Monitoring of ammonia concentrations from coir-husk litter of Brazilian poultry house using diode laser photoacoustic spectroscopy

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Abstract Ammonia (NH₃) from manure is a concern in raising broiler due to possible damages to production and the environment. Brazil is the main exporter of chicken meat in the world and is also responsible for large waste of poultry litter. The country, likewise, figures as top 5 producers of green coconut, which results in considerable volumes of waste, since 80%-85% of the fruit is unusable. This work analyzes the ammonia concentration profile of two bedding substrates for raising broiler, to know, coir-husk fiber and a commonly used pine wood shavings in a Brazilian climate. A differential home-made photoacoustic cell combined with a diode laser was employed for sensing ammonia at trace levels. Such combination confers selectivity as well as lower limits of detection to the system. The chemical compositions pH, N, C, Ca, Mg, P₂O₅ and K₂O were also determined, in addition to the moisture, dry matter and mineral content of substrates and litters. NH₃ concentrations varied from (0.9 ± 0.3) ppmv to (19 ± 3) ppmv and from (2.1 ± 0.5) ppmv to (21 ± 3) ppmv for the coir-husk fiber and wood shavings substrates, respectively. Results showed the feasibility of using coconut fiber as poultry litter in regions where this material is a common waste. Moreover, as NH₃ concentrations were lower for coconut fiber bedding compared to shavings, this coir-husk fiber is a potential residue to guarantee the environmental sustainability by Brazilian poultry farming. Coir-husk fibers presented significantly higher amounts of P and K in comparison to pine wood. NH₃ profiles revealed that coir-husk fiber emitted lower quantities than wood shavings. Besides, a delay on the NH₃ emission pattern was clearly seen when the coconut waste was the bedding material. Such a tendency was confirmed by the logistic model. Our findings, in turn, make the coir-husk an environmentally friendly alternative low-cost product for poultry litter as well as its potential use as natural fertilizer. The later deserves attention since there is a need to accurately assess the emissions of methane, nitrous oxide, and carbon dioxide during the composting process. In Brazil, the waste generated by the high production of green coconut is an environmental liability. The cost of poultry production has been high, reducing the profit of producers, who seek to make production cheaper. Measuring NH₃ from poultry activity in Brazil, a tropical country, aims to control management and reduce production losses, since NH₃ is a harmful gas to birds. The measurement of NH₃ concentrations at trace levels from raising broilers by photoacoustic diode laser
spectroscopy, to the best of our knowledge, has been reported for the very first time.

**Keywords** Ammonia · Environmental sustainability · Photoacoustic spectroscopy · Poultry litter

**Introduction**

Ammonia ($\text{NH}_3$) is a dangerous air pollutant present in animal excreta (cattle, horses, sheep, pigs and birds), synthetic fertilizers, products used in biomass burning and in refrigeration (ATSDR, 2020). The loss of volatilized $\text{NH}_3$ occurs when $\text{NH}_4^+$ is converted into gas in the reaction: $\text{NH}_4^+ \rightleftharpoons \text{NH}_3 + \text{H}_2\text{O}$ (alkaline conditions $\text{pKa} = 9.2$) (Bittman & Mikkelsen, 2009). Farmers using NH$_4^+$-based fertilizers (such as urea) are aware of the potential for loss and strive to minimize it. In the United States and Canada, 75% of anthropogenic NH$_3$ volatilization come from agriculture (Bittman & Mikkelsen, 2009); similarly the United Kingdom amounts to 88% (DEFRA, 2018), where livestock farming accounts for the most. Also in China, more than 60% of NH$_3$ volatilization come from livestock, generated by the inefficient conversion of animal feed (Paulot et al., 2014). Nitrogen is metabolized and excreted; during manure decomposition the microbial activities generate NH$_3$ and CO$_2$ (Sommer et al., 2004). The NH$_3$ formation depends on several factors such as the amount of urea, urease activity, pH, temperature, relative humidity, ventilation rate, bird age, bedding handling practice, litter and moisture content (Naseem & King, 2018). Although Brazil lacks a trans-sectoral national inventory on NH$_3$ atmospheric gas emission, estimates emerge according to agrarian potential (OECD, 2015).

With the increase in the world population, it has become necessary to increase world food production on a large scale which caused a worrying growth in ammonia emissions. Environmental problems related to ammonia include soil acidification, eutrophication, acid rain and impacts on human and animal health (Bouwman et al., 1997; Insausti et al., 2020). It is also important in the formation of fine particulate matter (Coe, 2020; Liu et al., 2019; Pinder et al., 2007). In health, NH$_3$ reacts with nasal moisture, forming a corrosive solution of NH$_4^+$, which affects the respiratory system, resulting in eyelash paralysis or loss (Naseem & King, 2018). Especially in poultry, ammonia can compromise the respiratory system of birds, turning them susceptible to viral diseases, including Avian Influenza (Anderson et al., 1964; Bouwman et al., 1997; Carlile, 1984; Insausti et al., 2020; Kristensen & Watthes, 2000).

Brazil is the world’s largest exporter of chicken meat, which makes Brazilian poultry farming an important economic activity for the country. According to the Brazilian Association of Animal Protein (ABPA), 35% of the 13 million tons of chicken meat produced supply the foreign market (ABPA, 2019). Due to its size, Brazilian poultry farming generates a large amount of ammonia, making it a serious environmental problem. In addition, the market is extremely competitive, for producers are constantly looking for strategies to increase production, reduce costs, and ensure meat quality. The challenges are enormous from both economic and environmental points of view, in a way that the country can continue to lead this sector. As in Hungary, where there was a growing trade surplus during the COVID-19 pandemic (Mizik, 2021), chicken meat production in Brazil continued to grow, achieving in 2020 the highest value in the last 10 years, maintaining its export volume with a slight increase in the last three years (ABPA, 2021).

An important step in poultry activity is the choice of litter during the life cycle of birds. Even though wood shavings are commonly used as litter in order to provide comfort, absorb moisture and prevent injury to animals, their use can increase production cost depending on the farm location. To ensure more sustainable production, it is important to use regional agricultural waste (de Avila et al., 2007). Brazil is a tropical country with a high production of green coconut (Martins & de Jesus Junior, 2011). Among the various potential uses for coconut waste, its use in poultry as poultry litter has not yet been found in the literature (Nunes et al., 2020). It has fibers with high porosity, N fixation potential (Mattos, 2011; de Oliveira et al., 2018) and high adsorptive potential (Etim et al., 2016; Kithome et al., 1999). Litter can emit more NH$_3$ under conditions of low relative humidity and high temperature (Seedorf et al., 1998).

To evaluate the NH$_3$ volatilization from poultry litter, a differential resonant photoacoustic sensor was used (Lima et al., 2014). The photoacoustic sensor differs from the traditional ones in the way it detects...
light absorption. In traditional transmission sensors, the fraction of the absorbed light is monitored by comparing the light intensity according to the presence or absence of gas absorption. In photoacoustic sensors, however, the absorbed light is directly measured (Hodgkinson & Tatam, 2013), ensuring greater sensitivity. Already consolidated in science, photoacoustics has been used to detect gases (according to the radiation source used) and different applications (Bueno et al., 2015; Corrêa, 2011; Filho et al., 2008; Linhares et al., 2019; Pereira et al., 2009; Pinheiro et al., 2019; Schmohl et al., 2002; da Silva et al., 2003; Sthel et al., 2011, 2012; Webber et al., 2005). Nonetheless, photoacoustics combined with the use of QW-DFB lasers as a radiation source is a novelty at monitoring NH₃ employed to indoor gas samples from broiler raising in Brazil, in which electrochemical and simple commercial infrared sensors are generally used—as the Chillgard RT—which tend to have lower selectivity and accuracy (Li et al., 2015). Another relevant aspect is that given its high adsorption capacity, ammonia is considered a molecule that is difficult to detect, particularly when applying conventional techniques (Li et al., 2015). Thus, this work aims to measure NH₃ and analyze its volatilization profile for litter broiler made from coir-husk, by means of a photoacoustic sensor combined with a diode laser.

It was possible to accurately measure and trace the profile of NH₃ volatilization of coir-husk and wood shavings litters and identify lower and later emissions in the litter that was used coir-husk fiber, which shows a potential for N fixation by this substrate, suggesting strongly its use in this sector. In addition, analyses of the chemical composition of these litters showed significantly higher concentrations of P and K in coir-husk fiber, essential components along with N in agricultural fertilization, in particular in food and biofuel crop production. On the other hand, tropical soils tend to be poor in N, P and K (Isah et al., 2020). Thus indicating that after use as poultry litter, this material can be composted and used as a natural fertilizer in agriculture (Frazão et al., 2021), once again promoting sustainability and making production cheaper, since Brazil has large agricultural areas, being one of world’s leading producers and suppliers of food, fibers and bioenergy (Fao, 2017) and is highly dependent on imported fertilizers, mainly from Russia, which makes this research highly important for the Brazilian agricultural sector.

Methods

Facilities and animals

The experiment was carried out in Campos dos Goytacazes, northeastern Rio de Janeiro State. It is located at latitude 21°45’16” south, longitude 41°19’28” west, and at about 11 m - 13 m above sea level. Two poultry open-sided-housing of 120 m² with the same facilities: five boxes with 2.1 m by 1.2 m (2.5 m²); side openings covered with 1’ screen and barn curtains; two circulation fans; three electric heaters; a thermohygrometer; and each box containing a manual feeder and an automatic drinker (Fig. 1) were used. The houses only differed in the type of litter substrate used. Each floor pen housed thirty-two seven-day-old fast-growth broiler chicks, with 181 g of average body weight (ABW), of the genetic strain Cobb-500®, for 12.7 chicks m⁻² or 2.3 kg m⁻² of early density. The broilers grew inside the boxes until 42-day-old, and in cases of death the chick was replaced to maintain the density. Later density was of 36.6 kg m⁻² because the broilers grew at an average rate of 77.37 g per bird per day. Feed and water intake were ad libitum.

The broilers were fed diets based on corn and soybean with decreasing values of metabolizable energy between 3000 kcal kg⁻¹ and 3150 kcal kg⁻¹, and increasing values of crude protein between 208 g kg⁻¹ and 183 g kg⁻¹ according to the growth phase: start (7-21 days-old), growth (22-35 days-old) and final (36-42 days-old) (Albino, 2017). There were no differences (p > 0.05) in the ABW (2.89 kg vs. 2.88 kg) nor in

Fig. 1 Ground floor plan of poultry housing with five floor pens
the average of feed intake (4.5 kg vs. 4.6 kg per bird) of the 42-day-old broilers between houses. The daily record of temperature and relative humidity (max., min., and average) are depicted in Fig. 2. Values varied from 24.1°C to 32.6°C (Fig. 2a), and from 54% to 78% (Fig. 2b), respectively; however, there were no significant differences ($p > 0.05$) between houses.

Substrates for litter

For each shed, a type of substrate was used to cover the floor pens, pine wood shavings and immature coconut coir-husk fiber. This separation was important to avoid interference in gas collection, thus guaranteeing accuracy in the collection process. Pine wood shavings were obtained commercially. Immature coir-husk fiber is the residue of the coconut water bottling industry and was donated by a coconut producer farm, located in the region. The husk of approximately 200 coconuts was removed with the help of a tractor and the fiber was placed on a table made of monofilament screen (Sombrite®) for sun drying, on which the material was turned over three times a day (at 8 h, 12 h, 16 h) for five days to avoid fermentation. The amount of substrate in each floor pen was standardized according to the percentage of dry matter of the materials, being 6.23 kg of coir-husk fiber and 6.00 kg shavings per floor pen. Samples of each substrate and of litter of each floor pen after the broilers leave (42 days old) were collected to assess the chemical composition by AOAC methodologies (Horwitz, 2000). The pH, N, C, Ca, Mg, P$_2$O$_5$ and K$_2$O were analyzed according to (Malavolta et al., 1997). From the values of C and N, the C/N ratio was calculated, an important variable for composting the bed and posterior use as a biofertilizer. The chemical composition of the substrates is shown in Table 1.

Sample gas collection

Gaseous samples were collected in each pen at the height of the bird beaks, by means of a suction pump (AVOCS), and stored in Tedlar bags 20 L, made of Polyvinyl fluoride (PVF), a material that minimizes adsorption of polar molecules such as ammonia (Fig. 3). To insert the gaseous sample in the photoacoustic detection system (PA), a Gilian-Sensidyne flow pump (model LFS-113DC) was used, adjusted to 200 sccm (standard cubic centimeter per minute). Seven collections were carried out corresponding to the 15th, 21st, 24th, 28th, 35th and 39th day of life of broilers, thus going through

![Fig. 2](image-url) Mean temperature (°C) and relative humidity (%) in the poultry housing during the experimental period. Vertical bars represent the standard deviation.

| Table 1 | Chemical composition of litter. A composite sample per each substrate |
|---------|---------------------------------|
| Composition [g kg$^{-1}$] | Coir-husk fiber | Wood shavings |
| Dry matter | 895 | 929 |
| Moisture | 105 | 71.0 |
| Mineral matter | 9 | 2 |
| C | 518 | 557 |
| N | 6.9 | 2.3 |
| Ca | 1.6 | 0.5 |
| Mg | 1.7 | 0.6 |
| pH (H$_2$O) | 3.7 | 4.6 |
| P$_2$O$_5$ | 1.8 | 0.4 |
| K$_2$O | 15.1 | 0.7 |
| C/N | 76 | 121 |
all stages of raising, which are: initial, growth and final. The collection started from the 15th day of life of broilers, for at the very beginning of raising there is low feed consumption and, consequently, low residue density, just as mentioned by (Calvet et al., 2011), that before the 15th day NH$_3$ concentration levels are negligible.

Photoacoustic sensing of ammonia

The photoacoustic sensor for NH$_3$ detection required a compact differential cell (6.6 cm × 5.4 cm × 3.0 cm), with high sensitivity, fast response time, low electronic and audible noise (Lima et al., 2014). Basically, the cell consists of two zinc selenide (ZnSe) optical windows with anti-reflective film according to the wavelength range. The resonator tubes have a cylindrical shape, 23.2 mm long and 3.8 mm in diameter, and are equipped with microphones (Knowles Electronics, TM 24547-C36) symmetrically coupled into the middle of the tubes. The microphones were carefully selected so that they have the same frequency of response, in other words, that they are matched. The resonant quality factor (Q) is approximately 10, with the resonant frequency around 6.4 kHz. For the radiation source a laser diode QW-DFB (EM4 model E0054271) was used, mounted on a butterfly support (Thorlabs, LM 1452). Figure 4 shows the assembly of this detection system. The laser diode was coupled to the cell via PM-type optical fiber (with 125 mm and 8 mm, outer diameter and core, respectively), which facilitates the alignment of the radiation beam.

**Fig. 3** Sample gas collection

**Fig. 4** Photoacoustic experimental setup for sensing ammonia
the aid of the laser driver (Melles Griot, 06 DLD 103) it was possible to adjust the diode current and temperature. The laser injection current was modulated with amplitude at 58 mA continuous +8 V, totaling 214.5 mA, and the duty cycle of 70%. The photoacoustic signal generated in the cell was amplified and filtered by a lock-in amplifier (LIA) at the resonance frequency of the photoacoustic cell. The LIA time constant was set at 300 ms. Mass flow controllers (Alicat Scientific MC-200SCCM-D) were used to prevent turbulent gas flow into the cell. Turbulent flows can cause undesirable background signals, in addition to damaging the microphone membranes.

Figure 5a shows the photoacoustic spectrum of 100 ppmv of NH₃ (certified) between 1529.5 nm and 1533.5 nm, obtained by varying the laser temperature in the range of -10 °C to 30 °C. Figure 5b shows the experimental NH₃ spectrum obtained from the Pacific Northwest National Laboratory (PNNL) database. We observed an aligned agreement between the coinciding NH₃ peaks in the spectra, and we highlight the one at 10.7 °C which corresponds to 1531.7 nm (dashed lines). For being the most intense absorption in this region, it was chosen for the calibration measures of the photoacoustic NH₃ detection apparatus. Another relevant aspect is the non-interference of water vapor absorption in this wavelength range. The NH₃ limit of detection (LOD) was 500 ppbv (parts per billion by volume). Figure 6 shows the calibration curve previously prepared and quite well linearly fitted with R² = 0.997. Horizontal and vertical bars are the standard deviations for both NH₃ concentration and PA amplitude, respectively. Further details concerning calibration procedures may be found in (Lima et al., 2014).

Data analysis

Data were analyzed by using mixed models with repeated measures along this analytical step together with Tukey’s test. In the analyses, a significance of 5% was considered. In order to outline the concentration pattern over time, trend curves of NH₃ volatilization were obtained for each treatment by means of the logistic model according to Eq. 1:

\[ y = \frac{a}{1 + b \exp(-cx)}, \]

where \( y \) represents the concentration on collection day \( x \), \( a \) represents the maximum concentration limit, \( b \) does not represent a biological value because it only reflects the choice of time zero, and \( c \) is the constant of the curve speed over time (de Barros Reicao Cordido, 2019).

![Fig. 5 NH₃ temperature scan (a). Experimental NH₃ spectrum obtained from the PNNL database (b)](image)

![Fig. 6 Calibration curve for ammonia. Horizontal and vertical bars stand for the standard deviations. A LOD of 500 ppbv was experimentally achieved](image)
Results and discussion

Ammonia volatilization

The profile of ammonia volatilization from the different litters in poultry houses during the raising of broilers is shown in Fig. 7. Results ranged from (0.9 ± 0.3) ppmv (parts per million by volume) to (19 ± 3) ppmv of ammonia for the coconut fiber substrate, and from (2.1 ± 0.5) ppmv to (21 ± 3) ppmv for the wood shavings substrate. The maximum NH$_3$ concentration, estimated by the logistic model (parameter $a$), was higher for the shavings litter substrate (20.85 ppmv) compared to that of green coconut coir-husk fiber (17.61 ppmv) (Table 2).

Moreover, in relation to NH$_3$ volatilization in poultry houses, significant interaction ($p < 0.01$) was observed between the factors, namely, the type of litter substrate and the day of sampling. In the pen with coconut coir-husk fiber litter there was a significant increase ($p < 0.01$) in the NH$_3$ concentration from day 28, whereas in the pen with wood shavings litter the increase was detected earlier, starting on day 21, as shown in Fig. 7a. In all samplings, the average NH$_3$ concentration values were higher when using wood shavings compared to those of coir-husk fiber, with significant differences between the types of substrate in the samples from days 21, 31 (*, $p < 0.05$) and 24 (***, $p < 0.0001$). However, in the samples of days 15, 28, 35 and 39 there were no differences ($p > 0.05$) in the volatilization profiles for the two types of substrates (Fig. 7a).

During broiler raising, the trend curves obtained by adjusting logistic models confirmed that the pattern of NH$_3$ volatilization differed when using different litter substrates. Figure 7b shows that the upper plateau of the volatilization curve for wood shavings litter was reached in broilers early stage of growth and remained until the end of the rearing cycle. On the other hand, when using coir-husk fiber, the concentration reached the upper plateau after 42 days, at slaughter age. The difference in NH$_3$ volatilization patterns may be attributed to a greater NH$_4^+$ adsorption capacity of the coir-husk fiber, which would explain the delay in NH$_3$ volatilization. The pH may have influenced this result, because it is responsible for controlling the magnitude of the electrostatic charges transmitted by the ionized molecules (Onal et al., 2006). The substrates pH was measured before broiler raising started, and it showed that the pH of the coconut shell fiber was 3.7, whereas that of wood shavings was 4.6. The lower the pH, the greater is the availability of H$_3$ ions, and consequently, the greater is N fixation in the form of NH$_4^+$. Moreover, in the experiments by (Kithome et al., 1999), coir-husk fiber

![Fig. 7 Effect of the bed substrate of experimental poultry on NH$_3$ concentration (ppmv) during broiler breeding). a Mean ± SD of the observed values. b Trend curves of NH$_4^+$ volatilization during broiler breeding, obtained by sigmoidal logistic models. * $p < 0.05$ and *** $p < 0.0001$](image)

### Table 2

Equation parameters adjusted to NH$_3$ volatilization data in poultry litter using different substrates

| Parameter | Green coconut shell fiber | Wood shavings |
|-----------|---------------------------|---------------|
| $a$       | 20.85                     | 17.61         |
| $b$       | $2.25 \times 10^7$        | $2.67 \times 10^{19}$ |
| $c$       | 0.80                      | 0.89          |
| Standard error | 2.94                  | 3.53          |
| Correlation coefficient | 0.95                  | 0.94          |
demonstrated a high capacity to retain cations and to dampen changes in pH given its high buffering resistance, hence avoiding or delaying NH$_3$ volatilization. The high buffering effect of coir-husk fiber has been attributed to weak acidic functional groups, such as carboxylic and phenolic groups.

A NH$_3$ concentration peak occurred in all samples collected on day 28. This phenomenon can be explained by the change in the production phase, with increased feed and energy consumption, that expands the broilers metabolic rate and density (kg of body mass m$^{-2}$) in this period. As part of the management, from the 29th day onwards, the opening of the curtains enabled the reduction of ambient temperature. Thus, NH$_3$ concentrations emitted in the following days (31, 35 and 39) were lower than the peak described. Most likely, there was an increase in NH$_3$ production in all stalls, which was dissipated by increased ventilation. (Calvet et al., 2011) observed greater concentration (35 ppmv) on the 28th during the winter period and a considerable increase of NH$_3$ in the summer from the 28th day on, in a poultry farm in Spain, where rice husk was used as substrate. (Pereira, 2017) also found a large increase in NH$_3$ concentration from the 28th day of the growth cycle on, in poultry houses in Portugal, and whose experiment used rice husk and happened during winter.

(Calvet et al., 2011) and (Pereira, 2017) used commercial multi-gas analyzers based on INNOVA photoacoustics (model 1412i-5). This type of detector uses optical filters for each gas species to be detected, differently from the photoacoustic sensor used in this work, which employs a very narrow absorption wavelength line laser to precisely select the molecule to be detected, thus preventing interference from other gaseous species contained in the sample. (Pereira, 2017) collected the gaseous sample by means of a 1.5 L Tedlar bag and measured the samples within 24 hours. Being familiar with the adsorption potential of a polar molecule such as ammonia, the amount of sample collected and the maximum NH$_3$ amount of 8.6 ppmv obtained in the experiment, compared to that of the experiment by (Calvet et al., 2011), who obtained a maximum of 35.9 ppmv, leads us to believe that the values obtained probably underestimated the real values of the collected sample, over the possibility that part of the NH$_3$ had been adsorbed on the collector surface at storage.

On the eve of the 24th day, the litters were turned over for homogenization in the two warehouses (standard bed management procedure). The NH$_3$ concentration on the 24th day increased considerably regarding shavings litters. Unlike the coir-husk fiber litter which was moister, the shavings litter remained drier and loose. Data related to humidity between litters, before and after the experiment, are presented in Tables 1 and 3. This significant difference in humidity may also have contributed to the NH$_3$ volatilization profile observed for both litters. Cobb’s management guide establishes a maximum of 10 ppmv of NH$_3$ to maintain air quality for broilers in sheds (COBB, 2013). (Donham et al., 2002), however, state that the recommended ammonia concentration for workers in poultry houses by AIHA, ACGIH and NIOSH must remain below 25 ppmv, so that there are no risks to human health.

It is a consensus in literature that NH$_3$ is the most important gas molecule released from litter materials

| Chemical composition of litter after experimental period. $n = 5$ per type of litter |
|---------------------------------------------------------------|
| **Composition [g kg$^{-1}$]** | **Immature coir-husk fiber** | **Wood shavings** | **p value** |
| Dry matter | $(42 ± 4) × 10$ | $(47 ± 2) × 10$ | 0.0137 |
| Moisture | $(58 ± 4) × 10$ | $(53 ± 2) × 10$ | 0.0137 |
| Mineral matter | $(19 ± 1) × 10$ | $(18 ± 1) × 10$ | 0.0725 |
| C | $(37 ± 2) × 10$ | $(39 ± 2) × 10$ | 0.4669 |
| N | $41.5 ± 0.7$ | $40 ± 2$ | 0.6408 |
| Ca | $28.8 ± 0.7$ | $21.6 ± 0.9$ | 0.5045 |
| Mg | $5.8 ± 0.1$ | $5.3 ± 0.3$ | 0.1747 |
| pH (H$_2$O) | $6.5 ± 0.1$ | $6.4 ± 0.1$ | 0.0185 |
| P$_2$O$_5$ | $49 ± 1$ | $43 ± 2$ | 0.4937 |
| K$_2$O | $53 ± 1$ | $45 ± 1$ | 0.0029 |
| C/N | $9.1 ± 0.6$ | $9.9 ± 0.5$ | 0.3401 |
devoted to poultry rearing (Swelum et al., 2021). Therefore, it deserves special attention. Particularly in broiler farming, where confinement is practiced, the primary source of NH₃ is the microbial decomposition of uric acid present in animal excreta. These bacteria are responsible for the microbial breakdown of urea and uric acid contained in fecal material up to 60%. Moreover, temperature, relative humidity, litter moisture and pH may also affect the way NH₃ is emitted from the bedding material. There were no significant differences between the litters concerning temperature and relative humidity data (Fig. 2) during a 42-day growth cycle. Thus, we suggest that these variables might not play a role on the NH₃ volatilization profile.

Prior to the experiment has begun, coir-husk fiber and wood shavings showed quite different values for litter moisture and pH. Besides, the C/N ratio is higher for the wood shavings (Table 1). That is to say, the availability of carbon (C) is higher as well, and C is known as an energy source for microorganisms (Mehnaz et al., 2018; Wang et al., 2021). These bacteria are responsible for the microbial decomposition of urea and uric acid contained in fecal material up to the production of NH₃. Such different initial values may be responsible for the delayed NH₃ volatilization in coir-husk litter. Post experiment, moisture, pH and C/N did not reveal any significant differences between the beds (Table 3). These data could be the reason that from the 35th day onwards, the profile of NH₃ volatilization was no longer significantly different.

Litter composition

Table 3 shows the chemical composition of the litters after the experimental broiler raising. The techniques employed to obtain these data were the same as those used for Table 1. Coir-husk fiber litters were significantly wetter compared to those made of wood shavings (p < 0.05). Levels of mineral matter, C, N, Ca, Mg, the C/N ratio and the pH did not differ between the types of litter in the samples collected after broiler rearing (p > 0.05). On the other hand, P₂O₅ and K₂O levels were significantly higher (p < 0.05) in litters with coconut coir-husk fiber compared to wood shaving ones. (Abad et al., 2002) claim that the P and K index in coir-husk fiber markedly exceeds the concentration ranges.

Before usage, C levels greater than 500 g kg⁻¹ were measured for both substrates, and the N content in the coconut coir-husk fiber (6.9 g kg⁻¹) was three times higher than that of wood shavings (2.3 g kg⁻¹). Consequently, the C/N ratio in coir-husk fiber (76) was lower than that of wood shavings (121) (Table 1). After the broilers were reared, litter samples showed no differences in-between related to levels of C of N, the C/N ratio and the pH (p > 0.05). C levels fell below 400 g kg⁻¹, whereas N rates increased above 40 g kg⁻¹, which led to C/N ratio values between 9 and 10 for both types of litter (Table 3). This reduction in C and increase in N is on account of birds manure deposited on the litter. Despite being a N-rich material, manure decomposition releases CO₂ and NH₃, where the N input is much greater than the N loss (Tan et al., 2019). It is worth mentioning that despite no significant difference is found in NH₃ concentrations between both litters by the end of broiler rearing cycle, this work did not verify variations in the litters regarding their chemical composition, pH and microbiological activity and load, occurred during breeding and raising period. Hence, it was not possible to establish relationships between the differences observed in the NH₃ concentration and the possible N retention capacity of the litters.

Conclusion

A compact photoacoustic sensor applied to poultry industry is proven to be efficient in determining NH₃ concentration variations from poultry litter containing different substrates, e.g., coconut coir-husk fiber and wood shavings. Concentrations between (0.9 ± 0.3) ppmv and (19 ± 3) ppmv for the coconut fiber and (2.1 ± 0.5) ppmv and (21 ± 3) ppmv for the wood shavings were measured. Besides, a delay on the NH₃ emission pattern was clearly seen when the coconut waste was the bedding material. Such a tendency was confirmed by the logistic model. Understanding the NH₃ volatilization pattern is important in order to determine when to apply emission reduction techniques, for actually these different volatilization patterns found herein reflect the state of litter. It is well known that Brazil is highly dependent on fertilizers imported mainly from Russia, with large areas of agricultural production, responsible
for an important part of the world supply of food, fiber and bioenergy. In this scenario, coir-husk fibers presented significantly higher amounts of P and K in comparison to pine wood. Our findings indicate that the coir-husk showed to be an environmentally friendly low-cost material for poultry litter as well as its potential use as natural fertilizer. The later deserves attention since there is a need to accurately assess the emissions of methane, nitrous oxide, and carbon dioxide during the composting process. Another point to be stressed out, is the possibility of turning the production cheaper. This can be achieved by replacing the wood derivatives with coconut residue. It is then important to deepen research on the physical structure of these materials in order to understand the effects on ammonia volatilization, because differences in the material porosity and contact surface area may interfere in the adsorption/desorption dynamics of this molecule.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Consent to publish Not applicable.

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

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