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Effects of *Fagopyrum dibotrys* Rhizoma meal Supplementation on Productive Performance, Egg Quality, Egg Nutritional Value and Serum Biochemical Parameters of Shanma Laying Ducks

Pingwen Xiong [1,2,3,†], Gaoxiang Ai [2,†], Jiang Chen [2,†], Wenjing Song [2], Qiongli Song [2], Dongyou Yu [1], Zhiheng Zou [2], Qipeng Wei [2], Chuanhui Xu [2], Weide Su [2], Xiaolian Chen [3,*] and Lizhen Hu [2,*]

[1] Key Laboratory of Molecular Animal Nutrition (Zhejiang University), Ministry of Education, Hangzhou 310058, China; xiongpingwen1990@163.com (P.X.); dyyu@zju.edu.cn (D.Y.)

[2] Institute of Animal Husbandry and Veterinary Science, Jiangxi Academy of Agricultural Sciences, Nanchang 330200, China; 18270713404@163.com (G.A.); jiangchen363@163.com (J.C.); wenjingsong@jxaas.cn (W.So.); songqiongli1975@126.com (Q.S.); zouzhihengxms@163.com (Z.Z.); weiqp66@sina.com (Q.W.); xuchuanhui0620@163.com (C.X.); suweide@jxaas.cn (W.Su.)

[3] Jiangxi Province Key Laboratory of Animal Green and Healthy Breeding, Nanchang 330200, China.

* Correspondence: xiaolianchen@126.com (X.C.); hulizhen1980@126.com (L.H.)

† These authors contributed equally to this work.

Abstract: The rhizoma of *Fagopyrum dibotrys* (D. Don) Hara, a traditional natural medicinal herb with extensive historical applications in China, has possessed multiple bioactive properties including anti-inflammatory, anticancer, antioxidant, antimicrobial, immunomodulatory and antidiabetic effects. However, the potential positive effects of *Fagopyrum dibotrys* rhizoma meal (FDRM) on productive performance in intensive farming laying duck production remain unclear. This study was conducted to evaluate the effects of FDRM supplementation in *Shanma* laying ducks diet by determining productive performance, egg quality, egg nutritional value and serum biochemical parameters. A total of 512 healthy 32-week-old *Shanma* laying ducks with similar laying performance and body weight were randomly allocated to 4 groups with 8 replicates of 16 ducks each. Ducks in the control group (F0 group) were fed only the basal diet, while the other groups (F1, F2 and F3 groups) were fed the basal diets supplemented with 1%, 2% and 3% FDRM, respectively. The experiment lasted for 49 days with ad libitum access to feed and water. Our results showed that supplementing FDRM in duck diet had no adverse effects on laying performance (P>0.05). Additionally, compared with the control group (F0 group), Dietary supplementation with FDRM significantly improved the shell strength, yolk color and shell proportion (P<0.05), while increasing the serum total protein (TP) content (P<0.05). The study also found that adding 2% FDRM (F2 group) pronouncedly enhanced the contents of total amino acids, essential amino acids and umami amino acids in eggs (P<0.05), optimized the composition of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA)(P<0.05), and reducing the saturated fatty acids (SFA) content. However, 3% FDRM addition (F3 group) dramatically increased the serum blood urea nitrogen (BUN) content (P<0.05), indicating it will reduced the dietary protein utilization efficiency. Overall, dietary supplementation with FDRM might improved egg quality and egg nutritional value of *Shanma* laying ducks through improving the shell strength, yolk color and shell proportion, optimizing yolk fatty acid and amino acid profiles, and enhancing serum TP content. Under the conditions of this experiment, FDRM could be utilized as a phytogenic feed additives in *Shanma* laying ducks diet, the optimal supplementation ratio identified was 2%.

Keywords: *Fagopyrum dibotrys* rhizoma meal; productive performance; egg quality; egg nutritional value; serum biochemical parameters; *Shanma* laying ducks

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1. Introduction

Laying duck industry serves as a pivotal pillar of China's agricultural economy. In the context of its rapid development, key industry concerns now revolve around enhancing production performance, optimizing egg quality, improving the nutritional value of duck eggs, reducing antibiotic usage, and achieving green and sustainable development. Amid growing concerns over antibiotic resistance and drug residues in products resulting from the widespread use of antibiotics, the Ministry of Agriculture and Rural Affairs of the People's Republic of China issued Announcement No. 194, explicitly mandating the cessation of production of commercial feed containing growth-promoting drug feed additives (except for traditional Chinese herbs) starting from July 2020. Against this backdrop, numerous studies have begun exploring the potential of plant-derived feed additives based on traditional Chinese herbs or plant extracts as alternatives to antibiotics, aiming to maintain or improve the health and production performance of poultry[1–3].

Phytogenic feed additives (PFA) refer to plant-derived components or extracts that exhibit pharmacological activities such as growth promotion, antiviral, antibacterial, antioxidant, and anti-inflammatory effects. Due to their environmentally friendly characteristics and multiple biological activities, PFA have garnered widespread attention. Research demonstrates that these additives can significantly enhance laying performance in poultry, improve egg quality, and strengthen antioxidant capacity in laying hens[4–7]. *Fagopyrum dibotrys* (F. dibotrys) (D. Don) Hara, a traditional Chinese medicinal herb, is renowned for its dried rhizome, which exhibits therapeutic properties such as heat-clearing, detoxification, lung health promotion, phlegm resolution, and swelling reduction. It is commonly employed in the treatment of various conditions, including acute lung injury[8], cardiovascular diseases[9], kidney or liver damage[10,11], and bronchial asthma[12]. Modern pharmacological studies have revealed that the rhizoma of *F. dibotrys* contains a diverse array of chemical constituents, including flavonoids, phenols, fagopyrin, triterpenoids, fatty acids, and steroids[13–15]. These compounds confer a wide range of bioactive properties, such as anti-inflammatory, anticancer, antioxidant, antimicrobial, immunomodulatory, and antidiabetic effects[16–18]. In livestock production, F. dibotrys serves as a high-value feed additive, demonstrating multiple benefits in poultry farming. When incorporated into poultry diets, it significantly enhances laying performance (e.g., laying rate and average daily feed intake) and improves egg quality, including shell strength, yolk color, and Haugh units. Additionally, it enriches the nutritional value of eggs by increasing unsaturated fatty acids and essential amino acids content. Beyond productivity enhancement, *F. dibotrys* modulates serum biochemical indices (e.g., immunoglobulin levels), thereby boosting immunity and disease resistance in laying hens. This reduces disease incidence and antibiotic dependency, ensuring sustainable and healthy production[19,20]. Nutritionally, *F. dibotrys* is characterized by its high crude protein content, balanced essential amino acids, abundance of trace minerals, and high digestibility, making it well-suited for animal digestion and absorption. It demonstrates significant efficacy in enhancing dietary protein utilization efficiency and serum antioxidant indices in livestock[21]. Moreover, its stems and leaves can be processed into non-conventional feed ingredients, offering a potential solution to alleviate the current shortage of feed resources[22,23]. Given these advantages, exploring the application of *F. dibotrys* rhizoma meal (FDRM) as a plant-derived feed additive in laying duck production may provide a novel strategy to improve production efficiency, reduce antibiotic dependence, and enhance overall livestock health.

Nevertheless, based on our knowledge, literature investigating the effect of FDRM in laying ducks' diet is very scarce. The optimal inclusion level, mechanisms of action, and its effects on productive performance, egg quality, nutritional value of eggs, and serum biochemical parameters still require systematic evaluation. China has a large scale production of traditional Chinese herbs or plant extracts for years. Therefore, it is important to utilize these herbal resources as feed ingredient and unveil their potential economic value in feed industry. Therefore, the aim of this study is to

 doi:10.20944/preprints202505.0096.v1

investigate the effects of FDRM on productive performance, egg quality, nutritional value of eggs, and serum biochemical parameters of laying ducks. The findings are expected to provide theoretical foundations and practical references for healthy duck farming, while promoting the sustainable utilization of natural plant resources in livestock and poultry production.

2. Materials and Methods

The experimental use of animals and related procedures were performed according to the Chinese Guidelines for Animal Welfare and approved by the Institutional Animal Care and Use Committee of Jiangxi Academy of Agricultural Sciences (Ethical Committee Number: 2025-JXAAS-XM-18).

2.1. Experimental Materials

The *Fagopyrum dibotrys* rhizoma meal (FDRM) used in this study was provided by Jiangxi University of Traditional Chinese Medicine. Fresh *F. dibotrys* rhizomata were selected, dried naturally, crushed and passed through the 80-mesh screen to prepare FDRM. The main bioactive compounds of FDRM are flavonoids and polyphenols, determined by spectrophotometric method, which the contents are 19.6 mg/g and 63.85 mg/g respectively. Moreover, the FDRM (dry basis) in this experiment contained the following nutrients: gross energy 15.48 MJ/kg, dry matter 86.40 %, crude protein 4.03%, crude fat 0.30%, crude fiber 14.10%, crude Ash 4.10%, calcium 0.41%, and total phosphorus 0.31%.

2.2. Ducks, Experimental Design and Treatments

This study was conducted on 32-weeks-old Longyan *Shanma* laying ducks for a 49-day period with a completely randomized design. A total of 512 laying ducks with similar productive performance (80.88 ± 5.17 %) and body weight (1.24 ± 0.02 kg) were used in this experiment. Ducks were randomly allocated to 4 groups with 8 replicates per group and 16 ducks per replicate (128 laying ducks per group). The control group (F0) was fed a basal diet, and the experimental groups were fed diets supplemented with 1% (F1), 2% (F2), and 3% (F3) of FDRM, respectively. all experimental diets were formulated to contain same nutrient levels.

2.3. Diets and Management

This trial was carried out at the test field of laying ducks in Gaoan, Institute of Animal Husbandry and Veterinary Science, Jiangxi Academy of Agricultural Sciences, PR China. The basal diet fed animals was corn-soybean meal diet, which was formulated based on the China's national standard "nutrient requirements for egg duck" (GB/T 41189-2021) to meet the nutrient requirements of Longyan Shanma ducks. Table 1 presents the composition and nutrient levels of experimental diets. The experimental laying ducks were raised in three-layer three-dimensional netting, consisted of 4 adjacent cages (40 × 38 × 38 cm; length × width × height) with 2 animals per cage, providing 28,880 cm^3 per animal in closed fully automated duck house. Each replicate was raised on the upper and middle floors and each groups were guaranteed to be equal in the number of distributed upper and middle layers. During the period of study, the housing temperature and relative humidity were 23.0 ± 2 ℃ and 55 to75 %, respectively. Furthermore, the photoperiod was set at 16L:8D through a 49-d experimental period. Animals were kept with ad libitum access to feed and water during the entire experimental period. The management, procedures of immunization and sanitation and disinfection of the test ducks were carried out in accordance with the standard breeding system.

Table 1. Composition and nutrient levels of experimental diets (air-dry basis) %.

Items	F0	F1	F2	F3
Ingredient				
Corn	52	51.6	51.4	51

 doi:10.20944/preprints202505.0096.v1

Soybean meal	23.9	23.81	23.75	23.65
wheat bran	9.35	9.85	10.1	10.6
Soybean oil	1	1	1	1
Limestone	8.47	8.46	8.47	8.5
$CaHPO_4$ ($2H_2O$)	1.39	1.39	1.39	1.36
Sodium chloride	0.3	0.3	0.3	0.3
Choline chloride	0.15	0.15	0.15	0.15
Vitamin premix[1)]	0.03	0.03	0.03	0.03
Mineral premix[2)]	0.2	0.2	0.2	0.2
DL-methionine	0.15	0.16	0.16	0.16
L-lysine·HCl	0.04	0.04	0.04	0.04
L-tryptophan	0.02	0.01	0.01	0.01
Rice bran and hull	3	2	1	0
Fagopyrum dibotrys rhizoma meal （FDRM）	0	1	2	3
Total	100	100	100	100
Nutrient levels[3)]				
Metabolizable energy (Kcal/kg)	2501	2502	2508	2501
Crude protein (%)	16.5	16.5	16.5	16.5
Ca (%)	3.6	3.6	3.6	3.6
NPP (%)	0.35	0.35	0.35	0.35
Digestible lysine (%)	0.854	0.853	0.853	0.852
Digestible methionine (%)	0.399	0.408	0.408	0.408
Digestible threonine (%)	0.210	0.200	0.200	0.201
Digestible tryptophan (%)	0.605	0.605	0.605	0.604

1)The vitamin premix provided the following per kg of diets:VA 7 500 IU,VD_3 2 500 IU,VE 20 IU,VK_3 2.5 mg,VB_1 3 mg,VB_2 6 mg,pantothenic acid 20 mg,pyridoxine 2.5 mg,nicotinic acid 27 mg,biotin 0.2mg,folic acid 1 mg. 2)The mineral premix provided the following per kg of diets:Cu (as copper sulfate)20 mg,Fe (as ferrous sulfate)50 mg,Zn (as zinc sulfate)70 mg,Mn (as manganese sulfate)70 mg,I (as potassium iodide) 0.4 mg, Se (as sodium selenite) 0.3 mg. 3).All nutritional levels were calculated based on Tables of Feed Composition and Nutritional Value in China (34th Edition, 2023).

2.4. Productive Performance

Throughout the trial, the ducks' egg production and egg weight were monitored daily, and feed consumption was meticulously recorded on a replicate basis at weekly intervals. At the end of the feeding trial, these values were allowed to analyze the daily egg weight (DEW), average egg weight (AEW), laying rate (LR), average daily feed intake (ADFI) and the ratio of feed to egg (F/E) of the ducks for the 49-d feeding period.

2.5. Egg Quality

At the last day of the experiment, eight freshly laid eggs were randomly collected for each repeat, which were used for conventional egg quality analysis (within 48 h after laying), including shape index, shell strength, shell thickness, haugh unit, yolk color, vitellus proportion, albumen proportion and shell proportion. The egg shape index was calculated by a caliper marked at 0.01mm intervals and was represented by the formula shape index (SI) = (egg length/egg width)[24]. Shell strength was measured on the vertical axis using a compression tester (EFG-0503, Robotmation, Tokyo, Japan). The shell thickness was determined (excluding shell membrane) using a micrometer with the least count of 0.01 mm and was expressed by the mean value of measurements from three locations (air cell, equator, and sharp end) of the egg. Haugh unit, yolk color and albumen height were analyzed by an Egg Multi-tester (EMT-5200, Robotmation Tokyo, Japan). The vitellus, albumen and shell were isolated and weighed to calculate their percentages of egg weight.

 doi:10.20944/preprints202505.0096.v1

2.6. Egg Nutritional Value

After measuring the egg physical parameters, the vitelluses were collected and freeze-dried for further analyses of egg conventional nutrition, amino acid composition and fatty acids profile. The egg conventional nutrition, including moisture, crude protein (CP), crude fat, cholesterol and Ca were determined in accordance with AOAC methods [25]. Crude protein (N x 6.25) content was measured by determining crude nitrogen content using the Kjeldahl method. Ether extract was measured using the Soxhlet method. The method for the Ca and cholesterol determination were used by an ultraviolet spectrophotometer and commercial kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China) as described by Zhang et al.[26]. According to the methods reported by Cullere et al.[27], the amino acids content and fatty acids profile of the eggs were analyzed.

2.7. Serum Biochemical Parameters

At the end of the 8 weeks, two laying ducks with close to the average weight were randomly selected from each replicate for collection of 5 mL of fasting blood samples from the wing vein. The blood samples were centrifuged at 3,000 rpm for 10 minutes, and the serum was separated and stored at -20°C for further use. The serum levels of triglycerides (TG), total cholesterol (TC), high-density lipoprotein (HDL), and low-density lipoprotein (LDL) were measured using commercial assay kits. Additionally, the levels of total protein (TP), albumin (ALB), blood urea nitrogen (BUN), alkaline phosphatase (AKP), and calcium (Ca) were determined. All assay kits were provided by the Nanjing Jiancheng Bioengineering Institute.

2.8. Statistical Analyses

All data were organized using Excel 2013, and then subjected to a one-way analysis of variance (One-Way ANOVA) using the Bonferroni method in SPSS 22.0 statistical software (SPSS Inc., Chicago, IL, USA) to test for multiple comparisons. The experimental results were presented as mean and pooled SEM. A value of $P<0.05$ was considered statistically significant, while a value of $0.05<P<0.10$ indicated a trend towards an increase or decrease.

3. Results

3.1. Productive Performance

The effects of dietary FDRM supplementation on productive performance of laying ducks were shown in Table 2. During the entire period, there were no significant effects ($P>0.05$) by adding FDRM in laying ducks diet, regardless of the supplementation levels, on DEW, AEW, DEN, LR, ADFI and F/E.

Table 2. Effects of FDRM on productive performance of laying duck[1].(33 to 39 weeks of age).

Items[4]	Groups				SEM[2]	*P-value*[3]
	F0	F1	F2	F3		
DEW[5] (g/d)	788.20	799.09	792.87	795.93	11.74	0.990
AEW (g)	64.94	65.09	64.93	64.34	0.22	0.650
DEN[6] [egg/(duck·d)]	0.76	0.77	0.76	0.77	0.01	0.977
LR (%)	75.85	76.79	76.36	77.36	1.14	0.977
ADFI [g/(duck·d)]	183.22	177.23	180.3	178.55	0.93	0.116
F/E (g/g)	3.74	3.57	3.67	3.61	0.05	0.706

[1]Data are the mean of 8 replicates with 16 ducks each, the same as below. [2]SEM (Standard error of the mean): the standard error of the average, the same as below. [3]In the same row, values with no letter superscripts mean no significant difference($P>0.05$), while with different letter superscripts mean significant difference($P<0.05$). The same as below. [4]DEW, daily egg weight; AEW, average egg weight; DEN, daily egg number; LR, laying rate;

 doi:10.20944/preprints202505.0096.v1

ADFI, average daily feed intake; F/E, The ratio of feed to egg. [5]DEW = Gross egg weight laid in experimental period/49. [6]DEN = Gross egg numbers laid in experimental period/49/16.

3.2. Egg Quality

The egg quality of laying ducks were depicted in Table 3. Compared with the F0 group, the shell strength and yolk color in F2 and F3 groups were dramatically increased (P<0.05). Furthermore, the yolk color in F1 group and the shell proportion in F3 group were pronouncedly (P<0.05) higher than that in F0 group. No significant differences were observed in shape index, shell thickness, albumen height, haugh unit, vitellus proportion and albumen proportion (P> 0.05), in response to dietary FDRM supplementation levels.

Table 3. Effects of FDRM on egg quality of laying ducks[1](39 weeks of age).

Items[4]	Groups				SEM[2]	*P-value*[3]
	F0	F1	F2	F3		
Shape index (SI)	1.36	1.35	1.35	1.35	0.003	0.782
Shell strength (N/m^2)	39.69^b	43.12^{ab}	43.88^a	44.80^a	0.61	0.006
Shell thickness (mm)	0.37	0.37	0.38	0.38	0.002	0.124
Albumen height (mm)	7.00	7.08	6.83	6.75	0.09	0.544
Haugh unit	80.74	81.59	80.20	79.32	0.64	0.674
Yolk color	5.52^b	5.76^a	5.77^a	5.73^a	0.03	0.003
Vitellus proportion (%)	31.55	31.54	31.74	31.60	0.13	0.953
Albumen proportion (%)	60.02	59.55	59.60	59.27	0.15	0.385
Shell proportion (%)	8.48^b	8.91^{ab}	8.83^{ab}	9.13^a	0.07	0.003

[4]Shape index (SI) = egg length/egg width.

3.3. Egg Nutritional Value

3.3.1. Egg Conventional Nutrition

For the conventional nutrient levels of the vitellus in laying ducks, there were no diet effects on the different parameters (moisture; crude protein; ether extract; cholesterol and Ca)(Table 4). Nevertheless, compared with the F0 group, the Ca content in F2 and F3 groups showed a tend improvement as the inclusion level of FDRM increased(0.05<P=0.073<0.10).

Table 4. Effects of FDRM on conventional nutrient levels in the vitellus of laying ducks (Fresh matter basis)[1].

Items	Groups				SEM[2]	*P-value*[3]
	F0	F1	F2	F3		
Moisture (%)	49.57	49.75	49.25	49.61	0.10	0.410
Crude protein (%)	17.70	18.00	17.88	17.96	0.07	0.420
Ether extract (%)	10.61	10.53	10.52	10.38	0.06	0.646
Cholesterol (mg/g)	9.06	8.26	7.96	8.66	0.19	0.211
Ca (mg/g)	0.58	0.58	0.61	0.62	0.01	0.073

3.3.2. Amino Acids Composition

As can be seen from Table 5, the contents of Thr, Val, Ile, Leu, Asp, Glu, Gly, Cys, total EAAs, total AAs, and umami AAs in the vitellus showed significant response to the increasing FDRM supplement levels (P<0.05). Compared with the control group (F0), there was no difference in the amino acid profile in F1 group (P>0.05), dietary supplementation with 2% FDRM (F2) group could markedly increase the contents of Thr, Leu, Asp, Glu, Gly, Cys, total EAAs, total AAs, and umami AAs (P<0.05), while the Thr and Asp concentrations in the group supplemented with 3% FDRM (F3) were statistically heighted (P<0.05), with no dietary effect on other amino acids contents (P>0.05). In

 doi:10.20944/preprints202505.0096.v1

addition, compared with the the F1 group, the F2 group could pronouncedly increase the content of Val, Ile, Leu, Gly, Cys, and total EAAs (P<0.05), but had no significant effect on the contents of other amino acids (P>0.05).

Table 5. Effect of FDRM on amino acids composition in the vitellus of laying ducks[1](mg/g, as-fresh basis).

Items[4]	Groups				SEM[2]	*P-value*[3]
	F0	F1	F2	F3		
EAAs						
Thr	6.25^{b}	6.38^{ab}	6.77^{a}	6.82^{a}	0.07	0.003
Val	8.09^{ab}	8.01^{b}	8.46^{a}	8.11^{ab}	0.09	0.002
Met	4.00	4.31	4.52	4.42	0.08	0.104
Ile	6.14^{ab}	6.04^{b}	6.56^{a}	6.20^{ab}	0.08	0.024
Leu	12.26^{b}	12.89^{b}	13.67^{a}	12.95^{ab}	0.19	0.004
Phe	6.56	6.46	7.04	6.67	0.10	0.195
Lys	10.10	10.52	11.00	10.84	0.13	0.073
NEAAs						
Asp	12.24^{b}	12.42^{ab}	13.29^{a}	13.26^{a}	0.15	0.009
Ser	11.29	11.03	12.08	11.35	0.14	0.066
Glu	17.44^{b}	17.77^{ab}	18.84^{a}	18.28^{ab}	0.18	0.026
Gly	4.29^{b}	4.35^{b}	4.69^{a}	4.47^{ab}	0.05	0.010
Ala	7.14	7.27	7.42	7.44	0.06	0.307
Cys	2.18^{b}	2.20^{b}	2.28^{a}	2.26^{ab}	0.02	0.003
Tyr	5.15	5.36	5.64	5.50	0.08	0.227
His	3.18	3.30	3.42	3.44	0.04	0.092
Arg	8.68	9.07	9.85	9.48	0.17	0.227
Pro	4.96	4.80	5.29	4.84	0.07	0.095
Total EAAs	53.73^{b}	54.99^{b}	58.75^{a}	54.80^{ab}	0.66	<0.001
Total NEAAs	74.39	77.08	79.13	79.80	0.97	0.198
Total AAs	128.12^{b}	131.61^{ab}	140.00^{a}	134.60^{ab}	1.34	0.008
Flavour AAs	52.46	53.62	55.49	55.61	0.57	0.158
Umami AAs	29.67^{b}	30.19^{ab}	31.93^{a}	31.54^{ab}	0.31	0.021
Sweet AAs	27.98	27.45	28.01	28.10	0.38	0.939
Aromatic AAs	11.37	11.82	12.63	12.17	0.17	0.054

[4]Asp, asparc acid; Thr, threonine; Ser, serine; Glu, glutamic acid; Gly, glycine; Ala, alanine; Cys, cysteine; Val, valine; Met, methionine; Ile, isoleucine; Leu, leucine; Tyr, tyrosine; Phe, phenylalanine; Lys, lysine; His, histidine; Arg, arginine; Pro, proline; EAAs, essential amino acids; NEAAs, non-essential amino acids; AAs, amino acids; Flavour AAs = Asp + Glu + Gly + Ala + Tyr + Phe; Umami AAs = Asp + Glu; Sweet AAs = Ser + Gly + Ala + Pro; Aromatic AAs = Tyr + Phe.

3.3.3. Fatty Acids Profile

Table 6 showed the effect of dietary FDRM addition on the fatty acid profile in the vitellus of laying ducks. The levels of C16:0 and total SFAs in the F1 and F2 groups exhibited a significant decrease compared to the F0 group (P<0.05), while the UFAs:SFAs ratio increased significantly (P<0.05). Moreover, the levels of C14:0 pronouncedly decreased in the F2 and F3 groups (P<0.05), the F3 group statistically heighted the contents of C20:1 and C20:3, markedly reduced the contents of total SFAs (P<0.05). Compared with the F0 group, the PUFAs:SFAs ratio in the vitellus from the F1 group displayed a remarkable enhance (P<0.05).

Table 6. Effect of FDRM on fatty acids profile in the vitellus of laying ducks[1](%).

Items[4]	Groups				SEM[2]	*P-value*[3]
	F0	F1	F2	F3		

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C14:0	0.40[a]	0.39[ab]	0.36[b]	0.34[b]	0.01	<0.001
C16:0	21.82[a]	21.19[b]	21.15[b]	21.44[ab]	0.08	0.034
C17:0	1.21	1.18	1.15	1.17	0.01	0.081
C18:0	6.64	6.62	6.67	6.64	0.02	0.884
C20:0	0.07	0.08	0.07	0.07	0.001	0.111
C16:1	4.65	4.73	4.75	4.72	0.02	0.116
C17:1	1.32	1.37	1.29	1.30	0.01	0.323
C18:1n9	45.70	45.88	46.01	46.34	0.10	0.106
C20:1	0.32[b]	0.33[ab]	0.33[ab]	0.34[a]	0.003	0.007
C18:2n6	15.20[ab]	15.42[a]	15.33[ab]	14.81[b]	0.09	0.033
C18:3n3	0.12	0.12	0.13	0.13	0.001	0.907
C18:3n6	0.90	0.91	0.91	0.92	0.003	0.082
C20:3	0.085[b]	0.089[ab]	0.087[ab]	0.092[a]	0.001	0.025
C20:4	0.93	0.95	0.93	0.94	0.004	0.197
C22:6	0.75	0.74	0.74	0.74	0.002	0.053
Total SFAs	30.31[a]	29.46[b]	29.41[b]	29.67[b]	0.10	0.033
Total MUFAs	51.98	52.31	52.40	52.71	0.11	0.204
Total PUFAs	17.96[ab]	18.23[a]	18.11[ab]	17.62[b]	0.08	0.041
Total UFAs	69.70	70.55	70.55	70.33	0.11	0.069
UFAs:SFAs	2.30[b]	2.40[a]	2.39[a]	2.37[ab]	0.01	0.040
PUFAs:SFAs	0.59[b]	0.62[a]	0.61[ab]	0.60[ab]	0.005	0.032

[4]SFAs = C14:0 + C16:0 + C17:0 + C18:0 + C20:0; MUFAs = C16:1 + C17:1 + C18:1n9 + C20:1; PUFAs = C18:2n6 + C18:3n3 + C18:3n6 + C20:3 + C20:4 + C22:6; UFAs = MUFAs + PUFAs; SFAs, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids; UFAs, unsaturated fatty acids.

3.4. Serum Biochemical Parameters

For serum biochemical parameters, the levels of TP and BUN along with the concentration of Ca in serum of laying ducks showed significant responses to increased dietary FDRM supplement levels (Table 7, $P<0.05$). The serum levels of TP in F2 group and BUN in F3 group were significantly ($P<0.01$) higher than that in F0 group. Additionally, in comparison to the F2 group, the F1 and F3 group dramatically lowered the Ca concentration in serum of laying ducks.

Table 7. Effects of FDRM on serum biochemical parameters of laying ducks[1].

Items[4]	**Groups**				**SEM**[2]	***P-value***[3]
	F0	**F1**	**F2**	**F3**		
TP (g/L)	30.26[b]	31.88[ab]	35.20[a]	32.4[ab]	0.49	0.002
ALB (g/L)	15.91	15.67	17.34	15.88	0.24	0.107
BUN (mmol/L)	6.25[b]	5.63[b]	8.47[ab]	10.29[a]	0.54	0.005
AKP (KU/100 mL)	20.28	19.76	20.24	22.94	1.21	0.900
Ca (mmol/L)	1.34[ab]	1.29[b]	1.46[a]	1.29[b]	0.02	0.030
TG (mmol/L)	6.32	4.29	5.06	4.67	0.33	0.169
TC (mmol/L)	2.43	3.85	2.37	2.58	0.21	0.210
HDL (mmol/L)	1.12	1.85	1.19	1.50	0.11	0.059
LDL (mmol/L)	0.76	0.83	0.67	0.66	0.04	0.449

[4]TP, total protein; ALB, albumin; BUN, blood urea nitrogen; AKP, alkaline phosphatase; Ca, calcium; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein ; LDL, low-density lipoprotein.

4. Discussion

In recent years, numerous studies have strongly supported the view that Chinese herbal medicines or plant extracts exert positive effects on poultry and livestock such as laying ducks, laying hens, geese, and broilers. These studies emphasize that phytogenic feed additives not only improve

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production performance, egg quality, intestinal health and egg nutritional value, but also increase dietary protein utilization, serum immunity and antioxidant capacityt[21,24,28–35]. This experiment aimed to investigate the effects of dietary supplementation with FDRM on laying performance, egg quality, egg nutritional value and serum biochemical indicators of *Shanma* laying ducks. In our study, we observed a series of positive effects of FDRM supplementation on laying ducks. These included significant increases in shell strength, yolk color, and shell proportion, while no significant impact was found on laying performance. Furthermore, the study also demonstrated that FDRM supplementation improved the nutritional value of eggs by increasing the content of unsaturated fatty acids and amino acids in the yolk while reducing saturated fatty acid levels. These findings indicate that dietary supplementation with FDRM had no adverse effects on laying performance of *Shanma* laying ducks,while concurrently improving the nutritional quality of eggs. Additionally, serum biochemical indicators revealed that FDRM supplementation significantly increased serum TP content and enhanced serum calcium concentrations. The aforementioned findings indicate that FDRM exhibits potential benefits in enhancing metabolic pathways associated with protein synthesis, consequently leading to improved the quality and nutritional value of duck eggs.

Numerous phytogenic feed additives, including *Eucommia ulmoides* leaf extract, peppermint leaf powder, *Moringa oleifera* leaf flavonoids, licorice extract, yucca schidigera extract, mulberry leaf extract, *Lonicera confusa* and *Astragali radix* extracts, as well as pine needle and *Artemisia* annua blends, have been demonstrated to possess potential health-regulating effects in laying hens. Scientific investigations reveal that these herbal formulations and their bioactive constituents not only enhance follicular development through endocrine modulation (e.g., estrogen level), deepen yolk pigmentation, and improve laying performance along with egg quality, but also exhibit multifaceted biological activities including antioxidant, immunomodulatory and gut health-impronement[26,36–42]. Collectively, FDRM demonstrates potential as a phytogenic feed additive for enhancing animal productivity and overall health status through modulation of intestinal ecosystem homeostasis and potentiation of immune system functionality[1,15,22]. Notably, current utilization and research on FDRM primarily focus on pharmaceutical formulations, nutraceutical products, functional beverages, and partial replacement in swine diets, while investigations of its rhizomata (medicinal organs) are predominantly limited to broiler applications. Crucially, the application of FDRM in laying duck production remains poorly documented. This study was therefore designed to systematically evaluate the efficacy of FDRM as a phytogenic feed additive in laying duck production, aiming to establish novel strategies for optimizing production efficiency and mitigating antibiotic dependency in poultry farming systems.

Our findings demonstrate that dietary supplementation with FDRM did not significantly affect daily egg weight, average egg weight, daily egg number, laying rate, average daily feed intake, and the ratio of feed to egg in laying ducks, but markedly enhanced shell strength and yolk coloration. This aligns with previous reports where supplementation of *Lonicera japonica* and *Astragalus* membranaceus extracts during late laying phases showed no impact on egg production, egg weight, and feed conversion ratio, yet significantly improved yolk pigmentation and sensory quality[41]. In contrast, Chen, et al. [24] and Feng, et al. [43] reported that dietary supplementation with honeycomb extracts and *Eucommia ulmoides* leaf powder in laying ducks have no significant improvements in production performance and egg quality. Similarly, in the study by Torki, et al. [44], it was observed that no significant differences in egg weight, egg index, yolk index, Haugh units, egg shell weight and egg shell thickness, in response to dietary supplementation with *Lavandula angustifolia* and/or *Mentha spicata* essential oils. These discrepancies might be attributed to variations in extracts types, poultry breeds and diets. Given the limited existing research on FDRM in laying duck nutrition, further mechanistic investigations are warranted to elucidate its functional properties.

Duck eggs, containing abundant protein and amino acids, fatty acids, minerals and vitamins, serve as an excellent source of essential nutrients for human food and health. The primary indicators for assessing their nutritional value and sensory quality typically encompass amino acid composition and fatty acid profiles[19,24]. As fundamental building blocks of life, essential amino acids (EAAs)

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such as lysine (Lys), methionine (Met), threonine (Thr), and phenylalanine (Phe) not only play critical roles in regulating lipid and protein metabolism but also constitute indispensable nutrients that cannot be endogenously synthesized by animals and must be supplemented through dietary intake[45]. This study revealed that compared to the control group (F0 group), the 2% FDRM-supplemented group (F2 group) significantly increased the contents of total amino acids (by 9.27%), total essential amino acids (by 9.34%), and umami amino acids (by 7.62%) in egg yolks, confirming the beneficial effect of FDRM on the nutritional value of duck eggs. The potential underlying mechanisms may involve enhancing antioxidant capacity and modulating the expression of genes related to amino acid metabolism[46]. Notably,Yao, et al. [7] also reported that sea buckthorn extract significantly improved the contents of total amino acids, essential amino acids, and umami amino acids in eggs through a similar mechanism. Nevertheless, current research remains insufficient in identifying the specific bioactive components within FDRM and their molecular targets, which represents a critical focus for future investigations. Accumulating evidence highlights the dual implications of fatty acid intake on human health. Research suggests that consuming excessive saturated fatty acids (SFAs) may increase the risk of type 2 diabetes and cardiovascular diseases, whereas unsaturated fatty acids (MUFAs/PUFAs) exhibit multiple health benefits, including anti-inflammatory effects, regulation of glucose and lipid metabolism, and promotion of muscle growth [47,48]. In the present trial, adding FDRM in laying duck diet led to an increase in the ratio of unsaturated to saturated fatty acids (UFAs:SFAs) and a decrease in total SFAs in egg yolks, with the 2% FDRM group showing a pronounced decrease in total SFAs. The study by Chen, et al. [24] demonstrated that the contents of total unsaturated fatty acids (UFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs) in duck eggs showed an increasing trend with the dietary supplementation level of honeycomb extracts, while the total saturated fatty acids (SFAs) content decreased significantly. These findings are highly consistent with the conclusions of the present study.

Serum biochemical parameters serve as critical indicators for assessing metabolic status and health conditions in animals, primarily encompassing serum enzymes, protein and lipid metabolites. Serum TP, composed of ALB and GLB, reflects protein absorption and metabolism in the body. Elevated TP levels indicate enhanced protein metabolism and immune competence[49–51]. The results of this trial demonstrated that supplementation with FDRM significantly increased the serum TP content, aligning with findings reported by Chen, et al. [50] and Zhang, et al. [19]. Serum BUN levels serve as an indicator of protein and amino acid utilization, with decreased concentrations suggesting favorable amino acids balance[52]. Tan, et al. [51] discovered that dietary *Fagopyrum dibotrys* supplementation with 1% in broilers decreased the serum BUN levels. However, this study revealed that the 3% FDRM supplementation group significantly elevated the serum BUN content compared to the control group, diverging from the aforementioned findings. This discrepancy suggests that dietary FDRM supplementation should not exceed 3%, as higher levels may compromise protein utilization efficiency.

5. Conclusions

This study found that adding FDRM to the diet of *Shanma* laying ducks could improve the shell strength, yolk color and shell thickness in duck egg. Additionally, it improved the fatty acid profile, increased the levels of total amino acids, essential amino acids and umami amino acids in egg yolks. Concurrently, elevated the serum total protein levels indicated augmented physiological processes related to protein synthesis. These modifications suggest that FDRM had a potential improvement in egg quality and egg nutritional value, with no negative impact on laying performance and health status of *Shanma* laying ducks. Under the conditions of this experiment, FDRM could be used as a phytogenic feed additive in *Shanma* laying duck diets, with an optimal addition level of 2% .

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