9]. Phytic acid present in oat grain may also have a negative health impact, as it has, among others, the ability to block the bioavailability of some micronutrients, such as iron, copper, zinc, or magnesium [10]. Additionally, due to the high fiber content of oat products, their digestion may lead to flatulence, bloating, and diarrhea [11].

The present article provides an overview of the composition of oat grains and various oat products and systematizes existing knowledge about various possibilities for utilizing health-promoting properties of oat grain ingredients or oat products.

2. Chemical Characterization of Oat Grain as a Raw Material in the Food Industry

The total protein content of oat grain is relatively high compared to other cereals, ranging from 7.4 to 24.5% d. m. (dry mass) (Table 1) [12]. The protein content of naked cultivars is about 5% higher than that of hulled cultivars [13]. Oat proteins can be divided into 4 main groups, such as globulins (50–80% d. m.), prolamins (4–15% d. m.), albumins (1–12% d. m.), and glutelins (10% d. m.) [14]. Proteins isolated from oat grain are characterized by high digestibility (90.3–94.2% d. m.) and biological value (74.5–79.6% d. m.) [15].

Table 1. Chemical composition of oat and other cereal grains (d. m.) [12].

<table>
<thead>
<tr>
<th>Cereal Species and Product</th>
<th>Protein</th>
<th>Lipids</th>
<th>Carbohydrates</th>
<th>Dietary Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole oat grain with husk (range)</td>
<td>7.4–16.2</td>
<td>2.2–9.2</td>
<td>53–66</td>
<td>20–38</td>
</tr>
<tr>
<td>Whole oat grain without husk (range)</td>
<td>10.5–24.5</td>
<td>3.1–15</td>
<td>62–75</td>
<td>7.8–12.2</td>
</tr>
<tr>
<td>Naked oat (range)</td>
<td>14–19.5</td>
<td>8.3–11.4</td>
<td>69–72</td>
<td>8.6–12.1</td>
</tr>
<tr>
<td>Wheat (average)</td>
<td>13.5</td>
<td>2.3</td>
<td>67.7</td>
<td>12.1</td>
</tr>
<tr>
<td>Rye (average)</td>
<td>10.2</td>
<td>2.0</td>
<td>63.9</td>
<td>16.1</td>
</tr>
<tr>
<td>Whole barley grain without husk (average)</td>
<td>12.0</td>
<td>2.4</td>
<td>65.9</td>
<td>15.4</td>
</tr>
<tr>
<td>Corn (average)</td>
<td>10.5</td>
<td>4.3</td>
<td>71.9</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Oat protein has been reported to have a higher digestibility-corrected amino acid score (PDCAAS) than wheat protein, but lower than soybean or pea protein [16]. The amino acid composition of oat grain is more favorable compared to other cereals due to its higher content of essential amino acids (lysine, methionine, threonine, tyrosine, leucine, valine, and phenylalanine) (Table 2) [12,13,17,18]. Research shows that people with coeliac disease, both adults and children, can safely consume products containing oat protein [15,19]. It is documented that wheat protein, gliadin, triggers inflammation in patients with coeliac disease.
disease. However, the corresponding protein in oats, avenin, has been shown not to contain similar immunogenic sequences present in gliadin [20].

Table 2. The content of exogenous amino acids in various cereal grains (g·kg\(^{-1}\) protein) [12].

<table>
<thead>
<tr>
<th>Exogenous Amino Acids</th>
<th>Wheat</th>
<th>Rye</th>
<th>Triticale</th>
<th>Barley</th>
<th>Oat</th>
<th>FAO/WHO Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysine (Lys)</td>
<td>26</td>
<td>38</td>
<td>34</td>
<td>32</td>
<td>42</td>
<td>55</td>
</tr>
<tr>
<td>Methionine (Met)</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Tryptophan (Trp)</td>
<td>13</td>
<td>16</td>
<td>11</td>
<td>12</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Valine (Val)</td>
<td>46</td>
<td>53</td>
<td>42</td>
<td>54</td>
<td>53</td>
<td>50</td>
</tr>
<tr>
<td>Isoleucine (Ile)</td>
<td>34</td>
<td>35</td>
<td>32</td>
<td>35</td>
<td>39</td>
<td>40</td>
</tr>
<tr>
<td>Leucine (Leu)</td>
<td>69</td>
<td>75</td>
<td>77</td>
<td>72</td>
<td>74</td>
<td>70</td>
</tr>
<tr>
<td>Threonine (Thr)</td>
<td>26</td>
<td>32</td>
<td>31</td>
<td>29</td>
<td>33</td>
<td>40</td>
</tr>
<tr>
<td>Phenylalanine (Phe)</td>
<td>43</td>
<td>52</td>
<td>50</td>
<td>51</td>
<td>53</td>
<td>26</td>
</tr>
<tr>
<td>Sum</td>
<td>274</td>
<td>318</td>
<td>294</td>
<td>302</td>
<td>338</td>
<td>308</td>
</tr>
</tbody>
</table>

The fat content of oat grain reaches approx. 2.2–11% d.m. Oat grain has the ability to accumulate more lipids in the endosperm compared to other cereals [21]. Unsaturated fatty acids account for 80% of all fatty acids present in oat grains, among which α-linolenic (1–5%), linoleic (24–48%), oleic (29–53%), docosahexaenoic, eicosapentaenoic, and arachidonic acid are the most abundant ones [22–24]. Among saturated fatty acids, palmitic acid is a predominant one, accounting for approx. 21.4–22.7% of total fatty acids in oats. Naked-grain oat cultivars are characterized by a significantly higher fat content than hulled oat cultivars [24,25]. When studying new oat cultivars, Kouřimská [21] noted that naked-grain cultivars had significantly higher amounts of linoleic acid and lower amounts of palmitic acid than hulled oat varieties. All analyzed oat samples had low atherogenicity (0.17–0.19) and thrombogenicity (0.30–0.34) indices. This demonstrates that the tested cultivars can be a good source of nutritionally valuable oil, which can play an important role in the prevention of cardiovascular disease [21].

The starch content of oat grain is lower compared to other cereals (Table 1). Moreover, compared to other cereals, oat starch has a smaller granule size, higher amylose content, and high viscosity and water retention capacity. Due to these characteristics, it is widely used in food products as a thickening, gelling, and coating agent [26].

Oat grain is a good source of dietary fiber, which is important for maintaining the proper functioning of the digestive system and the body as a whole. The content of total dietary fiber in oat grain ranges from 1 to 30% [13,27] and varies depending on, i.e., agronomic conditions, the anatomical structure of the kernel, the thickness of the seed coat and aleurone layer, the thickness of the endosperm cell walls, the degree of lignification of the seed coat, and whether the oat cultivar is hulled or naked. Cereal grains subjected to dehulling and milling lose significant amounts of fiber-rich parts. The ratio between soluble and insoluble fiber fractions is also altered. The total dietary fiber (TDF) content of hulled and naked oats was previously compared in some studies [13]. It was found that naked oats had significantly higher TDF levels compared to hulled oats, with values of 17.63% and 22.97%, respectively. Sykut-Domańska et al. reported that the average soluble fiber (SDF) and insoluble fiber (IDF) content of oat grain was estimated as 4.6–6.93% and 11.19–15.9%, respectively [28]. Naked oat cultivars were characterized by a lower content of both soluble and insoluble dietary fiber compared to dehusked oats.

Oat grain is an extremely valuable source of soluble fiber, especially (1-3)(1-4)-β-D-glucans, which range from 3.08 to as much as 8% d.m. [28,29]. β-glucans belong to very important fiber components due to their multidirectional preventive and therapeutic effects in many chronic non-communicable diseases [30]. β-glucans of cereal grains are composed of long unbranched chains of β-D-glucose linked by β-1,3-glycosidic (30%) and β-1,4-glycosidic (70%) bonds. Due to their structure, these polysaccharides comprise 82% of the water-soluble fraction [31]. Oat β-glucan was found to be structurally different from other cereal plant β-glucans. Most commonly, the ratio of the (DP3) and (DP4) fractions is
presented in the form of a quotient considered an indicator of β-glucan structure [32]. This quotient determines physical properties such as rheological properties in solution and gel state and solubility [32]. Another indicator that influences the aforementioned properties of β-glucan is its molecular weight. β-glucan from oats has the highest molecular weight among cereal plants, ranging from 65 to 3100 × 10^3 Da [32–34]. β-(1,3)-(1,4)-D-glucan from oat grain dissolves well in water, especially warm water, and above 50 °C it dissolves completely. During dissolution, β-glucan absorbs large amounts of water, forming gums with considerable viscosity [35–37].

Due to the uneven distribution of (1-3)(1-4)-β-D-glucans in the grain, their content in the individual milling products can vary considerably [28,38,39]. In the case of oat and barley grains, the (1-3)(1-4)-β-D-glucans are mainly concentrated in the cell walls of the endosperm proper. The content of (1-3)(1-4)-β-D glucans in the cell walls of the endosperm of oat grains is higher compared to barley grains, at approximately 85% and 75%, respectively. Among oat products, the β-glucan content in oat bran is 4.7–8.3% d. m., in rolled oats: 2.3–8.5%, quick oats: 2.2–7.7%, and instant oats: 1.4–5.5% [40,41].

Oat grain is an important source of many minerals essential for human health. The most important macro- and micronutrients present in oat grain include Ca, Mg, Fe, Mn, Cu, Zn, P, and K [42]. Studies show that Ca and Mn in oat grain are mainly located in the aleurone layer and the embryo disc. P, K, Fe, Cu, and Zn accumulate mainly in the aleurone layer and embryo [43]. The high phosphorus and potassium content makes oatmeal a valuable source of minerals in the diet. Oat products such as flakes, flour, and bars retain most of the minerals present in the raw grain [41]. Butt et al. have shown that oat grains are rich in B vitamins such as thiamine (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3), and pantothenic acid (vitamin B5) [44]. In addition, oatmeal and oat products also contain vitamin E, which has an antioxidant function and helps protect cells from oxidative damage [44].

Oat grain also contains bioactive substances such as phytosterols (sitosterol, campesterol, and stigmasterol) with a potential to lower blood levels of low-density lipoproteins (LDLs) and inhibit atherosclerosis [45], lignans (secoisolaricrins and matairesinol) shown to exhibit anticancer and antioxidant properties [46], and avenanthramides—phenolic compounds that are found exclusively in oat grains. Studies show that avenanthramides exhibit anti-inflammatory, antioxidant, and neuroprotective effects [47].

3. Oat in Food Technology

Oat grains are popularly used in various branches of the food industry (Table 3) [48]. One of the most popular oat products is oat flakes, often eaten as a breakfast cereal. Oat flakes are made from cleaned oat grain, in which lipolytic enzymes have been inactivated [49]. Typically, two types of oat flakes are produced: ordinary oat flakes (flaked directly after the process of grain cleaning and inactivation of lipases) and instant oat flakes (subjected additionally to hydrothermal treatment, and thus not requiring further processing/boiling before consumption) [50]. Oat flakes are also used as one of the components of cereal/fruit/nuts mixtures (muesli) or are processed into granola (oat flakes with sugar, oil, and nuts or fruits, subjected to the baking process) [51,52]. Oat grain flour is another popular oat product. Even though it is characterized by worse technological parameters compared to wheat flour, it is often used as an additive in the production of bread due to the large amount of previously discussed health-promoting substances in its composition [53,54]. In addition, oat flour has a very low glycemic index, unlike the popular wheat or rye flours, so it can be used in the production of bread for diabetics [55]. Oat grains certified as gluten-free are also broadly used to produce bread suitable for people suffering from celiac disease [56].

Oat groats, produced from oat grains in de-hulling and polishing processes, can be a substitute for such products as rice, pasta, or potatoes [57,58]. Another application of oat grains in the food industry is the production of sprouts. The sprouts are obtained as a result of the grain germination process and are intended to be consumed as a whole—as a sprout with germinating grain [59]. The sprouts are characterized by high enzymatic activity and
contain a set of nutritionally important ingredients, such as vitamins (A, B, C, and E) and minerals (i.e., fluorine, iron, zinc, copper, calcium, and iodine). In addition, sprouted grains contain substances that can improve the taste and smell of food products [60–63]. Oat malts should be mentioned as another important application of oat grains [64]. Malt is produced by controlled soaking, germination, drying, and degeneration of grains, primarily barley, but some malt producers produce malt from oat grains, which gives some types of beer unusual organoleptic characteristics. Such practices became popular in the 21st century, due to the so-called ‘beer revolution’, which significantly impacted the brewing industry [65–68]. Oat flakes are also used in the brewing industry due to the fact that beers brewed with the use of oat malt possess a certain creaminess, particularly well-received in dark beers or necessary for beer styles such as ‘oatmeal stout’ [69,70].

It is important to mention that with the growing popularity of vegan and vegetarian diets, the demand for protein concentrates made from plant-derived substrates has also increased [71]. One of the most popular sources of protein for the production of these food products is soybeans; however, oat grains have also found application in this branch of industry, especially in the region of Europe where soybeans, due to the climate, are not so popularly grown [14,72–74]. There is no way to omit here one of the other key food products for vegans and vegetarians, popularly made from oat grains, which are plant-based milk substitutes [75]. Oat ‘milk’ is made from crushed oat flakes or flour, which are subjected to hydrothermal processes and the action of β-amylase. Due to the increased content of maltose and dextrans, a drink with a degree of sweetness similar to lactose is obtained [76].

Oat grains are suitable for making oat drinks, but can also be used to make fermented products from plant-based drinks, such as oat ‘yoghurts’ [77]. It is also popular to use oat bran (a by-product of hulled oat milling) as an addition to desserts, milk, yogurt, or other food products in order to increase their fiber content [78,79]. In addition, the oat hydrolysates, i.e., oat β-glucans with amylopectins and small amounts of minerals, fat, and protein, are also produced from oat grains. The main oat hydrolysates from this group of food products are called Oatrim. These preparations contain various amounts of β-glucans (Oatrim 3, 5, 10 containing 3, 5, and 10% of β-glucans) [63]. These hydrolysates are used in the production of low-calorie ice creams, food concentrates, sauces, biscuits, sausages, and low-fat mayonnaise [80–82]. In addition, an increase in the use of β-glucans in the dairy industry can be observed, which results from their positive impact on the sensory, structural, and rheological properties of the processed products, such as yogurts or ice cream [83,84].

**Table 3.** Examples of possible uses of oat grain and its products in the food industry [48].

<table>
<thead>
<tr>
<th>Products</th>
<th>Process/Application Methods</th>
<th>Characteristic</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole oat grains</td>
<td></td>
<td>Decreased phytic acid content</td>
<td>Chen et al., 2020 [85]</td>
</tr>
<tr>
<td>Whole grain products</td>
<td></td>
<td>Strengthened antioxidant activity</td>
<td>Sibakov et al., 2014 [86]</td>
</tr>
<tr>
<td>Flakes (also called oatmeal)</td>
<td>Defatting treatment</td>
<td>Enhanced stability</td>
<td>Liu et al., 2019 [87]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Used for production of the following:</td>
<td>Konak et al., 2014 [88]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Pasta (decreased hardness),</td>
<td>Espinosa-Solís et al., 2019 [89]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Cookies (modified taste and texture parameters),</td>
<td>Sobota et al., 2015 [90]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– As an addition to meat products (reduced</td>
<td>Hüttner et al., 2010 [91]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hardness, chewiness and viscosity,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– increased capacity,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– bread,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Drinks (water holding)</td>
<td></td>
</tr>
<tr>
<td>Fermented drinks</td>
<td>Fermentation treatment</td>
<td>Intended for people suffering from the following:</td>
<td>Makinen et al., 2016 [92]</td>
</tr>
<tr>
<td>Milk substitutes</td>
<td></td>
<td>– Lactose intolerance,</td>
<td>Cui et al., 2023 [48]</td>
</tr>
<tr>
<td>Probiotic microorganisms</td>
<td></td>
<td>– Allergy to milk protein,</td>
<td>Selmerén et al., 2015 [93]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Irritable bowel syndrome,</td>
<td>Staka et al., 2015 [94]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Low immunity,</td>
<td>Vasudha and Mishra 2013 [95]</td>
</tr>
<tr>
<td>Non-dairy yogurt</td>
<td></td>
<td>– High cholesterol,</td>
<td>Angelov et al., 2018 [96]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Diarrhea,</td>
<td>Brückner-Güthmann et al., 2019 [97]</td>
</tr>
</tbody>
</table>
Table 3. Cont.

<table>
<thead>
<tr>
<th>Products</th>
<th>Process/Application Methods</th>
<th>Characteristic</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat concentrates</td>
<td>β-glucan, starch, and protein</td>
<td>Fermentation treatment, Hydration treatment, Direct mixing</td>
<td>Isolates used in the production of the following:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bread,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pasta (oat β-glucans significantly increased viscosity of pasta; 10–15% additive of β-glucans yielded functional pasta containing 3.3–5.5 g β-glucans/100 g with high cooking quality and sensory attributes),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fermented skimmed milk (decrease of blood serum cholesterol),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Meat products: chicken breast meat (increase in the content of soluble proteins and gel strength), low-fat beef patties (fat replacement, moisture retention enhanced)</td>
</tr>
</tbody>
</table>

4. Oat and Human Health

Oat grains and oat products are classified as functional foods due to their high content of β-glucans, phytosterols, antioxidant compounds (e.g., polyphenolic acids, tocols, phytic acid, avenanthramides), and polyunsaturated fatty acids [103]. The available data show that consumption of 100 g of oatmeal is able to cover the daily requirement for seven essential amino acids, with only sulfur amino acids and lysine being deficient [104].

Dietary fiber consists of two fractions—soluble (SDF) and insoluble (IDF). Both dietary fiber fractions have a positive effect on the human body, but each in a different way. The interaction of both fractions results in the best effect [44]. Oat soluble fiber is a fraction that contains mainly (1-3)(1-4)-β-D-glucans. SDF forms highly viscous gels, increases the density of the digestive contents, and prolongs intestinal transit time. It has the ability to capture toxic compounds and also prevents their absorption in the intestine. It has a detoxifying effect (due to the presence of glucuronic acid) and plays an important role in alleviating lipid metabolism disorders (reduces cholesterol concentration, binds bile acids, increases excretion of fats in the stool, and delays absorption of triacylglycerols). It also causes a decrease in the time of glucose absorption [105,106].

Insoluble dietary fibers usually have high water-holding capacity and the ability to promote softening of digesta, thus supporting regular bowel movements and contributing to increased fecal bulk [44,107]. Nevertheless, a high intake of insoluble dietary fiber could be also associated with some negative nutritional impacts—it may interact with nutritionally important minerals, resulting in their lower bioavailability and thus increasing the risk of mineral deficiencies [44].

5. Oat in the Treatment of Diseases of Affluence

The risk of many chronic non-communicable diseases such as obesity, type 2 diabetes, cardiovascular diseases, and many types of cancers can be reduced by consuming an adequate dose of β-glucans in the daily diet [102,105,106]. A recent clinical study on a group of nearly 50 patients showed the beneficial effects of high molar weight oat β-glucans in chronic gastritis in humans. Consumption of β-glucans resulted in reduced mucosal damage and positive changes in fecal SCFA levels, peripheral blood serum glutathione metabolism, and antioxidant defense parameters. The described effects were noted after 30 days of β-glucans use, shedding new light on the nutritional treatment of chronic gastritis [108]. The results of in vitro studies show that oat fiber, especially β-glucan from oats, also plays an important role in preventing infectious diseases and cancer by inducing trained immunity through metabolic reprogramming. These results indicate that dietary fiber can maintain long-term reactivity of the innate immune system [109].
5.1. Oat in the Prevention and Treatment of Metabolic and Cardiovascular Diseases

A well-documented property of β-glucan is its beneficial effect on glucose metabolism. For this reason, the use of oatmeal treatment is particularly recommended for people suffering from advanced type 2 diabetes. The hypoglycemic effect of β-glucans starts already at the stage of food digestion in the stomach. In an acidic environment, these soluble components of dietary fiber form solutions of very high viscosity, slowing down the digestion process. Consequently, there is a slower ejection of gastric contents into the duodenum and a slower further digestion of carbohydrates. Due to that fact, there is a lower rate of glucose release, which translates into lower postprandial glycemia and lower insulin requirements [110]. In a study conducted on patients with type 2 diabetes, it was found that the consumption of oat fiber reduced glycated hemoglobin (HbA1c), an indicator that controls blood glucose levels, leading to lower levels [111]. Research also shows the potential of avenanthramides from oats to lower postprandial blood glucose levels. Both avenanthramides C and B have been shown to significantly inhibit the activity of the intestinal glucose-transporting proteins GLUT2 and SGLT1. These results suggest that avenanthramides may contribute to the antihyperglycemic properties associated with oat consumption [112]. Oat products, especially flour, bran, and oatmeal, have a significantly lower glycemic index compared to barley, wheat, or maize products [105,113].

The in vivo study has shown that consumption of β-glucans from oat helped to lower total cholesterol and LDL fraction in plasma, with an additional positive effect on body weight reduction in obese individuals [5]. A study of the effects of β-glucans on cardiovascular disease risks (in vivo in animals) has shown that they reduced LDL cholesterol and very low-density lipoprotein (VLDL) by 25–31% and 0.2–2.3%, respectively, and lowered total cholesterol and triglycerides levels [114]. β-glucans have the effect of reducing the absorption of cholesterol from the small intestine by forming a gel that binds cholesterol molecules. In one study, 33 volunteers with high LDL cholesterol levels consuming 3 g of β-glucans per day for 4 weeks acquired a 5.4% reduction in LDL cholesterol levels [115]. Another study of 60 overweight or obese individuals found that consuming 6 g of β-glucans per day for 12 weeks reduced total cholesterol by 5.5% and LDL cholesterol by 7.5% [116]. The findings of these studies confirm that the consumption of oat products can be an effective way to lower blood cholesterol levels, with β-glucans being the main component responsible for this effect. Studies have shown that human intestinal microflora metabolizes dietary fiber and β-glucans and provides the body with short-chain fatty acids. Increasing the ratio of propionate to acetic acid (the main substrate for cholesterol biosynthesis) results in a decrease in cholesterol biosynthesis [117]. The study showed that propionic acid and butyric acid decreased mRNA levels of 3-hydroxy-3-methylglutaryl-CoA reductase (HMG-Co-A) (rate-limiting enzyme) of cholesterol synthesis in Caco-2/TC-7 enterocytes [118].

Regular consumption of oat grain and oat products can help prevent and treat hypertension and cardiovascular diseases. Hypertension is a major contributor to heart diseases including coronary heart disease, heart attack, and stroke [119]. The mechanism of the influence of oat products on hypertension is complex and involves many factors. Oatmeal and other oat products contain high amounts of dietary fiber, β-glucans, and phytosterols, which may have beneficial effects on the cardiovascular system. β-glucan, which is the main component of oat fiber, works in several ways to lower blood pressure. Firstly, β-glucans reduce the absorption of cholesterol in the gut, which reduces the risk of atherosclerosis and cardiovascular disease. Secondly, β-glucans increase salt excretion from the body, which helps regulate blood pressure. Thirdly, β-glucans stimulate the production of nitric oxide, which has a vasodilatory effect on the blood vessels and lowers blood pressure [30]. It has been shown that the consumption of 5–7 g of β-glucans per day by individuals suffering from hypertension was effective in reducing diastolic blood pressure values by 4 mm Hg and systolic blood pressure values by 7 mm Hg [31,103].

Phytosterols, which are natural substances found in oat grain, also have blood pressure-lowering effects. Phytosterols prevent the absorption of cholesterol in the gut, which
reduces the risk of atherosclerosis and cardiovascular disease. In this way, phytosterols help to maintain healthy blood vessels and regulate blood pressure [120].

5.2. Oat in Cancer Therapy

Cancers, which involve the uncontrolled growth of cells, are now counted, along with cardiovascular disease, among the main diseases of civilization of the 21st century. The β-glucans found in oat grain have been shown to be stimulators that activate, among other things, cytokines and macrophages, which are responsible for protecting the body from various infections and keeping its tissues in good condition (in vitro studies) [121,122]. The macrophages are characterized by the ability to engulf and destroy cancer cells and various pathogens [121,123]. Products extracted from oat grain have been confirmed to possess strong antioxidant (and thus anticancer) activity due to the presence of compounds such as, i.e., hydroxycinnamic and hydroxybenzoic acids, polyphenol derivatives, and vitamin E in their composition. Polyphenol derivatives show the ability to bind copper and iron, preventing their involvement during oxidation processes [104]. It has also been shown that β-glucans can counteract colorectal cancer. Under the influence of β-glucan contained in oat grain, some carcinogenic compounds (cresols, nitrosamines, estrogens) are dispersed, improving the rheological properties of the colonic contents. This prevents the fecal mass from leading to dangerous stasis, which creates inflammatory foci, often leading to ulceration, which in turn leads to cancerous foci [124,125]. In vivo and in vitro studies have confirmed that intestinal bacteria may contribute to the development of colorectal cancer by releasing genotoxic virulence factors, as well as by producing cancer-associated metabolites [126,127]. β-glucans are fermented in the cecum and colon by microflora [128,129], stimulate the growth of the probiotic Bifidobacterium and Lactobacillus bacteria, and promote the production of short-chain fatty acids (SCFAs) while inhibiting the growth of putrefactive bacteria [130–133]. Furthermore, β-glucans were shown to have the potential to prevent stomach, lung, larynx, pharynx, esophagus, breast, ovaries, uterus, and prostate cancer [33,34,121,123–125,134]. The destruction of tumor cells, through inhibition of tumor growth, related to the antiproliferative and proapoptotic properties of β-glucans was previously reported. β-glucans were also presented as cytotoxin-destroying, antimutagenic substances [134]. β-glucans shield human DNA and may play a huge role in the prevention of many cancers wherever there is exposure to mutagens and carcinogenic environmental effects. Gibinski et al. added that β-glucan from oat grain introduced into the body induces increased macrophage activity [33,34,123]. It has been shown that not only macrophages but also other cells of the immune system have receptors that can be activated by β-glucan. Activated macrophages engulf dead cells, resulting in tumor shrinkage [121,123–125].

5.3. Oat in the Fight against Overweight and Obesity

The consumption of high-fiber oat products has a positive effect on maintaining a healthy body weight and a normal body mass index [135–137]. Birketvedt et al. [138], in an in vivo study (a group of 60 patients), showed that the same diet without fiber resulted in a weight loss of 5.8 kg, and enriched with fiber in a loss of 8 kg. High-fiber foods are characterized by a reduced energy density, i.e., for the same meal weight and volume, they have a lower calorific value [135]. Products with a high fiber content enforce the natural need for prolonged chewing time, which increases the amount of saliva and gastric acids produced, and this in turn stimulates a more rapid achievement of the feeling of satiety, lasting even for several hours after a meal. The ability of dietary fiber (especially insoluble fraction) to bind a significant amount of water makes it a low-calorie filler that is good in satiating the feeling of hunger in the consumer [139]. Moreover, by forming viscous gels in the lumen of the small intestine, dietary fiber slows down the absorption of nutrients from food [140]. By stabilizing blood glucose and insulin levels, it also influences the body’s hormonal balance. High insulin levels change the body’s fat metabolism, promote fat accumulation in the form of body fat, and increase the feeling
of hunger [141]. Both in vivo and in vitro studies confirm that oat products high in (1-3)(1-4)-β-D-glucans play an important role in the diet. By stabilizing blood glucose levels, they contribute to lowering insulin levels and make it possible to reduce hunger and maintain a feeling of satiety long after consumption [110,142,143]. Kirwan et al. have shown that eating a cereal meal 45 min before exercise improved exercise time, maintained euglycemia for longer during exercise, and resulted in greater total carbohydrate oxidation during exercise. This meal provided a significant performance and metabolic advantage [144].

5.4. Oat in the Diet of People with Inflammatory Bowel Disease

Inflammatory bowel disease (IBD) is a chronic disease characterized by inflammation of the intestinal mucosa caused by an impaired immune response. It includes Crohn’s disease (CD) and ulcerative colitis (UC). Various methods are used to treat this disease, including pharmacotherapy, surgery, and lifestyle and dietary changes [145]. Cereals are not recommended in the diet of IBD patients with the exception of oat and rice [146]. Animal studies have shown that β-glucans from oat relieve disease symptoms, e.g., diarrhea [147]. Clinical studies confirm that oat products may have a beneficial effect on IBD patients due to the high content of soluble fiber including β-glucans, which have an anti-inflammatory effect and a positive effect on the intestinal microbiome mainly due to an increase in short-chain fatty acids and especially butyric acid in the feces [148,149].

5.5. Oat in the Diet of People with Coeliac Disease

Coeliac disease (CD) is an increasingly common genetic condition today. It is generally estimated to affect 1:200 or even 1:100 people [150–153]. To date, the only available treatment for patients with coeliac disease is a lifelong gluten-free diet. Despite strict adherence to the diet, patients have difficulty achieving full restoration of the intestinal microflora, which plays a role in the processing and absorption of nutrients [154]. The inclusion of oat products in therapeutic diets improves their texture, gives a greater feeling of satiety, and increases their nutritional value due to the presence of, among others, valuable minerals, vitamins, dietary fiber, and tocopherol [150–153]. Studies have shown that oat grain can be tolerated without significant changes in clinical symptoms [155,156], but there may be histological, serological, and immunological signs indicating an inflammatory reaction in the intestinal mucosa without signs of disease (in vitro studies) [157,158]. In vivo study showed that people who are sensitive to oat grain may have an increased incidence of diarrhea as a result of an inflammatory reaction in the intestinal mucosa (154). It may be that the processing of oat grain (such as drying, fermentation, gluten-free cleaning) and the choice of cultivar may be important factors in determining the body’s response to its consumption [159,160].

6. Conclusions

A healthy diet and fitness are the main pillars of the lifestyle being currently strongly promoted in order to ensure a long life in good mental and physical health. For this reason, there is a growing demand for foods with high nutritional value, minimally processed, and specific health-promoting properties. Oats and oat products are one of the answers to this trend. Whole-grain oat products have clinically documented preventive and curative effects on cardiovascular disease factors such as hypertension and atherosclerosis, obesity, gastrointestinal disorders, diet-related cancers, and many other conditions.

Oat grain is a valuable yet inexpensive raw material that can be used extensively in food technology. It is worthwhile to take an interest in oat in the sphere of research, processing, and use in nutrition. Wider use of oat grain in the food industry can create great opportunities for rational nutrition and thus contribute to improving the health of the population. However, the processing of oat grain meets certain difficulties related to, for example, antinutritional compounds and high fat content in the grain. Breeding work on new varieties of oat is still in progress, so it is important to constantly monitor the possibilities of their application. In addition, the growing market for oat grain concentrates

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