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Appraisal of the impact of aluminosilicate use on the health and performance of poultry

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Abstract: Aluminosilicates are feed additives used for multiple purposes in the poultry industry. Bentonites, zeolites, and kaolins are types of aluminosilicate compounds that appear in the marketplace due to their capabilities as mycotoxin adsorbents and other qualifications. While there are some differences among their efficacies, anecdotal evidence confirms that these additives ameliorate aflatoxicosis and manure ammonia emission, and improve the durability of pelleted diets. Furthermore, these supplements are safe at 0.2%–1% inclusion levels in the commercial diet of broilers and layers and did not have any adverse effects on productive indices, and even promoted birds' performance. Nevertheless, their upper levels, especially in purified diets, caused an unfavorable interrelationship with the adsorption of nutrients and anticoccidials. Overall, the origin, chemical composition, physical structure, inclusion level, and plausible interactions of aluminosilicates with other dietary components are important factors that should be considered before utilizing these compounds in practical farm situations.

Key words: Bentonite, zeolite, kaolin, poultry, health, performance

1. Introduction

This article describes the latest findings about aluminosilicate compounds and their applications in poultry production. Bentonite is an adsorbent aluminum phyllosilicate, essentially impure clay, consisting mostly of montmorillonite. Bentonites are generally classified as sodium, calcium, or mixed types, depending on the dominant exchangeable ion (1). Zeolites are crystalline hydrated aluminosilicates of alkali and alkaline earth cations of volcanic origin with three-dimensional structures (2). Kaolin is a simple stratified clay consisting of the mineral kaolinite. In systemic mineralogy, kaolinite ranks among the phyllosilicates, which are minerals formed by a net of tetrahedral and octahedral layers (3). They have a wide variety of pore sizes, from 2 to 20 µm (4). In general, aluminosilicates have three-layer nets. The chemical compositions of aluminosilicate compounds are shown in the Table. These aluminosilicates are generally inert and nontoxic to animals, and they have multifunctional properties. These aspects of aluminosilicates as well as other related issues will be discussed in detail.

2. Mycotoxicosis diminution

Aluminosilicate compounds have been used to prevent, reduce, or remedy mycotoxicosis in chickens, turkeys, and quails. Hepatic enzymes with blood components have been evaluated as health indices, and their alterations have been modified by aluminosilicate compounds in some studies. Addition of 1.5% clinoptilolite (a natural zeolite) to a broiler diet containing aflatoxin (AF) significantly reduced the thrombocyte counts caused by AF (5). In another study, decreased serum albumin caused by AF was significantly relieved by 0.5% bentonite. Furthermore, adding bentonite to a broiler diet containing AF increased total serum cholesterol (6). In addition, Rosa et al. (7) observed improvement in serum components in birds fed an AF-contaminated diet containing 0.3% bentonite. Furthermore, Kermanshahi et al. (8) added AFB_1 and 0.5%–1.0% sodium bentonite (SB) to the broilers' diet and found no significant impacts on serum constituents.

Internal organs of birds can be impacted by mycotoxins. Impacts of aluminosilicates are reviewed in this section. The histopathology of the liver as the target organ of AFB_1 showed that lesions attributed to aflatoxicosis were ameliorated by adding 0.3% bentonite (9,10). Miazzo et al. (11) found that adding 0.3% SB to a diet containing AFB_1 reduced the incidence and severity of hepatic histopathology changes associated with aflatoxicosis. Adding 2% clinoptilolite to an AF-containing diet alleviated the severity of lesions in the livers of broilers (12). Adding clinoptilolite (1.5% and 2.5%) to an AF-containing diet partially relieved both the incidence of

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Table. Chemical composition (%) and pore size of aluminosilicates in others' research.

Name of each product	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	CaO	MgO	K_2O	TiO_2	P_2O_5	Pore size (μm)	Reference
Egyptian bentonite	31–40.67	6.10–7.64	0.75–3.60	1.92–6.15	19.69–36.94	0.80–1.60	0.73–0.94	0.03–0.46	-	<2	Hassan and Abdel-Khalek (1)
Commercial bentonite	51–56	17–20	3–5	2–4	1–1.5	1.3–2.8	0.18–0.73	0.24–0.25	0.01–0.06	<2	Magnoli et al. (9)
Sodium bentonite	57.85	20.80	3.10	1.10	4.20	3.01	0.05	-	-	20	Pasha et al. (4)
Sodium bentonite	66.59	11.21	1.84	2.50	0.19	2.49	0.12	0.02	-	-	Safaeikatouli et al. (50)
Sodium bentonite	67.00	16.30	3.30	2.60	1.80	1.50	0.48	0.12	-	-	Hashemipour et al. (64)
Clinoptilolite	60.53	10.78	1.41	7.12	1	0.39	3.52	0.2	0.02	-	Hassanabadi and Safarkhanloo (62)
Natural zeolite	77.71	12.54	0.89	3.89	1.03	1.03	2.75	0.16	-	-	Kermanshahi et al. (65)

affected broilers and the severity of lesions in the organs of chicks (13–15). Additionally, Zhao et al. (16) indicated that 0.2% hydrated sodium calcium aluminosilicate (HSCAS) effectively ameliorated the negative effects of AFB_1 on growth performance and liver damage of broilers.

The tremendously detrimental impacts of mycotoxicosis are found in performance criteria such as weight gain and feed intake. Additionally, Santurio et al. (17) and Pasha et al. (18) indicated that low concentrations (0.5%) of SB reduced the deleterious effect of AF-contaminated diets on broilers. Furthermore, the addition of 5% clinoptilolite to an AF-containing diet significantly reduced the negative effects of AF on feed consumption, body weight gain, and the feed conversion ratio (FCR) of Japanese quail (19). Feed efficiency was also slightly improved by adding 1.5% clinoptilolite to AF-containing diets of broilers (14). Kubena et al. (20) demonstrated that HSCAS can provide protection against the toxicity of AF in young broiler chicks. In addition, HSCAS in chick diets at levels up to 4 mg/kg completely prevented the reduction in performance and changes in organ weights, serum chemistry, and gross pathology observed in chicks fed AFB_1 (21). No differences were found between the body weight gains of chicks fed diets without AF and those fed AF + 1% sodium zeolite, indicating almost total protection against the effects caused by AF (22). Moreover, Manafi et al. (23) showed that high-grade SB (0% and 1.0%) in broiler diets reduced the toxicity of AF and marginally ameliorated the effect of ochratoxin and AFB_1 on some parameters. Furthermore, Eckhardt et al. (24) recently indicated that calcium montmorillonite treatment against aflatoxicosis at concentrations of 2.5 and 5 g/kg improved the body weight, feed intake, and productive efficiency index of broiler chickens.

The main adsorptive mechanism of AF through these binders involves the formation of double hydrogen bonds between AFB_1 and aluminosilicate (25). It was suggested that the mechanism of AFB_1 on montmorillonite was AFB_1 adsorbed onto the edge of montmorillonite by a double hydrogen bond; AFB_1 molecules did not penetrate into the interlayer area of montmorillonite. It seems that adsorption of AFs is related to both the isomorphic substitution of the montmorillonite structure and to electrostatic interactions with surface charges. Results of the study by Magnoli et al. (10) indicated competition between AFB_1 and monensin for adsorption sites on SB when feed contains low levels of the toxin, indicating a nonselective adsorption capacity of their particular SB.

In contrast to the above-mentioned trials, some researchers indicated that aluminosilicates are not effective for all mycotoxins (26,27). Dwyer et al. (28) showed that treatment with inorganic adsorbents (acidic phyllosilicate clay, neutral phyllosilicate clay, or hydrated sodium calcium aluminosilicate, and a common zeolite or clinoptilolite) did not effectively diminish the growth-inhibitory effects of a mycotoxin (cyclopiazonic acid) or increase organ weights; however, there was some protection from hematological, serum biochemical, and enzymatic changes produced by cyclopiazonic acid as a mycotoxin. They demonstrated that in vitro binding of cyclopiazonic acid to clay does not accurately forecast its in vivo efficacy. In addition, the histopathological findings by Rosa et al. (7) in liver sections of broilers fed diets with AF + SB indicated a nonprotective effect of this adsorbent, because moderate hepatic steatosis was observed. Moreover, the results of Santin et al. (29) reflected that ochratoxin in the diet impaired productivity indices and HSCAS failed to improve these parameters.

The effectiveness of these additives apparently depends on their ability to bind AF in the intestine, with the toxin rendered unavailable for absorption (30). Pore size and montmorillonite purity (mainly evaluated by the quartz percentage content) seem to have no effect on the adsorption of AFs. Notionally, bentonite efficiency for detoxification may differ from one geological deposit to another and even within a batch from a special source (31).

3. Pellet hardener

These colloidal binders have been used to improve pellet quality in some trials (32). For instance, Salmon (33) demonstrated that the addition of 2.5% SB as a pellet binder to turkey diets increased the durability of pellets containing 0.3% or 0.6% added fat. In addition, Acar et al. (34) indicated that feed consumption and the feed:gain ratio of birds were increased by using binder, although final body weights were not affected. Moreover, Salari et al. (35) indicated that broiler chickens fed a pelleted diet with 1%–2% SB consumed more feed and showed better weight gain and FCR.

4. Reduction of eutrophication

From the viewpoint of environmental pollution, litter ammonia-nitrogen levels were significantly lowered when 10% clinoptilolite was incorporated into broiler diets (36). A study conducted by Hale (37) showed that a reduced-protein diet in combination with an acidulant like $CaSO_4$ and nitrogenous binding compounds like zeolite decreased NH_3 concentration (as measured in vitro) from laying hens' excreta. In agreement with them, Wu-Haan et al. (38) reported that emissions of NH_3 and CH_4 from laying henhouses were decreased via feeding a reduced-crude protein diet including zeolite as an adsorbent and $CaSO_4$.

It is noteworthy that the high-swelling and water-adsorbing propensity of aluminosilicates makes them attractive dietary additives to control undesirable moisture in animal production, such as wet droppings in caged layers (39). In addition, Safaeikatouli et al. (40) showed that dietary SB (1.5%–4.5%) remarkably reduced the moisture and nitrogen content of broiler litter. Contrarily, the addition of 1% zeolites to male broiler rations did not have a pronounced effect on litter moisture content (41). Moreover, excreta moisture was not affected by supplementing HSCAS in the diet of laying hens (42).

5. Impacts on antinutritional factors

In some studies, it was postulated that adsorbability of bentonites might relieve the adverse effects of dietary antinutritional factors. For instance, Ambula et al. (43) used bentonite to deactivate sorghum tannins in laying hen diets. The addition of 0.25% or 0.5% bentonite to a diet containing high-tannin sorghum did not improve layer performance. Recently, Gilani et al. (44–47) conducted a series of experiments on laying hens to assess SB as a feasible binder of free gossypol in cottonseed meal. The results showed that SB could reduce, but did not remove, the brown yolk discoloration of cold stored eggs. In addition, hen-day egg production, daily egg mass, and profitability were improved in hens fed a diet containing 1% SB, but not in those fed a diet containing 2% SB. Blood components were not affected by dietary treatments.

6. Impacts on productive traits of healthy birds

The results of various trials are collected here to consider all facets of aluminosilicates on the performance of healthy birds. For example, in meat birds, the addition of 1% zeolites to male broiler diets at age 21 days yielded significant improvements in body weight gains and feed efficiency (41). Fethiere et al. (48) reported that adding sodium from a synthetic zeolite or sodium chloride improved body weight, increased feed consumption, and improved FCR in broilers. Additionally, Ma and Guo (49) reported that adding Cu^{2+}-loaded montmorillonite to the diet of broilers significantly improved morphology and activities of maltase, aminopeptidase, and alkaline phosphatase in intestinal mucosa. Subsequently, montmorillonite enhanced body weight and feed efficiency. Furthermore, it has been indicated that zeolite, bentonite, and kaolin at a 1.5% level in the diet significantly improved the growth rate of broiler chickens (50). Unlike the above-mentioned results, no beneficial effects of 1% zeolite supplementation on the body weight of broilers were observed in the experiment of Waldroup et al. (51). In addition, Salari et al. (35) reported that feed intake and FCR were not affected by adding SB to the diet of broiler chicken. Furthermore, Damiri et al. (52) showed that the addition of SB into the broiler diet had no significant effects on feed intake, FCR, or economic values.

There are, however, no concrete results published regarding laying birds. A number of researchers reported about the fruitful impacts of aluminosilicates. For example, Olver (53,54) showed significant effects of clinoptilolite at the 5% level on egg production, shell thickness, feed efficiency, droppings moisture content, and mortality. Olver (55) found that heavier eggs were laid by layers fed SB compared to the control group. Roland et al. (56) demonstrated that egg production was influenced by sodium aluminosilicate level. Elliot and Edwards (57) showed that egg specific gravity was significantly increased with 1.5% synthetic zeolite supplementation in laying hens' diet, but egg weight and egg production were unaffected. In other research, egg specific gravity increased when 0.75% synthetic sodium aluminosilicate was supplemented to the diet of leghorn-type laying hens (58). Roland (56) hypothesized that the mechanism through which sodium aluminosilicates affect specific gravity is independent of phosphorus. When Na and Cl were not adjusted in the zeolite treatments, a significant reduction in production occurred. The beneficial effect of 1.36% sodium zeolite on egg specific gravity was independent of the particle size of calcium carbonate in the diet (59). The results of Rabon et al. (60) showed a pronounced increase in serum concentrations of Si and Al for hens fed 0.75% sodium zeolite. They concluded that Si and Al from sodium zeolite are absorbed by commercial leghorn hens, and a possible involvement of Si or Al should be considered in the mechanism of action of sodium zeolite associated with improved eggshell quality and bone development. In a trial by Yannakopoulos et al. (61), dietary inclusion of natural zeolite at levels of 4% and 6% increased both egg weight and albumen weight. Moreover, Hassanabadi and Safarkhanloo (62) showed that 1%–5% zeolite (clinoptilolite) supplementation significantly increased egg weight, eggshell thickness, and live body weight gain of the hens. Quisenberry (39) postulated that the major beneficial effect of these compounds appears to result from reducing the feed passage rate through the intestinal tract.

In contrast with the above-mentioned results, some studies did not demonstrate any positive effects of these additives. For instance, zeolite had little or no influence on egg weight, feed consumption, or egg production in the experiments of Roland et al. (63). Supplementing the diet with 0%, 1%, or 2% HSCAS for Hy-Line W-36 laying hens had no detrimental or positive effects on egg weight, eggshell weight, albumen quality, feed consumption, or FCR (42). Likewise, Hashemipour et al. (64) reported that hen-day egg production, egg weight, shell thickness, and shell weight percentage were not influenced by dietary

SB. The addition of SB decreased specific gravity and yolk color index compared to the control diet. They concluded that 2% SB was the optimal inclusion level to obtain the best productive benefits in laying hens. In other research, natural zeolite in the layer diet (1.5%–3% inclusion level) did not have adverse effects on bird performance (65).

7. Interrelationships with nutrients

Plausible interferences of aluminosilicate compounds with nutrients, particularly vitamin and mineral absorption in the body, are summarized here. Briggs and Spivey Fox (66) reported that purified diets containing vitamin A and 3% bentonite might produce symptoms of vitamin A deficiency; however, a commercial diet with 5% bentonite did not have deleterious effect in chickens. Moreover, Laughland and Phillips (67) indicated that high levels of SB reduced the availability of vitamin A in diets for chicks. These researchers used much higher levels of SB than are used in commercial circumstances. Elliot and Edwards (57) showed that phytin phosphorus retention and plasma dialyzable phosphorus were significantly reduced by adding 1.5% synthetic zeolite. Furthermore, weight gain and percentage of tibia bone ash were significantly reduced by adding 1% synthetic zeolite. Edwards (68) reported that feeding zeolite at a low level of dietary phosphorus caused a significant lowering of 16-day weight and bone ash of broilers. In addition, feeding a high phosphorus diet caused a high incidence of tibial dyschondroplasia that was lowered by feeding 1% zeolite. Thus, they concluded that feeding zeolite significantly decreased phytate phosphorus retention. Roland (56) indicated that sodium aluminosilicate improved egg specific gravity but had no effect on egg production when total phosphorus intake was 668 mg/hen per day or higher. They concluded that because of the strong interaction of sodium aluminosilicate with phosphorus for egg production, the level of dietary phosphorus must be considered when using sodium aluminosilicate.

Erwin et al. (69) demonstrated through an in vitro study that SB has a strong affinity for pure carotene. They suggested that SB is not specific for carotene and apparently binds other noncarotenoid pigments as well. Contrary to this result, Hashemipour et al. (64) indicated that addition of 3% SB into laying hens' diet significantly decreased the yolk color scale as compared to the control diet. In addition, Kermanshahi et al. (65) reported that 3% natural zeolite similarly reduced position on the yolk color scale compared to the control diet. Shryock et al. (70) illustrated that certain aluminosilicates may chemically interact with many dietary components, promoting their adsorption. Therefore, it is possible that the studied aluminosilicate might have adsorbed some dietary micronutrients involved in the molecular cycle of protein synthesis, reducing their absorption by birds and consequently interfering with the biochemical levels in birds' sera.

In contrast to the above-mentioned results, Chung et al. (71) reported that HSCAS at levels of 0.5% and 1% had no effect on manganese, vitamin A, or riboflavin utilization in chickens. However, zinc utilization was reduced by adding HSCAS at higher levels to the chicken diet. Furthermore, Ballard and Edwards (72) did not report any significant interaction of 1% zeolite with vitamin A in broilers' commercial diet. In another investigation, there were no significant effects due to 0.75% dietary inclusion of synthetic zeolite on 1,25(OH)(2)(D)(3), total calcium, ionic calcium, phosphorus, and pH of plasma in commercial leghorns. It was concluded that synthetic zeolite did not influence the synthesis of 1,25(OH)(2)(D)(3) (73). Additionally, Elliot and Edwards (57) and Edwards et al. (74) illustrated that the addition of 1% synthetic zeolite to the broiler diet did not influence the incidence of tibial dyschondroplasia.

Sodium zeolite at the 0.75% inclusion level decreased plasma P, available P, and tibia Mg, but increased tibia Ca, Zn, Al, and Mn concentrations. The addition of sodium zeolite enhanced tibia ash and density when dietary Ca was low; however, when added to diets containing 1.2% Ca, sodium zeolite reduced many bone mineralization indices, with the exception of tibia Ca (75). The results of Watkins and Southern (75) demonstrated that the effects of sodium zeolite are influenced by dietary concentration of Ca and P. However, Southern et al. (76) reported that SB did not adversely affect growth or tibia mineral concentrations in chicks fed nutrient-deficient diets. In addition, there was no interaction between HSCAS (1%–2% dietary inclusion) and energy or available phosphorus for any performance criteria in broilers (77).

8. Conclusions

The basis of diet, other additives, and the inclusion level of aluminosilicates are important issues that should be taken into account to obtain the best results. Due to the complexity of the interactions and factors that might influence them, further research is needed to determine the mode of actions of aluminosilicates in different metabolic pathways and molecular aspects in the body. As a research area, combining products of aluminosilicates with other additives like phytogenics or organic acids can shed further light on brand-new additives for various goals in poultry production.

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