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STUDY ON THE INFLUENCE OF ALUMINOSILICATES USED AS FEED ADDITIVES ON THE QUANTITY AND QUALITY OF MEAT: A BIBLIOGRAPHIC ANALYSIS

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Abstract

Aluminosilicates, including zeolites, have garnered attention in animal husbandry due to their diverse applications for improving meat quality. This review synthesizes research findings on the impact of zeolites on various meat quality parameters, covering performance analysis, meat composition, sensory aspects, and technological parameters. Notably, zeolites influence carcass weight differently, with varying effects observed across different animal species. Additionally, zeolite supplementation alters meat composition by affecting fatty acid profiles and water-holding capacity. Sensory parameters such as colour and texture are also influenced by zeolites, with particle size and coating with nanosilver playing significant roles. Moreover, zeolites affect technological parameters like pH and cooking loss, highlighting their multifaceted impact on meat quality.

Keywords**:** *zeolites, meat quantity, meat quality parameters, meat technological parameters, carcass traits*

INTRODUCTION

Aluminosilicates are a broad class of minerals composed of aluminium, silicon, and oxygen, often with other elements incorporated into their structure. These minerals are abundant in the Earth's crust and have diverse uses in ceramics, construction materials, and as catalysts[14].

Zeolites are hydrated crystalline aluminosilicates that contain other cations such as calcium, strontium, sodium, potassium, barium, and magnesium. They were discovered and named by the Swedish mineralogist Cronstedt in 1756, and currently, they can be natural or synthetic [11].

Clinoptilolite is a specific type of zeolite mineral characterized by its high adsorption capacity and ion exchange properties. It has applications in agriculture, environmental remediation, and animal feed additives due to its ability to capture toxins and improve nutrient absorption [35].

The Zeolit Production group of companies from Romania exploits the existing volcanic tuffs in the Rupea area, BrașovCounty. They sell a wide range of zeolite-based products, some of which directly contribute to the welfare and health of animals and birds. They help to detoxify the body, prevent, and combat gastrointestinal problems, increase the resistance of the eggshell, etc. Products based on zeolites that are for zootechnical use also help to protect the environment by reducing the level of pollution with gases resulting from the exploitation of animals. The products in the Zeco range are used either as feed additives for feeding different species of farm animals, or as ecological litter [35].

Mordenite is another type of zeolite mineral with a porous structure like clinoptilolite. Mordenite is used in various applications such as catalysts, adsorbents, and molecular sieves. These can be used as additives in animal feed or as materials for food packaging [15, 34].

According to the Scientific Opinion of the EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP), clinoptilolite (hydrated calcium aluminosilicate) is not absorbed, not degraded through feed metabolism, and consequently, it is excreted. For this reason, it is considered to pose no risk to consumers. The FEEDAP Panel considers that for all animals, a maximum addition of 10,000 mg clinoptilolite/kg complete feed does not present risks [13].

This paper aims to provide a bibliographic study on the effect of zeolites on the quantity and quality of meat from animals that have received feed with zeolites.

To achieve the stated objective, three research questions (RQ) are chosen:

• RQ1. What has been the evolution of the scientific literature on the effect of the use of zeolites in animal feed on the quantity and quality of meat?

• RQ2. How do zeolites used as feed additives influence the results obtained at slaughter (carcass weight, weight of different parts of it and meat quality)?

• RQ3. How do zeolites used as a feed additive influence meat quality parameters?

MATERIALS AND METHODS

From the academic databases Web of Science (WoS) and Scopus, 327 documents were collected in English. These were published between 1976 and 2023 inclusive. The query used two binary operators: "AND" and "OR", and the query strings used to collect the database were: (Zeolite OR Aluminosilicate OR Clinoptilolite OR Mordenite) AND (Meat OR Carcass OR Slaughter). This resulted in 450 articles. Articles present in both databases were manually eliminated. For bibliometric analysis, the Biblioshiny program provided by the Bibliometrix R-package(http://www.bibliometrix.org) was used [2].

RESULTS AND DISCUSSIONS

RQ1. How has the literature dealing with the influence of zeolites in poultry and livestock feed on meat production evolved so far?

Performance analysis

Following the query of the two databases WOS and Scopus, 327 documents were obtained, of which 236 are articles, 18 are proceedings papers, and only 5 are reviews. The annual production, within the period of 1976-2023, is presented in Figure 1.

The number of scientific articles published on this topic has registered a continuous upward trend, with variations depending on the year. Most scientific articles on this topic have been published in 2023, with 22 articles published.

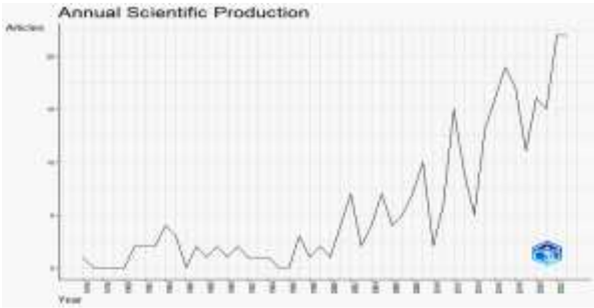

Fig. 1. Number of annual scientific articles from the WOS and Scopus databases, addressing the use of zeolites in feed, published between 1976-2023.
Source: Biblioshiny.

Table 1. Most relevant and most locally cited sources

Most relevant source		Most Local Cited Sources	
Sources	Articles	Sources	Articles
Poultry Science	12	Poultry Science	824
Nutrition Reports International	8	Journal Anim Science	287
Animals	7	Brit Poultry Science	184
Asian-Australasian Journal of Animal Sciences	6	Animal Feed Science and Technology	167
Journal of Animal Science	6	Meat Science	110
British Poultry Science	5	Asian Austral J Anim	97
Toxins	5	Res Vet Sci	87
Cuban Journal of Agricultural Science	4	J Appl Poultry Res	82
Environmental Science and Pollution Research	4	Bioresource TECHNOL	79
Journal of Animal and Veterinary Advances	4	J Agr Food Chem	78

Source: Biblioshiny, based on the WOS and Scopus dataset.

Table 1 identifies the most significant scientific journals in which articles on this topic were published, as well as the journals in which the most citations of articles on the effect of zeolites used as feed additives were registered.

In the both cases, Poultry Science ranks first, which can be explained by most of the research being conducted on poultry.

Is noticeable that only two journals in Table 1 predominantly focuses on meat or food characteristics in general, rather than on poultry and live animals.
These journals have had a variable number of articles on this topic over time (Figure 2).

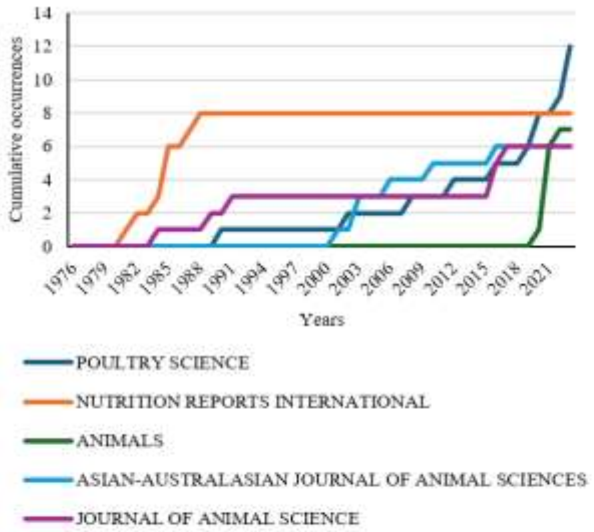

Fig. 2. Sources of articledproduction over time
Source: Biblioshiny, based on the WOS and Scopus dataset.

It can be observed that initially articles were published in Nutrition Reports International, but as new journals appear, they will publish more and more articles. In this scenario, the journal Animals stands out, publishing the first article on this topic in 2020.
Regarding the authors, annual production and the impact of articles can be considered. In this regard, an overview for the studied period is presented in Figure 3.
For the initial period studied, Pond WG is notable (with 3 articles in 1984 and 1985, and 1.6 citations in 1984) and Yen JT (with 2 articles in 1981 and 1983, and the highest number of citations being 1.3 in 1983). After 2012, Huang G and Kong X, along with Dastar B and Hassani S, stand out, while after 2021, Adamski M, Banaszak M, and Biesek J can be mentioned, each having 4 articles in 2021 and 2022 respectively.
The authors' activity can be assessed by the total number of published scientific articles (NP) and the number of accumulated citations (TC). Some indexes can also be used, such as: h-index (n articles with at least n citations), g-index (n articles that have at least n^2 citations) and m-index (which shows the ratio between the h-index and the number of years that have passed from the first published article).

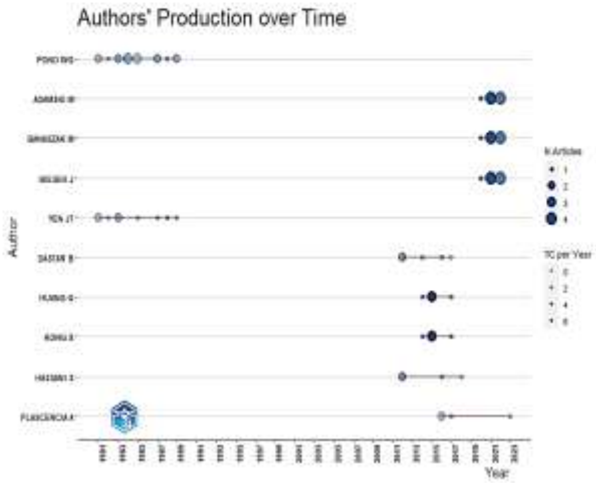

Fig. 3. The evolution of the number of scientific articles published by authors in a year and the number of citations received in that year
Source: Biblioshiny, based on the WOS and Scopus dataset.

From the data presented in Table 2, it can be observed that Pond not only has the highest values for NP and TC but also stands out with high values of h-index and g-index, followed by Yen.

Table 2. The 10 most relevant authors

Element	H index	g index	m index	TC	NP	PY start
Pond WG	11	16	0.25	279	16	1981
Yen JT	7	9	0.16	151	9	1981
Huang G	5	5	0.45	106	5	2014
Kong X	5	5	0.45	106	5	2014
Adamski M	4	7	0.8	54	9	2020
Banaszak M	4	7	0.8	54	9	2020
Biesek J	4	7	0.8	54	9	2020
Dastar B	4	5	0.31	56	5	2012
Alexopoulos C	3	3	0.13	132	3	2002
Hassani S	3	4	0.23	44	4	2012

Where: TC - total number of citations; NP - total number of publications; PY start - year of the first article publication
Source: Biblioshiny, based on the WOS and Scopus dataset.

The two authors have 9 joint research studies in this field.
The studies carried out by them address various topics related to the effects of dietary supplements, especially clinoptilolite or

zeolites, on various aspects of animal health and performance.

One objective pursued was the influence of clinoptilolite in feed on weight gain in pigs and lambs [24,25,31].

The following authors have relatively close h-index values, but Adamski, Banaszak, and Biesek have the highest m-index. These 3 authors have 9 joint articles, of which 7 have focused on the quality of meat resulting from animal feeding [3, 4, 5, 6, 7, 8, 9].

Production over time by main representative country is presented in Figure 4. The first concerns can be seen to have appeared in the USA, and after the 2000s they intensified. At the same time articles began to appear in Poland, Serbia, Iran, and China. In the last three years, China has the highest productivity.

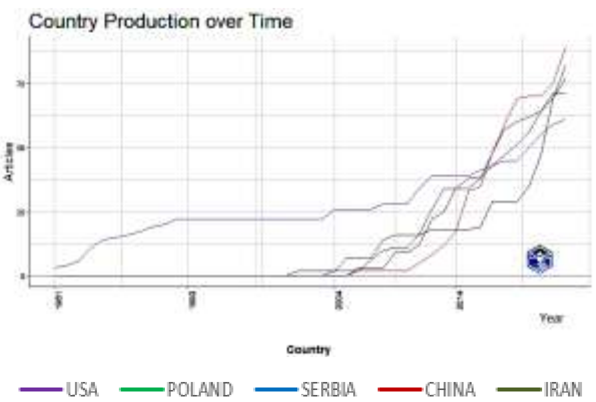

Fig. 4. Country production over time
Source: Biblioshiny, based on the WOS and Scopus dataset.

RQ2. To what extent can zeolites in poultry and animal feed influence the weight of carcasses/components resulting from slaughter?

The influence of zeolites on the carcass weight

The use of zeolites in animal husbandry, both as feed additives and to improve their welfare and the environmental protection, can contribute to the greening of the EU agriculture and the valorisation of natural resources, respectively, ensuring food security [26, 27].

So far, the influence of zeolites on carcass weight varies significantly. For example, Çabuk et al. (2004) found that supplementation of broiler feed with natural zeolite at doses ranging from 15 to 25 g/kg feed did not influence broiler live weight [10].

Similarly, supplementation with 5 g clinoptilolite/100 kg feed did not influence slaughter yield, carcass weight or carcass structure[18]. Other authors, such as Banaszak and colleagues (2022) observed an increase in muscle mass in the breast and legs, associated with overall body growth due to the addition of aluminosilicates in the feed. Moreover, an increase in liver weight was noted. The authors attribute these observations to the type of aluminosilicates used, as well as the composition and quality of the feed, alongside lipid metabolism and accumulation in the liver [6]. Prvulovic and Kojic found that the spleen increased in size with a 5% addition of zeolites, without affecting other organs [28].

Recently, Abdelrahman et al. (2023) tested the effect of using zeolites in different doses and with different particle sizes in the feed of broilers. The aim was to appreciate the evolution of body weight, the structure of the carcass meat and its technological quality. The presented conclusions show that supplementation with doses of maximum 10 g zeolite/kg feed positively influences the health of the birds and reduces mortality. At the same time, the use of zeolite as a feed additive above this dose has negative effects on productive performance [1].

Other authors show that adding zeolites to broiler feed nets or spreading them on permanent litter does not influence growth performance or slaughter yield. Addition of 5 g/kg natural zeolites to broiler feed had no effect on reducing NH_3 concentration in the house or litter moisture [29].

Christaki-Sarikaki et al. (2006) included natural zeolite at a rate of 2% in combination with flaxseeds, leading to a significant increase in thigh meat weight and a reduction in abdominal fat [12].

In the case of ducks, Biesek (2021) observed that using 4% zeolite in feed resulted in decreased body weight gain and increased feed conversion rate, but they noted an improvement in breast meat quality [9].

For pigs, it was observed that zeolites influence metabolism but do not affect weight gain [31].

Furthermore, Fabijańska et al. (2001) concluded that a 3% proportion of zeolites in feed reduces loin surface area [16].

Results regarding lambs or sheep are controversial. Stojković et al. (2012) found a significantly positive influence in lambs fed zeolite rations [32], while Toprak et al. (2016) using rations with 2% and 3% zeolite in lamb feed found no significant differences[33]. Similarly, no positive effects were reported in cattle [21,30].

RQ3. How do zeolites in poultry and animal feed influence meat quality parameters?

Meat Quality Parameters

Meat composition

Herc et al. (2021) added zeolite to the diet of rabbits at a concentration of 0.2 g/kg of body weight and observed that in the Longissimus dorsi muscle, the water content (73.630 ± 0.270 g * $100g^{-1}$) was significantly higher compared to the control (72.480 ± 0.530 g * $100g^{-1}$), but no significant difference was observed in the Musculus Vastus lateralis muscle[19].

Mallek et al. (2012) show that adding up to 1% zeolites to poultry feed does not alter protein content but interferes with the gelling process of proteins[22]. Changes were also observed in amino acid levels, as the use of zeolites in rabbit feed led to a significant increase in cysteine content, at 0.2898 ± 0.007 g * $100g^{-1}$ compared to the control, which recorded only 0.2772 ± 0.011 g * $100g^{-1}$[19].

According to Banaszak and colleagues (2022), a higher amount of intramuscular fat was found in the breast of broiler chickens, while a lower amount was observed in leg muscles [6, 7]. Adding zeolites to cattle feed led to a significant increase in n-3 fatty acids in intramuscular fat. A doubling of the linolenic acid (C18:3) content was achieved with a 0.5% addition of zeolites. Additionally, the linoleic acid (C18:2) content increased. They explained this by the alteration of intestinal microflora in the presence of zeolites, resulting in reduced degradation of PUFA acids. At the same time, researchers observed an increase in oleic acid (C18:1) but a decrease in palmitoleic acid (C16:1) content, possibly due to reduced Δ9 desaturase activity [20].

Mallek et al. (2012) used ZeoFeed, a commercial product with a minimum of 84% clinoptilolite, and found that Tunisian broilers fed with 0.5% zeolite showed double the linoleic acid content compared to the control group[22].

Similar results were obtained by Hcini et al. (2018) in the case of Turkey poults. The same authors found a significant reduction in lignoceric acid (C24:0). When 2% zeolites were added to the basal diet, the lignoceric acid content was reduced to less than half of the value obtained in the control birds [18].

Herc et al. (2018), using zeolite in rabbit feeding at a ratio of 0.2 g zeolite/kg of body weight, observed a significant increase in linoleic acid content compared to the control group only in the *Longissimus dorsi* muscle, while no significant difference was recorded in the *Musculus Vastus lateralis*muscle[19].

Regarding saturated acids, their level decreased, possibly due to the increase in unsaturated acids [20, 22].

The oxidative stability of lipids was investigated by Hashemi et al. (2014). They observed that the concentration of malondialdehyde decreased insignificantly when using zeolites coated with silver nanoparticles [17].

Sensory parameters of meat

The colour of meat can be expressed using the CIELAB system, also known as CIE Lab*, which represents lightness (L*), redness (a*), and yellowness (b*). While Banaszak et al. (2021) observed that adding aluminosilicates to the diet did not lead to a change in the colour of bird breast and leg muscles [4-5], Abdelrahman et al. (2023) concluded that the proportion (0-20 g of zeolite per kg of diet) or particle sizes of zeolite (1mm and 2mm) did not significantly affect brightness and b* immediately after slaughter. However, they did impact the a* values both at the time of slaughter and 24 hours post-slaughter. Particle size affected the final b* colour, with birds receiving larger particles showing more yellow colour and lower L* values in breast muscles[1].

Hashemi et al. (2014) reported the change in the color of broiler thigh muscle when nanosilver-coated zeolites were added to the feed. Thus, the L* values were higher in the experimental group compared to the control group, obtaining the highest values when zeolites coated with nanosilver were used. The b* values for the same thigh muscle were also significantly higher only for birds fed nanosilver. The a* values for this muscle were lower in the experimental group (6.72 for the 1% zeolite diet), compared to the control group (7.02). In the presence of nanosilver, the recorded value of the a* indicator (5.46) was obtained in the case of using 1% zeolite and 75ppm nanosilver) [17].

In the case of broilers raised in Tunisia, the addition of 1% zeolites to the feed, compared to the control group, caused a sharp increase in the hardness of the thigh muscles, from 1.53 to 2.76N. Their elasticity also increased from 3.23 to 5.50 mm [22].

Hashemi et al., (2014) observed for broiler breast muscles the influence of diets with zeolites coated or not with nanosilver on hardness and gumminess (the lowest value was obtained for feeds with 1% zeolites not coated with nano silver), cohesiveness (higher values only for feeds with 1% zeolites coated with 50 ppm and 75 ppm nano silver), and chewiness values (lower than control in the case of feeds with 1% zeolites and 1% zeolites coated with 25 ppm nano silver). For broiler thigh muscles, hardness, stickiness, and cohesion were not influenced by dietary treatment. They observed significantly higher values for hardness, gumminess, and chewiness with a diet containing 1% zeolites [17].

Technologicalparameters of meat

After slaughter, pH decreases due to post-mortem biochemical transformations. The final pH value depends on several factors, including pre-slaughter stress. Banaszak et al. (2021 and 2022) were unable to observe changes in pH45 and pH24 in broilers fed with and without zeolites, nor if these zeolites are coated with nanosilver[4, 5, 6, 7].

Mallek et al. (2012) show that adding zeolite to broiler feed reduces the compactness of the protein gel network, allowing better water binding and making the meat tender[22].

Hashemi et al. (2014) show that adding 1% zeolites to the feed leads to a decrease in WHC (64.51% compared to a control with 70.06%), but if zeolites (1%) coated with nanosilver (50ppm and 75ppm) are added to the feed, better results are obtained (74.32% and 74.11%, respectively) compared to diets containing only 1% zeolites. A possible explanation is that nanosilver intervenes in the antioxidant system in muscle tissue, thus affecting the activity of calpains and proteolysis, and ultimately [17].The presence of nanosilver alongside zeolites prevents oxidative processes in proteins, resulting in better WHC values.

The addition of zeolites to the feed of ducks caused an increase in the water retention capacity of the pectoral muscle and limb muscles, respectively, their yellow color was intensified [8].

In the case of cooking loss, the highest values were obtained with an addition of 5 g of zeolite per kg of feed and for a particle size of 1mm, while a higher addition (15 g of zeolite per kg of feed) or larger particle sizes (2mm) resulted in greater cooking losses[1].

A study carried out on the efficiency of the use of Romanian zeolites shows that they improve the use of nutrients and the feed conversion rate [23].

CONCLUSIONS

Zeolites exhibit a complex influence on meat quality parameters, with their effects varying depending on factors such as dosage, particle size, and animal species. While zeolite supplementation generally improves water-holding capacity and alters fatty acid composition favourably, its impact on carcass weight and sensory attributes like colour and texture is nuanced. Future research should delve deeper into the mechanisms underlying these effects to optimize zeolite usage in animal feed for enhanced meat quality.

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