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DUSTINESS OF CHOPPED STRAW AS AFFECTED BY LIGNOSULFONATE AS A DUST SUPPRESSANT

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Abstract: Many sources add to the concentration of bioaerosols in livestock buildings, and source control is the number one priority for keeping a low concentration. Straw is a common but dusty bedding material in livestock buildings and the present study is focused on the dustiness of chopped straw (barley) as affected by lignosulfonate (LS) as a dust suppressant. A LS-solution was aerosolized in a spray chamber fitted to an existing bedding chopper to allow the chopped straw to adsorb the LS-solution. The dustiness of straw treated with LS was compared to non-treated straw. As storage conditions may affect dustiness, the study included treated straw kept for 4 weeks in sealed plastic bags. Dustiness of the chopped straw was measured in terms of the potential of the straw to emit bioaerosols in a rotating drum. The LS-treated straw proved low in dustiness compared to the non-treated straw. The dustiness with respect to the mass of dust was reduced by at least a factor of 6, and for fungi and endotoxin the factors of reduction were 4 and 3, respectively. Dustiness of LS-treated straw kept in plastic bags was reduced by a factor of 2 for mass of dust and by a factor of 4 for endotoxin, but dustiness for fungi was increased by a factor of 3. It is concluded that lignosulfonate has potential as a dust suppressant for chopped straw.

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INTRODUCTION

Air quality control is an important aspect of environmental management of animal confinement buildings. Agricultural dust contains a myriad of substances, and exposure to high concentrations of airborne dust may cause adverse respiratory effects in agricultural workers [3] as well as in animals [11]. The air quality in livestock housing facilities is a function of the emission rate (source strength) of air contaminants, the dispersion of the contaminants, and the ventilation rate. Control of the source strengths is the number one priority for keeping a low concentration of air contaminants. Many sources may add to the concentration of air contaminants, including the livestock, feed, bedding material, and design of the building.

Straw is a common but dusty bedding material [11] and effective measures are needed to control this contaminant source. The bedding chopper is a mechanical device which cuts straw into short lenghts to be used as bedding by livestock. This operation creates a considerable cloud of dust that may include various amounts of fungi, bacteria, and endotoxin. During bedding chopper operation at dairy farms, exposure to fungi (*Aspergillus fumigatus*) was 1.1×10^6 cfu/m^3 compared to 10^4 cfu/m^3 before the operation [9]. It is known that the addition of small quantities of water to the cut side of a bale of straw may reduce the emission of dust from bedding choppers

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[6]. The focus of the present study was on dustiness of the chopped straw, and lignosulfonate (LS) was used as a dust suppressant. Lignin, a natural polymer consisting of phenylpropane units, is a major component of wood. The lignin content of wood ranges 27–37% (softwoods) and 16–29% (hardwoods). Two types of pulping processes of wood are common for paper making: kraft pulping and sulfite pulping. During kraft pulping (cooking of wood chips with sodium hydroxide and sodium sulfide) lignins mainly undergo molecular reactions. Under sulfite pulping conditions (cooking of wood chips with sulfite) lignin is sulfonated and rendered water soluble. LS is used in many chelation, binder or adhesive applications, and some examples of large volume binder use are animal feed binder, road dust binder, ceramics, brick and foundry cores. Therefore, LS may also have potential as a dust suppressant for chopped straw.

Bedding choppers come in different types and some are designed to deliver chopped straw of low dustiness. The present study reports the results of dustiness of chopped straw (barley) as affected by alternative designs of a bedding chopper. Emphasis was placed on a simple spraying system fitted to the chopper to add lignosulfonate (LS) as a dust suppressant. It was noted that the reported data were obtained with a pilot spraying system. The source strength of a bedding material is affected by characteristics of the material itself and by the actual handling of the material. The dustiness of the chopped straw was measured using a rotating drum dustiness tester in the laboratory. In this context, dustiness of the straw represents its potential to emit bioaerosols during handling operations.

MATERIALS AND METHODS

Straw samples. The methods of producing, collecting and storing straw may affect the microbiological quality of the straw [7]. The straw (barley) for testing was obtained from the same harvest of a specific area on a farm in an attempt to keep a similar composition of the straw throughout the study. The bales of straw were stored under cover at outdoor air temperatures from harvest (August) until dustiness testing in the laboratory (January-February the following year). It should be noted that moisture content of the straw was not measured throughout the study.

The bedding chopper. The straw was chopped in a barn to simulate typical environmental conditions at a farm. An existing non-portable chopper was used for the study. The chopper was fed from the top (Fig. 1) and the straw was cut into short lengths by the mechanical action of rotating blades. A duct was fitted to the bottom of the chopper to allow the chopped straw to be blown to a storage area. The duct included a dust separator to decrease the content of dust in the chopped straw. Note that it was possible to by-pass the separator. For this study the storage area was next to the chopper, and the chopped straw was delivered from a vertical duct (0.1 m internal diameter) blowing towards the floor. To allow spraying of the chopped straw with a dust suppressant, a spray chamber (a vertical duct, 0.6 m internal diameter, 1.5 m length) was fitted to the end of the existing duct. The spraying system had three nozzles to aerosolize the solution and the system was designed to deliver a constant mass of solution (25 kg) per 1000 kg of chopped straw. LS-solutions at two different levels (27% and 39%) entered the study.

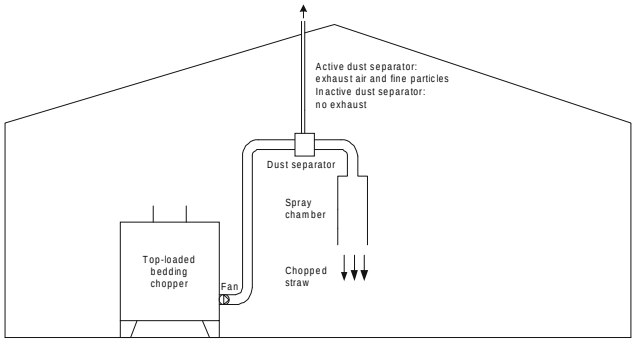

Figure 1. Experimental set-up (not to scale). The bedding chopper was fitted with a dust separator and a spray chamber.

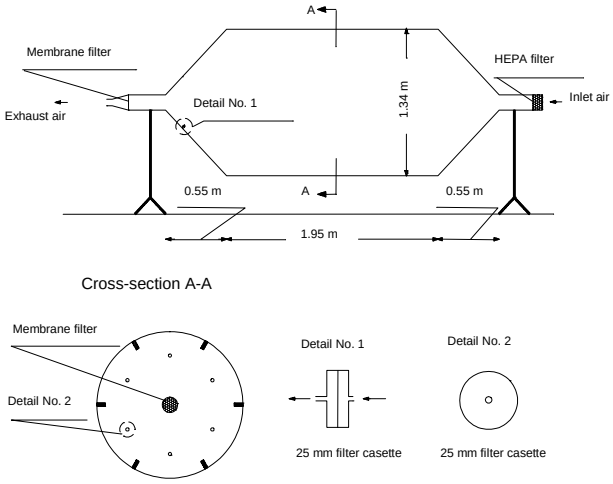

Figure 2. Rotating drum dustiness tester. The drum was operated at 7 rpm at an airflow rate of 420 l min^{-1}.

Throughout all the experiments (see: study design) the chamber was kept as an integral part of the chopper system. The chopped straw leaving the bottom of the spraying chamber settled onto a length of corrugated cardboard on the floor. In an experiment the cardboard was slowly moved to simulate a conveyor belt, and a sample (approx. 2.9 kg) of chopped straw was taken for dustiness testing in the laboratory. Samples were kept in sealed polyethylene bags in a box to minimize damage during transport.

Dustiness testing. By definition, dustiness of a material is the mass of dust generated per mass of

material undergoing testing. An equivalent definition is also readily applied to microorganisms. The term "microbial dustiness" thus refers to the generated number of airborne microorganisms (e.g. fungal spores) per mass of material undergoing testing.

A dustiness tester consists of two parts - a dust generator and a dust sampler. A large drum (volume 3.3 m^3) with conical ends was used as dust generator (Fig. 2). The drum was designed by scaling up the well known Warren Spring Laboratory (WSL) rotating drum dustiness tester from a diameter of 0.3 m to a diameter of 1.34 m [1]. The drum was fitted internally with 8 vanes attached to the walls to lift the straw (2.9 kg) as the drum was rotated along the horizontal axis, using 7 rpm in the experiments (5 min. test period). At one end of the drum a vacuum pump (420 l min^{-1}) was used to extract air from the drum, and the other end was connected to a high efficiency dust filter to clean room air entering the drum. Throughout the experiments air temperature was 9.6 ± 0.8°C and relative air humidity 53 ± 10%.

Straw samples for testing were carefully lifted from the polyethylene bag and placed in the drum. Dust was made airborne in the process of rotating the drum, and dust arriving at the outlet of the drum was collected onto filters. The dust sampler was a 140 mm diameter 8 µm cellulose nitrate membrane filter (Sartorius, Göttingen, Germany). To allow data to be obtained on the concentration of dust against time, an isokinetic probe in front of the filter delivered a sub-sample (1.9 l min^{-1}) of the air exhausted to a particle counter (GRIMM model 1200). It is noted that the data obtained were not corrected for the loss of particles that settled in the sampling line leading from the probe to the counter. To analyse the generated dust for content of endotoxin and microorganisms, 4 filter casettes were used for sampling at a cross-section 0.2 m from the outlet (Fig. 2). Two cassettes were used for sampling "total dust" and another two cassettes for sampling airborne microorganisms. A cassette sampling "total dust" was placed next to one sampling airborne microorganisms. "Total dust" was collected on teflon filters placed in closed-faced field monitors (25 mm diam., 8 µm; Millipore, Bedford, USA) with a 5.6 mm inlet at an airflow of 1.9 l min^{-1} (1.25 m s^{-1} inlet velocity). Airborne microorganisms were collected on sterile polycarbonate filters in closed-faced field monitors (25 mm diam., 0.4 µm; Nuclepore, Cambridge, MA, USA) with a 4.4 mm inlet at an airflow of 1.9 l min^{-1} (2.07 m s^{-1} inlet velocity). The mass of dust collected at the outlet of the drum and at the cross-section was determined by weighing the filters before and after the sampling. Before weighing, the filters used for collecting the dust were equilibrated at constant air temperature and humidity for at least 24 hours. The limit of detection in weighing the filters was 40 µg (25 mm diameter filter) and 100 µg (140 mm diameter filter). Samples obtained at the cross-section were analysed for content of endotoxin and microorganisms (see below).

The following model was used to derive dustiness of the chopped straw. At the cross-section let the average concentration of "total dust" (N = 2) and some type of microorganism (N = 2) be denoted C_{Dust} and C_{Micro}, respectively. The average (N = 2) concentration of

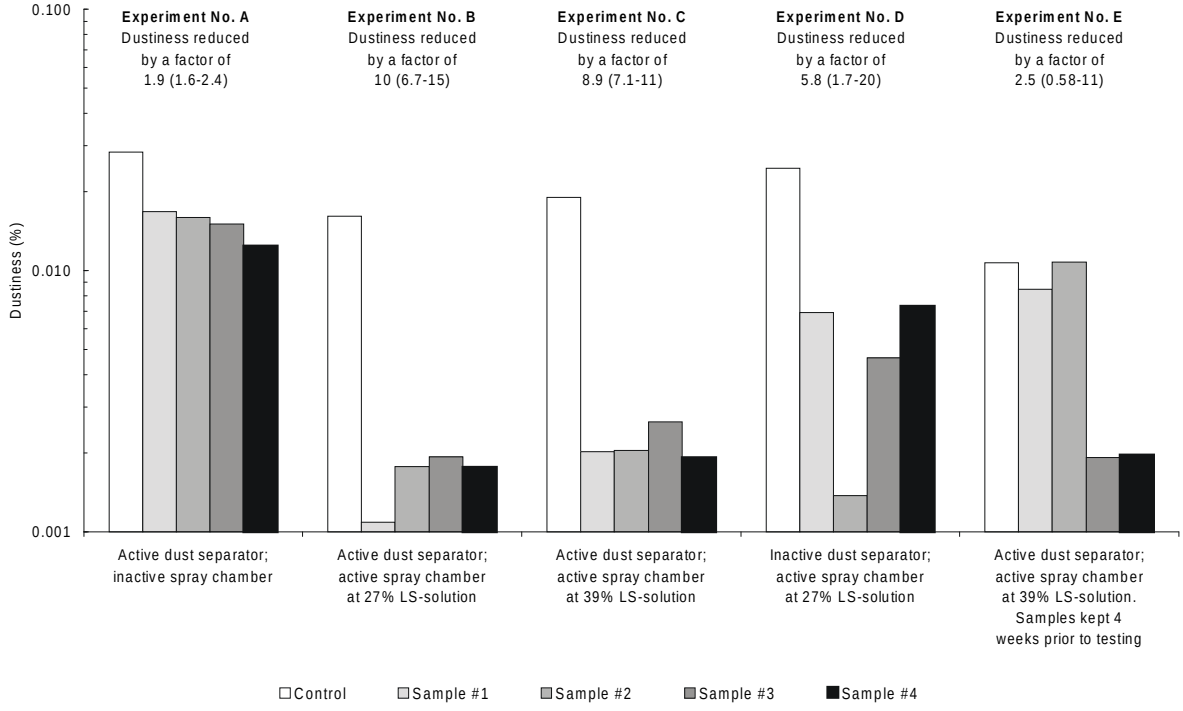

Figure 3. Dustiness (%) of chopped straw (barley) versus different techniques to reduce the dustiness. The factor of reduction in dustiness is given with reference to the control sample and is presented as the geometric mean and the 95% confidence interval in parentheses.

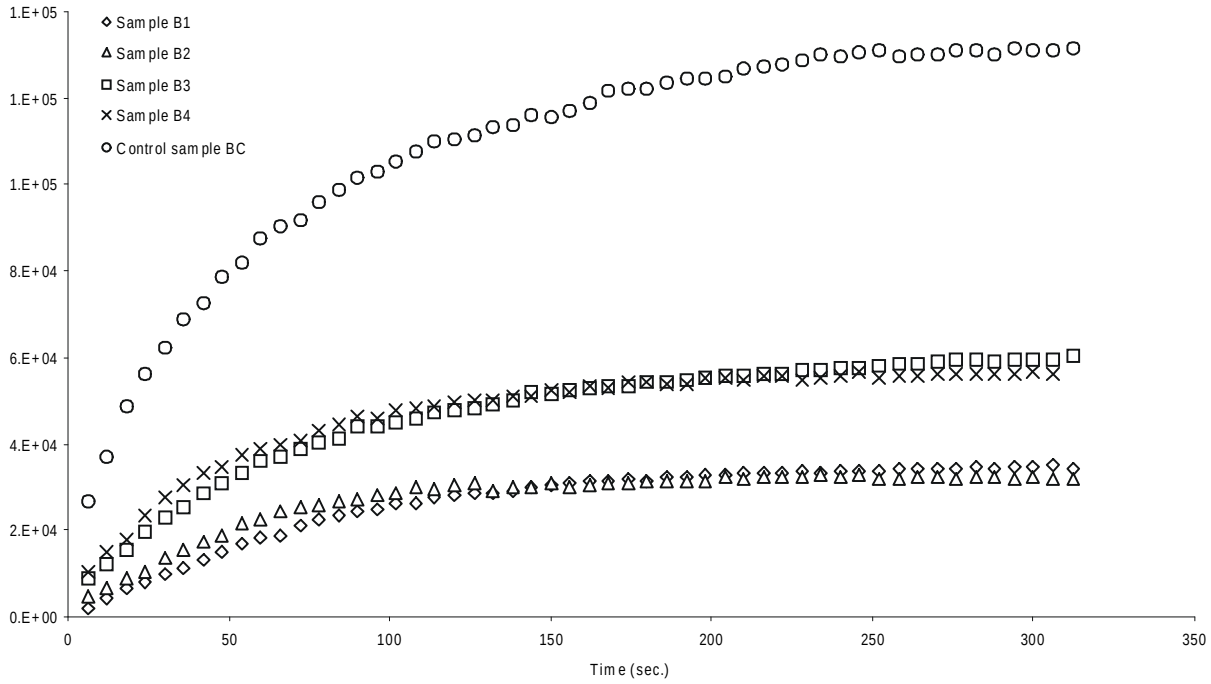

Figure 4. The concentration of airborne dust versus time after start of the rotating drum dustiness tester. Data are from experiment B.

endotoxin is denoted as C_{Endo}. A study on dustiness of household waste [2] indicated an even (±15%) distribution of the dust concentration at the cross-section of sampling. It therefore seems reasonable to characterize the dust in terms of number of microorganisms per mass of dust (P_{Micro}) or content of endotoxin per mass of dust (P_{Endo}) as derived from the following equations:

$$P_{Micro} = \frac{C_{Micro}}{C_{Dust}} \quad and \quad P_{Endo} = \frac{C_{Endo}}{C_{Dust}}$$

The indices of dustiness for dust (D_{Dust}), endotoxin (D_{Endo}), and microorganisms (D_{Micro}) expressed as mass (or number of microorganisms) per mass of chopped straw were estimated as follows:

$$D_{Dust} = \frac{M_{Out}}{M_{Straw}}, \quad D_{Endo} = \frac{M_{Out} \times P_{Endo}}{M_{Straw}} \quad and \quad D_{Micro} = \frac{M_{Out} \times P_{Micro}}{M_{Straw}}$$

where M_{Out} denotes the mass of dust collected at the drum outlet and M_{Straw} denotes the mass of chopped straw undergoing testing. In the use of the equations it is assumed that the particle size distribution at the cross-section is identical to the particle size distribution at the drum outlet.

Endotoxin. For analysis of endotoxin the collected "total dust" was resuspended in 10.0 ml sterile 0.05% Tween 20 aqueous solution by orbital shaking (250 rpm, 60 min) at room temperature and centrifuged (×1000) for 15 min. The supernatant was analysed (in duplicate) for endotoxin by the kinetic Limulus Amebocyte Lysate test (Kinetic-QCL endotoxin kit; BioWhittaker, Walkersville, Maryland, USA). A standard curve obtained from an *Escherichia coli* 055:B5 reference endotoxin was used to determine the concentrations in terms of endotoxin units (EU) per m^3 of air (1 ng = 14.0 EU).

Microorganisms. Microorganisms were quantified by a modified CAMNEA-method [8]. Basically, this method involves resuspension of the aerosols collected on the polycarbonate filter followed by an appropiate micro-biological analysis. For the resuspension, 5 ml sterile 0.05% Tween 80 aqueous solution was added to the filter cassette followed by a 15 min shaking period (500 rpm) at room temperature. For the microbiological analysis, the aerosols were only characterized in terms of viable counts of fungi (moulds). It should be noted that the analysis did not include total counts of microorganisms by fluorescence microscopy. The samples were plated (at 10-fold dilutions) immediately after the collection on Dichloran Glycerol agar (DG 18 agar, Oxoid, Basingstoke, England) to enumerate mesophilic fungi after incubation for 7 days at 25°C.

Study design. For practical reasons, it was not possible to test the dustiness of more than 5 straw samples per week in the laboratory. The bedding chopper allowed straw to be chopped with alternative techniques to reduce dustiness of the chopped straw. Below are listed the techniques utilized in the study and it should be noted that experiment E was included to evaluate the dustiness as affected from extreme storage conditions.

- Experiment A. The chopper fitted with the dust separator and the spraying chamber (no active spraying).

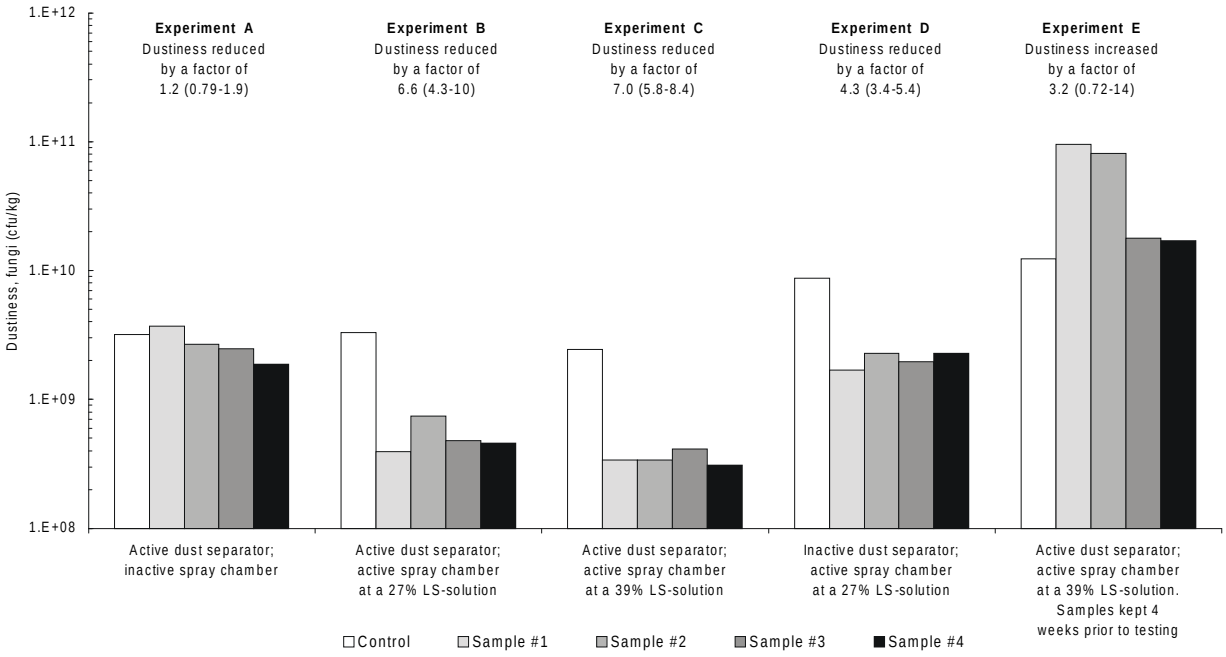

Figure 5. Dustiness of chopped straw (barley) in terms of colony forming units (cfu) of fungi emitted per unit mass (kg) of straw. Dustiness is given versus techniques to reduce the dustiness. The factor of reduction in dustiness is given with reference to the control sample and is presented as the geometric mean; 95% confidence interval in parentheses.

- Experiment B. The chopper fitted with the dust separator and the spraying chamber (27% LS-solution for spraying).
- Experiment C. The chopper fitted with the dust separator and the spraying chamber (39% LS-solution for spraying).
- Experiment D. The chopper fitted with the spraying chamber (27% LS-solution for spraying); the dust separator was inactive (by-passed).
- Experiment E. The chopper fitted with the dust separator and the spraying chamber (39% LS-solution for spraying). Prior to the dustiness testing, the chopped straw was kept for 4 weeks at extreme conditions (in sealed polyethylene bags at outdoor air temperature).

The straw for a given experiment was chopped on a Tuesday and 4 sub-samples (i = 1, 2, 3, 4) were taken for dustiness testing in the laboratory on Wednesday and Thursday. The period of chopping ranged over 5 consecutive weeks in the winter (January-February). To control the quality of the straw throughout the period one sample (control) of straw was also produced (on Tuesday) with the chopper fitted with the spraying chamber (no active spraying) and by-passing the dust separator.

Analysis of variance (Fisher's multiple comparison) was used to study the effect of the cyclone and the spraying system on the dustiness of the chopped straw. Within the given experiments A-E data were normalised to calculate the factors, F_i (i = 1, 2, 3, 4), of reduction in dustiness. The factor, F_i, was defined as $F_i = D_C/D_{Si}$. In this equation, D_C is the dustiness of the control sample and D_{Si} is dustiness of the actual sample. The calculated factors were log-transformed prior to the statistical analysis. The factors within an experiment were tested for normality by Anderson-Darling test. Variance homogeneity between experiments was tested by Bartlett's test. Minitab software was used for the statistical analysis (Minitab release 10Xtra, 1995).

RESULTS

Dustiness in terms of mass. The data obtained on dustiness of chopped straw are shown in Figure 3 versus the technique used to reduce the dustiness. Ideally, all results for the control samples should have been identical, but in reality some variation was observed in the data obtained (Fig. 3). In an attempt to cancel out the variation from one experiment to another, dustiness data for a given experiment (A-E) were held against the dustiness of the actual control sample, and the factors of reduction in dustiness, F_i, were calculated. At a 5% level of statistical significance the log-transformed factors were normally distributed within an experiment. The data on dustiness for some of the techniques had a large variation because of insufficient control of the spraying system (see discussion), and Bartlett's test indicated ($p = 0.006$) heterogeneous variances between the experiments. Homogeneous variances and normally distributed data are required for an analysis of variance to be valid. Considering experiments D and E as outliers (see Fig. 3), Bartlett's test indicated ($p = 0.45$) homogeneous variance for the remaining experiments. Fisher's multiple comparison indicated that the factor of dust reduction was small ($p < 0.001$) for experiment A compared to experiments B

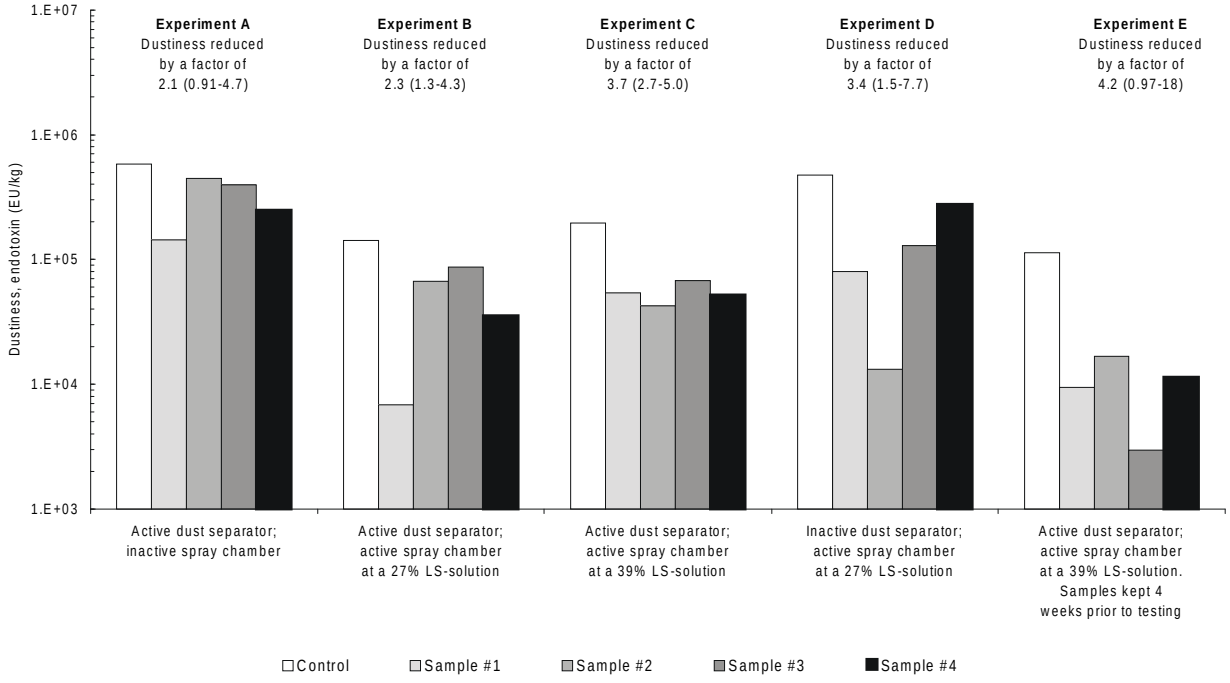

Figure 6. Dustiness of chopped straw (barley) in terms of endotoxin units (EU) emitted per unit mass (kg) of straw. Dustiness is given versus techniques to reduce the dustiness. The factor of reduction in dustiness is given with reference to the control sample, presented as the geometric mean; 95% confidence interval in parentheses.

and C. The estimated factors (mean and 95% confidence interval) are given in Figure 3 for all experiments. Although experiments D and E were excluded from the statistical analysis, the data (Fig. 3) suggest that the factor of dust reduction for experiment D was at a level comparable to the factors seen in experiments B and C. The concentration of dust was measured against time at the outlet of the rotating drum, and the emission of dust from the straw appeared to be a continuous process (Fig. 4).

Dustiness in terms of fungi. The obtained data on dustiness in terms of colony forming units (cfu) of fungi emitted per mass (kg) of the chopped straw are shown in Figure 5 versus different techniques used to reduce the dustiness. The factors of reduction in dustiness (F_i) were estimated, as mentioned above. For the factors Bartlett's test indicated ($p = 0.005$) heterogeneous variance among the experiments (A-E). Visual inspection of the data (Fig. 5) indicated an abnormal variance for experiment E, and considering this test as an outlier, Bartlett's test indicated ($p = 0.45$) homogeneous variance for all the experiments. At a 5% level of statistical significance, Fisher's comparison by pairs indicated a low factor of dustiness reduction for experiment A compared to the high factors seen for experiments B and C (no difference between B and C). The factor for experiment D was intermediate. The estimated factors (mean and 95% confidence interval) are given in Figure 5 for all experiments. Although experiment E was excluded from the statistical analysis, it has to be emphasized that the data suggest (Fig. 5) an increase in the dustiness factor for this experiment.

Dustiness in terms of endotoxin. The dustiness in terms of endotoxin units (EU) emitted per mass (kg) of straw is shown in Figure 6 versus the different techniques used to reduce the dustiness. The factors, F_i, of reduction were estimated as mentioned above, and Bartlett's test indicated ($p = 0.21$) homogeneous variance for all the experiments (A-E). For the factor in dustiness reduction, Fisher's comparison by pairs indicated (at 5% level of significance) no difference between the experiments. The estimated factors (mean and 95% confidence interval) are given in Figure 6 for all experiments.

DISCUSSION

The present study focused on a pilot spraying system to add LS as a dust suppressant to chopped straw. In the process of chopping the straw, it proved difficult to control the spraying system and occasionally blockage of one or more of the nozzles was observed. The blockage may explain the large variation in dustiness within some of the experiments (D and E). Consequently, a more careful design of the nozzles is required for the next generation of the spraying system.

In terms of mass, the dust separator reduced dustiness of the straw by a factor of 1.9 and a significant further reduction was seen from the spraying system. Spraying with LS alone reduced dustiness by a factor of 5.8, and in

combination with the dust separator dustiness was reduced by a factor of 10. No significant effect on the dust reduction factor was seen from increasing the concentration of the LS-solution, and this finding may suggest that further studies are needed to find an optimal concentration for the LS-solution. The dustiness of chopped straw kept for 4 weeks in a sealed plastic bag was at a level comparable to the data of experiment A (active dust separator, inactive spray chamber), but it has to be noted that the low dust reduction factor was presumably caused by blockage of the spray nozzles. It is known that the addition of small quantities of water to the cut side of a bale of straw may reduce the emission of dust from bedding choppers [6] but no data from the literature seem available on lignosulfonate as a dust suppressant for straw. It is well known that additives (e.g. fat) are useful for dust suppression of animal feed [5].

The dust separator on its own had little influence on the dustiness in terms of fungi (experiment A). The dustiness was reduced by a factor of 1.2. Compared to experiment A, a significant reduction in dustiness was seen from the spraying system on its own (experiment D). The reduction was by a factor of 4.3 and a significant further reduction was seen from the combined system (experiments B and C). As for dustiness in terms of mass, no significant influence was seen from the concentration of the LS-solution on the dustiness in terms of fungi. For chopped straw kept for 4 weeks in a sealed plastic bag, the combined system (active dust separator, active spraying) caused an increase in the dustiness by a factor of 3.2.

Gregory and Lacey [4] used a perforated rotating drum in a wind tunnel to generate bioaerosols from different batches of hay. The aerosols collected were analyzed for content of microorganisms and the microbial dustiness was estimated. In terms of culturable fungi, 28 batches classified as 'good hay' gave up to 3×10^9 cfu/kg, while the microbial dustiness of 17 batches of 'mouldy hay' ranged from 5×10^9 cfu/kg to 2.5×10^{11} cfu/kg. Except for experiment E (extreme storage conditions) data of the present study were similar to the data for 'good hay' as reported by Gregory and Lacey [4], and the data for 'mouldy hay' were similar to our data for experiment E. It is noted that Gregory and Lacey [4] supply detailed information on the composition of the collected microorganisms including data on the emission of actinomycete spores. Kotimaa *et al.* [7] also used a perforated rotating drum in a wind tunnel to generate bioaerosols from feeding and bedding materials collected from Finnish dairy farms. The aerosols collected were analyzed for content of microorganisms and the microbial dustiness was estimated. In terms of the total number of culturable microorganisms, baled hay was the most dusty (12×10^6 cfu/kg, mainly fungi) while storage-dried hay had a low dustiness (10^6 cfu/kg). Compared to data from the present study and that of Gregory and Lacey [4], the baled hay from Finnish farms may be considered lower in terms of microbial dustiness. However, different sampling and analytical procedures make it difficult to compare the results.

The data obtained on dustiness in terms of endotoxin emitted per mass of straw (Fig. 6) indicated that LS had some potential as a dust suppressant. The dustiness was reduced by a factor of 3 (experiment D). No data from the literature seem available for comparison, but recently Siegel *et al.* [10] analyzed 3 different bulk samples of hay for content of endotoxin and demonstrated that the content can vary greatly from one sample to the next. Three examined samples ranged in the endotoxin content from 9×10^7 EU to 6.1×10^9 EU per kg of hay.

Source control is a number one priority to maintain an acceptable air quality in livestock buildings. The present study focused on straw as an important contaminant source, but it has to be emphasized that other sources (e.g. food) are also of importance. The data from the study indicated that lignosulfonate has potential as a dust suppressant for straw and the study calls for an optimized system for adding lignosulfonate to the straw. However, small quantities of water (no lignosulfonate) may also be useful as a dust suppressant [6], and in optimizing the system experiments should include straw treated with plain water. As a hypothesis, the short term (days) influence on dustiness from lignosulfonate or water may be rather similar, but perhaps only lignosulfonate has a lasting (months) influence. As it is impossible to extrapolate from the laboratory test conditions in the present study to natural conditions, a comparative field study is needed in order to assess the effectiveness of LS-treated bedding material in lowering the bioaerosol concentration in animal housing facilities.

CONCLUSION

The present study focused on lignosulfonate as a dust suppressant for chopped straw. A non-optimized pilot spraying system was used and the data obtained indicated that lignosulfonate has potential as a dust suppressant. However, the extent to which the use of LS-treated bedding material may reduce the bioaerosol concentration in animal housing facilities has to be addressed in comparative field studies.

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