

Article

Dietary Supplementation of *Astragalus* Polysaccharides Modulates Growth Physiology, Metabolic Homeostasis, and Innate Immune Responses in Rice Field Eels (*Monopterus albus*)

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Abstract: To investigate the dietary effects of *Astragalus* polysaccharides (APSs) on the growth performance, lipid metabolism, antioxidant activity, and non-specific immunity of Asian swamp eel (*Monopterus albus*) during the domestication stage, fish were randomly allocated into quadruplicate groups receiving *Tenebrio molitor*-based diets supplemented with *Astragalus* polysaccharides (APSs) at graded concentrations of 0 (CON), 700 (APS1), 1400 (APS2), and 2100 (APS3) mg/kg body weight for 28 days. The results showed that dietary APSs at 700–1400 mg/kg·bw significantly enhanced the weight gain rate (WG) and decreased the feed conversion ratio (FCR) of *M. albus* ($p < 0.05$). Concurrently, hematological analysis revealed that hemoglobin levels increased by 19.9% and 23.0% in the 700 and 1400 mg/kg APS groups, respectively ($p < 0.05$). In terms of lipid metabolism, supplementation with APSs significantly increased the serum high-density lipoprotein (HDL) content in all treatment groups ($p < 0.05$). Lower serum triglyceride (TG) levels were found in the APS2 group ($p < 0.05$), and decreased triglyceride (TG), cholesterol (CHO), and low-density lipoprotein (LDL) levels were displayed in the APS3 group ($p < 0.05$). Among the antioxidant parameters, the supplementation with 700 mg/kg·bw APSs significantly increased the glutathione peroxidase (GSH-Px) and catalase (CAT) activity levels of *M. albus* ($p < 0.05$). The APS2 group had a significantly increased total antioxidant capacity (T-AOC) and CAT activity levels ($p < 0.05$), and the APS3 group had significantly increased CAT activity levels ($p < 0.05$). In addition, the APS1 and APS3 groups had significantly reduced malondialdehyde (MDA) levels ($p < 0.05$). In terms of non-specific immunity, the APS1 and APS2 groups showed significantly increased superoxide dismutase (SOD) and lysozyme (LZM) activity levels of *M. albus* ($p < 0.05$), and the addition of 700 mg/kg·bw APSs significantly increased the levels of alkaline phosphatase (AKP) activity ($p < 0.05$). Furthermore, the levels of acid phosphatase (ACP) activity were significantly increased in all experimental groups ($p < 0.05$). In conclusion, the optimal APS addition for *T. molitor* as biocarrier bait is 700 mg/kg, corresponding to 352 mg/kg, which elicits improvements in the growth parameters, lipid homeostasis regulation, oxidative stress mitigation, and innate immune potentiation of *M. albus* during the domestication stage.



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Keywords: *Monopterus albus*; *Astragalus* polysaccharides; growth; lipid metabolism; antioxidant capacity; innate immunity

Key Contribution: Dietary addition supplementation with *Astragalus* polysaccharides elicited improvements in the growth parameters, lipid homeostasis regulation, oxidative stress mitigation, and innate immune potentiation of *M. albus* during the domestication stage.

1. Introduction

The rice field eel (*Monopterus albus*), a protogynous hermaphroditic teleost species within the order Synbranchiformes, has emerged as a pivotal species in China's aquaculture industry owing to its substantial nutritional profile and pharmacological properties. As documented in the China Fishery Statistical Yearbook (2024), the national production of *M. albus* achieved a record yield exceeding 330,000 tons in 2024 [1]. However, the intensification of farming systems has precipitated physiological stress responses in this species, manifested through immunosuppression and increased disease susceptibility. Current prophylactic measures predominantly employ broad-spectrum antimicrobial agents, a practice that has engendered multidrug-resistant bacterial strains while exacerbating environmental contamination and residual toxicity in aquatic products. This paradigm underscores the urgent need to develop natural immunostimulants as sustainable alternatives within precision aquaculture frameworks. Phytogetic feed additives, particularly those derived from traditional Chinese medicine, have gained prominence due to their pleiotropic bioactivities, environmental compatibility, and absence of drug residues, positioning them as viable candidates for immunonutrition strategies in aquatic species [2].

Astragalus membranaceus, a leguminous plant with a 2000-year history in Chinese pharmacopeia, synthesizes *Astragalus* polysaccharides (APSs) as its principal bioactive constituents, comprising heteropolysaccharides with α -(1→4)-glucan backbones and arabinogalactan side chains [3]. Studies have demonstrated that APSs exhibit diverse biological functions, including lipid regulation, growth promotion, antioxidant activity, anti-inflammatory effects, and immunomodulation [4]. In recent years, dietary supplementation with APSs in livestock and poultry has been extensively documented for improving nutritional status and physiological conditions [5,6]. Beyond terrestrial applications, *Astragalus* polysaccharides exhibit cross-species applicability in aquaculture systems. Studies have reported that the addition of APSs significantly enhanced the growth potentiation of bluegill sunfish *Lepomis macrochirus* [7], koi *Cyprinus carpio* [8], and Nile tilapia *Oreochromis niloticus* [9]; improved the antioxidant capacity of largemouth bass *Micropterus salmoides* [10], large yellow croaker *Larimichthys crocea* [11], and turbot *Scophthalmus maximus* [12]; and enhanced the immunity of Nile tilapia [9], crucian carp *Carassius auratus* [8], and Amur catfish *Silurus asotus* [13]. Also, dietary APSs improved growth, immunity, and disease resistance in crustaceans, as well as enhancing growth performance and immune parameters in red swamp crayfish *Procambarus clarkii* [14] and upregulating immune-related gene expression in Chinese mitten crab *Eriocheir sinensis* [15]. A prior study evaluated the effects of a compound herbal formula (containing 0.05% andrographolide, 0.05% tributyrin, 0.02% taurine, and 0.05% APSs) on *M. albus* growth and physiology [16]. However, no research has yet investigated the isolated impact of APSs on the growth performance and immune function of *M. albus* during the domestication stage.

At present, most farmed *M. albus* originate from wild-caught juveniles, and they need to be domesticated during the feeding process, wherein *T. molitor* emerges as a superior functional carrier matrix for bioactive compound delivery during transitional husbandry

protocols. Artificial cultivation requires a 28-day initial feeding acclimation period, during which mortality rates reach 40–80%. Therefore, this study evaluated the effects of APSs on growth, lipid metabolism, antioxidant capacity, and non-specific immunity in *M. albus* during the domestication stage, aiming to identify effective additives for specialized feeds.

2. Materials and Methods

2.1. Experimental Materials

Experimental specimens of *M. albus* (25.26 ± 0.16 g) and colony-reared *T. molitor* larvae were sourced from the Zhuanghang Comprehensive Experiment Station (Shanghai Academy of Agricultural Sciences, Shanghai, China). *Astragalus* polysaccharides (APSs > 70% purity, Xi'an Ruibo BioTech, Xi'an, China) were integrated into *T. molitor* biocarriers, whose nutritional profile comprised 52.0% crude protein, 32.0% lipids, 5.5% fiber, and 5.0% ash on a dry weight basis.

2.2. Experimental Design and Feeding Management

A total of 720 *M. albus* were stratified into four experimental groups ($n = 3$ replicates) receiving APS-fortified *T. molitor* formulations at incremental doses of 0 (CON), 700 (APS1), 1400 (APS2), and 2100 (APS3) mg/kg·bw. The method of addition involved evenly sprinkling CGA on hungry *T. molitor*, which were fed to the fish within 30 min after eating. HPLC quantification revealed actual APS retention levels of 0.5, 352, 781, and 1120 mg/kg in the respective biocarriers. The 28-day trial was conducted in recirculating aquaculture systems (RASs) equipped with concrete tanks ($1.2 \times 1.5 \times 0.8$ m) with continuous water treatment protocols. Water parameters included dissolved oxygen (6.0–7.5 mg/L), temperature (22–28 °C), and a natural photoperiod. *M. albus* were fed once daily at 16:00 h, with a daily feeding rate of 2–3% body weight. Residual feed was removed 20 min post-feeding, and feed intake was recorded. Mortalities were counted, and *M. albus* were weighed daily. Final body weights were measured for each group at trial termination.

2.3. Sample Collection and Analysis

At the end of the feeding experiment, the *M. albus* were fasted for 24 h. Three individuals per group were anesthetized with MS-222 (100 mg/L) for blood collection via decapitation. Whole blood was incubated at 4 °C overnight, followed by centrifugation at 3000 rpm for 10 min to isolate serum. Livers were excised immediately on ice, rinsed with 0.9% saline to remove surface blood, blotted with filter paper, weighed, and then stored for antioxidant enzyme activity and non-specific immune enzyme activity analyses.

2.3.1. Growth Indicators

Post-trial biometric analysis employed standardized aquacultural metrics for physiological evaluation. Vitality metrics were quantified as follows: Survival Rate (%) = $(N_{\text{final}}/N_{\text{initial}}) \times 100$. Growth dynamics were assessed through the Weight Gain Ratio (%) = $[(W_t - W_0)/W_0] \times 100$, where W_0 and W_t represent the initial/final mean body mass (g). Nutritional efficiency was determined by the formula Feed Conversion Ratio = $\Sigma \text{Feed intake (g)} / \Delta \text{Biomass (g)}$.

2.3.2. Hematological Analysis

Whole blood parameters were quantified using a Mindray BC-2800vet veterinary hematology analyzer (Shenzhen, China), including white blood cell (WBC) count, red blood cell (RBC) count, hemoglobin (HGB) concentration, hematocrit (HCT), platelet count (PLT), mean platelet volume (MPV), and platelet distribution width (PDW).

2.3.3. Lipid Metabolism Analysis

Serum lipid profiling was conducted using commercial assay kits (Nanjing Jiancheng Institute of Biotechnology, Nanjing, China) through spectrophotometric quantification. Analytical parameters included the following: (1) triglyceride (TG) concentration and (2) cholesterol homeostasis markers comprising total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) subfractions. All biochemical analyses strictly adhered to manufacturer-certified protocols.

2.3.4. Antioxidant Capacity Assessment and Non-Specific Immunity Evaluation

Liver tissues were homogenized (1:9 *w/v*) in ice-cold 0.9% saline and centrifuged at 2500 rpm for 10 min, and the supernatant was collected for determination. The activity of total antioxidant capacity (T-AOC), catalase (CAT), malondialdehyde (MDA), glutathione peroxidase (GSH-PX), lysozyme (LZM), superoxide dismutase (SOD), alkaline phosphatase (AKP), and acid phosphatase (ACP) in the liver was determined using reagent kits (Jiancheng, Nanjing, China), and an assay was performed by referring to the kit's instructions. Simply, the liver was homogenized to obtain the supernatant, and the total protein (TP) content was measured for error calibration. Lastly, the supernatant and reagents were combined and used for measuring the abovementioned parameters using a microplate reader or colorimetry methods.

2.4. Statistical Analysis

All experimental data were recorded in Excel, with results expressed as mean $\pm$ standard deviation (SD). Statistical analyses were performed using SPSS 22.0. One-way analysis of variance (ANOVA) followed by Duncan's multiple range test was applied for multiple comparisons. Differences were considered statistically significant at $p < 0.05$.

3. Results

3.1. Growth Performance

Compared to the control group, the final weight and WG were significantly increased in the APS1 and APS2 groups ($p < 0.05$), while the FCR of the APS1 and APS2 groups was significantly lower than that of the control group ($p < 0.05$). Moreover, no significant differences ($p > 0.05$) in the SR were observed among all groups (Table 1).

Table 1. Influences of different doses of APSs on growth of *M. albus*.

Item	CON	APS1	APS2	APS3
Initial weight (g)	25.28 $\pm$ 0.09 ^a	25.44 $\pm$ 0.10 ^a	25.28 $\pm$ 0.10 ^a	25.06 $\pm$ 0.10 ^b
Final weight (g)	34.07 $\pm$ 0.42 ^b	39.61 $\pm$ 0.42 ^a	40.11 $\pm$ 0.26 ^a	34.28 $\pm$ 0.81 ^b
WG (%)	34.80 $\pm$ 1.24 ^b	55.68 $\pm$ 1.12 ^a	58.70 $\pm$ 0.52 ^a	36.82 $\pm$ 3.62 ^b
FCR	2.80 $\pm$ 0.20 ^a	2.01 $\pm$ 0.08 ^b	2.01 $\pm$ 0.04 ^b	2.92 $\pm$ 0.17 ^a
SR (%)	95.56 $\pm$ 1.93	97.78 $\pm$ 1.92	97.78 $\pm$ 0.96	95.00 $\pm$ 1.67

The means in the same column with different superscript letters are significantly different ($p < 0.05$). CON, 0 mg/kg·bw; APS1, 700 mg/kg·bw; APS2, 1400 mg/kg·bw; APS3, 2100 mg/kg·bw. Abbreviations: weight gain rate (WG), feed conversion ratio (FCR), survival rate (SR).

3.2. Hematological Parameters

As shown in Table 2, no significant differences ($p > 0.05$) were observed in hematological parameters, including WBC, RBC, HCT, PLT, MPV, and PDW, among all experimental groups. However, HGB exhibited a dose-dependent trend, increasing initially and then decreasing with rising APS supplementation. Specifically, HGB concentrations significantly increased in the APS1 and APS2 groups ($p < 0.05$), while the APS3 group showed no significant change compared to the control.

Table 2. Influences of different doses of APSs on whole blood indices of *M. albus*.

Item	CON	APS1	APS2	APS3
WBC (10^9 /L)	165.33 $\pm$ 16.19	168.07 $\pm$ 5.63	162.90 $\pm$ 7.11	166.77 $\pm$ 6.21
RBC (10^{12} /L)	1.74 $\pm$ 0.09	1.76 $\pm$ 0.11	1.71 $\pm$ 0.04	1.76 $\pm$ 0.34
HGB (g/L)	140.67 $\pm$ 2.08 ^b	168.67 $\pm$ 10.26 ^a	173.00 $\pm$ 8.72 ^a	146.33 $\pm$ 4.93 ^b
HCT (%)	21.70 $\pm$ 1.35	21.53 $\pm$ 2.07	22.70 $\pm$ 0.66	22.43 $\pm$ 0.61
PLT (10^9 /L)	48.33 $\pm$ 1.53	51.67 $\pm$ 3.22	53.00 $\pm$ 4.36	50.33 $\pm$ 7.37
MPV (fL)	6.10 $\pm$ 0.26	6.23 $\pm$ 0.68	6.40 $\pm$ 0.36	6.13 $\pm$ 0.68
PDW (%)	19.33 $\pm$ 0.50	19.20 $\pm$ 0.46	19.23 $\pm$ 0.35	19.40 $\pm$ 0.36

Alphabetic superscripts denote significant intergroup variations ($p < 0.05$) within hematological indices. CON, 0 mg/kg-bw; APS1, 700 mg/kg-bw; APS2, 1400 mg/kg-bw; APS3, 2100 mg/kg-bw. Abbreviations: WBC (white blood cell), RBC (erythrocytes), HGB (hemoglobin), HCT (hematocrit), PLT (thrombocytes), MPV (platelet volume), PDW (platelet size heterogeneity).

3.3. Lipid Metabolism Parameters

In Table 3, the HDL content in all APS groups was significantly higher ($p < 0.05$), and the TG levels in APS2 and APS3 were lower than those of the control group ($p < 0.05$). In addition, APS supplementation with 2100 mg/kg resulted in significantly decreased CHO and LOD levels ($p < 0.05$).

Table 3. Influences of different doses of APSs on lipid metabolism of *M. albus*.

Item	CON	APS1	APS2	APS3
TG (mmol/L)	3.53 $\pm$ 1.25 ^a	2.75 $\pm$ 0.08 ^{ab}	2.00 $\pm$ 0.34 ^{bc}	1.20 $\pm$ 0.05 ^c
CHO (mmol/L)	3.69 $\pm$ 0.26 ^a	3.41 $\pm$ 0.21 ^a	3.47 $\pm$ 0.22 ^a	2.53 $\pm$ 0.26 ^b
HDL (mmol/L)	0.58 $\pm$ 0.06 ^c	1.47 $\pm$ 0.11 ^a	1.62 $\pm$ 0.16 ^a	0.93 $\pm$ 0.15 ^b
LDL (mmol/L)	1.56 $\pm$ 0.38 ^a	1.49 $\pm$ 0.18 ^a	1.13 $\pm$ 0.04 ^{ab}	0.73 $\pm$ 0.09 ^b

Alphabetic superscripts denote significant intergroup variations ($p < 0.05$) within hematological indices. CON, 0 mg/kg-bw; APS1, 700 mg/kg-bw; APS2, 1400 mg/kg-bw; APS3, 2100 mg/kg-bw. Abbreviations: TG (triglyceride), CHO (cholesterol), HDL (high-density lipoprotein), LDL (low-density lipoprotein).

3.4. Antioxidant Capacity Parameters

In Figure 1, the antioxidant capacity parameters were influenced by the supplementation of APSs. T-AOC exhibited a quadratic response to increasing APS doses, peaking in the APS2 group with significantly higher activity levels compared to the control ($p < 0.05$). Similarly, GSH-Px activity followed a dose-dependent pattern, reaching the maximum levels in the APS1 group ($p < 0.05$). All experimental groups showed significantly higher CAT activity levels than the control group ($p < 0.05$). Furthermore, MDA content was significantly reduced in the APS1 and APS3 groups ($p < 0.05$).

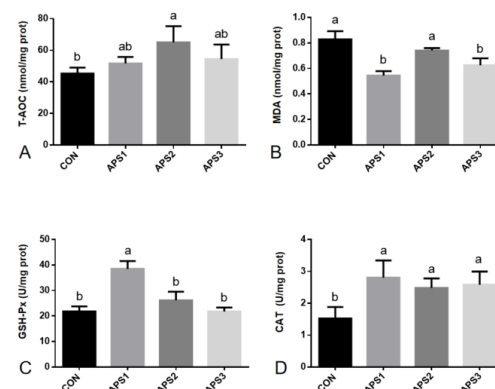


Figure 1. Antioxidant enzyme activities of *M. albus* livers in different experimental groups. Different letters indicate statistical significance ($p < 0.05$) between dietary regimens. (A): total antioxidant capacity (T-AOC), (B): malondialdehyde (MDA), (C): glutathione peroxidase (GSH-PX), (D): catalase (CAT). CON, 0 mg/kg-bw; APS1, 700 mg/kg-bw; APS2, 1400 mg/kg-bw; APS3, 2100 mg/kg-bw.

3.5. Non-Specific Immunity Parameters

In Figure 2, all experimental groups exhibited elevated hepatic non-specific immune enzyme activities when compared to the control group. The activities of SOD, LZM, and AKP displayed a quadratic dose–response pattern, peaking in the APS1 group (SOD and AKP, $p < 0.05$) and APS2 group (LZM, $p < 0.05$). In contrast, ACP activity showed a linear increase, with all APS-treated groups demonstrating significantly higher activity levels than the control ($p < 0.05$).

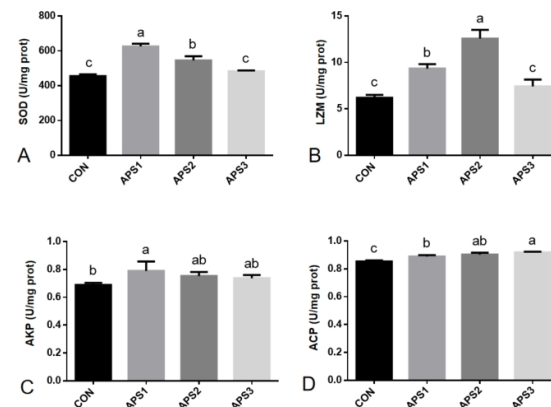


Figure 2. Non-specific immune enzyme activities of *M. albus* livers in different experimental groups. Different letters represent significant differences at $p < 0.05$; same or no letter represents no significant difference ($p > 0.05$). (A): superoxide dismutase (SOD), (B): lysozyme (LZM), (C): alkaline phosphatase (AKP), (D): acid phosphatase (ACP). CON, 0 mg/kg·bw; APS1, 700 mg/kg·bw; APS2, 1400 mg/kg·bw; APS3, 2100 mg/kg·bw.

4. Discussion

As the primary bioactive component of *Astragalus membranaceus*, APSs have been reported to enhance growth performance in various farmed fish species [17]. In this study, APS supplementation with 700 mg/kg and 1400 mg/kg in biocarrier bait significantly increased the WG and reduced the FCR in *M. albus* during the domestication stage. Similar findings were observed in large yellow croaker larvae, where dietary APSs with 500–1000 mg/kg improved growth performance [18], and a largemouth bass diet supplemented with 2000 mg/kg APS enhanced growth and feed utilization [10]. Comparable growth-promoting effects of APSs have also been documented in Nile tilapia [9] and bluegill sunfish [7]. Notably, however, the highest APS level (2100 mg/kg·bw) in this study resulted in no significant improvement in the FCR. This aligns with observations in crucian carp, where excessive APS supplementation failed to positively influence feed efficiency [19]. These discrepancies may arise from inter-specific variations, developmental stages, feeding methods, experimental designs, or trial durations. The present study employed a bioencapsulation strategy using *T. molitor* as carriers. Current farming practices rely heavily on wild-caught juveniles that resist formulated feeds during early acclimation. Live feeds, such as *T. molitor*, *Hermetia illucens*, and *Musca domestica*, are thus critical for transitional training. Moreover, live feeds provide comprehensive nutrition, particularly advantageous for juvenile and broodstock stages due to their high protein content and palatability. Additionally, the bioactive compounds encapsulated in live carriers remain structurally intact, avoiding the thermal denaturation and functional deactivation that often occur during the high-temperature processing of pelleted feeds. This method also minimizes nutrient leaching into water, which is a critical limitation of conventional feed delivery systems. By replicating the natural feeding ecology of *M. albus* during the initial acclimation phase, our experimental design provides actionable insights for commercial farming practices. These findings collectively suggested that moderate APS supplementa-

tion enhances growth performance, likely through the upregulation of digestive enzyme activities and the stimulation of nutrient absorption pathways [18].

Blood composition in fish is influenced by metabolism, nutritional status, and immune responses. As the primary bioactive component of *Astragalus membranaceus*, APSs exhibit potent hematopoietic activity by stimulating colony-forming unit-erythrocyte (CFU-E) and burst-forming unit-erythrocyte (BFU-E), thereby enhancing hemoglobin synthesis [20]. Our results demonstrated that dietary supplementation with 700 mg/kg and 1400 mg/kg APSs significantly elevated HGB levels in *M. albus* compared to the control group. Hemoglobin, primarily responsible for oxygen transport and storage, also regulates pH homeostasis, modulates carbon monoxide levels, and participates in immune responses [21]. Similar findings were reported in *Catla catla*, where HGB levels increased following APS supplementation at 200–300 mg/kg [22]. These results suggest that APSs may improve oxygen acquisition in *M. albus*, enhancing survival under hypoxic conditions (e.g., high-density farming or transportation stress) while simultaneously meeting the elevated oxygen demands of physiological metabolic processes.

As a critical metabolic transport system, blood regulates lipid metabolism in fish, with serum TG and total CHO levels serving as key indicators [23]. Our results revealed a dose-dependent reduction in serum TG and CHO levels in *M. albus* supplemented with APSs. Specifically, higher APS supplementation resulted in significant decreases ($p < 0.05$) in these parameters. This aligns with findings in Nile tilapia, where 0.1% *Astragalus* extract supplementation for 40 days significantly reduced serum TG and CHO [24], and mice (*Mus musculus*) demonstrated improved lipid metabolism following APS administration [25]. Notably, APS supplementation induced a quadratic response in serum HDL levels, peaking at intermediate doses while remaining significantly elevated compared to the control across all treatment groups. Conversely, LDL levels exhibited a gradual decline, with a significant reduction observed only at the highest APS dose (2100 mg/kg) ($p < 0.05$). These findings correlate with prior reports that APSs modulate lipid profiles in Nile tilapia exposed to heavy metal thallium [26]. Mechanistically, HDL facilitates reverse cholesterol transport from peripheral tissues to the liver for catabolism, whereas excessive LDL promotes arterial lipid deposition, increasing the risks of atherosclerosis and vascular injury [27]. We hypothesize that APSs delivered via mealworm carriers (1400–2100 mg/kg bw) regulate lipid metabolism in *M. albus* by modulating lipoprotein concentrations, thereby enhancing lipid transport efficiency. However, the precise molecular mechanisms underlying this require further investigation.

SOD, LZM, AKP, and ACP are key non-specific humoral immune factors in fish, playing critical roles in immunological responses [28]. SOD activity is closely associated with immune function, while LZM serves as a sensitive biomarker for detecting foreign invasions. Additionally, ACP and AKP hydrolyze phosphate groups and are recognized as vital indicators for evaluating the immune status of aquatic animals [29]. Extensive studies have demonstrated the broad application of APSs as immunostimulants in aquaculture. In this study, the activities of SOD, LZM, AKP, and ACP in *M. albus* were significantly elevated following dietary APS supplementation. Specifically, the addition of 700 mg/kg and 1400 mg/kg APSs markedly enhanced SOD, LZM, and ACP activities. Similar findings have been reported in large yellow croaker, in which 1000 mg/kg APSs significantly increased SOD, LZM, AKP, and ACP activities [30]. APS supplementation at 1200 mg/kg also improved SOD, LZM, AKP, and ACP activities in red swamp crayfish [14] and Chinese mitten crab [15], reducing disease susceptibility. Furthermore, the dietary inclusion of 0.15% and 0.30% APSs has been shown to enhance immunity and significantly elevate LZM activity in Nile tilapia [31]. Mechanistically, APSs may regulate host immunity by activating the TLR4-mediated MyD88-dependent signaling pathway [32]. Collectively,

this study demonstrates that APS supplementation enhances the immunity of *M. albus* by upregulating SOD, AKP, LZM, and ACP activities.

5. Conclusions

In summary, dietary supplementation with APSs elicited improvements in the growth parameters, lipid homeostasis regulation, oxidative stress mitigation, and innate immune potentiation of *M. albus* during the domestication stage. Based on the findings of this study, an optimal APS dosage of 700 mg/kg, corresponding to 352 mg/kg, is recommended when administered via *T. molitor* as a biocarrier bait.

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Informed Consent Statement: Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: The datasets generated for this study are available on request to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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