1 **Oat proteins as emerging ingredients for food formulation: where we stand?**

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8 **Abstract:**

9 Over the last decades, interest in oats (*Avena sativa* L.) as healthy foods increased due to their multiple
10 functional and bioactive components such as dietary fibers, polyphenols, and proteins. Protein extracted
11 from oats received considerable attention being more abundant (12-20%) and having a distinct composition
12 compared to other cereal grains. Oat proteins also present pleasant sensorial attributes compared to proteins
13 deriving from legumes and oil seeds. Protein isolates or concentrates can be dry- or wet- extracted, and a
14 subsequent enzymatic hydrolysis can release peptides with bioactive properties. Several strategies have
15 been successfully applied to improve the techno-functionality of oat proteins. In term of food application,
16 there are few oat protein-based food products available in the market, which urge food developers to build
17 tailored strategies and food portfolios of these ingredients. This review will address oat proteins extraction
18 technologies and pre/post-treatment strategies, main characteristics, and applications. Future research is
19 still required to take advantage of breeding progress to select high grain-protein oat varieties and to boost
20 the incorporation of oat proteins in foods, while keeping in mind the cost and the environmental impact.
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22 **Keywords:** oat protein, extraction, techno-functionality, health benefits, allergenicity

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1. Introduction

Interests in protein-rich diet are rising favored by its health-promoting effects, with particular attention to the source. Plant proteins are gaining interest as "better for you" and "better for the planet" alternatives to animal proteins [1]. As a result, the market request to innovative non-animal plant sources keeps increasing, where the main drivers are consciousness towards health, environment, and animal welfare. The urge to search for alternative non-animal protein sources opened the way to the valorization of non-fully exploited plants and industrial by-products. Oat (*Avena sativa* L.) is the sixth highest consumed type of cereal, with a global annual production of 23 million tones, where Russia is the largest producer of this crop worldwide [2].

Oats, wheat, barley and rye belong to the same *Poaceae* family, where oats are sub-classified into the *Aveneae* tribe while the other cereals belong to the *Triticeae* tribe [3]. Table 1 illustrated oat grain composition in comparison to other grains (cereals, legumes, and oil seeds) showing particularly high amount of protein and lipids compared to rice and wheat. Beyond β-glucan production, oat has recently attracted research and commercial attention as a superior cereal sources of low-cost dietary proteins (up to 20% protein) [4]. The distribution of proteins within oat grain is heterogeneous, following an increasing gradient from the interior to the periphery, where proteins are located primarily in the germ and the bran but less in the endosperm [5]. Like plant proteins, oat protein are industrially extracted using alkaline extraction-isoelectric precipitation process [6, 7]. Dry fractionation was also suggested as a sustainable process for plant protein production [8]. Moreover, oat protein concentrate can be recovered as a by-product from β-glucan production thereby improving the sustainability of the process and contributing in circular economy [9, 10]. Oat proteins are composed of globulins (70–80%) followed by albumins (1–12%), prolamins (4–15%) and glutenins (<10%), unlike other cereals where prolamins are the major storage proteins [11]. Compared to other cereals, oat proteins have higher content of essential amino acids such as lysine [12].

Table 1: Chemical composition of oat grains (g/ 100g on dry basis)

	Oat	Rice	Wheat	Pea	Soy
Protein	12-20	7-10	11-15	23–31	36-40
Carbohydrates	69-76	73-80	55-69	28–65	20-30
Fiber	5-10	1-8	12-15	22-27	5-12
Lipid	5-18	1-2	1-2	1–2	18-20
Ash	1-2	1-2	1-2	2-4	5-6

| **Reference**	[5, 13–16] [17]	[5, 18]	[19, 20]	[19, 21, 22]	[23, 24]

Plant proteins are gaining considerable interest as food ingredients with respect to the latest trends towards a healthy lifestyle, flexitarianism, vegetarianism and veganism [9]. Global oat protein market is forecasted to grow at a compound annual growth rate of 1.22% during the forecast period (2019-2024) [25]. These proteins are highly accepted by consumers compared to other plant alternatives such as soy, pea and lupine proteins since no off-flavors concerns are raised [10, 26]. From a sustainability standpoint, food products containing oat proteins showed lower carbon footprint and land use than their counterparts made with animal proteins [27]. Indeed, if 24% of animal-based food is replaced by oat protein concentrate-based food, greenhouse gas emissions could be reduced by 8% and land use by 14% [28]. The techno-functionality of oat proteins is still challenging, where low solubility, emulsifying capacity, foam ability and gel property can limit their application in foods [29]. Therefore, appropriate chemical, physical and enzymatic methods were developed to improve techno-functional and nutritional properties [30]. In the light of the considerations, this review will give an updated compilation of oat proteins from basics to applications.

2. Processing of oat proteins

Oat grains or flours can go through pretreatments prior to extraction or fractionation to increase protein yield. Heat treatment of oat grains ensured lipase inactivation (about 60%) thereby avoiding the development of rancidity in oats during storage [31, 32]. This treatment also enhanced the extraction yield [31, 32]. Dehulling (or pearling) is required for husked oat, where unpalatable hulls are removed by the combined action of friction and abrasion using abrasive devices (Satake or tangential abrasive dehulling device) [33]. A patented process for oat dehulling ensured the remove of 15% of grain weight with a prior phased of grain steeping in an aqueous medium for up to 4 hours [34]. In the case of naked oats, varieties with no hulls, hulls genes are removed allowing to reduce the production costs by avoiding the dehulling step [35]. The dehulled or naked oat grains can be subjected to defatting with ethanol, hexane or supercritical CO_2 extraction to remove lipids since oat has relatively high fat content (5 to 10%) [13–15]. Defatted oat grains can go through milling to produce oat flour. Prior to alkaline extraction, enzymatic treatment with amyloglucosidase can increase the release of proteins during extraction thanks to the breakdown of polysaccharides [36]. This enzymatic treatment can also enhance the techno-functionality of proteins by increasing solubility, water retention and foaming capacity [4]. Sprouting process was also used for boosting the bioactive and nutritional properties of oat-derived ingredients [37].

80 The alkaline method is the most commonly used method for extracting protein from oats [38]. The
81 extraction was performed at pH 9.2 to solubilize oat proteins, followed by isoelectric precipitation at pH 5,
82 washing with water, neutralization and subsequent drying to obtain oat protein isolates with up to 90%
83 protein (Fig. 1A) [4]. When the main purpose of extraction is β-glucan recovery (Fig. 1B), the denaturing
84 effect of high pH may be beneficial for protein solubilization contrary to the acidic extraction of oat β-
85 glucan [39]. Protein contents of oat protein concentrate can range from 69 to 90% [40]. Dry fractionation
86 (Fig. 1C) consists in milling oat grits or oat grains followed by air classification to obtain a fraction rich in
87 proteins containing 42% protein [41]. This mild method allows the retention of starch and lipid, which can
88 contribute in the physicochemical and tech-functional properties of oat protein concentrate [6]. In contrast
89 to dry methods, wet fractionation produces isolates with high protein purity and yield, yet it requires high
90 amounts of solvents and chemicals, which can potentially induce the loss of some health beneficial
91 components and changes in the structure of proteins[4, 42]. Moreover, this wet process requires high
92 water and energy consumption and generates high aqueous waste that can negatively impact the
93 environment [8].

94 Oat protein concentrate or isolates could be enzymatically hydrolyzed to produce bioactive peptides, which
95 can be further purified either by membrane or chromatographic methods to yield pure peptides [7]. Oat
96 proteins hydrolyzed with protease generate peptides with biological functions and improved functional
97 properties [43, 44], yet such a process can be time-consuming and expensive [45, 46]. Alternatively, partial
98 hydrolysis with alcalase can be used for protein hydrolysis, where it was reported to improve the functional
99 and antioxidant characteristics of oat protein isolate, particularly the hydrolysate with a moderate alcalase
100 hydrolysis (6%) [47]. Subsequent ultrasound treatment increased the efficiency of enzymatic hydrolysis by
101 increasing inhibitory activities of peptides against angiotensin converting enzyme [45].
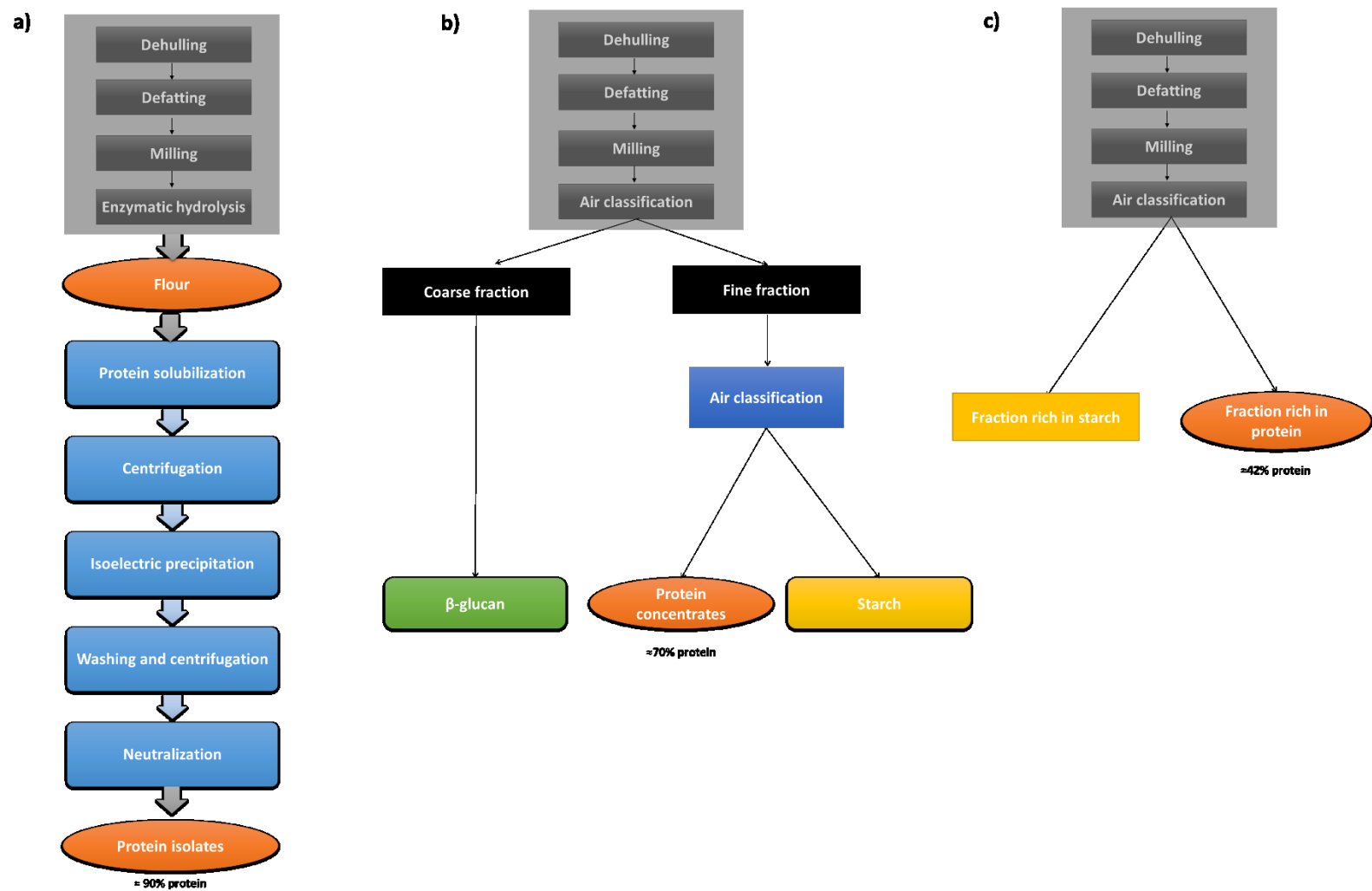
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Figure 1: Processing of oat proteins. a: Alkaline method [4]; b: Recovery of oat concentrate from β-glucan production chain [40]; c: Dry fractionation [6].

3. Structure and composition of oat proteins

Oat protein contains globulins (≈50–80%), albumins (≈1–12%), prolamins (≈4–15%) and glutelins (≈10%) [48]. Globulins are salt-soluble proteins, and consist of three fractions including 12S globulin as major fraction followed by 7S and 3S. Oat globulin (12S) is an oligomeric protein with six quaternary monomer subunits (each 54–60 kDa), which resembles the structure of soy 11S globulin (glycinin) [49, 50]. The two major subunits of 12S are A- and B-subunits, where A-subunit (32 kDa) is an acidic polypeptide and the B-subunit (22 kDa) is a basic polypeptide [51]. The 7S globulins are polypeptides ranging from 55 kDa to 65 kDa. The 3S fraction is characterized by two polypeptides with molecular weights of about 15 and 21 kDa [46, 52]. Albumins (19 to 21 KDa) are mainly enzymes playing roles in the overall protein quality and plant defense mechanism [53]. The alcohol-soluble prolamin fraction, avenins, consists of four fractions α, β, γ, and ω-avenins [54]. Avenins have a low molecular weight (20-40 kDa) and have structural homology to the sulphur-rich subgroup α-gliadins and γ-gliadins of wheat, the B-hordeins of barley, and the γ-secalins of rye [55]. These proteins have a storage function similar to wheat gluten, but with different amino acid composition (poor in proline and glutamine) [54]. Glutelins are polypeptides ranging from 10 to 90 kDa [53].

Amino acid composition of oat proteins was reported to vary significantly among the different protein fractions obtained by Osborne method [53]. Globulins present the highest amounts of most essential amino acids (*e.g.* phenylalanine, lysine, histidine and valine) and non-essential amino acids (*e.g.* glutamic acid, arginine) compared to albumins, prolamins and glutelins [53]. Globulins essential amino acids composition meets FAO-recommended values for adults for all amino acids except for methionine [56]. Based on the ratio of essential amino acid content to the total amino acid content, both albumin (39%) and globulin (36%) have values higher than 36%, and therefore, can be qualified as high-quality proteins unlike the prolamins and glutelins fractions [56]. Beside the fractionation, the amino acid composition of protein fractions varied importantly as function of used oat varieties according to variety (i.e. genetic) and also environmental factors. The extraction method (temperature, pH and solvents) was also noted to impact the outcome [57].

To evaluate the quality of oat proteins in terms of the amino acid composition and quantity, Table 2 included different types of proteins deriving from cereals (gluten-free and gluten containing), oil seeds and pulses. Commercial oat proteins have comparable composition to that of rice and better than wheat, while they showed low essential amino acid contents compared to soy and pea proteins [9, 58]. Oat is more abundant in the sulphur-containing amino acids cysteine and methionine, compared to pulses [59]. Therefore, oat and pulses proteins can be blended to have higher protein quality and specifically with greater lysine concentrations to satisfy the daily human amino acids requirement [60]. Based on the ratio of essential

amino acid content to the total amino acid content, oat proteins can be categorized as high-quality proteins since the essential amino acid content to the total amino acid content ratio reached 36% as recommended by FAO [56]. Noteworthy, depending on the variety and the purity, oat proteins can show variable protein scores [60].

Table 2: Amino acid content of oat proteins (values are presented in g per 100 g of commercially available isolated protein powder) [58]

	Oat	Rice	Wheat	Pea	Soy	FAO standard (adult)
Protein content[1]	64	79	81	80	91	
Essential amino acids[2]						
Isoleucine	1.3	2	2	2.3	1.9	1.3
Leucine	3.8	5.8	5	5.7	5	1.9
Threonine	1.5	2	1.8	2.5	2.3	0.9
Phenylalanine	2.7	3.7	3.7	3.7	3.2	1.9
Lysine	1.3	1.9	1.1	4.7	3.4	1.6
Histidine	0.9	1.5	1.4	1.6	1.5	1.6
Valine	2	2.8	2.3	2.7	2.2	1.3
Methionine	0.1	2	0.7	0.3	0.3	1.7
ΣEAA	13.7	22.1	18	23.6	19.9	-
Non-essential amino acids						
Serine	2.2	3.4	3.5	3.6	3.4	-
Glutamic acid	11	12.7	26.9	12.9	12.4	-
Glycine	1.7	3.4	2.4	2.8	2.7	-
Alanine	2.2	4.3	1.8	3.2	2.8	-
Cysteine	0.4	0.6	0.7	0.2	0.2	-
Arginine	3.1	5.4	2.4	5.9	4.8	-
Proline	2.5	3.4	8.8	3.1	3.3	-
Tyrosine	1.5	3.5	2.4	2.6	2.2	-
ΣNEAA	24.7	36.8	48.9	34.4	31.9	-
ΣAA	38.4	58.9	66.9	58	51.8	-
ΣEAA/ ΣAA	36	37	27	41	38	36

ΣEAA sum of all essential amino acids, ΣNEAA sum of all non-essential amino acids, ΣAA sum of all amino acids,

ΣEAA/ ΣAA: the essential amino acid content to the total amino acid content ratio

[1]: determined using the Dumas combustion method.

[2]: determined using ultra-performance liquid chromatography (UPLC) tandem mass spectrometry

4. Health benefits and concerns of oat proteins

In term of health benefits, several studies were conducted to determine the impact of oat protein and hydrolyzed oat proteins on human health (Table 3). The intake of oat protein increased swimming

endurance and the levels of liver glycogen, enhanced the activities of lactic dehydrogenase and superoxide dismutase and decreased the levels of blood urea nitrogen and malondialdehyde in serum [61]; This demonstrated the anti-fatigue function of oat protein but no clear indication was provided about the mechanism of action. Moreover, the daily consumption of oat protein (25 g) facilitated the recovery from exhaustive downhill running since it significantly inhibited limb edema following damaging exercise, and reduced the adverse effects on muscle strength, knee-joint range of motion, and vertical jump performance [62].

Oligopeptides deriving from hydrolyzed oat proteins were reported to have biological activities including antioxidant, anti-inflammatory and antihypertensive properties [7, 63, 64]. Oat proteins were found efficient in inhibiting renin (around 40.5%-70.9%) and enzyme angiotensin-I-converting enzyme (around 86.6%-96.5%) but poor relatively poor dipeptidyl peptidase-IV inhibition (around 3.7–46.3%) [63]. Based on in silico digestion, several peptide sequences (FFG, IFFFL, PFL, WWK, WCY, FPIL, CPA, FLLA, and FEPL) were identified as responsible of these inhibitory activities suggesting their potential use for treating hypertension and diabetes [63]. The antioxidant activity investigated using a cellular model was attributed to several factors including reduced production of intracellular reactive oxygen species, increased cellular glutathione, and increased activities of three main endogenous antioxidant enzymes [64]. Particularly, the peptides, LVYIL and YHNAPGLVYIL, were reported to be associated with increased activities of antioxidant enzymes with an increase of 29% in cell viability [64]. Antioxidant peptides (IRIPIL, FLKPMT, NSKNFPTL, LIGRPIIY, and FNDILRRGQLL) isolated from oat globulin hydrolyzed alcalase through ultra-filtration and ion-exchange chromatography showed bioactive effects [65]. These *in vitro* studies are promising but *in vivo* tests are required to identify antioxidant mechanisms of individual's peptides. The available *in vivo* studies focused on oat proteins or hydrolyzed and not on identifying specific high value peptides.

Table 3: Health benefits of oat proteins

Approach	Method	Impact	References
Animal study	male Kun-ming mice (n=30) were fed oat proteins (5.44 mg/g body weigh) dissolved in 2 mL distilled water daily for 30 days	increase swimming endurance and the levels of liver glycogen; enhance the activities of lactic dehydrogenase and superoxide dismutase; decrease the levels of blood urea nitrogen and malondialdehyde in serum	[61]

Human study	Healthy, untrained collegiate men (n=16) consumed oat protein (25 g protein) for 19 days	facilitate the recovery from exhaustive downhill running; ameliorate exercise-induced fatigue in mice; alleviate eccentric exercise induced skeletal muscle soreness; reduce the elevation of plasma IL-6 concentrations and serum creatine kinase, myoglobin and C reactive protein contents; inhibit limb edema following damaging exercise	[62].
In vitro study	Peptidomic approach of hydrolyzed oat proteins	antioxidant, anti-inflammatory and antihypertensive properties, and metal chelating properties	[7].
In silico digestion	The prediction of inhibitory peptides sequences from oat protein hydrolysates following in silico hydrolysis with theproteases, papain and ficin.	Inhibit the activity of renin, angiotensin-I-converting enzyme and dipeptidyl peptidase-IV	[63]
Cellular model	Human hepatocellular carcinoma (HepG2) cells were treated by isolated oat peptides	cytoprotection of cells; increase in cell viability	[64]
In vitro study	Determination of hydroxyl and 1,1-diphenyl-2-pycrylhydrazyl (DPPH) radical scavenging capacity	Identification of antioxidant peptides sequences: IRIPIL, FLKPMT, NSKNFPTL, LIGRPIIY, and FNDILRRGQLL	[65]

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176   In the face of these health benefits, the safety of oat proteins for celiac patients remain controversial [3, 66–

177   68]. Several studies supported the safety of oat proteins for celiac patients [69, 70], while others reported

178   oat avenins as triggers to immune reaction in some cases of celiac patients [66, 71, 72]. This contradiction

179   might be explained by the high diversity in oat varieties (differing in prolamin genes) with different

180   immune-reactivity potentials [66, 67, 71]. According to the Codex Standard, CODEX STAN118-1979, oats

181   can be tolerated by most but not all people who are intolerant to gluten [73]. The contamination of oat with

182   gluten-containing grains is currently the main problem faced by people with celiac disease, where several

183   advanced analytical methods are developed to detect the presence of epitopes related to celiac disease in

184   blends of oat contaminated with others grains [69, 71, 74]. Based on EU regulation, oats and oat products

185   can be considered gluten-free if the maximum gluten contamination level do not exceed 20 ppm [75].

186 Therefore, establishing a separate gluten-free oat production chain requires controlling all steps in the chain
187 as well as labelling these products must contain indication on any potential contamination.

5. Techno-functionality of oat proteins

189 Oat protein have a poor solubility and poor emulsification properties due to the unfolding of oat globulins,
190 resulting in a transition from β-sheet to a random coil conformation and formation of insoluble aggregates
191 at pH between 3.0 and 7.0 [9]. This low solubility in acidic conditions limits the use of oat proteins in
192 dispersed food systems such as foams and emulsions [76]. Several strategies were applied to enhance the
193 techno-functionality of oat proteins as summarized in Table 4. Enzymatic treatment by trypsin, alcalase,
194 transglutaminase or glutaminase increased protein solubility, foaming properties and emulsification due to
195 the reduction of tertiary structure and molecular weight and the increase in the flexibility of protein
196 secondary structure and exposed hydrophobic side chains [29, 50, 76]. Chemical modification by acylation
197 was reported to decrease water holding capacity and increase emulsion activity index, compared with those
198 of native proteins [77]. Maillard reaction under controlled dry-heating conditions was reported to enable
199 the conjugation of oat protein with polysaccharides *(e.g. Pleurotus ostreatus* β-glucan and dextran), where
200 the resulting conjugates have better solubility, emulsifying properties and thermal stability compared to oat
201 protein isolate [12, 49].

202 Native oat proteins can form strong gels only at alkali pH with a heating phase (110–120 °C), while under
203 acidic and neutral pH, the formed gels are found weak with poor water holding capacity [46]. Partial
204 hydrolysis by flavourzyme and trypsin improved oat protein gel properties resulting in gel with comparable
205 mechanical strength to egg white protein at pH 9 [11, 46]. Both oat protein and its hydrolysate-based gels
206 exhibited excellent water-holding capacity at neutral or mildly alkaline conditions suggesting it potential
207 uses as a new and cost-effective gelling ingredient of plant origin to provide texture and structure in food
208 products [46]. Inulin addition at low concentrations (0.1–0.5%) resulted in strong oat protein gels at neutral
209 pH [11]. Cold-set gelation of oat protein consists in a heating step to enable proteins denaturation and then
210 polymerization followed by a cooling and the addition of Ca^{2+} or glucono-δ-lactone (GDL), resulting in the
211 formation of a soluble protein aggregates at ambient temperature [51, 78]. These cold-set oat protein isolate
212 gels could resist acidic juice and pepsin digestion thereby protecting both α-amylase enzyme activity and
213 the viability of probiotics in harsh gastric conditions [78]. Thus, these gels might be used as delivery
214 vehicles for sensitive compounds in food and non-food applications [78].

215 **Table 4: Post treatment for a better techno-functionality of oat proteins**

Treatment	Impact on structure	Impact on techno-functionality	Reference
Enzymatic treatment by trypsin, alcalase, transglutaminase or glutaminase.	-reduce tertiary structure and molecular weight -increase in the flexibility of protein secondary structure and exposed hydrophobic side chains	increase protein solubility, foaming properties, emulsification, and gelling	[29, 50, 76] [11, 46]
Acylation	Formation of acyl linkage	decrease water holding capacity and increase emulsion activity index	[77]
Maillard reaction under controlled dry-heating conditions	to enable the conjugation of oat protein with polysaccharides *(e.g. Pleurotus ostreatus* β-glucan and dextran),	resulting conjugates have better solubility, emulsifying properties and thermal stability compared to oat protein isolate	[12, 49]
Inulin addition	Formation of soluble aggregates	Enhance gelling	[11]
Addition of Ca^{2+} or glucono-δ-lactone	proteins denaturation resulting in the formation of a soluble protein aggregates	Enhance gelling	[51, 78]

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6. Applications of oat proteins

The use of oat proteins is still limited in foods and beverages, yet the focus on improving the techno-functionality might boost industrial incorporation oat proteins in foods. A recent study [79] investigated the pretreatment of pea-oat protein blend by phytase and fermentation and subsequent extrusion cooking to produce meat analogue. After texturization and cooking, the resulting meat analogue had improved nutritional (reduction of antinutrients and increase in protein content and essential amino acids),

223   physicochemical (color and water/oil holding capacity) and textural properties (chewiness and resilience)

224   as well as flavor [79]. Concentrate of oat proteins were incorporated at three levels (1.1, 1.7 and 2.5%) in

225   fermented (*Lactobacillus delbrueckii* subsp. *bulgaricus* und *Streptococcus thermophilus*) yoghurt-product

226   [9]. The proteolytic enzymes present in the yoghurt culture cleaved oat proteins and released bioactive

227   peptides thereby enhancing the nutritional value of the product [9]. Furthermore, oat protein concentrates

228   (43% protein, 33% starch and 3.4% ash) enabled the increase of viscosity thanks to starch gelatinization

229   and resulted in a yoghurt combining nutritional benefits, sustainability and improved sensorial quality [10].

230   When oat protein isolates (90% oat protein and less than 1% starch) were used to make yoghurt, strong

231   sedimentation and high syneresis were induced due to the low oat protein functionality under acidic

232   conditions [10]. More work is required to provide a deeper knowledge into the role of starch and protein in

233   fermented oat protein concentrate based-yoghurts [9].

234   The use of oat protein for encapsulation may represent great opportunities for the consolidation of its

235   position in the market of food and nutraceutical products. Glycosylated oat protein (conjugated with β-

236   glucan) showed improved solubility, emulsifying capacity and thermo-stability compared to untreated oat

237   protein [12]. Given the poor bioavailability of β-carotene limits its utilization, β-carotene was encapsulated

238   by a conjugate formed by oat protein isolate and *Pleurotus ostreatus* β-glucan. Such conjugate protected

239   and stabilized β-carotene and increased its bioavailability and antioxidant activity [80]. Oat protein-shellac

240   combination gels also improved the bioavailability of resveratrol by protecting resveratrol along the

241   gastrointestinal tract of rats and improving its release in the intestinal environment, compared to free

242   resveratrol [81]. These studies suggest the potential use of oat proteins as a novel natural biopolymer

243   delivery system for bioactive compounds for food and biomedical applications [80, 81]. Future experiments

244   can focus on developing stable systems based on oat proteins at neutral pH [78].

245   **7. Conclusion**

246   In the frame of mapping new sources of alternative proteins, oat rises owing to the interesting properties of

247   its proteins compared to other cereal grains. Oat proteins have been launched in the market with a wide

248   spectrum of food and nutraceutical applications. As a functional food ingredient, the application of oat is

249   still in its early stages, where food companies are investing for producing high-quality oat proteins.

250   Noteworthy, native oat proteins present poor functional properties and consequently, attempts have been

251   made to improve their techno-functionality by chemical, physical and biological treatments. More

252   investigations are required to optimize and validate these processing steps to improve protein quality to

253   meet the food industry requirements. Safety, cost-efficiency, sustainability, bioactivity, and techno-

254   functionality are crucial features for the selection of processing and varieties to boost oat protein

255 applications. The contribution of breeding programs is of high relevance in positioning oat in the plant

256 protein market through the selection of high-quality protein varieties (up to 40% protein) [82].

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Figure caption:

Figure 1: Processing of oat proteins. a: Alkaline method [4]; b: Recovery of oat concentrate from β-glucan

production chain [40]; c: Dry fractionation [6]. This figure illustrates the three potential processing enabling

the production of oat protein ingredients (isolates or concentrates)

497   **Table caption**

498   **Table 1:** Amino acid content of oat proteins (values are presented in g per 100 g oat proteins) [58]. This
499   table summarizes oat protein quantity and amino acid composition of oat proteins in comparison with
500   different protein grains.

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