Outdoor measurements of airborne emission of staphylococci from a broiler barn and its predictability by dispersion models

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Abstract

A field study was undertaken to determine the distance travelled by airborne staphylococci from a commercial broiler barn and to evaluate qualitatively and quantitatively the accuracy of predicted downwind concentrations 1.5m above ground in the ambient air as revealed by a Gaussian plume and Langrangian particle dispersion model. Field measurements showed that coagulase-negative staphylococci emitted from the barn decreased exponentially on the downwind side of the building. At least 4260 colony-forming units per m^3 air were detected in 477m distance. The airborne transmission of the staphylococci was chiefly determined by the main wind direction, and this was in principle confirmed by the dispersion models applied here. However, the accuracy of predictability was unsatisfactory, and the values calculated by the two models were generally contradictory.
Keywords: bioaerosol emission, staphylococci, broiler, airborne transmission, dispersion models.

1 Introduction

Farm animal production is increasingly under public pressure because it is responsible for the release of considerable amounts of solid, liquid and gaseous emissions into the environment. Among the most important types of such aerial pollutants are the so-called bioaerosols, which are also released by the ventilation systems of livestock buildings. Bioaerosols in animal confinement buildings consist of a complex mixture of organic dust (e.g. proteins, polycarbohydrates), biologically active components (e.g. endotoxins, glucans) and microorganisms (e.g. bacteria, fungi). Sources of indoor releases are feed, bedding material, the animals themselves and their faeces [1]. Typically, bioaerosols are characterised by a range of biological properties which include infectivity, allergenicity, toxicity and pharmacological or similar effects [2]. Because of these impacts, bioaerosols are recognised as important health hazards at least for workers in livestock operations [1, 3]. Therefore, it is assumed that emitted bioaerosols may also play a role in respiratory affections of people living in the vicinity of animal enterprises.

Broiler barns are the most potent bioaerosol emitting facilities [4], but little is known on the role and fate of emitted bacteria in the surroundings, the transmission distances of these agents, their dynamic behaviour and dispersion in ambient air, and the individual receptor concentrations (immissions) at various distances in the vicinity. Some decades ago transmission distances from poultry facilities were reported in the range of approximately 100m to 300m [5-7], but it remained unclear if these basic data generally apply to the majority of poultry houses, including broiler barns. Such information is essential for the assessment of the exposure risk of residents now housed near broiler flocks.

One way to show the spatial distribution of airborne bacteria originating from the air of broiler barns is to use viable indicator bacteria which can be clearly related to a specific emitting livestock building, because animals or bedding materials themselves are unquestionably the source. Such indicator bacteria must have a sufficient survival time in the airborne state and occur at high emission rates, because the detection of these organisms at longer distances downwind of the animal housing depends on the strength of their source. Staphylococci in particular fulfil these requirements. This group of bacteria is the most predominant cultivable genus in broiler dust. At a concentration of approximately 10^9 CFU/g [8], staphylococci generally represent an overall proportion of > 80% of total bacteria [9]; furthermore, they can be specified on selective cultivation media and by biochemical and molecular biological detection methods [10].

The aim of this report was to present preliminary groundbreaking results on the outdoor dispersion of staphylococci downwind of a broiler barn. Computerised dispersion models were used to demonstrate the magnitude of agreement between the measured downwind receptor concentrations and those predicted by models.

2 Material and methods

2.1 Field investigations

A typical forced ventilated broiler barn with approximately 30,000 birds on litter was the source of staphylococci emission in this study. The rectangular building was located in a flat field with no relevant dispersion disturbing structures along the main wind direction. The building was situated nearly north-south along its length axis. Measurements were taken during the summer, when the broilers had been housed for at least 14 days.

Staphylococci were sampled with pump-operated all-glass impingers (AGI-30). Sampling times of 90 min were set to permit accumulation of sufficient amounts of bacteria in the impingers. A glycerine buffer solution was used to minimise evaporation losses during the relatively long sampling time. The exhaust air was drawn in by the AGI-30 through a sampling probe and nozzle suitable for isokinetic sampling requirements. An installed air-flow rectifier within the chimney produced a laminar air flow, which is necessary for isoaxial sampling conditions. The necessary year-round ventilation rates were achieved by two front wall fans and twelve roof fans, but the entire sampling set-up was mounted in only one of the twelve roof chimneys, as it was assumed that the particle concentration was representative of all exhaust air. During the sampling procedure corresponding ventilation rates were recorded automatically by the ventilation system. The staphylococci emission rates were then obtained by multiplying the bacterial concentration by the ventilation rate.

For the outdoor measurements, the AGI-30 were fixed in plastic holders (for UV protection) on weather masts at a height of 1.5m corresponding to the inhalation level of humans. Masts equipped in this way were then located on an east-west axis for downwind and upwind placement in the surroundings of the barn. The upwind positions were used as the reference. The positions of the masts relative to the centre point of the barn were determined with a tachymeter. In this way, it was possible to determine the detection distance and the position of the outdoor AGI-30 relative to the main wind direction. A weather station was used to measure wind direction and wind speed 300m downwind the barn in addition to other parameters (e.g. temperature).

After sampling, the impinger solutions were processed as soon as possible in the laboratory by the aerobe cultivation method. After 48 hours incubation at 36°C the CFU of staphylococci grown on mannit salt agar were counted and identified to the genus level [10]. Coagulase reaction was tested with the staphylase test kit (Oxoid Ltd., Basingstoke, England). The results of CFU were related to cubic metres of air (CFU/m^3).

Finally, the comparison of the downwind and upwind staphylococci concentrations was taken as the indication of the spatial extension of the bacteria-loaded plume. As it is very unlikely under practical field conditions that the endpoint of the maximum travelling distance will be determined, an exponential regression function was applied to extrapolate the likely maximum transmission distance.

2.2 Dispersion modelling

The results of selected field investigations were compared with a Gaussian plume model (TALIP version 1.2, engineering office of Thomas Lung, Berlin, Germany) and a Lagrangian particle dispersion model (LASAT version 2.9e, engineering office of Janicke, Dunum, Germany). Due to this intention field experiments were undertaken to make multipoint outdoor measurements to show the fate of concentrations in relation to the shape of the plume. For this purpose some of the sampling positions were located in a cross-sectional plane, i.e. from the centre to the periphery of the assumed particle plume.

The emission sources (roof and front wall chimneys) were defined as point sources with emission heights of 7 and 2.5m, respectively. The emission rates varied between 8.46 x 10^6 and 1.34 x 10^8 CFU/sec during the four field measurements used for the dispersion modelling. Because bacteria are normally adsorbed to dust, it was assumed that sedimentation and deposition velocities were 0.00 and 0.01m/sec (valid for particle sizes between 2.5 and 10µm), respectively.

The prevailing wind direction was southwest during three measurement periods and southeast in the fourth. Wind velocities were in the range of between 1.7 and 6.3m/sec. The dispersion category was 3.1 according to *Klug/Manier*. The terrain roughness was considered to be 0.1m, which is typical for flat fields with low vegetation height.

Both dispersion models were used to calculate the concentration field at a height of 1.5m with a grid resolution of 10 x 10m. To meet the geo-coordinates of the sampling places in the field, 2 x 10m grid cells within the x-y plane had to be considered in the x and y directions to obtain the theoretical mean concentration. Average emission time was set to 90 min according to the experimental sample period. For these very first calculations, wind field determinations were performed on flat terrain without turbulence-causing structures such as the broiler barn itself, and a grid with relatively low resolution was defined to shorten the computer processing time to an acceptable level.

3 Results

The microbiological differentiation of the outdoor downwind samples detected only coagulase-negative staphylococci (CNS). The upwind sampling place showed no staphylococci at all. But the experiments showed that the staphylococci emitted during a single event could overcome a transmission distance of 477m under the indoor and environmental conditions of the investigations. At this distance, there was still a concentration of 4260 CFU/m³. On the other hand, the concentration at the sampling position closest to the barn (73 m) was nearly tenfold that. These data and those from distances between 73 and 477m indicate a theoretical maximum transmission distance of approximately 530m ($r_s = -0.8792$, $p < 0.001$) when the AGI-30 is set at a detection limit of 300 CFU/m³ (Fig. 1).

In addition to single data points integrated in Figure 1, experimental data from multipoint outdoor measurements were used to show the interference of varying wind directions and to estimate the relative error between real and calculated staphylococci concentrations. The measured concentrations were generally high when the sampling position was permanently positioned in the centre of the plume, as is indicated by a small angle of deviation in relation to the main wind direction (Table 1), as can for instance be seen for P45 vs. P46 or P48 vs. P50. When the relative deviation from the main direction became greater, staphylococci concentrations then fell, because the less concentrated plume periphery led to a decreasing accumulation of staphylococci in the AGI-30. This practical and expected result was in principle verified by dispersion modelling (Fig. 2).

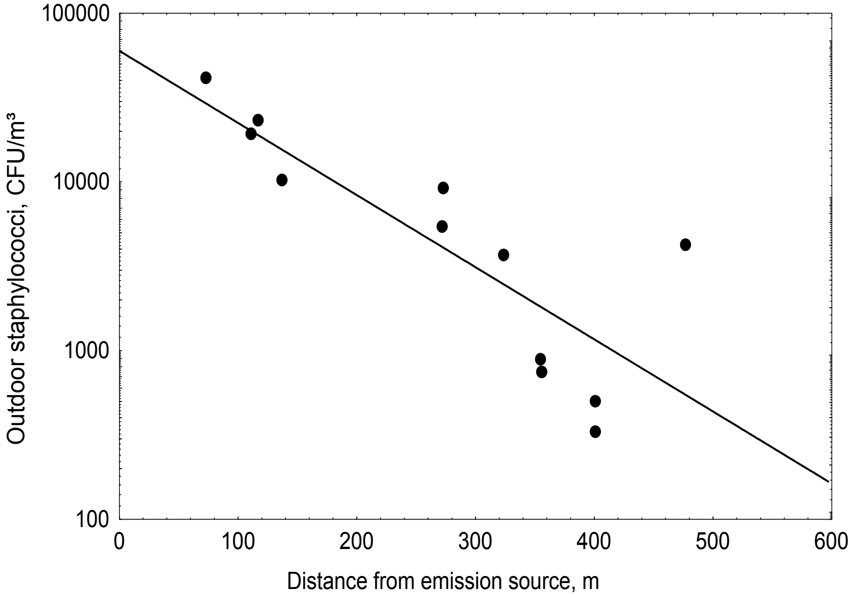

Figure 1: Fate of staphylococci concentrations at a height of 1.5m on the downwind side of the broiler barn. Curve fit by exponential regression. Birds' age ≥ 14 days, wind speed in main wind direction: 1.7-6.3 m/sec, outdoor temperatures > 16°C.

It is clear that positions P45 and P46 were in the centre of the plume and thus showed the highest staphylococci concentrations. The concentrations decreased at the edge of the highly concentrated plume centre, and P42 even showed lower concentrations than P45 and P46. Concentrations declined further at P43 and P44 down to 300 CFU/m^3 at the interface between plume and normal ambient air (see also Table 1).

As mentioned above, the application of dispersion models seems to be a suitable method for the confirmation of experimental data and the determination of their plausibility. The most important question is whether dispersion models are able to simulate the real conditions of pollutant burdens in the ambient air both quantitatively and consistently.

While Table 1 shows the experimental data, Table 2 compares the relative proportions of real and predicted concentrations of staphylococci. In most cases both models significantly underestimate (e.g. 7.6% matching) or overestimate (e.g. 451.7% matching) the actual receptor concentrations. Relatively good accordances were calculated in only a few cases, e.g. 89.8% and 110.7% for TALIP and 96.0% and 119.3% for LASAT. Furthermore -- and surprisingly -- the predicted percentages are contradictory.

Table 1: Distance- and wind direction-related concentrations of staphylococci downwind from the broiler barn during four field measurement days. Upwind (reference) concentrations were always below the detection limit. ID: identification.

Measurement day	Sample position ID	Distance to emission source (m)	Angle of relative deviation to main wind direction (°)	Downwind concentrations of staphylococci (CFU/m³)
1	P32	121	8	8502
1	P31	137	3	10278
1	P33	135	14	3682
2	P44	108	39	300
2	P43	113	27	3842
2	P42	125	15	18500
2	P45	117	5	23339
2	P46	114	10	20680
3	P49	248	13	4782
3	P50	272	8	5460
3	P48	273	0	9214
3	P51	280	8	4017
4	P54	324	7	3700
4	P53	356	7	3748

4 Discussion

It is commonly accepted that livestock operations are among the most important emitters of bioaerosols. Among all types of livestock housing, poultry facilities can cause the greatest emission loads, as has recently been shown in an emission inventory for livestock-related bioaerosols [11]. Such meso- to macroscalic inventories can give a broad overview of the theoretical distribution of emitted bioaerosol quantities over land. However, if their public health relevance is to be determined, their microscalic relevance (approximately 25 – 2500m from the emission source) has to be supported by knowledge of dispersion patterns and expectable receptor concentrations of bioaerosols, because emitted bioaerosols are suspected of playing a similar role to that of occupational exposure in animal confinement buildings [12].

The present study showed that calculable transmissibility is possible up to 530m. Due to the complexity of bioaerosols it is likely that other airborne agents are also able to travel such distances. More and more, the question arises as to whether the staphylococci concentration of 4260 CFU/m³ at 477m can have adverse health effects. Even though there are as yet no experimentally verified dose-response relationships for pathogens transmitted in bioaerosols, a level of 10^3 CFU/m³ has been used as an indicator of possible risk to human health [13, 14]. However, such threshold limit values should be used with caution, because an overall concentration of 10^3 CFU/m^3 is not uncommon for different environments [15].

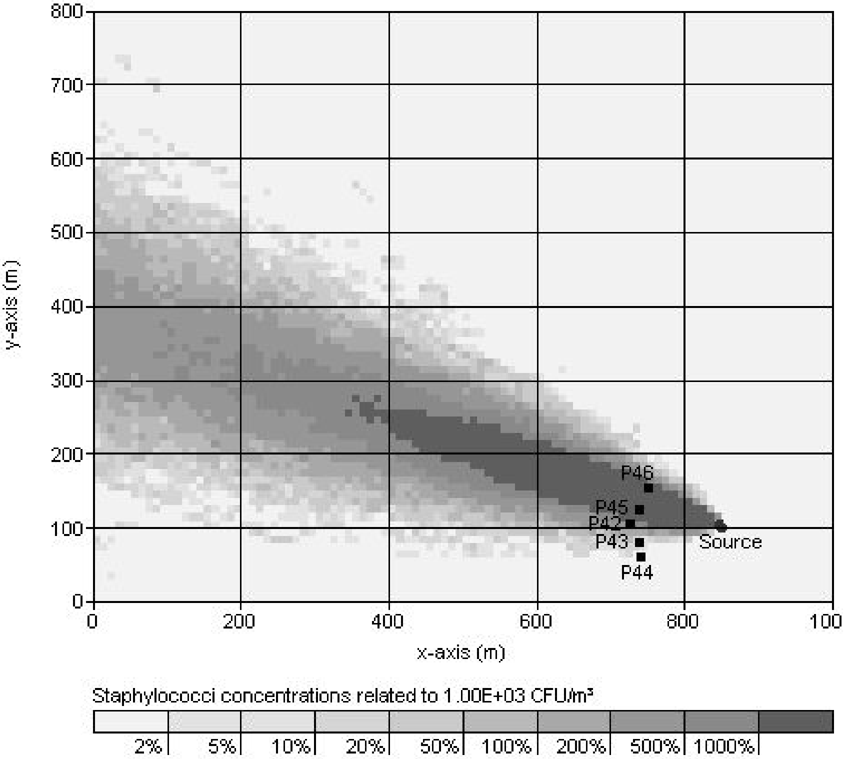

Figure 2: Exemplary plot concentration field predicted by LASAT at the downwind side of the staphylococci-emitting broiler barn. Sampling positions (P42-46) at 1.5m height are also indicated. Wind conditions: 2.8 m/sec, 108 °; dispersion category: 3.1.

Even if there were a consensus about the relation between dose and response in humans, it would still remain uncertain as to its applicability to the actual population at risk (due to individual susceptibilities), and as to the particular bioaerosol (due to composition-related combined effects and synergistic versus antagonistic effects.). The latter point is of special interest because only CNS were detected in our study, whose opportunistic pathogenic potential is difficult to predict. On the other hand, CNS are carriers of antibiotic resistance, and preliminary findings suggest that inhalation of such carriers may serve as an exposure pathway for the transfer of multidrug-resistant bacterial pathogens from animals to humans [16]. This suspicion is based on the fact that resistance bacteria were found downwind of swine confinement houses at levels found in previous studies to be potentially able to pose a hazard to human health [14], or at least capable of establishing antimicrobial resistance in human commensal flora [17]. It remains unclear if such causal relationships also apply to poultry production systems, but survey data are urgently needed in this field.

Table 2: Predictability of downwind staphylococci concentrations by the dispersion models TALIP and LASAT (< 100%: underestimation, > 100%: overestimation by the models).

		Relative proportion between measured and predicted downwind staphylococci concentrations (%)	
Measurement day	Sample position ID	TALIP	LASAT
1	P32	25.9	79.7
1	P31	27.2	96.0
1	P33	78.8	37.2
2	P44	451.7	9.3
2	P43	174.4	7.6
2	P42	112.4	15.4
2	P45	89.8	126.0
2	P46	55.9	281.2
3	P49	29.3	50.4
3	P50	47.6	119.3
3	P48	39.6	170.7
3	P51	73.4	128.5
4	P54	86.5	373.6
4	P53	110.7	245.1

Comparison with the measured field concentrations showed that the calculated dispersion models qualitatively confirmed the overall tendency of a decline from the centre to the periphery of the plume, while values predicted by the models were not as accurate as expected. Even though the dispersion models were designed using validated algorithms, we found that similar models predict different concentrations, as has been shown for instance for six Gaussian dispersion models [18]. Certainly, there are some known restrictions to the Gaussian dispersion model [19], but the more sophisticated Langrangian model was also not able to simulate realistic concentrations. Predictability may be improved by the inclusion of topographical data, wind shear and time-dependant fluctuations in speed and direction, or time series-related emission rates. The emission rate in particular is probably a crucial point, because bacteria were detected here by cultivation, which is limited for example by masking effects. Furthermore, arbitrarily and therefore quantitatively different occurring clustering and declustering effects of bacteria in the sampled air and in the sampling device make it difficult to obtain real figures comparable to the static calculated values. In future it may be possible better to exploit the fine-tuning capabilities of more complex dispersion models like the Lagrangian model by applying alternative sampling strategies and monitoring a great range additional transmission-relevant parameters during field measurements (e.g. vertical wind profile), thus enhancing predictability. However, once bacteria are released into the airborne state, the determination of their decay mechanisms will probably remain a limiting factor despite the fact that staphylococci are relatively tenacious.

5 Conclusions

The following conclusions can be drawn from the field study:

- Emitted aerial staphylococci were transmitted at least 477m from their source.
- The field yields decreased exponentially along the main wind direction.
- Only coagulase-negative staphylococci were detected at the sampling places.
- Dispersion models are suitable for the qualitative verification of field data and can be used to check the plausibility of real measurements. However, in this study results of TALIP and LASAT dispersion modelling partly produced inconsistent predictions along with sizable over- and underestimates compared to field measurements of CNS.
- The set of recorded data used as input data for the dispersion models was obviously insufficient to make predictions of model-related outdoor concentrations close to those obtained experimentally. Therefore, the model should be extended to include further parameters relevant to emission and dispersion.
- Future work should focus on the fine-tuning capabilities of dispersion models and make use of other relevant scientific disciplines such as meteorology.

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