Research Note: Growth and meat features of broiler chicken with the use of halloysite as a technological additive to feed and peat litter

Miroslaw Banaszk, Jakub Biesek, and Marek Adamski

Department of Animal Breeding and Nutrition, Faculty of Animal Breeding and Biology, Bydgoszcz University of Science and Technology, Bydgoszcz, Poland

ABSTRACT The current trends in the production of broiler chickens indicate the need to look for natural solutions that affect the efficiency of production and the quality of meat. The aim of the study was to evaluate the growth performance and quality of broiler chicken meat with the addition of halloysite in feed and litter. Two hundred Ross 308 were used and divided into 2 groups (10 replicates each). The control group (C) did not have any additive, while in the experimental group (H) 0.5% halloysite was used in feed and 0.500 kg/m² in peat litter. The production results and litter traits were checked. The presence of footpad dermatitis (FPD) was assessed. After 42 d, 20 birds were randomly selected and slaughtered. Dissection was performed. The slaughter yield and the percentage of carcass elements were calculated, including offal. Breast and leg muscles were analysed qualitatively (pH, colour, water-holding capacity, drip loss, chemical composition). In group H there were no changes to FPD, and in group C there were 6 cases of benign lesions and 1 with severe damage and scabs on the soles of the feet. Significantly higher pre-slaughter body weight was shown, as well as carcass and wings weight in group H. The H group had a higher pH24 than the C group, as well as higher protein and water content, and lower intramuscular fat and salt, both in the breast and leg muscles. No significant differences were found in growth performance carcass, meat’ colour or water-holding capacity features. The litter with halloysite was characterized by a lower pH but without statistical confirmation. Addition of halloysite to feed and litter reduced the occurrence of skin lesions and had a positive effect on higher protein content and lower intramuscular fat in the breast and leg muscles. This demonstrates the potential for the practical use of halloysite in the production of broiler chickens, both as a feed and peat litter additive.

Key words: chicken, peat, aluminosilicate, growth performance, meat quality

INTRODUCTION The efficiency of poultry meat production is influenced by many factors, including management, which can be understood as ensuring production conditions at an optimal level, as well as the quality of the raw material obtained (Suwarta and Hanafi, 2018). In the production of broiler chickens, a very important issue is footpad dermatitis (FPD). It is a disease entity of skin lesions on the soles of the feet and is a well-known problem in poultry production, affecting the efficiency as well as the preservation of bird welfare (Škrbić et al., 2015). For a good production results, maintaining appropriate conditions for birds and to obtain good quality meat, various feed and litter additives are used. Interesting solution with potential in poultry production is the use of clay minerals, including halloysite. Its production is concentrated mainly in New Zealand and USA, and in Europe, the halloysite mine is located in Poland, and its deposits are estimated at 10 million tons (Softys et al., 2013). Halloysite can be a cheap, accessible and natural solution as it is common in soils and weathered rock (Joussein et al., 2018). Halloysite is characterized by the ability to eliminate (reduce) growing fungi, reduce the level of heavy metals in the organs of animals, they can affect digestive processes, as well as the quality of litter and reduce harmful gas emissions (Kulok et al., 2005). As described by the cited authors, the beneficial effects of using aluminosilicates in animal feeding have been shown. By reducing impurities in the feed (or litter), halloysite can affect body weight gain, because the feed quality allows the full use of nutrients (Korniewicz et al., 2006). Other studies were conducted by Pizzaro et al. (2009), where the characteristics of the litter and the presence of FPD were controlled with the use of

© 2021 The Authors. Published by Elsevier Inc. on behalf of Poultry Science Association Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Received July 16, 2021.
Accepted October 10, 2021.
1 Corresponding author: jakub.biesek@pbs.edu.pl
aluminosilicates. Lowered pH of the litter and ammonia was demonstrated, however in both groups the occurrence of changes on the soles of the feet was similar. The quality of the meat in terms of colour is important to consumers, but it also shows that the meat is not defective (PSE or DFD). Lightness (L*) is closely related to the pH of meat, as well as water-holding capacity (or drip loss) and the chemical composition of meat (Fletcher, 2002). Mineral clays can improve chickens’ growth and quality of meat (Dhama et al., 2014). The aim of the study was to evaluate the production indicators and meat characteristics of broiler chickens that were kept with 0.500 kg/m² of halloysite to peat litter and fed with 0.5% halloysite added to feed.

**MATERIAL AND METHODS**

The rearing of broiler chickens and the performance of the experiment was in accordance with the law and EU directive no. 2010/63/EU.

**Chickens Rearing**

Two hundred male Ross 308 broiler chickens were reared. The rearing was carried out in a closed building, in a litter system, using peat litter for 42 d. The rearing conditions were in accordance with Ross 308 broiler chicken keeping standards with some modifications. On the day of insertion, the average temperature in the chicken house was 30°C and after 3 d it gradually decreased to 20°C (29th d of rearing). For the first 3 d, a continuous lighting system was used, similarly for the last 2 d of rearing (with a period of lower light intensity for 1 h), and in the remaining period, the chickens were kept with blackout period for at least uninterrupted 6 h between 15 and 21 d of rearing (possibility for regeneration). Humidity was on average 65% and ventilation was around 0.5 m³/s. The lighting of the broiler house was 20 lx. Birds had access to feed and fresh water ad libitum. The feed was a commercial complete mix divided into 3 feeding stages: starter, grower 1, and grower 2. Chickens were divided into 2 groups of equal numbers, in accordance with the principle of randomization of trials. Each group was divided into 10 repetitions of 10 birds. The pens were made of stainless material with dimensions of 1 × 1 m. The feeders were mounted on the walls of the pens (1 per pen), with easy access to them, and 2 nipple drinkers per pen were provided. The first group was the control group (C). In the experimental group (H), the addition of halloysite to feed and litter was applied. In the feed, 0.5% halloysite was added in each feeding period. Halloysite was added at the feed production stage, so it was a homogeneous mixture. The halloysite was in a loose (dusty) form, and had a specific surface area of 65 to 86 m²/kg, bulk density 0.70 to 0.85 g/cm³, and also contained aluminum (13.00%), silicon (12.00%), calcium (0.40%), manganesium (0.30%), sodium (0.10%), potassium (0.08%), phosphorus (0.30%), iron (9.00%), titanium (1.00%), and manganese (0.20%). Feed was pelleted form. The composition of the feed was suitable for broiler chickens, in line with the nutritional requirements (feeds came from a commercial feed factory). The feed was produced in accordance with the rules and hygiene of feed production for broiler chickens. Characteristics of halloysite were presented on the basis of the supplier’s declaration. During the entire rearing period, the litter was sprinkled with halloysite in the amount of 0.500 kg/m² in the dusty form (on the days of the feed change).

**Growth Performance**

During the rearing period, the chickens were weighed (BW) on the day of insertion (d 1), as well as during the feed changes (d 14, 22) and on the day of slaughter (d 42). The feed consumption (FI) was recorded. Based on the collected data, body weight gain (BWG) as well as feed conversion ratio (FCR) were calculated for each feeding period and for the entire rearing period. The European Broiler Index (EBI) was also calculated from formula: (average grams gained/day of rearing x % survival rate)/FCR x 10. The deaths of chickens were recorded.

**Peat Litter Quality and Footpad Dermatitis**

During the rearing period, the moisture content of the litter as well as its pH and nitrogen content were measured. This was to record changes taking place in the peat. For the pH and total nitrogen content tests, peat was collected on d 1, 14, 22, and 42. Collective peat samples from each group, weighing 1 kilogram, were collected into string bags. There were 5 replications (1 replication was from 2 pens). The pH was determined by the potentiometric method (Sukovata et al., 2010) according to the standards (PN-ISO 10390:1997) using the Orion 2 Star Thermo pH meter, at a temperature of 20°C with automatic reading. The percentage of total nitrogen was determined according to the PN-EN ISO 5983-1:2006 standard. FOSS Kjeltec 8400 Analyzer Unit, Sampler 8420 and FOSS Tecator Digestor were used. In addition, on the day of slaughter, the condition of the soles of the chickens’ feet was checked in order to determine the presence of footpad dermatitis using the point scale with 3 grades: 0, means no change or very small, slight superficial discoloration and mild epidermal keratosis; 1, means mild skin changes, discoloration, superficial lesions and dark spots on the pads; 2, means severe damage, ulcers, scabs, hemorrhages, and swelling of the paws. The results are given as the percentage of birds with skin lesions in each group.

**Features of Broiler Chicken Meat**

In 42nd d, 10 chickens from each group were randomly selected and slaughtered. Previously, the birds were starved for 10 h (fresh water access was provided). The birds were stunned and made a quick cut between the
cervical vertebrae and the occipital condyle for rapid bleeding. The slaughter was carried out by qualified workers in accordance with the humanity standards. After slaughter, the carcasses were immersed in water at 65°C for 5 s and plucked. Then the feet in the ankle joint were cut off and the carcasses were eviscerated, leaving edible offal (heart, gizzard, and liver). After 45 min of slaughter, a pH45 was measured in the pectoralis major muscle. The carcasses were placed sequentially with numbers, which ensure the accuracy of the analyses performed. The carcasses were then cooled in a cold store (Hendi, Poznan, Poland) at 4°C for 24 h. After the time has elapsed, the pH24 measurement has been repeated. Carcasses and offal were weighed. Dissection was performed, cutting off the neck with skin, wings, abdominal fat, skin with subcutaneous fat, breast muscles (m. pectoralis major and minor), and leg muscles (deboned). The remains of the carcass included the trunk and bones of the legs. The dressing percentage as well as the percentage of individual elements in the carcass were calculated. The breast and leg muscles were intended for qualitative analysis. Right breast and leg muscles were assessed using a colorimeter (Konica Minolta, Tokyo, Japan), using the CIE Lab scale, where L*, brightness; a*, redness; b*, yellowness. The color assessment was performed on the outer side of the muscles. Then right breast muscles were weighed (M1) and placed in string bags with incisions. These were placed in larger bags and suspended in a cold store for 24 h at 4°C. Based on the value, the percentage of water loss by the drip loss method was calculated. Left breast and leg muscles were ground in a meat homogenizer to perform water-holding capacity and chemical composition. The water-holding capacity was achieved by weighting a sample of meat with weight of 0.300 g ±5% (M1). The tests were placed between 2 pieces of Whatmann tissue paper and put on weights of 2 kg for 5 min. The trials (M2) were then weighed. The percentage of water loss was calculated. The chemical composition of the meat was carried out using spectrometry (FoodScan, Foss, Hilleroed, Denmark) using near-infrared transmission (NIT). The percentage of protein, collagen, salt, intramuscular fat and water was analyzed. All of quality analyses were done in 10 replications. Analyses where described by Banaszak et al. (2020).

Statistical Analysis

The data were compiled in a statistical program (Statistica software, 13.3, 2017, Cracow, Poland). Mean values and standard error of the mean (SEM) have been calculated. Using Student’s t-test between groups, for independent variables, statistically significant differences were verified, with the significance level P-value <0.05. For the production results 10 replications were done in each group. For the quality of carcass and meat, 10 replications were provided. For the litter features 5 replications were done, although 1 sample was done from 2 pens. The results for the presence of footpad dermatitis were not statistically analyzed as they were calculated for the whole group, without division into replicates.

RESULTS AND DISCUSSION

Growth Performance

No statistically significant differences between body weight groups were demonstrated when analyzing Table 1, as well as body weight gain, feed intake and feed conversion ratio (P > 0.05). Deaths were recorded during the rearing. In the first 3 d, 3 chicks were died in group C and 6 chicks in group H. However, deaths were associated with weak and crippled chicks, which was not dependent on the research factor.

Peat Litter Quality and Footpad Dermatitis

In both groups pH of peat litter at 6.10-6.55 level was shown, and dry matter content was above 94%, expressed as a mean value from the mentioned days of sampling. Nitrogen content in peat litter was 6.10-6.55. There were no statistically significant differences (P > 0.05). In group C, 6% of birds showed mild skin lesions, discoloration, superficial damage and dark spots (1 point), as well as serious damage and scabs (2 points) in 1%. In group H, no skin lesions were shown that could be attributed to score 1 or 2 (0, no lesions or very small, slight superficial discoloration and mild keratosis of the epidermis) (Table 1). The assumptions may be made with the effect of the addition of halloysite to peat. Peat The quality of the bedding depends on the material as well as the building conditions and even the feeding of the poultry, including what additives are used (Skrbić et al., 2015). Liuskanto (2015) concluded that the addition of halloysite to peat increases moisture absorption and phosphate, nitrate or potassium retention by exchanging cations and anions or creating deposits. It is thought that litter and living conditions were optimal in the building, in all groups, as most scientific reports suggest as pH value of litter in the production of chickens at a level close to 8.0 (this may be related to the type of litter, and time of analyses).

Features of Broiler Chicken Meat

The birds to be slaughtered were randomly selected from each group. Statistically significantly higher body weight (P = 0.019) and carcass weight (P = 0.030) were shown in group H, but this did not influence into dressing percentage as no statistically significant differences were found (P = 0.442). A statistically significant higher wings weight was found in group H compared to group C (P = 0.003). No statistically significant differences (P > 0.05) were found in the other characteristics shown in carcasses. Group H, where halloysite was used to feed and peat litter, had a significantly higher pH24 compared to group C (P = 0.033) in the breast muscles. In the
Table 1. Growth performance of broiler chickens, peat litter features and footpad dermatitis scores.

| Item                      | Group | N = 100 | C    | H    | SEM  | P-value* |
|---------------------------|-------|---------|------|------|------|----------|
| BW (g)                    |       |         |      |      |      |          |
| 1-d old chicks            | 40.92 | 41.04   | 0.18 | 0.745|
| 14 d                      | 310.66| 305.48  | 3.13 | 0.423|
| 22 d                      | 1230.04| 1222.72 | 13.16| 0.789|
| 42 d                      | 3098.57| 3059.30 | 38.23| 0.621|
| BWG (g)                   |       |         |      |      |      |          |
| 1–13 d                    | 269.74| 264.44  | 3.17 | 0.418|
| 14–21 d                   | 919.38| 917.25  | 11.28| 0.928|
| 22–42 d                   | 1866.53| 1836.57 | 30.61| 0.615|
| 1–42 d                    | 3057.65| 3018.26 | 38.25| 0.620|
| FI (g; per bird)          |       |         |      |      |      |          |
| 1–13 d                    | 300.00| 288.70  | 3.46 | 0.104|
| 14–21 d                   | 1232.30| 1261.40 | 10.84| 0.187|
| 22–42 d                   | 2797.11| 2760.72 | 26.06| 0.500|
| 1–42 d                    | 4440.57| 4510.34 | 51.23| 0.511|
| FCR (kg/kg)               |       |         |      |      |      |          |
| 1–13 d                    | 1.11  | 1.09    | 0.01 | 0.428|
| 14–21 d                   | 1.34  | 1.38    | 0.01 | 0.236|
| 22–42 d                   | 1.50  | 1.51    | 0.02 | 0.908|
| 1–42 d                    | 1.46  | 1.49    | 0.02 | 0.265|
| EBI                       | 489   | 452     | 13.71| 0.191|
| Deaths (birds)            | 3     | 6       | -    | -    |

**Peat litter features**

| Item                      | Group | N = 100 | C    | H    | SEM  | P-value* |
|---------------------------|-------|---------|------|------|------|----------|
| pH                        | 6.55  | 6.10    | 0.18 | 0.264|
| Dry matter [%]            | 94.67 | 94.75   | 0.95 | 0.971|
| Nitrogen [g; kg]          | 3.27  | 3.47    | 0.48 | 0.854|

**Footpad dermatitis [% in group]**

0, means no changes or very small, slight superficial discoloration and mild epidermal keratosis; 1, means mild skin changes, discoloration, superficial lesions and dark spots on the pads; 2, means severe damage, ulcers, scales, hemorrhages and swelling of the paws.

*No significant differences were found between group C and H, with P-value > 0.05; C, control group; H, halloysite group; 0.5% of halloysite in feed and 0.500 kg/m² in peat litter. Abbreviations: BW, body weight; BWG, body weight gain; EBI, European Broiler Index; FCR, feed conversion ratio; FI, feed intake. Feeding stage: 1–13 d, starter feed; 14–21 d, grower feed; 22–42 d, finisher feed, N = number of samples.

Table 2. Carcass features and meat quality of broiler chicken.

| Item                      | Group | n = 10 | C    | H    | SEM  | P-value* |
|---------------------------|-------|--------|------|------|------|----------|
| Preslaughter body weight (g) | 2993.80| 3205.50 | 46.77| 0.019|
| Weight of carcass (g)      | 2251.49| 2441.10 | 44.74| 0.030|
| Dressing percentage (%)    | 75.14  | 76.15   | 0.64 | 0.442|
| Neck with skin (g)         | 103.89 | 108.54  | 4.03 | 0.579|
| Neck with skin (%)         | 4.63   | 4.44    | 0.16 | 0.552|
| Wings (g)                  | 211.50 | 241.47  | 5.52 | 0.003|
| Wings (%)                  | 9.44   | 9.91    | 0.20 | 0.247|
| Heart (g)                  | 15.54  | 14.93   | 0.62 | 0.638|
| Gizzard (g)                | 29.90  | 31.99   | 1.78 | 0.570|
| Liver (g)                  | 65.31  | 64.58   | 2.51 | 0.889|
| Carcass remains (g)        | 611.10 | 662.72  | 35.30| 1.480|
| Breast muscles (g)         | 681.57 | 773.67  | 38.94| 0.247|
| Breast muscles (%)         | 30.19  | 31.68   | 1.55 | 0.645|
| Leg muscles (g)            | 464.33 | 477.62  | 11.98| 0.593|
| Leg muscles (%)            | 20.59  | 19.59   | 0.36 | 0.174|
| Total muscles (g)          | 1145.90| 1251.29 | 45.02| 0.252|
| Total muscles (%)          | 50.78  | 51.26   | 1.61 | 0.887|
| Skin with subcutaneous fat (g) | 198.55| 197.35  | 4.67 | 0.902|
| Skin with subcutaneous fat (%) | 8.82 | 8.12    | 0.19 | 0.066|
| Abdominal fat (g)          | 25.60  | 26.08   | 2.08 | 0.911|
| Abdominal fat (%)          | 1.13   | 1.07    | 0.09 | 0.734|
| Total fat (g)              | 224.15 | 223.43  | 6.01 | 0.954|
| Total fat (%)              | 9.95   | 9.18    | 0.23 | 0.104|

**Quality features of breast muscle**

| Item                      | Group | n = 10 | C    | H    | SEM  | P-value* |
|---------------------------|-------|--------|------|------|------|----------|
| pH45                      | 6.46  | 6.36   | 0.04 | 0.165|
| pH24                      | 6.11b | 6.26a  | 0.03 | 0.033|
| Color                     |       |        |      |      |      |          |
| L*                        | 53.04 | 52.96  | 0.64 | 0.953|
| a*                        | 3.46  | 3.96   | 0.33 | 0.469|
| b*                        | 5.69  | 5.86   | 0.38 | 0.832|

(continued)
Table 2 (Continued)

| Item n = 10 | Group | C       | H       | SEM  | P-value |
|-------------|-------|---------|---------|------|---------|
| Water holding capacity (%) | 35.10 | 35.69   | 0.42   | 0.501 |
| Drip loss (%) | 1.02  | 1.25    | 0.10   | 0.276 |
| Protein (%)  | 21.91b | 22.07a  | 0.02   | <0.001 |
| Collagen (%) | 0.96  | 0.95    | 0.02   | 0.793 |
| Salt (%)     | 0.26a | 0.19b   | 0.01   | <0.001 |
| Intramuscular fat (%) | 2.92b | 2.61a   | 0.04   | <0.001 |
| Water (%)    | 73.95b | 74.18a  | 0.04   | <0.001 |

Quality features of leg muscle

| Color | L*      | a*       | b*      |
|-------|---------|----------|---------|
|       | 50.00   | 49.18    | 0.47    |
|       | 4.05    | 4.69     | 0.33    |
|       | 4.23    | 3.88     | 0.35    |
|       | 37.93   | 36.54    | 0.41    |
|       | 18.73b  | 18.86b   | 0.02    |
|       | 1.46    | 1.41     | 0.01    |
|       | 0.31a   | 0.27a    | 0.01    |
|       | 7.95a   | 7.46a    | 0.06    |
|       | 71.55b  | 72.00b   | 0.05    |

a,bDifferent letters in a row (between groups C and H) indicate statistically significant differences, at the level of P-value <0.001; C, control group; H, halloysite group: 0.5% of halloysite in feed, and 0.500 kg/m² in peat litter; **, pH<0.001; salt, pH<0.001; protein, pH<0.001.

In breast muscles, the protein and water content of group H was statistically significantly higher, at the same time significantly lower intramuscular fat and salt content than in group C (P < 0.001). In the leg muscles also statistically significantly higher protein and water content, and lower intramuscular fat and salt was shown in group H, compared to group C (P < 0.001; salt, P = 0.001). Values of L*, a*, b*, drip loss and water-holding capacity in the breast and leg muscles shown in Table 2, did not differ statistically significantly (P > 0.05). Studies of Prvulovic et al. (2008) showed using 5 g/kg hydrated aluminosilicate (antitoxic nutrient-ATN) for feed showed significantly higher protein content and lower fat content in the breast muscles which corresponds to our results. The pilot studies (Banaszak et al., 2020) concluded that the addition of halloysite affects the higher height of intestinal villi and their width and surface area, as well as the depth of intestinal crypts, and this is associated with digestive functions (increased). The use of kaolin, bentonite and zeolite also affected the quality characteristics of meat (Safaei et al., 2016). The authors discussed that the addition of silicate minerals increases protein digestibility, increases protein in meat and reduces intramuscular and abdominal fat. This is related to the relationship of reduced lipid oxidation and improved protein digestibility. Similar conclusions were made by other authors, using different aluminosilicates in the production of broiler chickens and their impact on the quality and chemical composition of meat (Christaki et al., 2006; Safaei et al., 2014). The pH value is associated with perimortem and postmortem glycolysis process (Swatland, 2008). Slower pH decrease (toward meat acidification) was associated with lower water loss from meat (Le Bihan-Duval et al., 2008). In addition, it is suggested that low pH promotes lipid oxidation, thus the less intramuscular fat in related to the lower the oxidation (Gong et al., 2010). The research results indicate no negative effect of halloysite in peat litter and feed on production results and meat quality. The addition of halloysite positively influenced the condition of the soles of the feet. Further research, including microbiological mechanisms, could be continued.

ACKNOWLEDGMENTS

This research was funded by the project “Safe Farm – innovative products, processes and marketing in the production of broiler chickens”, implemented in 2020-2022 and co-financed from the European Agricultural Fund for Rural Development: Europe investing in rural areas.” The authors thank the Kuyavian-Pomeranian Association of Poultry Breeders and Egg Producers (Poland) (www.bezpiecznaferma.pl) for the opportunity to conduct research and implement their results for further poultry management practice, as well as the Agency for the Restructuring and Modernization of Agriculture (Poland; founder of project). Thanks to the Laboratory of Chemical Research and Instrumental Analyzes of the Faculty of Animal Breeding and Biology of the Bydgoszcz University of Science and Technology for their support in the preparation of analyses of pH and total nitrogen in the litter.

DISCLOSURES

The authors declare that they have no conflicts of interest.

REFERENCES

Banaszak, M., J. Biesek, J. Bogucka, A. Dankowiakowska, D. Olszewski, B. Bigorowski, M. Grabowicz, and M. Adamski. 2020. Impact of aluminosilicates on productivity, carcass traits, meat quality, and jejunum morphology of broiler chickens. Poult. Sci. 99:7169-7177.
Christaki, E. V., P. C. Florou-Paneri, P. D. Fortomaris, A. S. Tserveni-Gousi, and A. L. Yannakopoulos. 2006. Effects of dietary inclusion of natural zeolite and flaxseed on broiler chickens' body fat deposition in an extended fattening period. Archiv Fur Geflugelkunde 70:106–111.

Dhama, K., R. Tiwari, R. U. Khan, S. Chakraborty, M. Gopi, K. Karthik, M. Saminathan, P. A. Desingu, and L. T. Sunkara. 2014. Growth promoters and novel feed additives improving poultry production and health, bioactive principles and beneficial applications: the trends and advances – a review. Int. J. Pharmacol. 10:129–159.

Fletcher, D. L. 2002. Poultry meat quality. World’s Poult. Sci. J. 58:131–145.

Gong, Y., R. S. Parker, and M. P. Richards. 2010. Factors affecting lipid oxidation in breast and thigh muscle from chicken, turkey and duck. J. Food Biochem. 34:869–885.

Joussein, E., S. Petit, J. Chruchman, B. Theng, D. Righi, and B. Delvaux. 2018. Halloysite clay minerals – a review. Clay Minerals 40:383–426.

Korniewicz, D., D. Kołacz, Z. Dobrzański, A. Korniewicz, and M. Kulok. 2006. Effect of dietary halloysite on the quality of feed and utilization of nutrients by fatteners. Electr. J. Polish Agric. Univ. 9:59.

Kulok, M., R. Kołacz, Z. Dobrzański, and I. Wolska. 2005. The influence of halloysite on the content of bacteria, fungi and mycotoxins in feed mixtures. ISAH, Warsaw, Poland 354–357.

Le Bihan-Duval, E., M. Debut, M. M. Berri, N. Sellier, V. Santé-Lhoutellier, Y. Jégou, and C. Beaumont. 2008. Chicken meat quality: genetic variability and relationship with growth and muscle characteristics. BMC Genet 9:1–6.

Liuskanto, S. 2015. The use of halloysite for nutrient and moisture retention in soils. Bachelor’s Thesis. Tampere University of Applied Sciences, Tampere, Finland.

Pizzaro, R. M., D. E. Icochea, S. P. Reyna, and P. N. Falcon. 2009. Effect of treatment of broiler litter with aluminosilicate. Revista de Investigaciones Veterinarias del Perú 20:213–220.

Prvulovic, D., D. Kojic, G. Grubor-Lajsic, and S. Kosaric. 2008. The effects of dietary inclusion of hydrated aluminosilicate on performance and biochemical parameters of broiler chickens. Turk. J. Vet. Anim. Sci. 32:183–189.

Safaei, M., F. Boldaji, B. Dastar, S. Hassani, M. S. A. Mutalib, and R. Rezaei. 2014. Effects of inclusion kaolin, bentonite and zeolite in dietary on chemical composition of broiler chickens meat. Asian J. Anim. Vet. Adv 9:56–63.

Safaei, M., R. Rezaei, F. Boldaji, B. Dastar, M. Taran, and S. Hassani. 2016. The effects of kaolin, bentonite and zeolite dietary supplementation on broiler chickens meat quality during storage. Vet. Sci. Dev. 6:6156.

Škrbić, Z., Z. Pavlović, M. Lukić, and V. Petričević. 2015. Incidence of footpad dermatitis and hock burns in broilers as affected by genotype, lighting program and litter type. Ann. Anim. Sci. 15:433–445.

Sołtys, J., J. Schomburg, P. Sakiewicz, A. Pytlinski, K. Jóźwiak, and B. Sołtys. 2013. Halloysite from Dunino Deposit as a Material for the Production of Mineral Sorbents. Sorbenty Mineralne. Surowce, energetyka, ochrona środowiska, nowoczesne technologie. AGH, Cracow, Poland, 457–469 in Polish.

Suwarta, S., and R. Hanafie. 2018. The influence of business management on income and the risk of income in the broiler chicken farming. J. Socioecon. Dev. 1:25–31.

Swatland, H. J. 2008. How pH causes paleness or darkness in chicken breast meat. Meat Sci. 80:396–400.