

PHARMACOLOGICAL POTENTIAL AND NOVEL DRUG DELIVERY APPROACHES OF AVENA SATIVA: A COMPREHENSIVE REVIEW

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ABSTRACT

Avena sativa (oat) is a widely cultivated cereal crop that has attracted increasing scientific interest due to its remarkable nutritional value and diverse pharmacological properties. Beyond its traditional role as a staple food, oats are now recognized as a rich source of bioactive compounds such as β -glucan, avenanthramides, flavonoids, sterols, phenolic acids, and saponins, which collectively contribute to multiple health-promoting effects. This review aims to comprehensively summarize the phytochemical composition, pharmacological activities, and recent advances in novel drug delivery approaches related to Avena sativa. Extensive literature indicates that oat-derived constituents exhibit significant antioxidant, anti-inflammatory, antidiabetic, antihyperlipidemic, cardioprotective, neuroprotective, antiatherogenic, immunomodulatory, and dermatological activities. Among these, avenanthramides represent unique

phenolic compounds specific to oats and are largely responsible for their potent anti-inflammatory and antioxidant effects through modulation of oxidative stress and inflammatory signaling pathways. In recent years, considerable attention has been directed toward the development of innovative delivery systems, including nanoparticles, hydrogels, nanoemulsions, and topical formulations, to enhance the stability, bioavailability, and therapeutic efficacy of oat bioactives. The integration of Avena sativa constituents into novel

drug delivery platforms highlights their potential application in pharmaceutical, nutraceutical, and cosmeceutical products. Overall, this review emphasizes the therapeutic relevance of oats and supports their future development as a promising natural source for functional ingredients and drug delivery systems, while also underlining the need for further *in vivo* and clinical investigations to validate their clinical efficacy and safety.

1. INTRODUCTION

Cereals have been one of the most vital staple foods for humans since ancient times, offering both nutritional and therapeutic advantages. Of these, *Avena sativa*, or simply Avena sativa, has received more scientific attention because of its distinct chemical composition and potential for therapeutic use.^[1] Oat preparations have long been used to promote digestion and metabolic balance as well as help with skin irritation, anxiety, and exhaustion.^[2] Current pharmacological research has verified that *Avena sativa* contains a number of bioactive substances that contribute to its wide range of biological activities, particularly β -glucan, avenanthramides, saponins, flavonoids, and sterols.^[3] Avenanthramides, exclusive phenolic alkaloids found only in *Avena sativa*, exhibit strong antioxidant and anti-inflammatory acts by inhibiting nuclear factor κ B (NF- κ B) and downregulating pro-inflammatory cytokines.^[4] The soluble fiber β -glucan is especially well-known for its cholesterol-lowering and glycemic-control qualities.^[5]

In addition, epidemiological and clinical evidence indicates that regular oat consumption improves the composition of the gut microbiota while lowering the risk of obesity, type 2 diabetes, and cardiovascular disease.^[6] Because of their calming, moisturizing, and antipruritic qualities, oat extracts and colloidal oatmeal have been extensively used in dermatological formulations in addition to their nutritional advantages.^[7] *Avena sativa* is now recognized as a potential natural source of therapeutic agents in addition to being a functional food because of its many health-promoting benefits. Its phytochemical makeup, pharmacological properties, and new developments in innovative drug delivery techniques that improve the bioavailability and therapeutic use of its bioactive components are all intended to be compiled in this review.

1.1 CLASSIFICATION

Taxonomic Rank	Name
Kingdom	Plantae
Division	Magnoliophyta
Class	Liliopsida
Order	Poales
Family	Poaceae
Genus	Avena
Species	Avena sativa L.

1.2 Vernacular Names

Language	Name
English	Avena sativa
Hindi	Jai
Marathi	Jav/Jai
Sanskrit	Yava
Tamil	Avena sativa
Gujarati	Javi
Kannada	Haavi Godhi
Punjabi	Jai

1.3 Cultivation

Throughout Europe, North America, and portions of Asia, *Avena sativa* is extensively grown in temperate and subtropical climates.^[8] Maharashtra, Madhya Pradesh, Uttar Pradesh, and Punjab are where they are primarily grown in India.^[9] Cool weather, moderate rainfall, and loamy soil that drains well are ideal for growth. Full sunlight is necessary for the crop to develop properly, and it typically reaches maturity four to five months after seeding.^[7] Because *Avena sativa* can be grown on marginal lands and is reasonably tolerant of low temperatures, it is a useful rotation crop for sustainable agriculture

2. PHYTOCHEMISTRY OF AVENA SATIVA

The wide range of nutritional and pharmacological qualities of oats, or *Avena sativa*, are attributed to their abundance of bioactive phytochemicals. The main groups of compounds are β glucans, avenanthramides, phenolic acids, flavonoids, saponins, sterols, tocopherols, and unsaturated fatty acids.^[3,8,11] These components work together; constituents act synergistically to produce protective effects: antioxidant, anti-inflammatory, metabolic, anti-inflammatory, and antioxidant protective effects.^[3,10]

2.1. β -Glucans

Composed of linear D-glucose units connected by β -(1 \rightarrow 3) and β -(1 \rightarrow 4) glycosidic bonds, β -glucans are soluble non-starch polysaccharides. They constitute about 3–7% of oat kernels and are thought to be the main functional component in charge of the glycemic control and cholesterol-lowering effects^[8,14] β -glucans alter gut microbiota, delay the absorption of glucose, bind bile acids, and increase intestinal viscosity^[8,14] Compared to β -glucans from barley or yeast, the ratio of β -(1 \rightarrow 3) to β -(1 \rightarrow 4) linkages confers superior solubility and physiological activity.^[10]

2.2. Avenanthramides

Oats are nearly the only source of avenanthramides (Avns), special phenolic alkaloids. Ferulic, p-coumaric, and caffeic acids are examples of hydroxycinnamic acids that are structurally conjugated of anthranilic acid.^[11] Avn A, Avn B, and Avn C are the most prevalent of the more than 25 different avenanthramide structures that have been identified.^[13] By inhibiting the NF- κ B, MAPK, and COX-2 pathways and suppressing the expression of VCAM-1 and ICAM-1 on endothelial cells, these compounds have strong anti-inflammatory^[4] anti-atherogenic^[15] and antioxidant properties.^[15,16]

2.3 Phenolic Acids

Ferulic, caffeic, p-coumaric, syringic, and vanillic acids are the main phenolic acids found in oats, both free and bound, and they are mainly found in the bran layer.^[9] These substances work in concert with avenanthramides and vitamin E to neutralize reactive oxygen species (ROS) by acting as hydrogen or electron donors.^[16]

2.4 Flavonoids

Apigenin, tricetin, luteolin, and their glycosides are among the substances found in the flavonoid fraction of *Avena sativa*^[11] Tricetin, one of the flavonoids found in *Avena sativa*, has been identified in a number of cereal species and, by modifying the cyclooxygenase and apoptotic pathways, demonstrates significant antiproliferative and pro-apoptotic properties^[17,18,19] These results imply that the overall chemoprotective potential of *Avena sativa* may be enhanced by tricetin, a flavone derived from cereals that is also present in oats.

2.5. Saponins

Avenacogenin, which is mostly found in the outer pericarp, is the source of oat saponins, primarily avenacosides A and B, which are steroidal glycosides^[20] By forming complexes

with bile acids and cholesterol, they decrease intestinal absorption and have antifungal, antimicrobial, cholesterol-lowering, and immunomodulatory properties that support the plant's defense mechanisms.^[20]

2.6. Sterols and Tocopherols

Significant amounts of phytosterols, including stigmasterol, campesterol, and β -sitosterol, which competitively prevent intestinal cholesterol absorption, are also found in *Avena sativa*.^[5] Furthermore, as lipid-soluble antioxidants, tocopherols and tocotrienols (derivatives of vitamin E) shield membrane lipids from oxidative stress and peroxidation.^[5]

2.7. Lipids and Fatty Acids

About 5–9% of oats are made up of lipids, which are primarily unsaturated fatty acids like palmitic, linoleic, and oleic acids^[8] Glycolipids and phospholipids improve the solubility and transport of lipophilic bioactives while also supporting membrane stability.^[10]

2.8. Minor Constituents

Alkaloids, avenacosides, protease inhibitors, and starch-derived oligosaccharides are among the other minor constituents that have been identified and have been shown to have anti-inflammatory, antioxidant and anti-obesity properties^[1,4] These substances increase *Avena sativa*'s overall therapeutic potential and complement the main phytochemical classes.

Avena sativa's wide range of biological activities can be attributed to its varied phytochemical composition. Its pharmacological efficacy as a functional food, nutraceutical, and therapeutic agent is based on the synergistic interaction of β -glucan, avenanthramides, flavonoids, and saponins.^[1,3,4]

3. PHARMACOLOGICAL PROPERTIES OF AVENA SATIVA

The diverse phytoconstituents of *Avena sativa* L. (*Avena sativa*) include β -glucan, avenanthramides, flavonoids, saponins, sterols, and phenolic acids, which are responsible for the plant's wide range of pharmacological activities. These substances support a variety of therapeutic outcomes, including anti-inflammatory, antioxidant, metabolic, neuroprotective, and dermatological advantages.

3.1. Antioxidant Activity

Avenanthramides, special phenolic alkaloids that are only present in *Avena sativa*, are the main mediators of the plant's antioxidant activity. Cellular components are shielded from

oxidative stress by these substances, which effectively neutralize reactive oxygen species (ROS) and stop lipid peroxidation.^[1,3] Additionally, they strengthen natural antioxidant defenses like catalase and superoxide dismutase. Furthermore, oat polyphenols and vitamin C have been shown to work in concert, increasing their capacity to scavenge free radicals.^[16]

3.2. Anti-inflammatory Activity

The main way that *Avena sativa* has strong anti-inflammatory effects is by blocking proinflammatory mediators and signaling pathways. By blocking the NF- κ B and MAPK pathways, avenanthramides reduce the levels of important inflammatory cytokines like TNF- α , IL-1 β , and IL-6.^[4] In inflammatory conditions like eczema and atopic dermatitis, topical formulations containing colloidal oatmeal have been clinically proven to reduce pruritus, erythema, and irritation.^[7,21] These effects justify its inclusion in modern dermatological and cosmeceutical formulations.

3.3. Antidiabetic Activity

Preclinical and clinical studies have provided ample evidence of *Avena sativa*'s antidiabetic potential. The intestinal viscosity is increased by the soluble dietary fiber β -glucan, which slows the absorption of carbohydrates and improves the postprandial glycemic response^[8] Frequent use of *Avena sativa* products reduces glycated hemoglobin (HbA1c) levels, improves insulin sensitivity, and lowers fasting blood glucose^[5] Furthermore, saponins and polyphenolic compounds may help protect pancreatic β -cells and modify glucose transporters^[22] Together, these processes show that *Avena sativa* significantly lowers blood sugar levels by modifying insulin response, pancreatic beta cell function, and carbohydrate absorption.

3.4. Antihyperlipidemic Activity

By binding bile acids in the intestine and increasing their excretion, oat β -glucan has strong antihyperlipidemic activity and lowers serum cholesterol levels.^[23] According to clinical trials, β -glucan (3 g/day) significantly reduces the concentration of total and LDL cholesterol without changing HDL cholesterol levels^[6] Furthermore, *Avena sativa*'s saponins and plant sterols promote lipid homeostasis by preventing the absorption of cholesterol in the intestines and the synthesis of cholesterol in the liver^[3] *Avena sativa* is recognized as a useful dietary ingredient that can help prevent and treat hyperlipidemia and cardiovascular diseases due to these combined effects. *Avena sativa* is recognized as a useful dietary ingredient that can help prevent and treat hyperlipidemia and cardiovascular diseases due to these combined effects.

3.5. Cardioprotective Activity

Avena sativa's lipid-lowering, antioxidant, and anti-inflammatory qualities are the main factors contributing to its cardioprotective potential. It has been demonstrated that diets high in β -glucan lower blood pressure, enhance endothelial function, and enhance cardiovascular health in general^[24] By lowering oxidative stress and preventing vascular inflammation, avenanthramides further shield cardiac tissue. C-reactive protein levels are lowered by long-term *Avena sativa* supplementation, which may have protective effects against coronary artery disease.^[15] Together, these results show that *Avena sativa* has multifactorial cardioprotective effects by improving vascular function,^[1] reducing inflammation^[24] and modulating lipid metabolism.^[25]

3.6. Anti-atherogenic Activity

By enhancing vascular elasticity and inhibiting the oxidation of LDL cholesterol, *Avena sativa* has anti-atherogenic properties. Avenanthramides decrease the recruitment of monocytes to arterial walls by suppressing the expression of adhesion molecules on endothelial cells.^[26] These processes aid in delaying the development of plaque and the advancement of atherosclerosis in conjunction with lipid-lowering effects.^[27] *Avena sativa* is a useful functional food for preventing atherosclerosis because of the synergistic interaction between β -glucan and avenanthramides, which enhances the plant's vascular-protective potential.^[6,7,8,22]

3.7. Neuroprotective Activity

In experimental models, extracts from *Avena sativa* have shown neuroprotective activity by improving neuronal function and reducing oxidative damage. *Avena sativa* flavonoids and phenolic acids increase neurotrophic factors (BDNF) and decrease lipid peroxidation in brain tissue.^[20] Additionally, by enhancing cerebral blood flow and lowering neuroinflammation, β -glucan may promote neuronal survival.^[21] These results demonstrate the potential role of *Avena sativa* in preventing neurodegenerative diseases. The combined antioxidant, antiinflammatory, and vasodilatory actions of *Avena sativa* constituents collectively contribute to its neuroprotective potential and cognitive health benefits.

3.8. Antidepressant Activity

Avena sativa's ability to modulate neurotransmitters like dopamine and serotonin is thought to be the source of its antidepressant properties. *Avena sativa* ethanol extracts have been shown to have mood-enhancing effects by significantly reducing immobility time in rodents forced-

swim and tail suspension tests. Additionally, clinical studies indicate that people who take standardized oat extract supplements have better mood, focus, and attention.^[10] Its psychotropic effects are probably due to a combination of neurochemical and antioxidant modulation. The possible use of *Avena sativa* as a natural adjunct in the treatment of mild to moderate depressive disorders is supported by these findings taken together.

3.9. Dermatological and Wound-Healing Activity:

The U.S. FDA has approved colloidal oatmeal as a skin protectant, and it works well for a number of inflammatory skin conditions. Its polysaccharides create a barrier of defense, preserving skin moisture and lowering trans-epidermal water loss.^[22] β -glucan has been shown to have wound-healing properties by increasing fibroblast proliferation, collagen synthesis, and reepithelialization in wound models.^[23] *Avena sativa* is a crucial component of dermatological formulations, especially for eczema, psoriasis, and atopic dermatitis, due to its anti-inflammatory, antioxidant, and moisturizing qualities.

3.10. Hepatoprotective Activity

According to experimental research, extracts from *Avena sativa* shield the liver from oxidative stress and toxins. *Avena sativa*'s phenolic antioxidants normalize serum enzymes like ALT and AST, lower hepatic lipid peroxidation, and replenish glutathione levels.^[21] These outcomes imply that *Avena sativa* might aid in metabolic detoxification and liver protection. Therefore, regular ingestion or formulation of bioactives derived from oats may offer therapeutic potential in the management of oxidative liver disorders and chemically induced hepatotoxicity.

3.11. Immunomodulatory Activity

By promoting the activity of natural killer (NK) cells and macrophages, the β -glucan fraction of *Avena sativa* has immunomodulatory effects.^[18] It improves innate immune responses by increasing the production of cytokines such as interleukin-2 and interferon γ . These characteristics are especially helpful in increasing the effectiveness of vaccines and the host's resistance to infections. Overall, *Avena sativa* is positioned as a promising nutraceutical adjuvant for immune enhancement and infection prevention due to the immune-stimulatory properties of oat-derived β -glucan.

3.12 Antitumor and Anticancer Activity

Avena sativa saponins and avenanthramides have been shown to have cytotoxic and antiproliferative effects on a variety of tumor cell lines, such as breast (MCF-7) and colon (HT-29) cancer cells.^[24] Their mechanism includes reducing angiogenesis, inducing apoptosis through caspase activation, and suppressing NF- κ B signaling. These results demonstrate the potential of *Avena sativa* as a natural source of anticancer agents, even though research on this topic is still in its early stages. The anticancer efficacy and therapeutic selectivity of bioactives derived from *Avena sativa* may be further improved by incorporating them into targeted delivery systems.

4. RECENT APPROACHES IN NOVEL DRUG DLIVERY SYSTEM:

Avena sativa is also described in ethnopharmacological sources as having stimulant, diuretic, antispasmodic, demulcent, anti-obesity, anti-helminthic, and protease inhibitory properties.^[15,17,25] To verify their pharmacological mechanisms and therapeutic efficacy, these traditional uses need more scientific validation.

To support their pharmacological significance, future research should concentrate on bioassay-guided isolation of the active ingredients causing these effects.

4.1 β -Glucan- based carrier system

Oat β -glucan's mucoadhesive nature, biocompatibility, and vulnerability to colonic microflora degradation make it an excellent carrier matrix for NDDS. Its application in oral delivery micro- and nano-systems is highlighted in a recent review, which also notes improved stability, targeted release in the colon and intestine, and possible immunomodulatory effects.^[33] For instance, β -glucan nanoparticles and microparticles have been created to improve immune cell absorption or release co-loaded medications in a colon-specific manner.^[34] Lee et al. showed in an experiment that β -glucan particles were functionalized for immune activation and gene delivery.^[36] Particle size (nano vs. micro), surface modification (to enhance uptake or targeting), and degradation behavior in the gut environment are important formulation parameters. By using oat β -glucan as a delivery scaffold, bioactives can more efficiently reach the colon or immune cells and avoid early GI degradation.

4.2. Coating and stabilisation of nanoliposomes with β -glucan

Coating traditional nanoliposomes with β -glucan, which is derived from cereals like oats, is an inventive way to enhance stability during gastrointestinal digestion and offer controlled

release of encapsulated agents. Compared to uncoated liposomes, β -glucan-coated nanoliposomes (GNLs) demonstrated a significantly lower release of encapsulated β -carotene during simulated GI digestion, suggesting protection against bile and enzyme attack and the possibility of extended release.^[36] The concept is directly applicable to oat phenolics or other oat-derived actives, even though the payload in this study was β -glucan more generally and β -carotene.

4.3. Avenanthramide- targeted delivery and formulations

Oats contain special polyphenols called avenanthramides (Avns), which have potent anti-inflammatory, antioxidant, and cell-protective properties. Even though specific NDDS research on Avns is still in its infancy, reviews highlight their therapeutic potential and urge the use of cutting-edge delivery methods to maximize their efficacy. In neurodegeneration, Avns alter the PI3K/AKT/Nrf2 signaling pathways, which emphasizes the necessity of better delivery to reach neural tissues.^[37] Avns' structural diversity and biosynthesis make them potentially valuable compounds for use in pharmaceuticals.^[38] NDDS like phytosomes, liposomes, nanogels, or targeted nanoparticles may be very helpful in light of these bioactivities and the structural sensitivity of Avns. For example, their translational potential would be increased by encapsulation to improve tissue-specific targeting (e.g., neural or dermal), protected release, and membrane permeability.

4.4. Topical and wound-healing NDDS using oat bio actives

In addition to oral administration, topical formulations and wound dressings are increasingly using oat β -glucan and phenolic extracts. Hydrogels, patches, and nanofiber mats can benefit from β -glucan's mucoadhesive, film-forming, and immunomodulatory qualities. The translation of β -glucan carriers in wound healing has been reviewed, despite the paucity of focused NDDS studies specifically on oat extracts. You can point out in your review that this is a promising but understudied field, such as β -glucan-based hydrogel patches loaded with avenanthramides for anti-inflammatory dermal therapy or skin repair.

4.5 Microencapsulation and functional food NDDS

When utilized in functional food formats, microencapsulation techniques (spray drying, freeze drying, and coacervation) are used to stabilize oat bioactives (particularly Avns) against deterioration during processing and storage as well as to control release in the gastrointestinal tract.^[39] In 2024, for instance, Napiórkowska demonstrated the viability of oat-based carrier systems in encapsulation technology by encapsulating wheat germ oil and

juniper essential oil in artificial microcapsules made of oat protein and Arabic gum as wall materials.^[41] Similarly, Aktaş in 2024 developed double emulsions using oat oil and starch for improved polyphenol delivery.^[42]

According to these studies, oat-derived matrices can function within the NDDS framework as deliverable systems and bioactive carriers.^[41,42] Although not always strictly categorized as "drug-delivery," these methods play an NDDS role in the nutraceutical-pharmaceutical interface. *Avena sativa*-derived bioactives' stability, absorption, and therapeutic efficacy are all greatly improved by these formulation techniques, which increases their potential for use in pharmaceutical and nutraceutical development.

5. CONCLUSION

Oats, or *Avena sativa*, are a nutrient-dense cereal crop with a wide range of pharmacological potential that has been validated by contemporary science as well as traditional usage. Significant antioxidant, anti-inflammatory, antidiabetic, cardioprotective, neuroprotective, and dermatological properties are demonstrated by its varied phytoconstituents, especially β -glucan, avenanthramides, flavonoids, and saponins. Mechanisms involving the regulation of oxidative stress, inflammatory pathways, lipid metabolism, and neuronal protection mediate these effects. Additionally, the creation of innovative drug delivery methods like hydrogels, nanoparticles, phytosomes, and microencapsulation has improved the bioavailability, stability, and therapeutic efficacy of bioactives derived from oats, increasing their potential in the pharmaceutical, nutraceutical, and cosmeceutical industries. To close the gap between laboratory data and clinical application, future research should prioritize pharmacokinetic studies, clinical validation, and molecular mechanism elucidation. All things considered, *Avena sativa* is a promising functional food and therapeutic agent that provides a safe, all-natural method of managing and preventing a number of chronic and metabolic illnesses.

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