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The incorporation of sumac seed powder (*Rhus coriaria* L.) into the diet of quail breeders as a novel feed additive

Fayiz M. Reda,[*] Mahmoud Alagawany,[*] Areej M. Alsolami,[†] Hemat K. Mahmoud,[‡] Ayman S. Salah,[§] Maha Abdullah Momenah,[#] Mohammed Y. Alshahrani,[‖] Khaled A. El-Tarabily,[¶,1] and Rasha M. Saleh[**]

[*]*Poultry Department, Faculty of Agriculture, Zagazig University, Zagazig, 44519, Egypt;* [†]*Department of Biology, College of Science, Jouf University, Sakaka, 72388, Saudi Arabia;* [‡]*Department of Animal Production, Faculty of Agriculture, Zagazig University, Zagazig, 44519, Egypt;* [§]*Department of Animal Nutrition and Clinical Nutrition, Faculty of Veterinary Medicine, New Valley University, New Valley, 71511 Egypt;* [#]*Department of Biology, College of Science, Princess Nourah bint Abdulrahman University, Riyadh, 11671, Saudi Arabia;* [‖]*Department of Clinical Laboratory Sciences, College of Applied Medical Sciences, King Khalid University, Abha, 9088, Saudi Arabia;* [¶]*Department of Biology, College of Science, United Arab Emirates University, Al Ain, 15551, United Arab Emirates; and* [**]*Department of Animal Physiology, Faculty of Veterinary Medicine, Mansoura University, Mansoura, 35516, Egypt*

ABSTRACT A total of 150 adult quails, aged 8 wk, were divided into 5 groups to study the effect of sumac seed powder on reproductive and productive parameters, egg quality, digestive enzymes, and quail breeders' blood profiles. Dietary supplements containing sumac powder were formulated as follows: group 1 (**G1**) (control, only basal diet); group 2 (**G2**) (basal diet + 1 g sumac powder/kg diet); group 3 (**G3**) (basal diet + 2 g sumac powder/kg diet); group 4 (**G4**) (basal diet + 3 g sumac powder/kg diet); and group 5 (**G5**) (basal diet + 4 g sumac powder/kg diet). The feed conversion ratio was significantly higher at all levels of sumac powder ($P < 0.05$) compared to the control group (G1). Overall, during the study (8−16 wk), quail-fed 3 g sumac powder/kg diet (G4) showed no significant increase ($P > 0.05$) in the feed intake compared to the control group. Sumac powder supplementation significantly ($P < 0.05$) increased egg number, egg weight, egg mass, fertility, and hatchability. While supplementing with sumac powder did not impact other egg quality parameters, it did significantly ($P < 0.05$) increase yolk percentage, Haugh unit, and unit surface shell weight. Furthermore, when compared to the control group (G1), birds given 2, 3, or 4 g of sumac powder/kg diet showed a significant improvement ($P < 0.05$) in hematological parameters such as red blood cells, white blood cells, and hemoglobin, as well as a decrease in glucose levels. Feeding quail with a 3 g sumac powder/kg diet (G4) resulted in significantly ($P < 0.05$) higher globulin levels and improved albumin/globulin ratio compared to other treatments and control (G1). Sumac powder intake significantly ($P < 0.05$) reduced plasma lipid profile, liver enzymes (aspartate aminotransferase, and alanine aminotransferase), and kidney functions (creatinine, and urea). Furthermore, the supplementation of sumac powder resulted in a substantial increase ($P < 0.05$) in the levels of amylase, lipase, and protease. Sumac powder administration also significantly ($P < 0.05$) improves immunity by boosting IgM, IgG, IgA, and lysozyme levels in quail breeders' plasma. Supplementing with sumac powder, on the other hand, increased levels of reduced glutathione, total antioxidant capacity, catalase, and superoxide dismutase. The results of the current study indicated that the addition of 1, 2, 3, and 4 g of sumac powder to the diet of Japanese quail breeders led to improvements in egg quality, digestive enzymes, reproductive and productive performances, and most blood hematological and biochemical parameters.

Key words: blood metabolites, immunity, organic poultry, quail breeder, sumac

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INTRODUCTION

There has been a rise in interest in herbal active components in recent decades due to the benefits they offer to human and animal health (Ahmadian et al., 2020). Essential oils derived from aromatic plants are well known for their ability to stimulate the immune system,

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[1]Corresponding author: ktarabily@uaeu.ac.ae

act as antibiotics and antibacterials, aid digestion, lower cholesterol levels (Alagawany et al., 2017; Sabir and Aydin, 2017; Mohammed et al., 2021), have antioxidant properties (Aydin and Alcicek, 2018; Salah et al., 2021), and improve growth rate (Stankovic, 2020).

Sumac (*Rhus coriaria* L.) belongs to family Anacardiaceae and thrives globally in temperate and subtropical temperatures, particularly in North America and Africa (Capcarova et al., 2011). In the medical practice of the Middle Ages, sumac was employed to cure at least 6 different diseases. The Middle East was the primary location for these applications since it was more convenient to acquire sumac there than it was in Europe (El Ghizzawi et al., 2023). According to Özcan and Haciseferogullari (2004), evaluating the health benefits and mineral content of sumac fruit could be beneficial for dietary preparation.

As a result of its antifungal, anti-inflammatory, antibacterial, antioxidant, antitumorigenic, antiviral, and cytotoxic properties, sumac is presently widely used as a culinary spice and in traditional herbal medicine (Capcarova et al., 2011). Sumac has a suppressive effect against both gram-positive and gram-negative bacteria; however, it is more efficient at targeting gram-positive bacteria than it is at targeting gram-negative bacteria (Ahmadian-attari et al., 2008).

Citric and malic acids, flavonols, phenolic acids, and anthocyanins are abundant in more than 90% of the plants belonging to family Anacardiaceae, which includes sumac (Sakhr and El Khatib, 2020). Sumac seeds have a high concentration of vitamin C, gallic acid, and benzoic acid, and they are a great source of flavones such as myricetin, quercetin, and kaempferol (Kheiri et al., 2015; Sakhr and El Khatib, 2020; El Ghizzawi et al., 2023). Although sumac contains numerous minerals, the concentrations of some macro minerals, such as phosphorus, potassium, calcium, and magnesium, are significantly higher (Sakhr and El Khatib, 2020). According to El Ghizzawi et al. (2023), the linoleic, palmitic, and oleic fatty acids present in sumac are believed to play an essential role in metabolism. Also included are 17.5% stearic acid, 27.4% palmitic acid, 34.8% linoleic acid, and 37.7% oleic acid (Kizil and Turk, 2010; Ardalani et al., 2016).

Numerous studies have been conducted on the effects of sumac on broilers (Mansoub, 2011; Golzadeh et al., 2012; Ghasemi et al., 2014; Kheiri et al., 2015), layers (Arpasova et al., 2014), rabbits (Capcarova et al., 2011), and egg composition in layers (Gulmez et al., 2006; Galik et al., 2013).

Numerous studies (e.g., Kheiri et al., 2015) have shown that when added to diet as a nutritional supplement, tiny amounts of sumac powder (0.2−0.5%) will lower plasma cholesterol levels and boost feed efficiency. According to Abdulwahid et al. (2022), Japanese quails had a considerable increase in egg production percentage and feed efficiency after supplementing their basal diets with sumac and onion powder. This was achieved while simultaneously decreasing feed consumption, lipid peroxidation, cholesterol, and triglyceride levels (Abdulwahid et al., 2022).

To the best of our knowledge, there is a limited amount of information available regarding the positive effects that sumac powder supplements have on the performance of quail breeders. Therefore, the purpose of the current study was to answer the question of whether or not dietary sumac powder improves the fertility and productivity of quail breeders, as well as the quality of their eggs, their lipid profile, the functioning of their kidneys and livers, and their immunoglobulin levels.

MATERIALS AND METHODS

Birds, Experimental Design, and Diets

The effects of sumac seed powder on reproductive and productive parameters, egg quality, digestive enzymes, and quail breeders' blood profiles were studied in a study involving 150 adult quails (aged 8 wk) and were divided into 5 groups. Each group has 5 replicates of 6 quails (2 males and 4 females).

The dietary supplements using sumac powder were formulated as follows: group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet).

Table 1 displays the basal diet. Birds were grown in conventional cages (90 × 40 × 40 cm^3) with constant access to food and water under identical conditions. Food and water were provided *ad libitum*. Environmental, hygienic, and managerial situations of all birds were recorded.

Sumac powder was supplied by Biochem Egypt Limited, Hadayk El Ahram, Giza, Egypt. The ethics statement was in agreement with the guidelines of the Ethics Committee of the Egyptian Research for the Use and

Table 1. Ingredients and nutrient contents of experimental diets utilized by quail breeders.

Ingredient	%
Yellow corn	58.70
Soybean meal	27.50
Corn gluten meal	4.60
Vegetable oil	1.80
Limestone	5.54
Dicalcium phosphate	1.20
Salt	0.30
Premix[1]	0.30
L-Lysine	0.06
DL-Methionine	0.00
Calculated composition[2]	
Metabolizable energy (ME), Kcal/kg	2901
Crude protein	20.00
Calcium	2.50
Nonphytate	0.35
Lysine	1.00
TSAA	0.70

[1]Layer Vitamin-mineral premix. Each 1 kg consists of vitamin A, 8,000 IU; vitamin D3, 1,300 ICU; vitamin E 5 mg; vitamin K, 2 mg; vitamin B1, 0.7 mg; vitamin B2, 3 mg; vitamin B6, 1.5 mg; vitamin B12, 7 mg; biotin 0.1 mg; pantothenic acid, 6 g; niacin, 20 g; folic acid, 1 mg; manganese, 60 mg; zinc, 50 mg; copper, 6 mg; iodine, 1 mg; selenium, 0.5 mg; cobalt, 1mg.

[2]Calculated according to National Research Council (1994).

Care of Laboratory Animals by Zagazig University (ZU-IACUC/2/F/313/2023).

Production Performance

On a biweekly basis, we monitored the feed intakes and the feed conversion ratio (**FCR**). Feed consumption was recorded biweekly and adjusted for mortality rate, while FCR (g feed/g egg) was calculated as the egg mass value divided by the amount of feed consumed. Egg weight and egg numbers were recorded daily to calculate the egg mass (egg number × egg weight).

Determination of Hatchability and Fertility Percentages

At the end of the first (12 wks of age) and second (16 wks of age) months, all collected eggs during the last 4 d were incubated to evaluate the reproduction traits. Baby quails were counted once they had fully hatched, and the eggs that had not hatched were taken away and cracked to determine the percentages of hatchability and fertility.

Baby quails from the entire egg set and hatched chicks from eggs that were fertilized were used to express the hatchability traits. The fertility and hatchability percentages were determined accordingly by the following formulas (Genchev, 2012):

$$\text{Fertility\%} = (\text{number of fertile eggs/total eggs}) \times 100$$

$$\text{Hatchability \%} = (\text{number of hatched chicks/total eggs}) \times 100$$

Determination of the Egg Quality Traits

Three eggs from each replicate were used to evaluate egg quality traits. The egg quality (exterior and inner metrics) including egg width, egg length, shell weight, shell thickness, albumen %, yolk%, yolk index, Haugh unit, and unit surface shell weight, were determined as recommended by Romanoff and Romanoff (1949). The external egg quality characteristics such as egg shape index, shell ratio, were determined as previously described by Ahmed (2022). The albumen and yolk were separated from one another without causing any damage to the egg yolk, and the third process involved determining the weight of the egg yolk. The albumen and yolk percentages were used in the calculation of the internal egg quality values (Nasr et al., 2015).

Determination of Blood Parameters

At 16 wk of age, 30 quails were used to evaluate blood biochemical parameters. To study different blood parameters (such as red blood cells, hemoglobin, white blood cells and glucose), blood was drawn from quail wing veins using gauge needles in labeled screw-top tubes. The plasma obtained was then mixed with 200 μL of EDTA, an anticoagulant, following the protocol suggested by Zhou et al. (2023).

Evaluation of Liver, Kidney, and Serum Lipid Profiles

Blood samples were obtained from the slain birds and immediately placed in a tube containing an anticoagulant before being centrifuged at 3,000 rpm for 10 min to get plasma. After filling the clean tube with plasma, it was tightly sealed and kept at −20°C until needed.

A spectrophotometer (Apel 310 Spectro-photometer, Saitama, Japan) was used to perform the biochemical measurements. The biochemical profiles aspartate aminotransferase, alanine aminotransferase, urea, creatinine, total protein, total globulin, albumin/globulin ratio, triglycerides, total cholesterol, high-density lipoprotein, low-density lipoprotein, and the very low-density lipoprotein levels were measured using an automated analyzer and a Biodiagnostic commercial kit (Biodiagnostic, Giza, Egypt) following the manufacturer's instructions as described by Zhou et al. (2023).

Determination of the Activity of the Digestive Enzymes

Amylase, protease, and lipase activity levels in the ileum (small intestine) of the birds were assessed at the end of the experiment. Dissection of the quail ileum began at the Meckel's diverticulum and continued for 2 cm beyond the ileocecal junction. To prevent contamination, the contents of the ileum were carefully collected in sterile, screw-capped vials.

For the purpose of determining the ileal enzyme activity, the approach that was established by Najafi et al. (2005) was utilized. Amylase assay was performed at 55°C for 20 min in a 40 μL reaction mixture, with 35 μL of 1% (w/v) soluble starch in 50 mM of citrate buffer, pH 6, and 5 μL of adequately diluted enzyme solution. Dinitro salicylic acid (**DNSA**) (Sigma-Aldrich Chemie GmbH, Taufkirchen, Germany) was used to measure the reducing sugar produced from starch at 540 nm, with glucose serving as the standard. One unit of enzymatic activity is defined as the amount of enzyme needed to produce 1 μM of glucose/min under the assay conditions. The technique recommended by Tietz and Fiereck (1966) was used for the lipase enzyme. The methods described by Lynn and Clevette-Radford (1984) were used to measure protease activity.

Measurement of the Immunological Parameters

Immunoglobulin isotypes IgM, IgG, were assayed using enzyme-linked immunosorbent assay (**ELISA**) technique (Gao et al., 2023). Lysozyme activity, an enzyme that contributes in the fight against infection, was assessed by taking blood samples at the end of the trial. The lysozyme activity was evaluated using the standard activity of each assay, which was calibrated in units of activity per mg under experimental conditions (37°C), allowing a direct comparison of these 2 assays. The turbidimetric assay was performed using a 0.36 mg/mL *Micrococcus lysodeikticus* suspension and a microtiter plate reader capable of analyzing enzyme kinetics at 450 nm as suggested by Helal and Melzig (2008).

Measurement of the Antioxidant Activities

At the time of the slaughter, blood samples were drawn, centrifuged at 4,500 rpm for 20 min, and the plasma that was separated was stored at -20°C. Malondialdehyde, a lipid oxidation marker; antioxidant enzyme levels, superoxide dismutase, catalase, glutathione, and total antioxidant capacity were all measured using Biodiagnostic commercial kits from MyBiosource.com, San Diego, CA following the manufacturer's instructions.

Determination of Calcium and Phosphorus Levels in the Blood of Quail Breeders

Calcium and phosphorus levels in the blood of quail breeders were measured as recommended by Reitman and Frankel (1957).

Statistical Analysis

The experiment was analyzed using a fully randomized design. The FCR, feed intake, egg mass, egg weight, egg number, hatchability and fertility percentage, egg quality, renal and hepatic function, lipid profile, digestive enzymes, and immunity were assessed using SPSS software (IBM SPSS 23 Statistics for Mac OS, Armonk, NY). Statistical analysis was adopted via one-way analysis of variance (**ANOVA**). All tested means (treatment) were compared by LSD test at a probability of $P < 0.05$.

RESULTS AND DISCUSSION

The Impact of Sumac Powder on the Productive and Reproductive Parameters

Feed intake was not significantly affected ($P = 0.8222$) by sumac powder supplementation from 8 to 16 wk (Table 2). Experimental group G4 (basal diet + 3 g sumac powder/kg diet) had the lowest feed consumption (Table 2). Adding sumac powder to quail breeder diets significantly ($P = 0.0001$) improved FCR (Table 2). The experimental group G4 had the best value of FCR (2.42 g feed/g gain), as demonstrated in Table 2.

Our results corresponded with previous studies (Mansoub, 2011), who found that feeding broiler chickens with 2% sumac improved feed consumption, body weight, weight gain, and FCR, and the results were shown to be statistically significant. The results reported by Zadeh et al. (2021) also showed that the FCR rose in the group given sumac fruit powder, as compared to the control group. Our findings also agreed with Abdulwahid et al. (2022) who found that combining onion and sumac powders in the Japanese quail diet reduced feed consumption while producing the highest FCR. In light of the fact that both sumac and onion include a high concentration of flavones, potassium, calcium, magnesium, and phosphorous, as well as L-ascorbic acids, gallic acid, and benzoic acid, it is possible that these findings might be attributed to the high and diverse chemical contents that both plants possess (Kheiri et al., 2015). According to Ghasemi et al. (2014), sumac's active components, eugenol, and cinnamaldehyde, boosted FCR and increased body weight via increasing feed utilization.

Adding sumac powder to the diet of quail breeders enhanced egg production significantly ($P<0.05$) throughout the trial (Table 3). During 8 to 16 wk, G4 (basal diet + 3 g sumac powder/kg diet) reported the highest egg number/bird (27.52 eggs/bird, $P = 0.0008$) (Table 3). Supplementing sumac powder to quail's breeder meal significantly improved egg weight and mass ($P < 0.0001$), with G4 (basal diet + 3 g sumac powder/kg diet) showing the best results (13.67, and 376.02 g/bird, respectively) over 8 to 16 wk (Table 3). Our results agreed with previous studies (Abdulwahid et al., 2022), which found that quail had the highest egg

Table 2. The effects of different amounts of sumac powder on feed intake and feed conversion ratio of quail breeders.

Parameters	Sumac level					SEM	P value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Cumulative feed intake (g/bird)							
8-12 wk	912.75 a	907.75 a	905.67 a	905.88 a	912.55 a	9.122	0.9628
12-16 wk	929.28 a	925.5 a	932.34 a	913.33 a	908.95 a	11.892	0.5948
8-16 wk	921.01 a	916.63 a	919.01 a	909.6 a	910.75 a	6.760	0.8222
Feed conversion ratio (g feed/g egg)							
8−12 wk	3.24 a	2.98 ab	2.59 bc	2.48 c	2.71 bc	0.134	0.0170
12−16 wk	3.33 a	2.87 b	2.41 c	2.38 c	2.65 bc	0.063	0.0002
8−16 wk	3.28 a	2.92 b	2.49 c	2.42 c	2.67 bc	0.078	0.0001

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

Table 3. The effects of different amounts of sumac powder on egg number, egg weight, and egg mass in quail breeders.

Parameters	Sumac level					SEM	P value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Egg number/bird							
8–12 wk	23.88 b	24.45 b	26.59 a	27.73 a	26.58 a	0.503	0.0015
12–16 wk	22.22 b	24.01 b	27.56 a	27.32 a	26.05 a	0.611	0.0004
8–16 wk	23.05 b	24.23 b	27.07 a	27.52 a	26.31 a	0.557	0.0008
Egg weight (g)							
8–12 wk	11.83 a	12.51 b	13.24 c	13.25 c	12.68 b	0.361	0.0964
12–16 wk	12.58 a	13.47 b	14.07 c	14.09 c	13.28 b	0.385	0.1157
8–16 wk	12.20 a	12.99 b	13.65 c	13.67 c	12.98 b	0.085	<0.0001
Egg mass (g/bird)							
8–12 wk	282.69 c	306.00 bc	352.43 ab	367.78 a	336.63 ab	13.519	0.0112
12–16 wk	279.12 c	323.44 b	387.08 a	384.26 a	346.50 b	8.635	0.0002
8–16 wk	280.86 c	314.72 b	369.7 6a	376.02 a	341.56 b	8.351	<0.0001

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

Table 4. The impact of different sumac powder dosages on quail breeders' fertility and hatchability rates.

Parameters	Sumac level					SEM[1]	P value[2]
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Fertility %							
8–12 wk	78.19 c	84.45 b	89.80 ab	93.78 a	92.33 a	1.750	0.0005
12–16 wk	77.06 c	84.06 b	89.21 ab	92.19 a	94.86 a	2.126	0.0012
8–16 wk	77.63 d	84.26 c	89.50 b	92.98 a	93.59 a	0.717	<0.0001
Hatchability %							
8–12 wk	70.26 c	78.24 b	82.30 ab	88.45 a	86.91 a	2.096	0.0008
12–16 wk	74.83 c	82.94 b	88.17 ab	87.99 ab	90.89 a	1.858	0.0009
8–16 wk	72.55 c	80.59 b	85.23 a	88.22 a	88.90 a	1.118	<0.0001

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

productivity metrics when onion and sumac powders were added to their diet (Abdulwahid et al., 2022).

The antibacterial properties of cinnamon and sumac, according to Mansoub (2011), can increase the absorption of amino acids and decrease the number of harmful microorganisms in the digestive tract. It could cause the increase in egg production observed in our study when all sumac seed powder levels were applied. It is likely that increased metabolism of proteins, carbohydrates, and plant organic materials in the major organs could stimulate quail development and egg production.

In contrast to our data, Zadeh et al. (2021 reported that, when compared to the control group, there was a significant drop in both the rate of egg production and the mass of eggs ($P < 0.05$). Similarly, Gumus et al. (2018) showed that adding sumac to the food at a 0.5% level had no statistically significant influence on egg production or weight when compared to the control group, which contradicts our findings. The egg weight decreased (1.4%), while egg production increased (3.45%) in the 0.5% sumac group (Gumus et al., 2018).

The results that we have obtained are in contrast to the findings that were reported by Arpášová et al. (2014). They stated that the incorporation of oregano oil or sumac into the diets of laying hens did not have any discernible impact on the quantity, mass, or weight of eggs produced. They also reported that laying hens given sumac had a weight rate of 57.35 to 58.10 and an egg production rate of 135.5 to 136.9 (Arposova et al., 2014).

In the present study, Table 4 displays the results of a study that examined the effects of sumac powder on the hatchability and fertility rate of quail breeders. The results revealed a strong and considerable improvement in fertility and hatchability percentage. In our study, increasing the amount of sumac seed powder compared to the control group significantly improved fertility and hatchability percentage (based on total number of eggs laid) (Table 4). Compared to the control, using all levels of sumac seed powder boosted hatchability (measured by the number of viable eggs laid) (Table 4). This is in agreement with the results obtained by Shata (2017).

G4 (basal diet + 3 g sumac powder/kg diet) exhibited the highest fertility percentage (93.78%), and hatchability percentage (88.45%) during 8 to 12 wk, with a corresponding P value of 0.0005 and 0.0008, respectively, indicating a clear and substantial increase in the results (Table 4). G5 (basal diet + 4 g sumac powder/kg diet) had the best fertility and hatchability percentages at 12 to 16 and 8 to 16 wk (94.86% and 90.89%, respectively) ($P = 0.0012$ and $P = 0.0009$, respectively), as well as (93.59% and 88.90%, respectively) ($P < 0.0001$ and $P < 0.0001$, respectively) (Table 4).

Table 5. The influence of different sumac powder concentrations on egg quality in quail breeders.

Parameters	Sumac level					SEM	*P* value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Albumen %	54.97 a	54.09 a	53.02 a	53.34 a	54.44 a	1.351	0.8516
Yolk %	31.61 c	32.26 bc	32.94 abc	34.01 a	33.61 ab	0.393	0.0122
Shell %	14.9 a	13.65 a	14.05 a	12.64 a	11.95 a	1.435	0.6598
Shell thickness (mm × 10^{-2})	0.21 a	0.22 a	0.23 a	0.22 a	0.21 a	0.017	0.9368
Egg shape index	78.27 a	79.2 a	80 a	79.64 a	79.71 a	1.497	0.9359
Yolk index	41.5 a	43.1 a	42.63 a	42.63 a	43.94 a	1.762	0.9016
Haugh unit	81.49 c	82.59 bc	83.83 a	83.36 ab	84.24 a	0.369	0.0028
Unit surface shell weight (mg cm^{-2})	46.54 b	47.66 a	48.32 a	48.37 a	47.82 a	0.277	0.0061

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

It is possible that the significant amount of vitamins (E, C, and B) and minerals (zinc, and selenium) present in sumac seed in our study is responsible for enhancing hatchability and fertility. There is also the possibility that the essential oils found in sumac seed were responsible for the enhanced output of the hens when they were given the herb, which possesses medicinal properties.

The Effect of Sumac Powder on Egg Quality

Table 5 indicates how dietary sumac powder concentrations affect quail breeders' egg quality. The results revealed no significant differences in albumen percentage, shell percentage, shell thickness, egg shape index, or yolk index ($P = 0.8516$, $P = 0.6598$, $P = 0.9368$, $P = 0.9359$, and $P = 0.9016$, respectively) (Table 5).

On the other hand, the results revealed a significant increase in yolk percentage, Haugh unit, and unit surface shell weight ($P = 0.0122$, 0.0028, and 0.0061, respectively). G4 had the greatest levels of yolk percentage, and unit surface shell weight (34.01 and 48.37%, respectively) (Table 5). In addition, as compared to the control group and other treatments, G5 has the highest Haugh unit (84.24) (Table 5).

Our findings are consistent with those of Sabir (2014), who showed that administering varied quantities of sumac to quail breeders had no significant impact ($P > 0.05$) on other egg metrics such as Hough unit, albumen weight, yolk weight, and shell and yolk weight. Our findings are also consistent with Gumus et al. (2018), who reported that as compared to the control, the yolk index was 6.8% higher in the 0.5% sumac, and 4.5% higher in the 0.25% sumac + 0.25 turmeric supplementation ($P > 0.05$).

Consistent with our findings, Incharoen and Yamauchi (2009) observed that using fermented dry ginger resulted in a non-significant rise in the yolk index. The increased egg production in laying hens, which has resulted in a decline in shell quality, could be the cause of the lower eggshell thickness in birds given sumac.

The Influence of Sumac Powder on Hematological Parameters

Table 6 shows the effects of different dietary quantities of sumac powder on haematological and glucose levels in quail breeder blood. A significant rise in the levels of hemoglobin ($P = 0.0010$), red blood cells ($P < 0.0001$), and white blood cells ($P = 0.0002$) was observed in the blood when sumac powder was supplemented (Table 6).

When compared to the control group and other therapies, G4 had the greatest hemoglobin level (15.25 g/dL) (Table 6). G3 showed an elevated white blood cell count (22.77 g/dL), and G5 showed an elevated red blood cell count (4.08 g/dL) compared to the control and other treatment groups (Table 6). G5 also showed a lower glucose level (114.25g/dL) and adding sumac powder to the quail breeder's food significantly reduced blood glucose levels ($P < 0.0001$) (Table 6).

Our results are in agreement with those of Shata (2017), who found that quail breeders given 2% sumac seed powder had a statistically significant increase

Table 6. The effect of varying concentrations of sumac powder on hematological properties in quail breeders.

Hematological parameters	Sumac level					SEM	*P* value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Hemoglobin (g/dL)	8.90 c	11.31 bc	12.93 ab	15.25 a	14.72 a	0.766	0.0010
Red blood cells count X $10^6/\mu L$	2.18 c	3.16 b	3.60 ab	3.70 a	4.08 a	0.154	<0.0001
White blood cells count X $10^2/\mu L$	13.38 b	14.88 b	22.77 a	22.45 a	20.68 a	1.024	0.0002
Glucose	178.90 a	168.25 a	152.75 b	117.40 c	114.25 c	4.105	<0.0001

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

($P \leq 0.05$) in white blood cells, hematocrit, red blood cells, and hemoglobin. In our study, the increase in white blood cells may be attributed to the capacity of sumac to strengthen the immune system.

Broiler diets treated with 1.0 and 1.5% sumac powder significantly reduced blood glucose and uric acid levels ($P < 0.01$), as shown by Azizi et al. (2020), as compared to control and 0.5% diets. According to the findings of Golzadeh et al. (2012), the plasma fasting glucose level of broilers fed a diet consisting of 10 g of sumac/kg was significantly lower ($P < 0.05$) compared to the control group and 2.5 g.

In our study, the tested sumac-based dietary supplements decreased the amount of glucose in the quails. This could be because their chemicals inhibit the digestion and hydrolysis of starch and other carbohydrates by enzymes involved in glucose metabolism (Vidyavati et al., 2010; Barber et al., 2021).

The efficiency of sumac extract as a hypoglycemic agent was evaluated by blocking alpha-amylase, which is a glycoside hydrolase (Giancarlo et al., 2006). The extract of sumac ethyl acetate has the potential to assist in the management and prevention of diabetes, obesity, and hypoglycemia as stated by Giancarlo et al. (2006).

The Impact of Sumac Powder on the Liver and Kidney Functions

In the quail breeders, the incorporation of sumac powder into their diet had a significant influence ($P < 0.05$) on the enzymes of the liver and the function of the kidneys, as demonstrated in Table 7.

G4 (basal diet + 3 g sumac powder/kg diet) showed a significant increase ($P < 0.0001$) in serum globulin level compared to the control group (Table 7), whereas dietary intake of sumac powder did not significantly affect serum total proteins and albumin levels ($P > 0.05$) (Table 7).

Sumac powder enhanced liver function and supplementing the basal diet with 3 g sumac powder/kg (G4) produced the best effects and the lowest levels of aspartate aminotransferase and alanine aminotransferase (149.90, and 9.19IU/L, respectively) (Table 7).

Furthermore, the consumption of sumac powder through the diet resulted in a significant increase ($P < 0.05$) in renal function, as well as a reduction in the levels of creatinine and urea in the blood (Table 7). The G3 group (basal diet + 2 g sumac powder/kg diet) showed the lowest result of creatinine (0.50 mg/dL) (Table 7), and G2 (basal diet + 1 g sumac powder/kg diet) showed the lowest levels of urea (1.35 mg/dL) (Table 7).

In our study, all of the doses of sumac seed powder resulted in a decrease in the levels of liver enzymes (aspartate aminotransferase and alanine aminotransferase). According to Shata (2017), birds were found to be able to tolerate additions of up to 2.5% sumac seed powder without any adverse effects on their renal and hepatic functions.

The results that we obtained in Table 7 are in agreement with the findings of Gumus et al. (2018), who reported that the consumption of sumac and turmeric individually increased the rates of aspartate aminotransferase and alanine aminotransferase in laying hens. A study conducted by Azizi et al. (2020) found that uric acid levels were considerably lower ($P<0.01$) in broiler diets supplemented with 1 or 1.5% sumac powder compared to control diets and those supplemented with 0.5%.

The Impact of Sumac Powder on the Profile of Lipids

The dietary treatments that contain different amounts of sumac powder have a significant impact ($P < 0.05$) on the levels of total cholesterol, triglycerides, high-density lipoprotein, and low-density lipoprotein as shown in Table 8.

Both total cholesterol and low-density lipoprotein were found to be at their lowest levels in G5 (basal diet + 4 g sumac powder/kg diet) (134.08 mg/dL, and 46.54 mg/dL, respectively) (Table 8). Additionally, the level of very low-density lipoprotein, and triglyceride was found to be the lowest in quails in G3 which were fed the basal diet supplemented with 2 g sumac powder/kg diet (54.23 and 271.15 mg/dL, respectively) (Table 8).

Furthermore, when compared to the control and other groups, G4 (basal diet + 3 g sumac powder/kg diet) had the greatest level of high-density lipoprotein at

Table 7. The effect of varying concentrations of sumac powder on liver and kidney functions in quail breeders.

Liver and kidney functions	Sumac level					SEM	P value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Total protein (g/dL)	3.5 a	3.76 a	3.99 a	4.17 a	4.09 a	0.174	0.1330
Albumin (g/dL)	2.19 a	2.26 a	2.15 a	2.11 a	2.29 a	0.112	0.7840
Globulin (g/dL)	1.31 c	1.50 c	1.85 b	2.06 a	1.80 b	0.062	<0.0001
Albumin/globulin ratio (%)	1.68 a	1.31 bc	1.32 bc	1.19 c	1.47 b	0.047	0.0009
Aspartate aminotransferase (IU/L)	265.58 a	233.40 b	203.02 c	149.90 e	183.30 d	5.505	<0.0001
Alanine aminotransferase (IU/L)	18.61 a	15.01 b	13.01 b	9.19 c	12.71 b	0.683	<0.0001
Creatinine (mg/dL)	0.78 a	0.67 ab	0.50 c	0.61 bc	0.51 c	0.043	0.0069
Urea (mg/dL)	3.38 a	1.35 d	2.57 bc	2.89 ab	1.99 cd	0.215	0.0007

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P>0.05$) different.

Table 8. The impact of different doses of sumac powder on lipid profile in quail breeders.

Lipid profile	Sumac level					SEM	*P* value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Total cholesterol (mg/dL)	214.23 a	182.15 b	148.62 c	144.73 c	134.08 c	7.802	0.0002
Triglycerides (mg/dL)	397.55 a	351.23 b	271.15 c	292.35 c	285.95 c	11.227	<0.0001
High-density lipoprotein (HDL) (mg/dL)	18.10 c	23.62 b	26.95 ab	30.58 a	30.35 a	1.680	0.0019
Low-density lipoprotein (LDL) (mg/dL)	116.63 a	88.29 b	67.43 c	55.67 cd	46.54 d	4.545	<0.0001
Very low-density lipoprotein (VLDL) (mg/dL)	79.51 a	70.25 b	54.23 c	58.47 c	57.19 c	2.245	<0.0001

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

30.58 mg/dL (Table 8). The hypocholesterolemic effects of sumac may be due in part to its polyphenolic components. Several studies have shown that polyphenols can reduce the absorption of cholesterol in the intestines, slow down the transport of reverse cholesterol, and even encourage the outflow of bile acid (Jung, 1998). Additionally, free gall bladder acids have the ability to increase their amount of outflow by attaching themselves to bacteria and fibers. This aligns with the extensive research that has shown herbs to positively affect blood cholesterol levels (Jung, 1998). Furthermore, Mansoub (2011) proved that sumac extracts had antibacterial, hypoglycemic, and antioxidant properties.

The results of our study on blood chemical parameters (Table 8) did not coincide with the findings of Golzadeh et al. (2012), who came to the conclusion that there was no significant difference in plasma concentrations of low-density lipoprotein, triglycerides, or high-density lipoprotein between the treatments.

On the other hand, our findings (Table 8) were consistent with those of Mansoub (2011), who revealed that, in comparison to the control group, there was a notable significant ($P < 0.05$) increase in the concentration of high-density lipoprotein in the blood, as well as a notable significant ($P < 0.05$) decrease in the concentration of serum triglycerides, total cholesterol, and low-density lipoprotein.

The Impact of Sumac Powder on Digestive Enzymes

Table 9 shows that dietary quantities of sumac powder significantly ($P < 0.05$) increased the digestive enzymes of quail breeders. In comparison to the control and other treatments, G4 (basal diet + 3 g sumac powder/kg diet) showed a significant increase in amylase (78.95 IU/L), and protease (2.59 IU/L) enzymes ($P < 0.0001$ and $P = 0.0005$, respectively). On the other hand, G5 showed a significant ($P < 0.0001$) increase (46.40 IU/L) in lipase (Table 9). Gopi (2014) and Świątkiewicz et al. (2018) found that herbal plants enhance pancreatic digestive enzymes, liver function, and digestion stimulation in birds. Kizil and Turk (2010) reported that sumac oil includes stearic, palmitic, oleic, and linoleic acids. Furthermore, the active compounds in these therapeutic plants are frequently referred to as photobiotic or botanical secondary metabolites, which increase animal health and productivity (Ghazaghi et al., 2014).

Table 9. The impact of different doses of sumac powder on digestive enzymes in quail breeders.

Digestive enzymes	Sumac level					SEM	*P* value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Amylase (IU/L)	36.90 c	40.55 c	74.15 a	78.95 a	61.85 b	2.494	<0.0001
Lipase (IU/L)	10.95 c	12.60 c	27.40 b	32.73 b	46.40 a	2.670	<0.0001
Protease (IU/L)	1.58 c	1.97 b	2.33 ab	2.59 a	2.49 a	0.097	0.0005

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

Table 10. The effects of varying quantities of sumac powder on immunity in quail breeders.

Immunity	Sumac level					SEM	*P* value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Immunoglobulin M (mg/dL)	0.30 c	0.38 c	0.75 a	0.68 a	0.54 b	0.040	<0.0001
Immunoglobulin G (mg/dL)	0.36 c	0.48 bc	0.45 bc	0.55 ab	0.66 a	0.048	0.0161
Immunoglobulin A (mg/dL)	0.40 d	0.58 c	0.86 ab	0.96 a	0.78 b	0.041	<0.0001
Lysozyme (U/mg)	0.24 d	0.35 c	0.42 bc	0.50 ab	0.54 a	0.028	0.0002

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

Table 11. The impact of varying quantities of sumac powder on the antioxidant levels of quail breeders.

Antioxidants	Sumac level					SEM	*P* value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Superoxide dismutase (U/mL)	0.12 d	0.25 c	0.42 b	0.45 ab	0.51 a	0.024	<0.0001
Malondialdehyde (nmol/mL)	0.55 a	0.42 b	0.33 b	0.23 c	0.16 c	0.029	<0.0001
Total antioxidant capacity (ng/dL)	0.13 c	0.23 b	0.35 a	0.42 a	0.38 a	0.026	<0.0001
Catalase (ng/dL)	0.21 d	0.36 c	0.55 ab	0.59 a	0.46 bc	0.036	0.0002
Reduced glutathione (ng/dL)	0.32 c	0.34 c	0.50 b	0.48 b	0.62 a	0.032	0.0005

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

Table 12. The impact of various doses of sumac powder on calcium and phosphorus levels in the blood of quail breeders.

Minerals	Sumac level					SEM	*P* value
	0 g/kg diet (G1)	1 g/kg diet (G2)	2 g/kg diet (G3)	3 g/kg diet (G4)	4 g/kg diet (G5)		
Calcium (mg/dL)	10.96 d	11.82 cd	13.69 bc	14.81 ab	16.71 a	0.731	0.0023
Phosphorus (mg/dL)	6.69 b	6.61 b	7.80 b	8.23 ab	9.51 a	0.489	0.0108

Group 1 (G1) (control, only basal diet); group 2 (G2) (basal diet + 1 g sumac powder/kg diet); group 3 (G3) (basal diet + 2 g sumac powder/kg diet); group 4 (G4) (basal diet + 3 g sumac powder/kg diet); and group 5 (G5) (basal diet + 4 g sumac powder/kg diet). SEM, standard error of the means. Within rows, values followed by the same letter are not significantly ($P > 0.05$) different.

The Effect of Sumac Powder on Immunological Parameters

Table 10 shows that immunological parameters are considerably affected by dietary quantities of sumac powder ($P < 0.05$). When compared to the control group and other treatments, G5 (basal diet + 4 g sumac powder/kg diet) showed the greatest concentrations of IgG (0.66 mg/dL) and lysozyme (0.54 U/mg) (Table 10). G3 (basal diet + 2 g sumac powder/kg diet) had the highest concentration of IgM at 0.75 mg/dL, whereas G4 (basal diet + 3 g sumac powder/kg diet) had the highest concentration of IgA at 0.96 mg/dL (Table 10).

The utilization of 1.5% sumac led to a notable and statistically significant increase ($P < 0.05$) in the proportion of bursa Fabricius and spleen relative weights, and in the titers of infectious bronchitis virus, and infectious bursal disease in the entire duodenum, ileum, and jejunum (crypts and villi height). According to Shata (2017), when 2 or 2.5% sumac seed powder was used, the spleen, bursa, and thymus all had significantly higher relative weights compared to the control group and the group given 1.5% sumac seed powder. In contrast, Kheiri et al. (2015) found that both 0.02% whey powder and 0.02% sumac significantly reduced the bursa of Fabricius percentage compared to the control group, but the spleen percentage exhibited a clearly raised ($P < 0.05$) increase.

The Impact of Sumac Powder on Antioxidant Parameters

Natural products are mostly used to protect animals and their products from oxidation (Elwan et al., 2019; Bilal et al., 2021). The antioxidant status of quail breeders was significantly influenced ($P < 0.05$) by dietary treatments with different amounts of sumac powder, as shown in Table 11. Significantly lower levels of malondialdehyde (0.16 nmol/mL) and greater levels of superoxide dismutase, and reduced glutathione (0.51 U/mL and 0.62 ng/dL, respectively) were seen in Group 5 (basal diet + 4 g sumac powder/kg diet) (Table 11).

Whereas G4 (basal diet + 3 g sumac powder/kg diet) showed significantly elevated total antioxidant capacity and catalase levels (0.42 and 0.59 ng/dL, respectively) (Table 11). This result might be explained by the fact that sumac contains a high concentration of flavonoid compounds in addition to a wide range of other substances that are powerful antioxidants (El Ghizzawi et al., 2023).

Shata (2017) found that compared to the control group, quail plasma total antioxidant capacity levels were considerably higher when supplemented with 2, 1.5, and 2.5% sumac seed powder, respectively which are in agreement with our results (Table 11). Additionally, Candan and Sokmen (2004) suggested that methanolic extracts of sumac fruits possess good antioxidant activity against lipid peroxidation and free radicals *in vitro*, which could lend credence to *in vivo* investigations. In a prior study, Kheiri et al. (2015) noted that these compounds have the potential to help enhance blood-reduced glutathione levels while simultaneously decreasing serum malondialdehyde levels.

The Effect of Sumac Powder on Phosphorus and Calcium Blood Levels

Dietary treatments with some different concentrations (only G3, G4, and G5) of sumac powder have a significant impact ($P < 0.05$) on the levels of calcium in the blood of quail breeders (Table 12). The highest amounts of calcium were seen in G5, which had been supplemented with 4 g sumac powder/kg diet (16.71 mg/dL) (Table 12).

On the other hand, dietary treatments with only 4 g sumac powder/kg diet (G5) have a significant impact (*P*

< 0.05) on the levels of phosphorus in the blood of quail breeders (Table 12). The highest amounts of phosphorus were seen in G5, (9.51 mg/dL) (Table 12).

Our findings are in agreement with those of Shata (2017), who demonstrated that Japanese quail chicks who were fed diets that were supplemented with sumac seed powder statistically reported the highest levels of calcium and phosphorus plasma contents, in comparison to the control group.

CONCLUSIONS

The results of our research led us to the conclusion that dietary sumac powder supplements at doses of 1, 2, 3, and 4 g/kg of diet could improve blood metabolites, immunity, digestive enzymes, reproductive and productive performance, and egg quality in quail breeders. Therefore, sumac powder can be applied to improve the overall health of quail breeders as well as their ability to produce high-quality eggs.

DISCLOSURES

The authors declare no conflict of interest.

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