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IMPACT OF LOAD LAYOUT ON INTERNAL VENTILATION DURING THE TRANSPORT OF BROILERS

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KEYWORDS

animal welfare, computational modeling, precision livestock farming.

ABSTRACT

The characterisation of ventilation during the transport of broilers is essential to identify and solve problems related to the microclimate of the load. This study aimed to evaluate the ventilation patterns in alternative load layouts, i.e., with a central span or an air corridor, used in Brazil. Computational fluid dynamics simulations and wind tunnel tests were performed on virtual models and small-scale prototypes, respectively. The results showed that the load layout with a "central span" promoted positive ventilation patterns and increased wind circulation between the crates. However, it reduces the load transport capacity by approximately 20% (70 fewer crates), increasing the number of journeys. Therefore, the modification of the layout can optimise ventilation throughout the load; however, it becomes necessary to reduce the number of crates stacked on the truck, which is not feasible for the commercial transport of broilers because it makes it more onerous.

INTRODUCTION

Heat stress during transport is a current animal welfare challenge to be overcome by Brazilian poultry farming (Vieira et al., 2019; Sakamoto et al., 2020). The characterisation of ventilation during animal transport is essential to develop alternatives to reduce death on arrival (DOAs), especially those related to the formation of "thermal cores" (Machado et al., 2021a). Conceptually, the “thermal core” is the most critical thermal zone of the load, where enthalpy values are the highest (Barbosa-Filho et al., 2009; Pinheiro et al., 2020).

In this context, studies using computational fluid dynamics (CFD) techniques are being carried out to characterise ventilation during animal transport (Gilkeson et al., 2016; Machado et al., 2021a; Machado et al., 2021b). Based on this concept, load ventilation of live broilers with conventional layouts associated with spacer devices, which were designed to create corridors (vertical and horizontal) for air circulation between the crates, was previously evaluated (Pinheiro et al., 2021).

The conventional layout, characterised by stacking the crates in columns with a distribution of lengthwise rows, resulting in a load with a quadrangular prism format, is the most used by Brazilian carriers. However, alternative layout models aim to increase ventilation along the body during the journey.

In the Northeast region of Brazil, carriers use the sectioning of stacked crates, resulting in a central space (central span) in the load. On the other hand, in the South/Southeast regions, the crates are stacked in the same arrangement as the conventional load layout, but with space between the rows to serve as a wind circulation corridor (air corridor).

This study aimed to evaluate the ventilation patterns of the load with alternative layouts (with a central span and air corridor) used in the transport of live broilers in Brazil.

MATERIAL AND METHODS

Database

Initially, ten broiler transport operations in the metropolitan region of Fortaleza, CE, Brazil, were monitored. These journeys were carried out on a typical commercial route of 35 km on a paved road. During this period, technical information was collected on the typology of the truck and the crates used in the commercial transport of broilers.

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The average truck speed and environmental conditions during the journey were recorded. The ambient temperature and relative humidity were recorded every 10 min using three mini weather stations (Onset, U23-001 HOBO Pro v2, Massachusetts, USA). The equipment was positioned above the truck cabin. The incidence of radiation was obtained from station 82397–Fortaleza (3º49'12 "S 38º32'24″ W and 29.89 m altitude) of the National Institute of Meteorology of Brazil (INMET).

Treatments

This study evaluated the load ventilation patterns in virtual models using the layout with “central span” (Figure 1A) and with “air corridor” (Figure 1B). Solid Edge ST10 software was used to develop and refine the virtual models. However, owing to processing limitations (hardware), it was reduced from 350 to 280 crates arranged in the truck trailer, without changes in the usual geometric pattern of the load, guaranteeing accurate results.

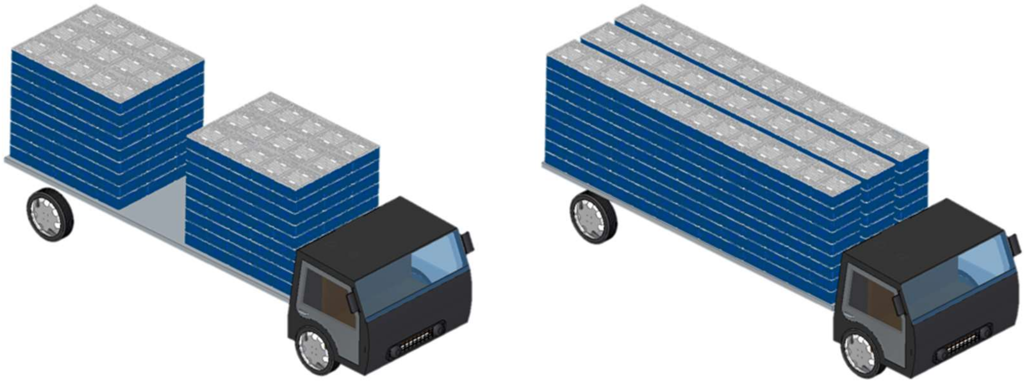

FIGURE 1. Virtual models: layout with central span (A) and with air aisle (B).

CFD Simulation

Once the geometric plane was defined, the SolidWorks Flow Simulation package was used for computational fluid dynamics (CFD) analysis. An adaptive mesh generation was chosen, with hexahedral cells structured in most of the domain, except around the truck, where tetrahedral cells were used. Thus, the truck's surface layers were refined to solve the boundary layer flow problem near the diffuser wall.

Boundary conditions to simulate the actual flow conditions during transport were designed in the simulations (Table 1). The number of mesh cells in the central span model was 14,720, resulting in a maximum orthogonal quality of 83.20%. The air corridor model presented a mesh with 15,432 cells and a maximum orthogonal quality of 85.80%.

SolidWorks Flow Simulation extends the solution-adaptive refinement procedure to regions of the computational domain for more accurate and optimised CFD simulations. The Navier-Stokes equations were solved to determine the patterns of load ventilation in a three-dimensional computational space using this software. The general conservation convection-diffusion equation can be described using [eq. (1)].

TABLE 1. Boundary conditions.

Variables	Values
Prescribed speed (m/s)	20
Temperature (°C)	25
Relative humidity (%)	75
Radiation (Kj/m²)	420
Atmospheric pressure (mm Hg)	760

$$\frac{\partial \phi}{\partial t}+\frac{\partial u_j \phi}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\Gamma_\phi \frac{\partial \phi}{\partial x_j}\right)+S_\phi \qquad (1)$$

In which:

ϕ stands for the variables of interest, which can be the three velocity components u (m/s), temperature T (°C), contaminant concentration c (kg/kg), age of airθ (s), turbulent kinetic energy k_t (m²/s²), and dissipation of turbulent kinetic energy ε (m²/s³), and where Γ_ϕ and S_ϕ represent the diffusion coefficient and source term ofϕ, respectively

Prototyping and wind tunnel testing

The models were refined after the CFD tests, and prototypes were manufactured on a 1:10 scale. Plywood was used for the truck (length 450 mm, width 400 mm, and height 350 mm). The crates were manufactured using 3D printers (XYZ DaVinciPro, XYZprinting®), using polylactic acid as the material. Wind tunnel tests with a test area of 500 mm × 500 mm for a period of 40 ± 3 min were carried out, simulating a volume of six broilers (2.5 kg) to obtain the density of six broilers per crate in both layouts (Figure 2).

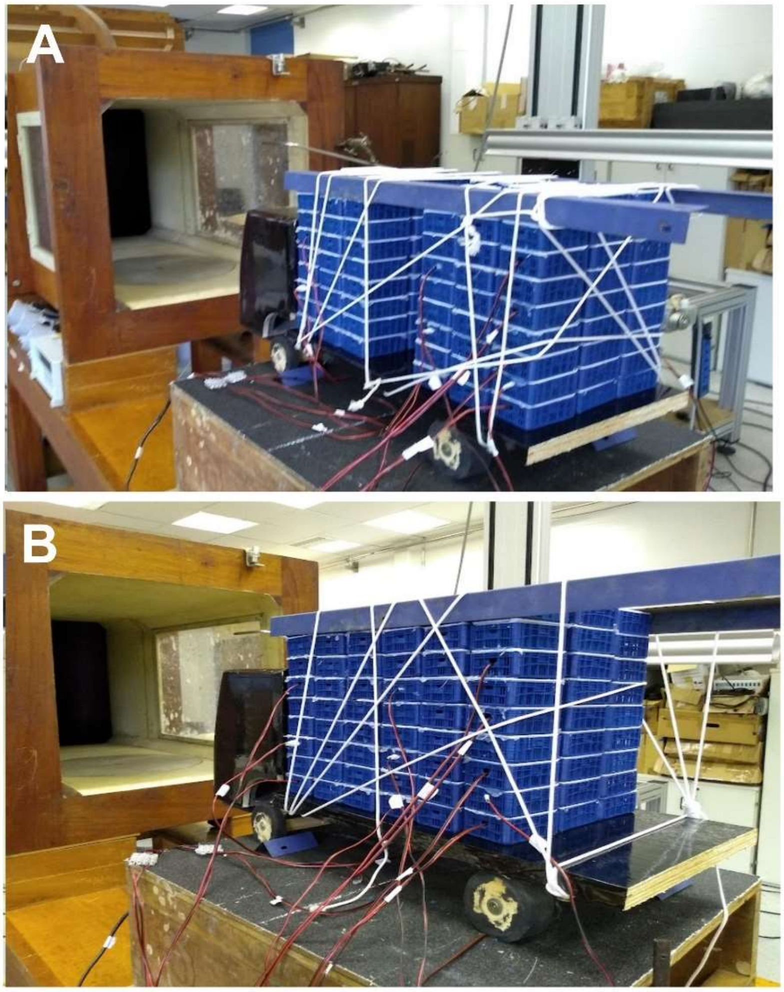

FIGURE 2. Representation of wind tunnel tests with truck prototypes using a "central span" (A) and air corridor (B) layout

During the test, ten repetitions were standardised in all tests, and the following wind speeds were used: 10, 15, 20, and 30 m/s. Ventilation inside the crates was measured every minute using thermistor sensors with a measurement sensitivity of 0.001 m/s. These sensors were distributed throughout the load, as shown in Figure 3.

FIGURE 3. Sensor distribution in wind tunnel tests.

Statistic

The ventilation data inside the crates in the evaluated layouts were submitted to a non-parametric statistical analysis, based on the Kruskal-Wallis test, using the SAS NPAR1WAY procedure of the Statistical Analysis Software (SAS Inst. Inc., Cary, NC), adopting $P < 0.05$, as the threshold level of significance.

RESULTS AND DISCUSSION

The main characteristic of load ventilation in the air aisle layout is wind circulation with speeds of 2–5 m/s, between the vertical aisles between the rows of crates (Figure 4A). However, an airflow displacement pattern was observed, marked by ventilation drag towards the rear region, after colliding with the vehicle cabin (Figure 4B). Therefore, a ventilation profile similar to the conventional layout is used to transport broilers (Pinheiro et al., 2021).

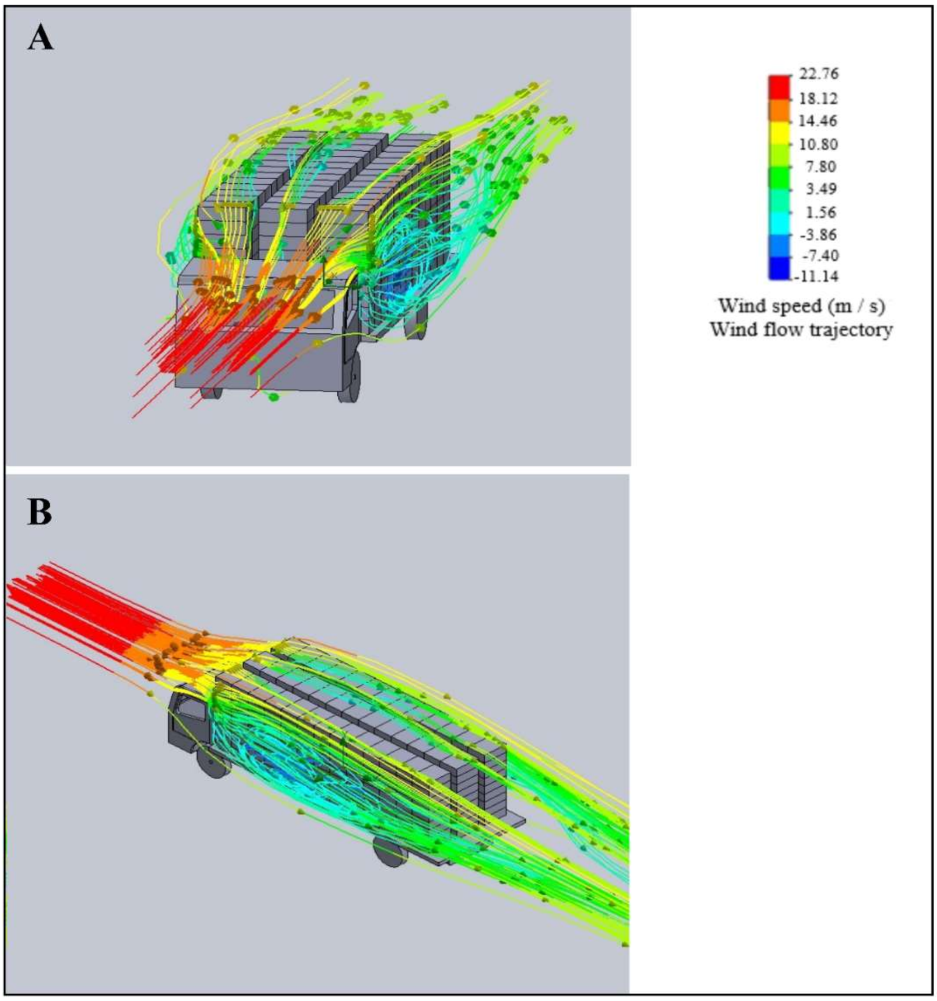

FIGURE 4. Ventilation pattern in the air aisle layout used for transporting live broiler: front (A) and side (B) views of the truck.

Therefore, the simulations suggested that the creation of vertical corridors between the crates results in a low ventilation rate along the length of the load. This can be associated with energy losses after impact with the truck cabin, which ranged from 35% (Machado et al., 2021b) to 45.5% (Pinheiro et al., 2021), and due to friction (loss of load) between the wind and the crates as it travels through the crates inside the load.

After colliding with the truck cabin, the wind flow loses energy and moves mainly to the side (Figure 5A). The sectioning of the load in the layout with a “central span” resulted in a turbulence pattern (Figure 5B). This can improve the welfare of the animals, especially by improving air quality, due to the greater removal of dust, suspended particles, and gases harmful to animals and humans (Seedorf & Schmidt, 2017).

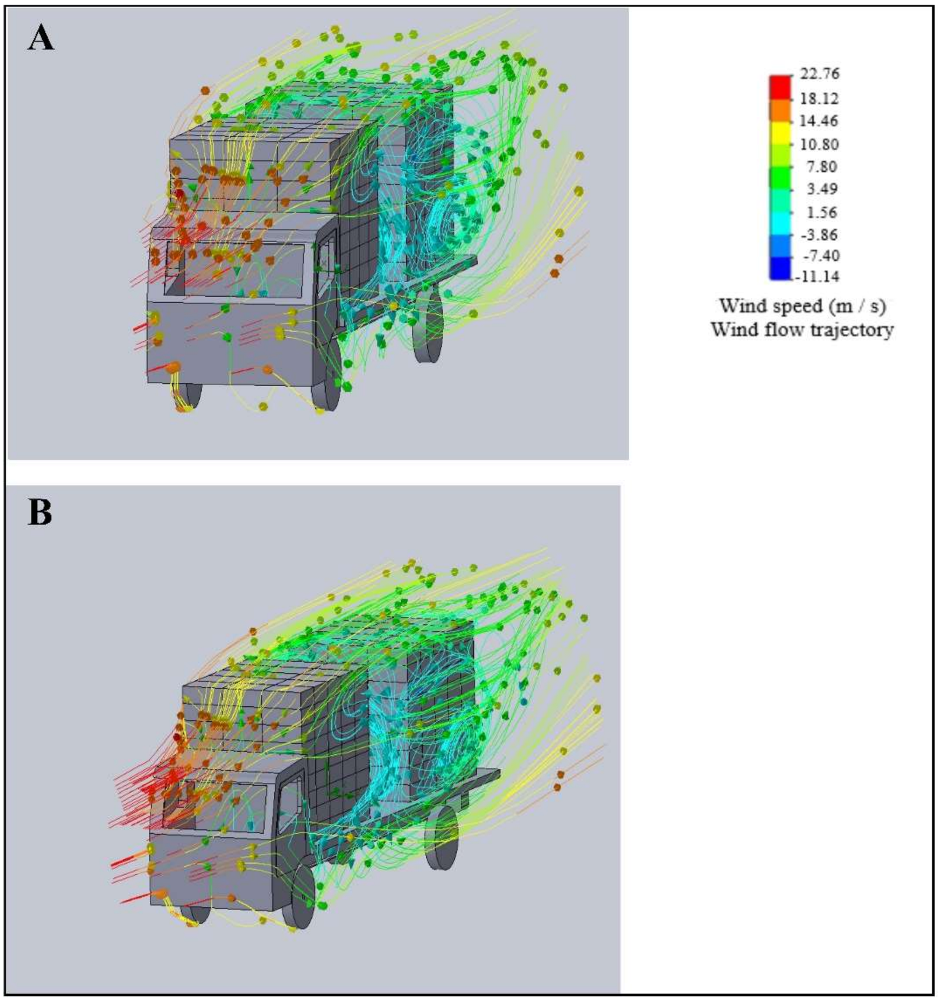

FIGURE 5. Ventilation pattern in the "central span" layout used for the transport of live broiler: front (A) and side (B) views of the truck.

Depending on the wind intensity, there could be greater ventilation inside the transport crates. This could also be advantageous in reducing the thermal stress of broilers by reducing the energy contained in the load. Machado et al. (2021a) showed that thermal nuclei are associated with the ventilation dynamics in the load and verified that this thermal condition occurs inversely to the ventilation pattern.

The turbulence in the central span can be associated with an increased ability to channel wind from the sides to the interior of the load (Figure 6A). Therefore, these results indicate a new suction region, in addition to the region naturally situated in the back region of the load. This air renewal in the load can be a viable solution for reducing and homogenising thermal energy during animal transport. (Gilkeson et al., 2016; Norton et al., 2013).

In a study of the transport of broilers under commercial conditions in Brazil, Spurio et al. (2016) evaluated four conditions: conventional layout and alternative layout, with and without the load wetting method. The layout proposed by the authors consisted of vertical corridors (width 10 cm) between the rows of crates associated with plates at specific points to channel the wind to the most deficient regions of the load. The authors found a reduction in the occurrence of pale, soft, exudative (PSE) meat by 66.3% with wetting and 49.6% without wetting in loads using the alternative layout.

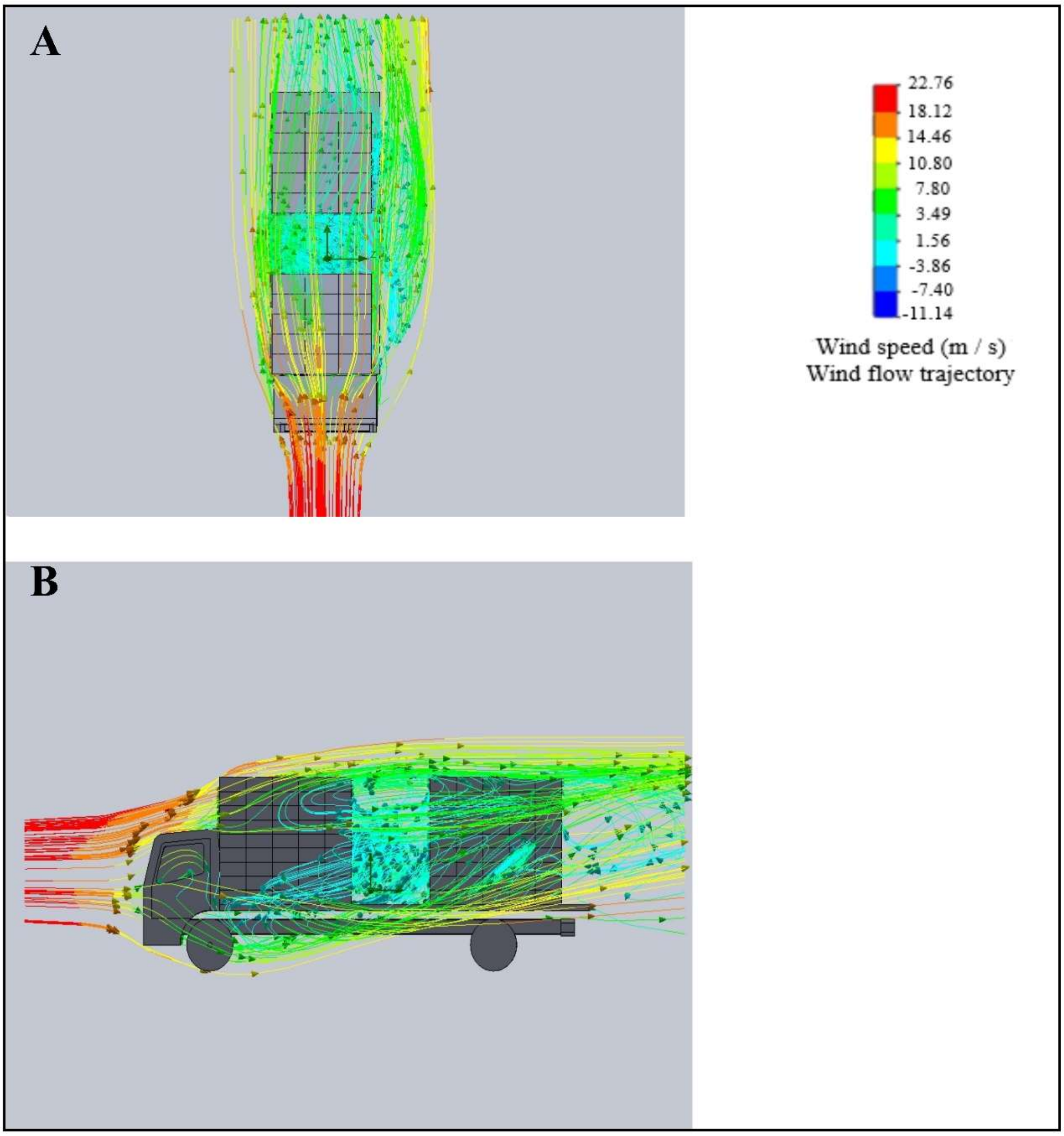

FIGURE 6. Ventilation pattern in the air aisle layout used for transporting live broiler: top (A) and side (B) views of the truck.

However, for significant changes in the thermal comfort of broilers to occur during transport, ventilation inside the crates must be intensified. The wind tunnel tests showed a linear increase in the VIC (Velocity Inside the Crates) with a gradual increase in the test speed (Figure 7). This result was expected because it occurs naturally by increasing the simulated speed in a wind tunnel.

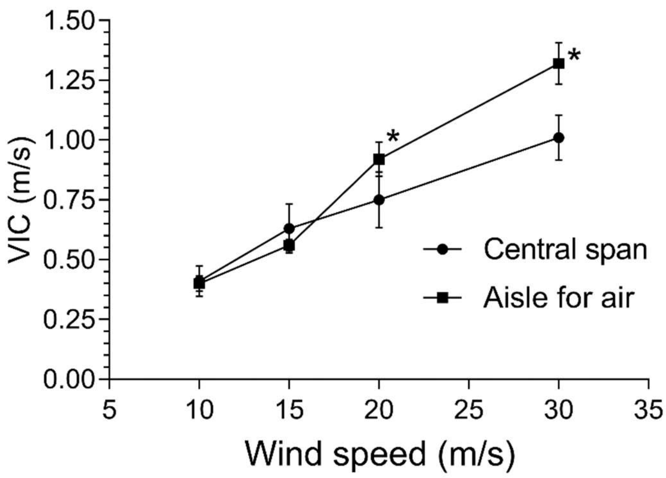

FIGURE 7. Variation of ventilation inside the crates (VIC) ± standard mean error as a function of the test speed in the wind tunnel in the evaluated layouts.

Figure 7 shows a significant trend of higher VIC rate in loads with a central span layout in relation to an air corridor layout at the highest tested speeds. However, the speed of 30 m/s (108 km/h) is above the limit established for most Brazilian highways. In addition, there was also a higher (P=0.045) rate of VIC at a speed of 20 m/s (72 km/h) in loads using the "central span" layout (Table 2). These results confirm those obtained in the CFD simulations, and are particularly important as it reflects the average speed recorded during monitored trips under commercial conditions in Brazil.

TABLE 2. Ventilation inside the crates (m/s) for the evaluated layouts simulating journeys with a truck speed of 20 m/s.

Layout	Average	Median	Max	Min	SE[1]	P value
With "Central span"	0.931[a]	0.856	1.82	0.25	0.14	0.048
With "Air Corridor"	0.769[b]	0.629	1.64	0.48	0.11	

[1]SE = Mean standard error

From a cost point of view, the layout with a "central span" is not feasible as it implies a reduction of approximately 20% (70 fewer crates) in the number of crates stacked along the truck, that is, a smaller load-carrying capacity. Other studies have suggested that reducing the density of broilers in crates may be an efficient alternative to some extent (Hussnain et al., 2020; Benincasa et al., 2020) and may increase VIC (Pinheiro et al., 2021).

The results show that the layout or the type of load assembly (stacking the boxes along the truck) can optimise ventilation inside the load, but it requires a reduction in operational efficiency and an increase in transport costs. Thus, the design and dimensions of commercially available transport crates seem to indicate the most coherent direction for future investigations to improve the welfare of broilers during transport.

Moreover, the constant training of employees involved in the operation is valuable for reducing losses and ensuring better animal welfare conditions. Precision animal husbandry tools accessible to producers and transporters, such as thermographic cameras, video cameras, sensors, and traceability applications, can aid in transport planning and loss control.

CONCLUSIONS

The layout with a "central span" can optimise the internal ventilation of the load. However, it becomes necessary to reduce the number of crates stacked on the truck, which is not feasible for the commercial transport of broilers because it makes it more onerous. Therefore, studies on the aerodynamic and thermal profiles of crates commercially used for the transport of broilers are suggested.

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