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Exploring the application and prospects of wheat aleurone in metabolic disorders among adolescents

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Abstract. The growing prevalence of metabolic disorders, including obesity, type-2 diabetes, and hypertension among adolescents, poses a significant global health challenge. While pharmacological treatments exist, their limitations necessitate safer, dietary-based strategies. The wheat aleurone layer, a component of the wheat kernel situated between the endosperm and bran, is densely packed with bioactive compounds such as arabinoxylan, β-glucans, minerals, and phenolic acids. This review synthesizes current evidence on its nutritional composition and physiological mechanisms relevant to metabolic health. Studies indicate that aleurone-derived arabinoxylan effectively modulates gut microbiota, enhances short-chain fatty acid production, and mitigates postprandial glycemic spikes without causing severe gastrointestinal distress common with other fibers. Furthermore, its high antioxidant capacity and mineral profile contribute to improved lipid metabolism and insulin sensitivity, as demonstrated in animal models and adult human trials. Although clinical data specific to adolescent populations remain scarce, the physicochemical properties of aleurone layer suggest it is a promising functional ingredient. Future research should focus on developing palatable, low-glycemic index food products tailored for younger demographics to address the early onset of metabolic diseases.

Keywords: wheat aleurone, metabolic disorders, adolescents

1. Introduction

Metabolic diseases are generally systemic disorders caused by abnormalities in the metabolism of substances and energy, including diabetes, pathological obesity, and hypertension. Most of these conditions arise from disruptions in the body's metabolism of carbohydrates, lipids, and other substances, posing significant threats to human health.

With changes in global consumption patterns and dietary structures, the prevalence of metabolic diseases has been rising year by year. A Chinese guideline and consensus on the prevention and control of a certain metabolic disease shows that between 2015 and 2017, the disease's prevalence rate reached 11.2% in China and continues to increase [1]. Metabolic disorders can further trigger issues such as obesity and overweight. In recent years, this trend has become particularly evident among adolescents. According to *the Report on the Nutrition and Chronic Disease Status of Chinese Residents (2015)*, the overweight rate among 6- to 17-year-old adolescents nationwide reached as high as 9.6%, while the obesity rate was 6.4%. Drug treatment can

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provide long-term management for these diseases, but it has certain drawbacks [2]. For instance, when repaglinide is combined with metformin, it can exert a certain inhibitory effect, while it will significantly increase the risk of hypoglycemic episodes. Beyond drug treatment, dietary intervention, as the foundation for the prevention and treatment of metabolic diseases, is becoming increasingly important. The health benefits of entire grains have been confirmed by numerous evidence-based studies [3]. The abundant minerals and substances that they contain play a vital role in controlling metabolic disorders. The wheat aleurone layer, which exists between the endosperm and the seed coat of a wheat grain, accounts for 60% to 70% of the main nutrients in a single wheat grain [4]. It is full of minerals, proteins, minerals, and vitamins, and has prominent functions such as antioxidative, anti-cancer, regulation of intestinal flora, and lowering blood sugar. These functions are of great significance in preventing and alleviating metabolic disorders. The real breakthrough came from Wu et al., who pinpointed the "cyclone vortex micro-nano separation technique" as a superior method for isolating aleurone [5]. By enabling large-scale production for the food industry, the tech has paved the way for serious research into aleurone's role in managing metabolic diseases. Nevertheless, there are still without a clear, systematic rundown of how aleurone is actually used in practice—and when it comes to studies focused on teenagers, the research well is pretty much bone-dry. To fill that gap, this paper is devoted to mapping out what makes aleurone nutritionally valuable and biologically active, with a close eye on its real-world use in younger groups, especially those predisposed to metabolic issues. The goal here is to lay down some practical groundwork for both clinical applications and the food producing industry.

2. What's inside the wheat aleurone layer

The aleurone layer is essentially a single-layered band-like structure composed of thick-walled cells, located inside the endosperm and tightly surrounding it. Under the microscope, these cells look hexagonal. Their walls take up a hefty chunk of the space—about 35% of the cell volume (v/v). And they're not uniform. The outer wall is relatively thick—clocking in at around 2 μm—while the inner wall tapers down to a mere 0.5 μm, and both layers are essentially stacked with Arabinoxylan (AX) and β-glucan [4]. The aleurone layer accounts for 6~9% of the mass of a single wheat grain and 48~52% of the bran mass. Located in the outermost layer of the endosperm, this nutrient-dense zone is often hailed as "the soft gold of wheat." Despite accounting for only a small portion of the grain, it concentrates over 60% of the minerals, 80% of the niacin, and 60% of the pyridoxine found in whole wheat [6].

2.1. Dietary fiber

Dietary fiber is kind of a big deal when it comes to maintaining fitness. Zoom in on the molecular level, and you'll spot loads of water-loving functional groups studding the surface of fiber fractions like cellulose, pectin, and gums—mostly hydroxyl and carboxyl groups. These groups are absolute sponges for water: they latch onto water molecules by hydrogen bonds, locking moisture in place. On top of that, the fiber matrix itself is loose and riddled with tiny pores, so it soaks up water and swells up noticeably once it gets wet. Additionally, the long-chain molecules of dietary fiber intertwine with each other, forming a three-dimensional network structure. There are numerous voids inside for accommodating water; after absorbing water, the molecular chains fully extend, ultimately causing a significant increase in the overall volume. This expansion does double duty. First, the added bulk prompts the gallbladder to contract reflexively, flushing out bile acids. This enhances cholesterol metabolism and trims down cardiovascular risk [7]. Second, it acts as a mechanical stimulant, speeding up gut motility to keep constipation and colorectal cancer at bay [8]. Aleurone is naturally rich in dietary fiber. Granted, more isn't always better; excessive intake can interfere with organic matter

metabolism, sparking absorption issues or metabolic disorders [9]. Aleurone sidesteps this problem. Its fiber density—ranging from 15.51 to 48.00 g/100g—lands squarely in the Goldilocks zone: high enough to be effective, but low enough to avoid the nasty side effects [10].

2.2. Arabinoxylan

Not all dietary fibers are created equal. Depending on how they dissolve, how they're built, and what the specific function in the body, people break them down into categories like cellulose, pectin, β-glucan, and inulin. And the differences are stark—each type brings its own quirks in terms of chemistry, how well it survives food processing, and the actual health benefits it delivers. AX stands apart from common fibers. It swings above its weight when comes to structural specificity, producing stability, and diverse bioactivities, marking it as a top-tier functional ingredient. According to Bagdi et al., it's also the undisputed heavy hitter in the aleurone layer, accounting for about 62.65% of the total dietary fiber content [10].

In physiological aspect, AX just works smarter. It can strike a much better balance in controlling the gut and metabolism. While prebiotic heavyweights like inulin and FOS ferment rapidly, AX takes a more measured, sustained approach to fermentation. It does most of its work in the mid-to-lower colon and give the entire gut microbiome a balanced tune-up while efficiently churning out Short-Chain Fatty Acids (SCFAs). Uniquely, it doesn't cause a gas flare-up. This low-gas profile makes it way easier on the system than inulin, and it can spare users from the bloating and diarrhea that often make people to quit other fibers. Basically, it's a gut-friendly option that works for just about everybody [11-13].

As for blood sugar control, AX plays as a double-game. Its soluble fraction turns the gut contents into a viscous goo and slows everything down. This can inhibit starch breakdown, slow glucose absorption, and thereby prevent a sharp rise in blood sugar after meals. At the same time, the insoluble stuff takes the scenic route straight down to the colon. Once there, it ferments slowly, providing a steady, behind-the-scenes metabolic tune-up that lasts for hours. This one-two punch makes AX a much tougher contender than single-task fibers such as beta-glucan or pectin [14, 15].

In addition, compared with cellulose with only water-absorbing and swelling properties, AX blends mechanical peristalsis with microbial softening and then keeps the gut in check. It fixes constipation but steers clear of the "dry and hard" trap that comes with too much insoluble fiber. It holds a lot of benefits to adolescents under the current dietary structure.

2.3. Protein

Protein plays an irreplacable role in constructing body's somatic cell, while also the principle source of different types of necessary amino acids. Quantitatively, protein accounts for 21% of the dry weight of the aleurone layer [4]. What's really fascinating is what Buri et al. dug up when they tested a standardized Aleurone Sample (ASP-01). They found a jackpot of lysine and threonine—5.5 g/100g and 4.4 g/100g, respectively. That's nearly double what you'd get in gluten protein [4]. This characteristic precisely compensates for the deficiency of "lysine, and the first limiting amino acid" in wheat endosperm. The protein of common grains is limited in biological value due to the low levels of lysine and threonine [16]. From the cytological perspective, the aleurone layer stores its proteins in neat little packages called aleurone grains, wrapped up with phytic acid and minerals. When people eat them, their gut enzymes chip away at the phytate, slowly liberating the amino acids. This gives the body a much longer window to soak them up [4]. For teenagers, who are pushing their bodies to the limit with school and sports, this sustained release is a game-changer. As for lysine, it's not just for bulking up muscles. It's also the starting point for making collagen, growth hormone, and a bunch of other enzymes [3]. The high-quality protein in the cereal layer can not only

meet the basic needs for growth and development, but also help the body quickly restore energy after intense exercise and delay muscle fatigue. It has practical significance for the physical fitness reserves of adolescents.

2.4. Antioxidant capacity

Step away from your average slice of bread. The wheat aleurone layer flexes stronger antioxidant muscles, and it all comes down to its specific arsenal of phenolic compounds and vitamin E. Ferulic acid is the most prominent compound here, but it doesn't stop there. The aleurone layer also brings p-coumaric acid, sinapic acid, vanillic acid, lignans, phytosterols, and a solid hit of carotenoids (around 46.5 mg/kg) to the party [6]. Most ferulic acid is trapped in an esterified state, covalently bonded to the O-5 spot on arabinoxylan side chains. Getting it out requires physical milling, enzymes, or gut microbes to do the dirty work [17]. Rosa's team used ultrafine grinding plus enzymatic treatment to crack this code. The result? A massive spike in bioavailability and an antioxidant activity boost of 1- to 4-fold compared to untreated aleurone [18]. Mechanistically, ferulic acid is a triple threat. It scavenges free radicals (·OH, O_2^{-}·, DPPH·) via its phenolic hydroxyls, chelates pro-oxidant metals (Fe^{2+}, Cu^{2+}), and synergizes with vitamin E—present as α-tocopherol and tocotrienols—to form a protective network against lipid peroxidation [19]. For teens battling metabolic syndrome, this is a game-hanger. By inhibiting COX-2 and downregulating the NF-κB pathway (along with TNF-α and IL-6), it slams the brakes on chronic inflammation, reduces LDL oxidation, and repairs endothelial function [20]. There's more: these phenolic acids also block glucose transporters and digestive enzymes in the gut. This works hand-in-hand with the sugar-steadying effects of arabinoxylan (see section 2.1.2) [21]. In conclusion, the aleurone layer's antioxidant capacity isn't a solo act. It's the result of multiple components—phenolic acids, vitamin E, and phytosterols—all coupled together. This combo has serious potential for early intervention in metabolic disorders, though waiting on more adolescent-specific research to seal the deal [22].

3. The application of wheat bran layer in metabolic diseases

Beyond its basic bioactivities—think antioxidant, anti-inflammatory, and gut-modulating—the wheat aleurone layer tackles glycolipid metabolic chaos through multiple mechanisms. It shows serious promise for the dietary management of obesity, T2DM, hypertension, and dyslipidemia. One caveat is that the available clinical and animal data are derived predominantly from adult populations or rodent models, whereas direct intervention data specific to adolescents remain scarce [10, 21]. Yet, aleurone's compositional traits line up perfectly with the pathological cascade of teen metabolic disease—diets loaded with sodium and sugar, not enough fiber, and too much sitting that triggers early insulin resistance. Its value as a "non-pharmacological, preemptive intervention" definitely begs to be explored.

3.1. Obesity and overweight

Most cases of being overweight or obese are tightly tangled up with metabolic diseases. Weight control through diet and exercise through sensible eating and exercise, and you can wrestle those abnormal metabolic markers back into line. For some patients who rely on daily meds just to keep their metabolism functioning normally, that might even mean they can eventually scale back or ditch certain drugs. Packed with fiber, the aleurone layer acts like nature's appetite suppressant. As the fiber drinks up water and expands, it makes you feel significantly fuller. This simple mechanism is a solid first step toward controlling body weight without feeling deprived. In a 4-week intervention, daily aleurone fiber supplementation drove significant drops in weight (82.99 ± 16.49 vs. 87.51 ± 16.44 kg), BMI (28.81 ± 3.91 vs. 29.81 ± 3.83), visceral fat (772.42 ± 411.04 vs. 935.99 ± 473.56 g), and total fat mass (28,686.22 ± 7065.85 vs. 30,831.96 ± 7140.30 g), all with p

< 0.01 [23]. Brutal honesty check: the subjects were adults (22–42 years old). But the science holds up for younger crowds. AX is a stealth weapon—it ferments without the gas and bloating you get from inulin, so it will not make a teenager miserable during a long school day. And because it releases energy slowly, it stops that after-school starvation that sends kids raiding the snack cabinet. It's incredibly practical for teen weight control.

The story doesn't end at the gut. By modulating the microbiome, fiber dives deep into energy metabolism. Gut microbes feast on AX and other prebiotics, spitting out Short-Chain Fatty Acids (SCFAs). These SCFAs then conduct a hormonal symphony, tweaking appetite signals and stabilizing your energy homeostasis to keep body weight firmly under control.

3.2. Diabetes

Speaking of metabolic villains, diabetes is right at the top. It's a classic metabolic disorder that poses a massive threat to overall health. T2DM is the most common form by a long shot. For these patients, daily habits and food choices are absolutely critical for keeping blood sugar stable. That's why dietary intervention isn't just a footnote—it's one of the most targeted management strategies we've got. The wheat aleurone layer's arabinoxylan-rich composite fiber helps smooth out those blood sugar spikes, effectively keeping glucose levels on an even keel. This isn't just theory on paper; animal tests confirm it. In rats with insulin resistance triggered by a high-fat diet, supplementing with wheat aleurone led to significant drops in Fasting Blood Glucose (FBG) and HOMA-IR, alongside a clear improvement in ISI [22]. This reveals that the cereal layer not only assists to control blood sugar but also intervene in the progression of diabetes at the molecular level by reducing insulin resistance.

3.3. Hypertension

Some studies have shown that consuming dietary fiber from the bran layer can effectively lower blood pressure [8]. About 80% of a wheat kernel's minerals are packed into the aleurone layer [6]. That includes a hefty dose of potassium, which steps in to help the body flush out excess sodium. By doing so, it takes a load off the blood vessels, easing vascular pressure and keeping blood pressure steady. But it's not just about the minerals. The aleurone layer is also loaded with B-complex vitamins. These help the body bounce back from fatigue, which in turn takes some of the strain off your blood pressure.

3.4. Hyperlipidemia

Dyslipidemia is a major red flag for atherosclerotic cardiovascular disease. The wheat aleurone layer fights back on multiple fronts to bring those lipid levels down. Take this animal experiment, for example. Researchers grabbed 40 SD rats and randomly split them into four groups of ten. They set up a baseline control, a high-fat control, and two aleurone intervention squads—one getting a low dose (1.5 g/kg·d) and the other a high dose (2.5 g/kg·d). They kept this daily oral gavage going for five weeks straight. Here's how the data shook out: by week five, the high-dose group hit 295.44 g—right in line with the low-dose group (292.57 g) and a far cry from the high-fat controls (336.17 g). They also ate less, averaging 14.52 g/d. Lipid profiles told a similar story: total cholesterol (2.51 vs. 3.08 mmol/L), triglycerides (0.31 vs. 0.47 mmol/L), and LDL-C (2.06 vs. 2.49 mmol/L) all dropped significantly, while HDL-C jumped to 0.95 mmol/L [22]. These results, pulled from the high-dose group after five weeks, show that the aleurone layer can effectively clean up the mess caused by a high-fat diet. It does this by enhancing satiety, fine-tuning lipid metabolism, and deploying its antioxidant arsenal, ultimately reversing dyslipidemia, insulin resistance, and hepatic steatosis.

4. The related products

Spotting the nutritional goldmine in wheat aleurone, some food and nutrition enterpriseshave caught on fast. They're keenly aware of its market potential and are already pushing hard to develop new products. The real-world proof is here: aleurone-centered liquid staples have broken into the commercial market with solid feedback. A great example is the "Maiyangyou Liquid Wheat Staple" (bottled cereal drink). According to the GI evaluation by the Beijing Century Kehuan Academy of Ecological Agriculture, using pure glucose as the reference (GI = 100), the product sits at a modest 52 on the GI scale. That comfortably beats the national standard cutoff of 55 for low-GI foods. A 226 ml serving also yields a GL of just 2, which is well below the low-GL threshold of 10. The blood glucose response curve tells the story: after drinking it, blood sugar climbs far more slowly than it does with glucose, hits a lower peak, and falls gently. There's no post-meal rollercoaster, just a minimal glycemic load. Front and center on the ingredients list is wheat aleurone—the key functional ingredient that delays sugar uptake and drags down the GI value [24].

5. The application prospects in the youth population group

The GI evaluation for the Maiyangyou beverage was conducted on healthy adults aged 22–42 (6 men and 6 women, normal BMI) , so it doesn't capture the adolescent physiological stage. But that gap needs filling fast [24]. Given the rising tide of teen metabolic issues and the trend of earlier onset, early dietary intervention is now the top priority for prevention. Case in point: China's 6–17 age group has an overweight rate of 9.6% and an obesity rate of 6.4% [2]. Thankfully, their condition is typically early-stage insulin resistance—highly reversible and a golden window for dietary intervention before the damage becomes permanent. It's a stellar carrier. Wu et al.'s tech is now mature, and large-scale production hits a sweet spot amid rapid global dietary shifts. Match it to youth trends—RTD brews, flavored bars, low-GI formats—and you've got a recipe for innovative, real-world dietary intervention that doesn't rely solely on drugs [5]. Science already has our back here. Studies confirm that low-GI breakfasts significantly flatten out post-meal blood sugar spikes and keep hunger pangs at bay before the next meal in kids and teens [25]. This lines up perfectly with aleurone's "low-gas, slow-burn energy" profile. It's a match made in heaven for school settings. Moving forward, people should be developing aleurone-based products tailored specifically for campus breakfasts and between-class snacks.

6. Conclusion

The wheat aleurone layer—the "nutritional treasure trove" of the kernel—owes its high application value in preventing and treating metabolic disorders to its unique microstructure and chemical profile. This review breaks down exactly what makes the aleurone layer tick. At the heart of it is Arabinoxylan (AX). Think of AX as a double agent: it leverages both its soluble and insoluble sides to do the heavy lifting. By slowing down the sugar rush, balancing out the entire colonic microbiome, and pumping out Short-chain Fatty Acids (SCFAs), it effectively keeps blood sugar, lipids, and body weight firmly in check. The aleurone layer speaks directly to teenage needs. Its top-notch protein and micronutrients support growing bodies, and its low-GI profile provides a novel food-based angle to counteract the declining age of onset age-drop in metabolic diseases. Nevertheless, the current research has a clear age bias. Most clinical and animal evidence is skewed toward adults, and people are seriously lacking studies on teens. Plus, whether these functional foods actually taste good and get accepted by the market is still an open question. They haven't quite made it to the finish line yet. So, what's next? With the cyclone tech now mature, scaling up aleurone production is a done deal. Future

studies need to focus on addressing the data gap in the data for teenagers. Combined with strategic sensory optimization, this approach can accelerate the research and development of aleurone-based Foods for Special Medical Purposes (FSMPs) and functional staple foods, thereby establishing a novel, drug-free strategy for dietary intervention.

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