Europ.Poult.Sci., **85.** 2021, ISSN 1612-9199, © Verlag Eugen Ulmer, Stuttgart. DOI: 10.1399/eps.2021.XX

Influence of different litter types on ammonia and carbon dioxide emission in broiler production

Einfluss verschiedener Einstreuarten auf die Ammoniak- und Kohlendioxidemission in der Broilerproduktion

S. Knežević[1]*, **S. Vidaković Knežević**[1], **M. Pajić**[1], **Z. Ružić**[2], **M. Đukić Stojčić**[3], **M. Živkov-Baloš**[1] and **M. Đorđević**[4]

[1] Scientific Veterinary Institute "Novi Sad", Rumenački put 20, Novi Sad, Serbia

[2] Faculty of Agriculture Novi Sad, Department of Veterinary Medicine, Novi Sad, Serbia;

[3] University of Novi Sad, Faculty of Agriculture Novi Sad, Department of Animal Science, Novi Sad, Serbia

[4] University of Belgrade, Faculty of Veterinary Medicine, Department of Animal Hygiene, Belgrade, Serbia

*Correspondence: slobodan.knezevic@niv.ns.ac.rs

Manuscript received 27 January 2021, accepted 3 June 2021

Abstract

Harmful gases, such as ammonia (NH_3) and carbon dioxide (CO_2), affect both birds and workers involved in broiler production. Five hundred and seventy-six one-day-old ROSS 308 broilers were reared on six types of litter (Treatment 1: chopped wheat straw; treatment 2: wood shavings; treatment 3: mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat; treatment 4: wheat straw pellets; treatment 5: softwood pellets and treatment 6: pellets of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat). Using chamber emission of harmful gases, NH_3 and CO_2 were measured weekly for each treatment. The results showed that the critical level of NH_3 was reached for the first time on day 28. By the end of the rearing period, NH_3 concentrations were above the permitted value in all the treatments, with no significant difference between treatments ($P > 0.05$). The carbon dioxide values did not exceed the critical level during the fattening period. Litter types made no significant difference ($P > 0.05$) to carbon dioxide concentrations. The type of litter significantly affected the final body weight. This paper describes the influence of different materials and material combinations used as litter in broiler production. As birds are in constant contact with the litter, careful selection, appropriate management and proper storage and use of poultry litter contributes to improving in-house air quality and reducing air emissions from animal production facilities.

Key words

Ammonia; broiler; carbon dioxide; harmful gas; litter

Zusammenfassung

Schädliche Gase, wie Ammoniak (NH_3) und Kohlendioxid (CO_2), beeinträchtigen sowohl die Tiere als auch die Arbeiter in der Broilerproduktion. Fünfhundertsechsundsiebzig (576) Eintagsküken der Linie ROSS 308 wurden auf sechs unterschiedlichen Einstreuarten aufgezogen (1: gehäckseltes Weizenstroh, 2: Holzspäne, 3: Mischungen aus 1/3 gehäckseltem Weizenstroh, 1/3 Holzspänen und 1/3 Torf, 4: Weizenstrohpellets, 5: Weichholzpellets und 6: Pellets aus 1/3 Weizenstroh, 1/3 Holzspänen und 1/3 Torf). Die Emission der Schadgase NH_3 und CO_2 wurde mit Hilfe einer Emissions-Test-Kammer wöchentlich für jede Einstreuvariante gemessen. Die Ergebnisse zeigten, dass der kritische Wert von NH_3 zum ersten Mal am Tag 28 erreicht wurde. Am Ende der Aufzuchtperiode lagen die NH_3-Konzentrationen bei allen getesteten Varianten über dem zulässigen Wert, wobei keine signifikanten Unterschiede zwischen den Einstreuarten auftraten ($P > 0,05$). Die Kohlendioxidwerte überschritten während der Mastperiode nicht den kritischen Wert. Es bestanden keine signifikanten Unterschied in den Kohlendioxidkonzentrationen zwischen den verwendeten Einstreuvarianten ($P > 0,05$). Alle untersuchten Einstreuvarianten beeinflussten signifikant das Endkörpergewicht der Masthähnchen ($P < 0,05$). Dieser Beitrag beschreibt den Einfluss verschiedener Materialien und Materialkombinationen, die in der Masthähnchenproduktion als Einstreu verwendet werden. Da die Masthähnchen in ständigem Kontakt mit der Einstreu stehen, tragen eine sorgfältige Auswahl, ein angemessenes Management und eine ordnungsgemäße Lagerung und Nutzung der Geflügeleinstreu zur Verbesserung der innerbetrieblichen Luftqualität und zur Verringerung der Luftemissionen aus Tierproduktionsanlagen bei.

Stichworte

Ammoniak; Masthähnchen; Kohlendioxid; Einstreu; Schadgas

Introduction

High concentration of gases, such as ammonia (NH_3) and carbon dioxide (CO_2), in broiler production can affect indoor and outdoor air quality (NI et al., 2017; RELIĆ et al., 2019), welfare and production efficiency (DAWKINS et al., 2004), and health of both birds and personnel involved in broiler production (SCHMIDT et al., 2002; KIRYCHUK et al., 2006). Ammonia is a highly irritant, colourless gas, produced by microbial degradation of poultry waste. The main sources of NH_3 are uric acid, urea, ammonia/ammonium (NH^{4+}) and undigested proteins (NAHM, 2005). Carbon dioxide originates from manure breakdown and animal respiration (NI et al., 2017). The concentrations of NH_3 and CO_2 are regulated by EU COUNCIL DIRECTIVE, 2007/43/EC (2007) and should not exceed 20 ppm and 3000 ppm, respectively, measured at the level of birds' heads. Increased ventilation can lower the concentration of gases in poultry houses to safe levels. However, the released gases pollute the external environment and can affect health of people living in the vicinity of the broiler production facilities.

Bedding materials are often referred to as "litter", although poultry litter is commonly a mixture of excreta, feed, feathers, skin, manure and bedding materials (NAHM, 2005). Litter serves a number of important purposes for poultry. It provides comfort for birds, absorbs moisture, should have a low caking index and cannot be toxic for birds and personnel working in broiler production. Additionally, it should be inexpensive, environmentally friendly and suitable for further use (TASISTRO et al., 2007; GARCIA et al., 2012). Selecting adequate litter is a significant task for broiler producers. A wide range of materials are used as litter in broiler production such as wood shavings, sawdust, wheat straw, paddy straw, sand, rice husk, sugar cane pulp, oat hulls, maize cobs, peat moss, pelleted newspaper and coconut husk (SWAIN and SUNDARAM, 2000; MENDES et al., 2011; GARCÊS et al., 2013). The most commonly used litter materials in Serbia are wheat straw (chopped, non-chopped and pelletised), wood shavings and peat.

Since the emission of harmful gases is an important issue in broiler production, different bedding materials and different additives have been studied and used in order to reduce their emission (BREWER and COSTELLO, 1999; NAHM, 2005; TASISTRO et al., 2007; MILES et al., 2011). Identifying suitable litter material mixtures and formulations may significantly contribute to reduce harmful gas emissions in broiler production facilities. Therefore, the aim of this study was to measure NH_3 and CO_2 emission levels when different materials and formulations were used as litter in broiler production.

Material and Methods

Ethical Statement

This study was approved by Ethics Committee of Serbian Ministry of Agriculture, Forestry and Water Management under the number 323–07–00240/2019–05.

Design and Husbandry

The experiment was carried out between May and June 2019 at the experimental farm of The Faculty of Agriculture in Novi Sad (Republic of Serbia). All procedures were licensed by Ethics Committee of Serbian Ministry of Agriculture, Forestry and Water Management (license number 323–07–00240/2019–05).

Five hundred and seventy-six one-day-old ROSS 308 broiler chickens were randomly selected for six treatments, with three replicates per treatment. The treatments in this study were the following: (1) chopped wheat straw, (2) wood shavings, (3) mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat, (4) wheat straw pellets, (5) softwood pellets and (6) pellets of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat. Each replicate consisted of 32 chickens placed in a concrete-floored pen with a surface area of 2 m^2 and a stocking density of 16 chickens/m^2. Chicks were not sexed at the beginning of experiment. However, sexing was performed at the end of study.

In accordance with the demands of the Ross hybrid, basic environmental parameters were provided (Aviagen, 2018). Ventilation consisted of two cooling pads placed on the opposite side of four exhaust fans, each with the maximum capacity 5,000 m^3/h. Broilers were fed the same commercial feed. Chickens aged 0 to 14 days were fed a starter with 22% crude protein, growers 15 to 28 days old had a feed with 20% crude protein, while finishers at 29 to 42 days old were fed a 19% crude protein finisher diet. Water and feed were given *ad libitum*, using nipple drinker lines and bell feeders. Broilers were vaccinated against infectious bronchitis (on day 1 at the hatchery), infectious bursal disease (on days 13 and 23) and Newcastle disease (on day 16), as required by the country's veterinary authority. Broilers were reared until 42 days of age.

Litter management

Prior to littering, all pens were cleaned, fumigated and ventilated for two days. 6 kg/m^2 of litter was spread evenly in the pens. The pellets used in the treatments was 6 mm in diameter, while the chopped straw was 5–10 cm long. There was no additional litter maintenance after placing the broilers.

Ammonia, carbon dioxide and hydrogen sulphide measurements

There was no air separation among pens. Therefore, gas emissions were measured at each treatment using a chamber according to the modified method of Đukić Stojčić et al. (2016). The length, width and height of the chamber were 1.14 m × 1.0 m × 0.69 m, respectively, with a volume of 0.79 m^3. Gas emissions were measured from each pen on days 0, 7, 14, 21, 28, 35 and 42.

At each measurement occasion, with minimum disturbance, a certain amount of litter, between the waterline and feeders, was covered for 60 s in order to capture the volatilising gases. Through an opening placed at the top of the chamber, tubes of portable gas detectors were inserted and adjusted to the level of the birds' heads. Ammonia and carbon dioxide were measured using a portable detector MultiRAE Lite PGM-6208 (System Inc., America), while hydrogen sulphide was measured by PS200 MultiGas Detector (Gas Measurement Instruments Ltd Company). These instruments can detect up to 100 ppm of NH_3, 50.000 ppm of CO_2 and 100 ppm of H_2S. Prior to measuring sessions, both detectors were calibrated. The samples were taken 3 times from each pen.

Production parameters

On the 42nd day, all the broilers were weighed, and mean body weight (BW) per treatment was calculated.

Statistical Analysis

In this article, Shapiro-Wilk's method was used for testing for normal distribution ($P > 0.05$), which implies that the distribution of the data is not significantly different from a normal distribution. The data were analysed using one-way models of analysis of variance (ANOVA). Significant differences between treatments were set at $P \leq 0.05$ and probabilities were determined by Duncan's post hoc test. All statistical analyses were performed using R version 3.2.2 statistical software (R Foundation for Statistical Computing, Vienna, Austria).

Results

Throughout the fattening period, NH_3 concentrations had a tendency to increase in all treatments except for treatments II (wood shavings) and III (mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat), where the maximum NH_3 level was observed on day 35. After that, NH_3 emission level declined.

Ammonia level above the permitted 20 ppm was first detected on day 28 in the treatment II where wood shavings were used as litter. By the end of fattening period, NH_3 concentrations exceeded the permitted 20.0 ppm in all treatments. There were significant ($P < 0.05$) differences in ammonia concentrations on every measurement day except on day 42, when no difference was observed regardless of the type of the litter used (Table 1).

Table 1. NH_3 emissions (mean, ppm) from all treatments during the fattening period

Mittlere NH_3-Konzentrationen (ppm) für alle untersuchten Einstreuvarianten während der Mastperiode

Treatments	Days						
	0	7	14	21	28	35	42
I	1.00 ± 0.000^{a}	0.560 ± 0.530^{b}	1.67 ± 0.500^{a}	4.78 ± 1.72^{ab}	11.9 ± 4.17^{c}	19.4 ± 9.34^{b}	26.8 ± 9.85^{a}
II	0.560 ± 0.530^{b}	1.00 ± 0.000^{a}	1.56 ± 0.530^{a}	5.67 ± 1.58^{a}	22.7 ± 6.20^{a}	32.1 ± 13.2^{a}	30.1 ± 6.13^{a}
III	0.330 ± 0.500^{bc}	1.00 ± 0.000^{a}	1.56 ± 0.530^{a}	5.00 ± 1.22^{ab}	17.7 ± 5.87^{b}	34.1 ± 11.9^{a}	25.0 ± 3.64^{a}
IV	1.00 ± 0.000^{a}	1.00 ± 0.000^{a}	1.56 ± 0.530^{a}	4.67 ± 1.58^{ab}	11.8 ± 4.24^{c}	16.1 ± 7.30^{b}	23.8 ± 14.6^{a}
V	0.670 ± 0.500^{ab}	1.00 ± 0.000^{a}	1.00 ± 0.000^{b}	4.56 ± 1.01^{ab}	15.1 ± 4.14^{bc}	20.1 ± 4.20^{b}	26.7 ± 4.69^{a}
VI	0.000 ± 0.000^{c}	1.00 ± 0.000^{a}	1.44 ± 0.530^{ab}	4.11 ± 0.930^{b}	12.6 ± 4.07^{c}	16.8 ± 6.61^{b}	29.0 ± 10.5^{a}

[a-c] Means within the same column with no common superscript letter are significantly different ($P < 0.05$). Data are means with standard deviation of 3 replicates. Treatment I: chopped wheat straw; treatment II: wood shavings; treatment III: mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat; treatment IV: wheat straw pellets; treatment V: softwood pellets and treatment VI: pellets of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat.

Table 2 shows mean concentrations of CO_2 in all treatments during the fattening period of broilers. Initial CO_2 concentration was the highest in treatment IV (456 ± 72.6 ppm), where pelletised wheat straw was used as litter. At the end of rearing, no significant ($P > 0.05$) difference in CO_2 concentrations was observed among treatments.

Table 2. CO_2 concentrations (mean, ppm) for the various treatments during the fattening period

Mittlere CO_2-Konzentrationen (ppm) für alle untersuchten Einstreuvarianten während der Mastperiode

	Days						
Treatments	0	7	14	21	28	35	42
I	289 ± 33.3^{bc}	233 ± 50.0^{c}	1056 ± 265^{a}	1356 ± 436^{ab}	1389 ± 629^{a}	1833 ± 606^{ab}	1844 ± 604^{a}
II	278 ± 44.1^{bc}	278 ± 66.7^{bc}	1144 ± 445^{a}	1667 ± 707^{a}	1522 ± 387^{a}	2022 ± 547^{a}	2344 ± 1019^{a}
III	322 ± 44.1^{b}	267 ± 100^{bc}	1044 ± 615^{a}	1344 ± 453^{ab}	1467 ± 497^{a}	1700 ± 709^{ab}	2133 ± 809^{a}
IV	456 ± 72.6^{a}	311 ± 92.8^{bc}	1200 ± 773^{a}	1300 ± 447^{ab}	1567 ± 660^{a}	1656 ± 517^{ab}	1944 ± 543^{a}
V	244 ± 52.7^{c}	344 ± 72.6^{b}	1033 ± 112^{a}	1078 ± 476^{b}	1822 ± 585^{a}	1344 ± 428^{b}	1900 ± 770^{a}
VI	311 ± 60.1^{b}	433 ± 100^{a}	1300 ± 427^{a}	1111 ± 468^{b}	1733 ± 400^{a}	1556 ± 604^{ab}	1656 ± 391^{a}

$^{a-c}$ Means within the same column with no common superscript letter are significantly different (P < 0.05). Data are means with standard deviation of 3 replicates. Treatment I: chopped wheat straw; treatment II: wood shavings; treatment III: mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat; treatment IV: wheat straw pellets; treatment V: softwood pellets and treatment VI: pellets of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat.

Hydrogen sulphide was not detected during this study. Therefore, there will be no further mentioning of this in the discussion part.

Average BW of broilers can be found in Table 3. There was no effect (P > 0.05) of litter type on final BW of female broilers. However, BW of male broilers on day 42 was significantly (P < 0.05) affected by the litter type. Consequently, the unsexed broilers reared on pelletised softwood had the highest BW gain, followed by broilers on pelletised wheat straw and chopped wheat straw, while the lowest BW gain was observed in the treatments with pelletised and non-pelletised mixtures of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat (Figure 1).

Table 3. Final body weight (g) of broilers at day 42.

Endkörpergewichte (g) der Broiler am 42. Lebenstag.

				Treatments		
Sex	I	II	III	IV	V	VI
Unsexed	2769 ± 349^{ab}	2727 ± 312^{b}	2719 ± 357^{b}	2791 ± 341^{ab}	2832 ± 351^{a}	2693 ± 315^{b}
Male	2965 ± 279^{AB}	2955 ± 224^{AB}	2965 ± 242^{AB}	2997 ± 258^{AB}	3039 ± 256^{A}	2909 ± 231^{B}
Female	2459 ± 186	2456 ± 136	2406 ± 197	2457 ± 128	2480 ± 150	2451 ± 198

$^{a-b}$ Means within the same row with no common superscript letter are significantly different (P < 0.05). $^{A-B}$ Means within the same row with no common superscript letter are significantly different (P < 0.05). Data are means with standard deviation of 3 replicates. Treatment I: chopped wheat straw; treatment II: wood shavings; treatment III: mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat; treatment IV: wheat straw pellets; treatment V: softwood pellets and treatment VI: pellets of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat.

Europ.Poult.Sci., 85. 2021, ISSN 1612-9199, © Verlag Eugen Ulmer, Stuttgart. DOI: 10.1399/eps.2021.XX

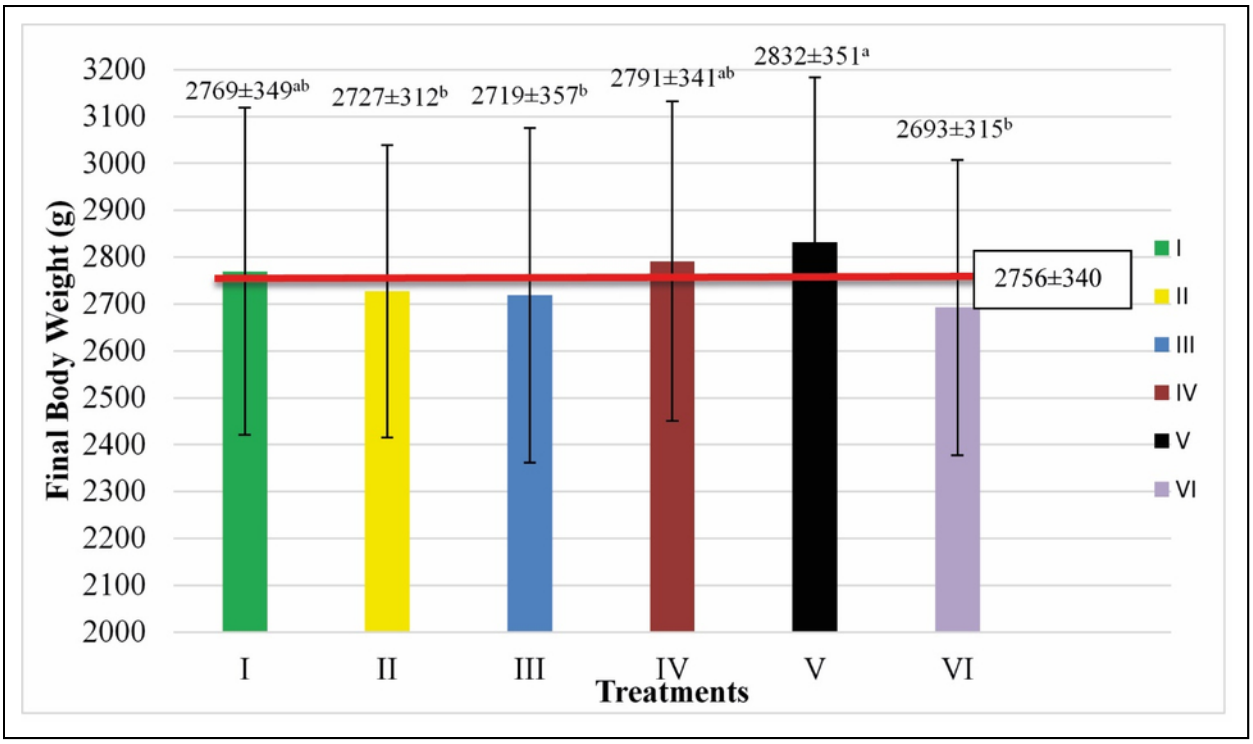

Figure 1. Final body weight (g) of broilers at day 42. [a-b] Means with no common superscript letter are significantly different (P < 0.05). Data are means with standard deviation of 3 replicates. Treatment I: chopped wheat straw; treatment II: wood shavings; treatment III: mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat; treatment IV: wheat straw pellets; treatment V: softwood pellets and treatment VI: pellets of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat. The red line represents the overall mean (2756 ± 340 g) of all treatments.

Endkörpergewicht (g) der Masthähnchen am Tag 42. [a-b] Mittelwerte innerhalb des Säulendiagramms mit unterschiedlichen hochgestellten Buchstaben unterscheiden sich signifikant (P < 0,05). Die Daten repräsentieren Mittelwerte mit Standardabweichung von 3 Wiederholungen. I: gehäckseltes Weizenstroh, II: Holzspäne, III: Mischungen aus 1/3 gehäckseltem Weizenstroh, 1/3 Holzspänen und 1/3 Torf, IV: Weizenstrohpellets, V: Weichholzpellets und VI: Pellets aus 1/3 Weizenstroh, 1/3 Holzspänen und 1/3 Torf. Die rote Linie repräsentiert den Mittelwert (2756 ± 340 g) aus allen untersuchten Einstreuvarianten.

Discussion

The factors affecting the variations in gas emission are numerous and intertwined. However, the chamber method may potentially be limited because a sealed chamber represents a static method which allows only for periodic ventilation and this significantly reduces air movement. Therefore, it is helpful to compare relative differences of harmful gas concentrations between treatments during the fattening period of broilers. This type of method has successfully been used in earlier research (TASISTRO et al., 2007; ĐUKIĆ STOJČIĆ et al., 2016). However, the obtained results were difficult to compare with other studies because of different measurement methods (static in closed chambers or dynamic when the chamber has ventilation), chamber size and used litter types.

Increasing patterns of NH_3 concentration were observed in treatments I, IV, V and VI. Several studies recorded similar emissions (ELWINGER and SVENSSON, 1996; REDWINE et al., 2002; KNÍŽATOVÁ et al., 2010). The peaks of NH_3 concentrations, observed on day 35 in treatments II (wood shavings), and III (mixture of 1/3 chopped wheat straw, 1/3 wood shavings and 1/3 peat) are consistent with those reported by REDWINE et al. (2002) who found an increase in NH_3 concentrations until day 35, and ATAPATTU et al. (2017) until day 25. The study was conducted in the end of spring and beginning of summer, when the temperature rises. This may be one of the reasons for higher NH_3 emission. However, this study showed that the choice of litter type does not significantly affect NH_3 concentration at the end of the fattening period. ELWINGER and SVENSSON (1996) came to the same conclusion. By the end of the study, the high broiler density could restrict exchange of water and gas between litter and air causing the increase of moisture and significant rise of NH_3 emission in all treatments.

Also, the study by BILGILI et al. (2009) showed that there were no difference between eight bedding materials tested in two trials, with NH_3 concentrations varying from 69 to 99 ppm, and 65 to 105 ppm. The higher values of NH_3 may be affected by the size of chamber used to trap the air.

However, AL-HOMIDAN et al. (2018) reported that NH_3 concentration was significantly affected by litter type. Comparing wheat straw with wood shavings, TASISTRO et al. (2007) reported 19.0% higher NH_3 emissions when wood shavings are used. This is in accordance with our study that reported the same results on days 28 and 35. Before the end of fattening period, the differences could be attributed to physical structure and density of litters to retain NH_3.

NH_3 concentrations in our study were between zero and 34.1 ± 11.9 ppm at the level of the birds' heads throughout the fattening period. ATAPATTU et al. (2017) highlights the importance of measurement height above the litter. Ammonia concentrations were 11.6% and 18.6% lower at 90 and 150 cm from the surface of litter, respectively than that at 30 cm. Using chopped wheat straw (1.6 kg/m^2), and taking the measurements from the ceiling, KNÍŽATOVÁ et al. (2010) reported NH_3 concentrations between 0.0 and 29.1 ppm.

The critical values of NH_3, above 20.0 ppm, were reached for the first time on day 28 in treatment II, where wood shavings were used. By the end of the fattening period, NH_3 concentrations were higher than 20.0 ppm in all treatments. The NH_3 and CO_2 concentrations increased as the growing cycle progressed. Namely, with age the feed consumption increases and this leads to an increased excretion of faeces and an increased accumulation in the litter. Faeces contains nitrogenous compounds: uric acid and undigested protein. Ammonia and CO_2 derives from nitrogenous compounds, in the presence of water and oxygen, through chemical and microbial decomposition (NAHM, 2003).

The initial concentrations of CO_2 varied from 233 ± 50 to 456 ± 72 ppm on the first two measurement days. The increase of CO_2 emission found in this study after day 14 was also noticed by PEREIRA et al. (2018). The increase of CO_2 from litter could be explained by higher microbial activity, litter and broiler age (CALVET et al., 2012; LIN et al., 2012).

By the end of the fattening period, no significant difference ($P > 0.05$) was observed between treatments, and CO_2 levels did not exceed the permitted 3000 ppm.

Commonly, broiler producers have few options when it comes to litter materials due to availability, cost or both. Several studies have reported that litter type could affect bird performance and welfare (HUANG et al., 2009; RASHID et al., 2017). However, many studies reported that litter type did not affect BW (GRIMES et al., 2006; TAHERPARVAR et al., 2016). In the present study, we found that both statements are correct. The unsexed broilers reared on pelletised softwood had the highest BW gain, followed by broilers on pelletised wheat straw and chopped wheat straw, while the lowest BW gain was observed in the treatments with pelletised and non-pelletised mixtures of 1/3 wheat straw, 1/3 wood shavings and 1/3 peat (Figure 1). The observed differences in BW may be attributed to the fact that broilers display their natural behaviour on wood-based litter and straw (MUNIR et al., 2019), thus increasing broiler comfort and performance. On the other hand, the greater BW of broilers could be attributed to the fact that chicks were not sexed at the beginning of experiment. An overall positive effect was found in the treatments with chopped wheat straw, wheat straw pellets and softwood pellets, where 61.29%, 61.96% and 63.04% were male chickens, respectively. The treatments that had higher body weight had more male chickens compared to other treatments. The presence of male chickens in treatments II, III and VI were 54.35%, 56.04% and 52.75%, respectively. The male broiler chickens tend to grow heavier than the females indicating the presence of sexual dimorphism.

Conclusion

The study shows that broiler age and litter type increase ammonia and carbon dioxide emissions. By the end of fattening period, the broilers were exposed to ammonia concentrations above the maximum recommended level in all treatments. The CO_2 concentrations were below the maximum recommended level in all treatments throughout the whole fattening period. Based on these findings, and in order to maintain the NH_3 levels below the recommended level, further investigations will be conducted. Different natural materials and their combinations will be examined in order to obtain more precise data. The sex had a significant effect on the final body weight and it is necessary to distinguishing the sex of chickens before or after the study.

Acknowledgements

This study is part of the first author's PhD thesis. The research was supported by the Ministry of Education Science and Technological Development, Republic of Serbia as a part of the Project numbers TR 31084 and TR 31071.

Authors' contributions

KS and DM created the experimental design. KS, VKS and PM carried out the experiment, made substantial contribution to collection, analysis and interpretation of the data and participated in manuscript writing. RZ performed statistical analysis and made substantial contributions to interpretation of data. KS, VKS and ĐSM made contributions to conception and design of the article and drafted the manuscript. ŽBM read the manuscript and made corrections in the document. All authors have approved the final version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

AL-HOMIDAN, I., M.M. FATHI, A. AL-SHUMAYMIRI, 2018: Chopped palm leaves as an acceptable bedding material for broiler production. J. Appl. Poult. Res. **27**, 59-64.

ATAPATTU, N.M., L.G.E. LAKMAL, P.W.A. PERERA, 2017: Effects of two litter amendments on air NH3 levels in broiler closed-houses. Asian-Australas. J. Anim. Sci. **30**, 1500-1506.

AVIAGEN, 2018: ROSS Broiler Management Handbook. http://en.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-BroilerHandbook2018-EN.pdf [accessed 14.06.2020].

BILGILI, S.F., J.B. HESS, J.P. BLAKE, K.S. MACKLIN, B. SAENMAHAYAK, J.L. SIBLEY, 2009: Influence of bedding material on footpad dermatitis in broiler chickens. J. Appl. Poult. Res. **18**, 583-589.

BREWER, S.K., T.A. COSTELLO, 1999: In situ measurement of ammonia volatilization from broiler litter using an enclosed air chamber. Trans. ASABE **42**, 1415-1422.

CALVET, S., F. ESTELLÉS, M. CAMBRA-LÓPEZ, A.G. TORRES, 2012: Measuring ventilation using carbon dioxide balances: Evolution of CO_2 production from litter in two broiler cycles. In 2012 IX International Livestock Environment Symposium (ILES IX) (p. 3). Trans ASABE, 1-6.

COUNCIL DIRECTIVE, 2007/43/EC, 2007: of 28 June 2007 laying down minimum rules for the protection of chickens kept for meat, Official Journal of the European Union, L 182/19. https://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:182:0019:0028:EN:PDF [accessed 14.06.2020].

DAWKINS, M.S., C.A. DONNELLY, T.A. JONES, 2004: Chicken welfare is influenced more by housing conditions than by stocking density. Nature **427**, 342-344.

ĐUKIĆ STOJČIĆ, M., S. BJEDOV, D. ŽIKIĆ, L. PERIĆ, N. MILOŠEVIĆ, 2016: Effect of straw size and microbial amendment of litter on certain litter quality parameters, ammonia emission, and footpad dermatitis in broilers. Arch. Anim. Breed. **59** (1), 131-137.

ELWINGER, K., L. SVENSSON, 1996: Effect of dietary protein content, litter and drinker type on ammonia emission from broiler houses. J. Agric. Engng. Res. **64**, 197-208.

GARCÊS, A.P.J.T., S.M.S. AFONSO, A. CHILUNDO, C.T.S. JAIROCE, 2013: Evaluation of different litter materials for broiler production in a hot and humid environment: 1. Litter characteristics and quality. J. Appl. Poult. Res. **22**, 168-176.

GARCIA, R.G., I.C.L. ALMEIDA PAZ, F.R. CALDARA, I.A. NÄÄS, D.F. PEREIRA, V.M.O.S. FERREIRA, 2012: Selecting the most adequate bedding material for broiler production in Brazil. Rev. Bras. Cienc. Avic. **14**, 121-127.

GRIMES, J.L., T.A. CARTER, J.L. GODWIN, 2006: Use of a litter material made from cotton waste, gypsum, and old newsprint for rearing broiler chickens. Poult. Sci. **85**, 563-568.

HUANG, Y., J.S. YOO, H.J. KIM, Y. WANG, Y.J. CHEN, J.H. CHO, I.H. KIM, 2009: Effect of bedding types and different nutrient densities on growth performance, visceral organ weight, and blood characteristics in broiler chickens. J. Appl. Poult. Res. **18**, 1-7.

KIRYCHUK, S.P., J.A. DOSMAN, S.J. REYNOLDS, P. WILLSON, A. SENTHILSELVAN, J.J. FEDDES, W. GUENTER, 2006: Total dust and endotoxin in poultry operations: comparison between cage and floor housing and respiratory effects in workers. J. Occup. Environ. Med. **48**, 741-748.

KNÍŽATOVÁ, M., Š. MIHINA, J. BROUČEK, I. KARANDUŠOVSKÁ, J. MAČUHOVÁ, 2010: The influence of litter age, litter temperature and ventilation rate on ammonia emissions from a broiler rearing facility. Czech. J. Anim. Sci. **55**, 337-345.

LIN, X.J., E.L. CORTUS, R. ZHANG, S. JIANG, A.J. HEBER, 2012: Air emissions from broiler houses in California. Trans. ASABE **55**, 1895-1908.

MENDES, A.S., S.J. PAIXÃO, R. RESTELATTO, R. REFFATTI, J.C. POSSENTI, D.J. DE MOURA, T.M.R. DE CARVALHO, 2011: Effects of initial body weight and litter material on broiler production. Rev. Bras. Cienc. Avic. **13**, 165-170.

MILES, D.M., D.E. ROWE, T.C. CATHCART, 2011: Litter ammonia generation: Moisture content and organic versus inorganic bedding materials. Poult. Sci. **90**, 1162-1169.

MUNIR, M.T., C. BELLONCLE, M. IRLE, M. FEDERIGHI, 2019: Wood-based litter in poultry production: a review. Worlds Poult. Sci. J. **75**, 5-16.

NAHM, K.H., 2003: Evaluation of the nitrogen content in poultry manure. Worlds Poult. Sci. J. **59**, 77-88.

NAHM, K.H., 2005: Factors influencing nitrogen mineralization during poultry litter composting and calculations for available nitrogen. Worlds Poult. Sci. J. **61**, 238-255.

NI, J.Q., C.A. DIEHL, L. CHAI, Y. CHEN, A.J. HEBER, T.T. LIM, B.W. BOGAN, 2017: Factors and characteristics of ammonia, hydrogen sulfide, carbon dioxide, and particulate matter emissions from two manure-belt layer hen houses. Atmos. Environ. **156**, 113-124.

PEREIRA, J.L., S. FERREIRA, V. PINHEIRO, H. TRINDADE, 2018: Ammonia, nitrous oxide, carbon dioxide and methane emissions from commercial broiler houses in Mediterranean Portugal. Water Air Soil Pollut. **229**, 377.

RASHID, A., M.T. BANDAY, S. ADIL, A.A. KHAN, S. QURESHI, M. UNTOO, M.A. PAL, 2017: Effect of chemically treated litter on ammonia emmission, performance and carcass characteristics of broiler chicken. J. World Poult. Res. **7**, 88-93.

REDWINE, J.S., R.E. LACEY, S. MUKHTAR, J.B. CAREY, 2002: Concentration and emissions of ammonia and particulate matter in tunnel–ventilated broiler houses under summer conditions in Texas. Trans. ASAE **45**, 1101-1109.

RELIĆ, R., E. SOSSIDOU, A. DEDOUSI, L. PERIĆ, I. BOŽIČKOVIĆ, M. DUKIĆ-STOJČIĆ, 2019: Behavioral and health problems of poultry related to rearing systems. Vet. Fak. Derg. **66**, 423-428.

SCHMIDT, D.R., L.D. JACOBSON, K.A. JANNI, 2002: Continuous monitoring of ammonia, hydrogen sulfide and dust emissions from swine, dairy and poultry barns. In: 2002 ASAE Annual Meeting. Biol. Eng. Trans. 1-14.

SWAIN, B.K., R.N.S. SUNDARAM, 2000: Effect of different types of litter material for rearing broilers. Br. Poult. Sci. **41**, 261-262.

TAHERPARVAR, G., A. SEIDAVI, L. ASADPOUR, R. PAYAN-CARREIRA, V. LAUDADIO, V. TUFARELLI, 2016: Effect of litter treatment on growth performance, intestinal development, and selected cecum microbiota in broiler chickens. Rev. Bras. de Zootec. **45**, 257-264.

TASISTRO, A.S., C.W. RITZ, D.E. KISSEL, 2007: Ammonia emissions from broiler litter: response to bedding materials and acidifiers. Br. Poult. Sci. **48**, 399-405.