# What technical solutions can be used to shelter mulard ducks during periods when there is a risk of avian influenza? Main results of the PROSPeR project

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## Abstract

The increased number of avian influenza cases on duck farms for the production of foie gras has led to a major reassessment of how these animals should be reared, particularly the obligation to shelter the animals during high-risk periods (i.e. to keep them indoors). As a result, farmers face the same twofold challenge: managing the indoor climate, which is inextricably related to managing litter and farmers' workloads, while ensuring animal performance and welfare. The PROSPeR project aimed at overcoming these difficulties by developing innovations and technical choices adapted to different situations that can be encountered on livestock farms, in order to help farmers manage sheltering. To clarify and objectively examine farmers' choices, the work performed combined three complementary approaches: a farm feedback approach, an experimental approach and a computing approach. Three main types of decision-making tools for professionals were developed to help farmers make choices in their sheltering management: (1) a decision-support tool combined with case studies to share feedback about different sheltering situations, (2) a variety of supporting materials that cover the four key success factors for sheltering and (3) a calculator to assess whether the density chosen and associated litter requirements are manageable, depending on the type of building and weather conditions.

**Keywords:** sheltering, sheltering, ducks, avian flu

## 1. Introduction

The upsurge in cases of avian influenza on duck farms producing foie gras has led to a major reassessment of the systems used to rear these animals. Changes have been made at the technical level (e.g. sheltering if the health risk in the region increases), structural level (e.g. standardising the single flock) and organisational level (e.g. introducing additional biosafety measures). As this virus is spread in particular through contact between palmipeds and contaminated wild birds during migration, one of the main challenges for the industry is to ensure that these animals are sheltered during periods of risk (DGAL, 2016). While the concept of sheltering may seem simple to grasp, as it involves rearing animals under protected conditions (i.e. in enclosed buildings), in reality it covers a more complex range of production systems and rearing practices. This complexity arises from the many combinations of different structural characteristics inherent in livestock farming (types of buildings, types of soil, equipment, etc.) and the many different management practices that can be used (choice of density, type and quantity of litter, mulching methods, age at which some animals are removed to decrease density or at which all animals are sent to slaughter, etc.). All systems, however, face the same two-fold challenge: managing the building environment, which is inextricably related to litter management and the farmer's work, while ensuring animal performance and welfare. In addition to the known difficulties in managing the environment and litter in buildings, sheltering also increases fear responses, described by farmers as nervousness, reported from the age of 5-6 weeks, and certain bodily lesions (pododermatitis, scratches, etc.). The aim of the PROSPeR project was to address these obstacles by recommending innovations and technical choices adapted to the situations that may occur in livestock farming, with a view to help farmers manage sheltering in case the health risk in their region increases. To clarify and objectively examine the choices that farmers make in their management of sheltering, the work performed combined three complementary approaches:

- **An operational focus approach**, consisting of organising, developing and sharing feedback from farmers about a variety of technical aspects (controlling the environment, mulching and litter management, feeding and watering methods, etc.) via (1) online surveys, (2) telephone and face-to-face interviews with production organisations and farmers, supplemented by farm visits, and (3) organisation of trade days focusing on sharing experiences.
- **An experimental approach**, consisting of testing and evaluating under controlled conditions a variety of practices likely to have a positive influence on (1) environmental conditions and litter quality, (2) manure characteristics and water wastage and (3) animal behaviour.
- **A predictive approach**, with a view to (1) simulating the cost:benefit ratio of innovative equipment that requires major investment (dehumidifiers) and (2) supporting and objectively examining farmers' choices for stocking density and mulching methods (type, quantity, stage of litter application) for different types of buildings and weather conditions, using modelling.

These approaches are presented in this article. This combination of livestock observations, trials under controlled conditions and modelling is particularly useful for determining the size of buildings and equipment, optimising their renovation, predicting effects of livestock management and adapting them to the diversity of buildings and climates (Chetouane *et al.,* 2019).

## 2. Organising, promoting and sharing feedback from farmers

To attempt to contain the successive health crises caused by the spread of the avian influenza virus on farms, French authorities made it mandatory to shelter mulard ducks, depending on the risk of the virus circulating and the zone in question (French decree of 29 September 2021 on biosafety measures) during the PROSPeR project. This decree led farmers to adapt production systems urgently and gain experience by implementing measures directly on farms. Farmers provided feedback in two stages:

- **At the start of the project (2019-2020), when sheltering** had been practised by only a handful of farmers: the profession, which had little experience with the subject, was interested in the **potential adaptations** that could be made on farms;
- **From the middle of the project (2021-2022), when sheltering** was no longer a hypothesis but a reality for many farmers, particularly in areas with a high density of palmiped farms (538 communes listed in the decree were considered to be Dissemination Risk Areas: the profession had widely practised it by then, and it was possible to **capitalise effectively on** experiences on farms.

## 2.1. Materials and methods

### *2.1.1. Online surveys performed at the start of the project*

During the initial outbreaks of avian influenza, palmiped farmers experimented with sheltering during batches and/or throughout the rearing phase, or wondered how to perform it on their farms, which caused a great deal of uncertainty and questioning. In fact, feedback from farmers who performed sheltering and acquisition of references on this subject were necessary to provide better advice to those involved in the future. To this end, an online survey was created (Pertusa *et al.*, 2020). The aim of the survey was to perform an initial assessment of the situation to identify the initial feedback and solutions implemented or devised by farmers to ensure that their animals were sheltered, in the context of their work. The survey, performed using Lime Survey software, consisted mainly of closed questions that covered building characteristics, feeding, watering, environmental management, animals, litter, waste and technical and economic results of the farm. One section was also devoted to the investments that farmers made to adapt their production tools to the health context. Finally, the surveys included more open-ended questions, giving farmers the opportunity to express their views on their practices and the difficulties they faced. For each topic, 5-15 questions were asked. In addition, depending on certain answers, additional conditional questions were asked. These included questions about experiences with sheltering, which could be answered only by farmers who had actually done so. The survey took 1.0-1.5 hours to complete. These surveys, validated beforehand by the partners in this project, were sent to palmiped farmers (in integration schemes and short distribution channels) via production organisations and Chambers of Agriculture throughout France.

### *2.1.2. Telephone and face-to-face interviews with production organisations and farmers performed from the middle of the project*

The 2020-2021 sheltering experience provided a unique opportunity to supplement these results and share the experience gained with other farmers. To this end, 10 production organisations were contacted and questioned about the following:

- The structure of the stock/buildings, distinguishing between the existing stock and new developments;
- Assumptions about what density to use for each type of building;
- Technical recommendations given to farmers during the sheltering period for a variety of key points on the farm (heating, linear feed troughs, rationing, etc.);
- Innovations that improve management of water and humidity in the building and/or help prevent behavioural problems, particularly related to feeding and watering practices, litter and the environment, and other practices for preventing behavioural problems;
- Examples of successes and difficulties encountered.

These interviews enabled us to develop a building typology in the form of a decision tree with four branching points:

- Type of **use**: a "hot" building, in which both the start-up phase and growing-finishing phase are performed *vs.* a "cold" building, in which only the growing-finishing phase is performed;
- Type of **ventilation**: cross ventilation, "Louisiana" type or longitudinal ventilation in gables;
- Type of **building:** depending in particular on its width: building with a skylight (> 12 m wide), building without a skylight (6-9 m wide) or other type of building (mobile hut, tunnel, shed, etc.);
- Assumptions about **animal densities** during the start-up and/or growing-finishing phase (5 or 3 ducks/m² after removing some animals to decrease density, at the end of start-up or not).

A panel of 16 farms representative of 19 case studies was then selected. These farms were the subject of an individual interview with the farm manager, sometimes accompanied by a technician, performed on site by an intern trained in semi-structured interviews. The survey consisted of 10 open-ended questions, with follow-up questions that covered the following five topics: farm characteristics, management of the environment and litter, management of feeding and watering, animal welfare, feedback and future prospects. Before or at the end of the interview, additional qualitative and quantitative data, related directly to costs and expenses as well as to building characteristics, were collected from the farmer or directly from the building.

## 2.2. Results

### *2.2.1. Online surveys performed at the start of the project*

The survey developed was relatively complex, which led us to keep the sample size small, but to fill it with contrasting situations of production patterns, site structure and experience with animal sheltering. The survey therefore enabled these situations to be studied in greater depth. Twelve farmers (six who had sheltered their animals and six who had considered how they would shelter their animals if necessary) responded to the online survey, describing changes to their systems, difficulties they had encountered and the initial solutions they had identified to manage sheltering (Pertusa *et al.*, 2020). Eight of them had invested €5000-261,000 to expand their buildings and buy additional equipment (feed chains and silos, pipette lines, straw blowers, etc.). Half of them had also built outdoor areas, and three had invested in a new building. For most of them, the difficulties encountered were litter management, given the arduous nature of the work, and nervousness of the animals. To address this, reducing the density of the animals was a priority for most of the farmers surveyed. On average, the 12 farmers estimated an ideal technical density of 4.5-5.4 ducks/m² to ensure satisfactory economic results. For some systems, this represents a halving of duck numbers. Enriching the environment, choosing high-quality, absorbent litter and treating the animals (beak trimming and declawing) are important practices. In addition, nearly all farmers considered a straw blower essential for handling the estimated increase of ca. 45-60 min of extra time needed per week per m² to mulch during the sheltering period, compared to a “traditional” period. In addition, for half of the farmers surveyed, one or even two intermediate cleanings of the manure are necessary for good technical management of the batch. In addition, the importance of a warm-up time at the start of the batch, ventilation of buildings (to control the humidity) and increased monitoring of the animals (3-4 passes a day) to prevent certain technical problems (by assessing the general condition of the ducks) or possible leaks, are also considered as practices that should not be ignored.

### *2.2.2. Telephone and face-to-face interviews with production organisations and farmers performed from the middle of the project*

The information received as feedback about sheltering from 2020-2021 was summarised in 19 summary leaflets, one for each case study, and associated with a decision tree intended for palmiped farmers (Do *et al.*, 2023). This collection, in the form of case studies, contains testimonials and advice from farmers about different types of buildings and density choices, organised into a decision tree with four branching points that shows farmers which leaflet(s) they should consult that describe the case study or studies most similar to their situation. These leaflets are available free of charge from the ITAVI website (https://www.itavi.asso.fr/publications/quelles-solutions-techniques). They take the form of a four-page document that combines quantitative and quantitative data measured or observed for the last batch sheltered and quotes from farmers' testimonials that share their experiences (comments, advice, tips) that cover several key elements:

1. **System economics**: description of the production system itself, amount of money invested, operating costs for litter and energy and measured zootechnical performance (live weight, feed conversion ratio and mortality);
2. **Management of litter and the environment**: input/output quantities, frequency of operations and the farmer's organisation/equipment;
3. The **farmer's work**: the time and physical and mental strain involved in monitoring the animals, mulching, cleaning and disinfecting the building;
4. The **welfare and body condition of the animals**: assessment of nervousness, feathering, cleanliness of their plumage, degree of body lesions and lameness, homogeneity and overall health of the batch.

These leaflets have also contributed to a more comprehensive collection of solutions, in the form of technical data sheets and PowerPoint presentations. This collection resulted from the project partners capitalising on feedback from the production organisations and farmers interviewed, the expertise of the project partners in their respective domains (environment/living space, feed, animal welfare/behaviour) and the results of trials performed as part of the project. It considers the four key success factors for sheltering:

- **Adapting the density to the type of building** by addressing issues related to the choice of density for different types of buildings, the useful and usable area on the farm, optional equipment, heating conditions, etc.;
- **Controlling the water consumed and discharged (wasted) by animals** by addressing issues related to feed formulation, through space and rationing, as well as the access to and quality of water;
- **Managing litter** by considering issues such as the type of soil and litter, mulching and grazing, as well as the organisation of these operations and the relationship between litter quality and the condition/health of the animals;
- **Ensuring performance and animal welfare** by addressing issues related to nervousness and possible management practices.

### 2.3. Dissemination by organising professional days focused on sharing experiences

During the project, four events were organised for industry professionals, which brought together 240 farmers and technicians:

- One day centred around the testimonies of farmers, presented in the form of a **round table of ca. 10 farmers** who had taken part in the previous work, which resulted in the production of case studies in interaction with the public, made up of more than 100 farmers looking for information about this theme;

- Two half-days, one in Nouvelle-Aquitaine (face-to-face) and the other in the Occitanie region (videoconference), focused on the **four key success factors for sheltering, based** on feedback from the production organisations and individual farmers interviewed by the project partners, the expertise of the project partners in their respective domains (environment/living area, feed, animal welfare/behaviour) and the results of trials performed as part of the project;
- One half-day videoconference focused on **presenting the project's main deliverables and results**.

All supporting materials from these events are available free of charge on the ITAVI website (https://www.itavi.asso.fr/publications/accompagner-la-filiere-foie-gras).

## 3. Implementing innovative practices on experimental stations

To remove technical barriers associated with sheltering (i.e. managing the building environment and litter and ensuring animal performance and welfare), seven trials were performed during the project at three experimental sites in the Nouvelle-Aquitaine and Brittany regions:

- Two aimed at identifying limiting factors and recommending ways to optimise litter management during sheltering;
- Four aimed at identifying ways to ensure optimum growth for the animals while trying to limit behavioural problems and increase litter quality;
- One aimed to recommend ways to ensure that the animals adapt well to sheltering, in particular by decreasing their emotional reactivity, which can cause nervousness problems.

### 3.1. Testing limiting factors and recommending ways to optimise litter management during sheltering

#### *3.1.1. Materials and methods*

*Effect of animal density (4, 5 or 6 ducks/m²) during sheltering*

For sheltering, the densities used during the growing-finishing phase vary on farms from 3-6 ducks/m² depending on the type of building, with a consensus on 5 ducks/m² in nearly all cases but a lower density for tunnel and/or shed systems. While it seems clear that density strongly influences litter quality during sheltering, no data are available under controlled conditions. A trial that compared three densities (low (D4) = 4 ducks/m², control (D5) = 5 ducks/m² and high (D6) = 6 ducks/m²) was performed at the ASSELDOR site in the Dordogne department. It involved 508 one-day-old male mulard ducklings of the MMGAS × PKL strain, divided among 12 pens of 8.2 m² each, with four replicates (pens) per treatment. The animals were fed a conventional three-phase diet: starting feed (crumbs) at 22.6% CP at 2850 kcal ME from D1-D7, starting feed (pellets) at 17% CP at 2800 kcal/kg ME from D8-D28 and growing-finishing feed (pellets) at 15% CP at 2800 kcal/kg ME from D29-D80. This feed was distributed *ad libitum* from D1-D56 and then only 1 h per day from D57-D80. The length of the feed trough was 15, 12 and 9 cm per duck for treatments D4, D5 and D6, respectively. Shredded straw was used as litter throughout the trial, with no intermediate cleaning. Litter was mulched on demand. Measurements were taken of the following: the animals' zootechnical performance (individual live weight and feed consumption per pen on D28, D46 and D80), body condition at the same ages and the quantities of litter used and manure removed per pen.

*Bioclimatological study of livestock buildings*

Trials were planned at an experimental facility in which the climate around the building, the rearing chamber and its equipment, and the livestock management, in particular the animal density and litter chosen, could be controlled (Robin *et al.*, 2022). These trials supplemented data acquired from growing ducks in a similar facility, which has since been demolished (Robin *et al.*, 2002a, 2002b), and characterised in more detail the factors that influence evaporation from litter. The aim was to model the factors that influence the formation of water vapour in a building (animal intake, environmental conditions, external climate). Trials under controlled conditions were planned at the INRAE experimental facility for bioclimatological study of livestock buildings in the Ille-et-Vilaine department. It contains six rearing chambers of 5 m² each, each equivalent to a livestock building, enabling animals to be reared under conditions similar to those of commercial farms, while choosing the climate around these buildings. Two air conditioning systems are used to maintain a constant climate around the chambers. One provides warm conditions (12-40°C around the chambers), while the other provides other cold conditions (-10°C to 15°C). Because the chambers are naturally ventilated (i.e. "static" ventilation), the results produced can be applied to any type of livestock building. They are equipped with measurement systems to quantify the heat and gas production of the livestock systems.

#### *3.1.2. Results*

*Effect of animal density (4, 5 or 6 ducks/m²) during sheltering*

The trial showed a significant difference in live weight (+80 g; $P < 0.001$) between D4, D5 and D6 at 7 weeks of age, in favour of the lowest density (3501 g *vs.* 3421 g). This difference subsequently decreased and was no longer significant on D80. More feed was wasted in D6 (+0.13 and +0.15 FCR points from D28-D49 and D49-D80, respectively). The quantities of straw used varied from 23-35 kg/m², with no difference in the quantity of straw per animal as a function of density (mean 8.3 kg of straw per duck). These data were used to help calibrate the model developed in the project and provide farmers with lookup charts.

*Bioclimatological study of livestock buildings*

Too little time remained in the project to observe animals at the facility. However, it was possible to finish installing the system and perform initial tests to characterise the litter at the facility without animals present. The chambers were adapted for duck rearing, in particular to weigh the "animals + litter", improve the airtightness of the chambers to decrease the minimum flow rate to 3 $m^3/h/m^2$ and decrease the detection threshold of heat production to 1 W per chamber (Robin *et al.*, 2022). Tests with artificial production of water vapour led us to improve the calculations by distinguishing the specific heat of dry air and that of water vapour when calculating the sensible heat flux. Preliminary tests on composts were performed to ensure the precision of the water vapour measurements and identify the potential variability in metabolic water production by manure. These tests showed that the main factor that limited the precision was manure sampling: water content needed to be measured more than 10 times to improve the measurement precision to less than 5%. Theoretical analysis of metabolic water production by manure showed that its contribution to water vapour emissions could vary from 0-100%. We therefore now recommend relating the carbon balance (emitted mainly in the form of $CO_2$) and the hydrogen balance (emitted mainly in the form of $H_2O$) to the gross weight loss (dry matter and water) to validate the quantification of air flows and associated gas losses. Regarding litter management, initial tests to characterise litter performed at the facility without animals showed that the quantity of metabolic water produced in the litter likely could not exceed 10% of the liquid water evaporated by the livestock system (estimated at 2-5% during a trial designed to maximise this percentage). Moreover, wood chips were able to drain liquid water (vertical flow of waste water under the troughs) and maintain open porosity in the air connected to the outside (diffusion and evacuation of water vapour due the heat produced by the manure).

### 3.2. Testing feeding practices to maintain animal growth while limiting behavioural problems and improving litter quality during sheltering

#### 3.2.1. Materials and methods

*Effect of meal frequency (one vs. two meals per day) on rationing during the growing-finishing phase*

Splitting the feed consists of increasing the frequency of feed intake, without changing the total amount of energy ingested. This practice decreases the time between meals, which is ca. 22 h on duck farms during the growth phase, with the feed ration frequently being distributed in the morning. According to Sazy (1996), this duration leads to visible weight loss in animals after 8 h, but which stabilises after 16 h. Other studies have shown that, for chickens, splitting meals increases feed-use efficiency and that the animals quickly become accustomed to split feeding (Svihus, 2013). A trial performed at an experimental station on ducks ready for fattening showed that, for a given daily quantity of feed (220 g/d), ducks obtained more value from the feed when the ration was distributed in two meals per day instead of only one (Bernadet and Lague, 2017). In fact, ducks fed one meal per day were lighter at the time of over-feeding. Split feeding decreased post-overfeeding breast and leg weights, but had no effect on foie gras performance. Distributing two meals per day improved the feed-intake index and suggests that splitting the feed, thus decreasing the time between meals and the duration of fasting, improves energy and protein use. Lavigne *et al.* (2017) obtained contradictory results when distributing a non-restrictive quantity of feed in one or two meals per day, as ducks that received two meals per day were lighter at the time of over-feeding. Given these results, the aim of this trial, performed at the UEPFG (Unité Expérimentale Palmipèdes à Foie Gras) experimental station in the Landes department, was to test effects of meal frequency (one *vs.* two) on the technical and economic performance and behaviour of ducks during the rearing and over-feeding periods. The ducks were reared in larger batches under sheltering conditions and received a given daily quantity of feed. To do this, 3200 ducks of the MMG × PKL strain were reared according to two rationing treatments in eight pens of 80 m², with four replicates per treatment. The ducks were fed a two-phase diet (starting feed (pellets) with 17.5% CP at 2850 kcal/kg ME from D1-D21, then growing-finishing feed (pellets) with 15% CP at 2850 kcal/kg ME from D22-D80) distributed *ad libitum* from D1-D35. Then, 220 g of feed were distributed per duck in one meal of 1 h per 24 h (R1) or two meals of 30 min at 10.5 h intervals (R2) from D36-D80. The length of the feed trough was 5 cm per duck. Shredded straw was used as litter and distributed in the same way for all treatments using a straw blower. Complete intermediate cleaning was performed on D56. Measurements were taken of the following: the animals' zootechnical performance (individual live weight and feed consumption per pen on D35, D51, D63, D72 and D80; weight of various cuts from 80 ducks per treatment on D72), body condition at the same ages assessed using the lookup tables developed by Litt *et al.* (2015) and the quantities of litter used and manure removed per pen.

**Effect of decreasing the concentrations of CP (15% *vs.* 13.5%) and ME (3000 kcal/kg *vs.* 2800 kcal/kg) in growing-finishing diets**

Sheltering ducks leads to a decrease in activity and less exposure to temperature variations, which justifies changing the feed formula to one with lower protein and energy concentrations. To verify this hypothesis, a trial was performed at the ASSELDOR site in the Dordogne department to compare two diets during the growing-finishing phase (Bijja, 2020): a growing-finishing control feed used outside the shelter (15% CP and 3000 kcal/kg ME; PE+) and an experimental growing-finishing feed (13.5% CP and 2800 kcal/kg ME; PE-).

The trial involved 480 one-day-old male mulard ducklings of the MMG × PKL strain, divided among 12 pens of 40 animals (density of 5 ducks/m²), with six replicates per diet. The ducks were fed a starting diet (pellets) containing 17% CP at 2800 kcal/kg ME from D1-D21, followed by a PE+ or PE- diet from D22-D77. From D1-D56 this feed was distributed *ad libitum*, and from D57-D77 it was distributed 1 h per day.

The length of the feed trough was 12 cm per duck. Shredded straw was used as litter throughout the trial, with no intermediate cleaning. Litter was mulched on request. Measurements were taken of the following: the animals' zootechnical performance (individual live weight and feed consumption per pen on D28, D46 and D77; weight of various cuts from 80 ducks per treatment on D77), body condition at the same ages and the quantities of litter used and manure removed per pen.

*Effect of adding organic acids (0%, 0.05% or 0.1% incorporation rate) to growing-finishing diets*

Adding organic acids to poultry feed is known to stabilise intestinal flora, prevent digestive disorders and improve the digestibility of the ration. These effects raise questions about the benefits of adding them to growing-finishing feed, as they could help improve manure quality (quantity and concentration) and thus litter quality. To verify this hypothesis, a trial was performed at the ASSELDOR site in the Dordogne department to compare three diets during the growing-finishing phase: a control growing-finishing diet (15% CP and 2800 kcal/kg ME) not supplemented with organic acids (AO0) or the same feed supplemented with 0.05% organic acids (AO5) or with 0.1% organic acids (AO10). These incorporation rates were defined with the feed supplier and formulator. The trial involved 480 one-day-old male mulard ducklings of the MMG × PKL strain divided among 12 pens of 40 animals (density of 5 ducks/m²), with four replicates (pens) per diet. The ducks were fed a two-phase diet: starting feed (pellets) with 17% CP at 2800 kcal/kg ME from D1-D21, then AO0, AO5 or AO10 feed from D22-D80) distributed *ad libitum* from D1-D56 and then for 1 h per day from D57-D80. The length of the feed trough was 12 cm per duck. Shredded straw as used as litter throughout the trial, with no intermediate cleaning. Litter was mulched on request. Measurements were taken of the following: the animals' zootechnical performance (individual live weight and feed consumption per pen on D28, D46 and D80; weight of various cuts from 80 ducks per treatment on D80), body condition at the same ages assessed using the lookup tables developed by Litt *et al.* (2015) and the quantities of litter used and manure removed per pen.

*Effect of adding clay (0%, 1.5% or 2% incorporation rate) to growing-finishing diets*

Several products based on natural substances are added to poultry feed to improve digestive efficiency and performance, and decrease the water content of manure. Among them, several types or derivatives of clay have been tested and recommended. A trial was performed at the ASSELDOR site in the Dordogne department to compare three diets during the growing-finishing phase: a control growing-finishing feed (15% CP and 2800 kcal/kg ME) not supplemented with clay (ARG0), or same feed supplemented with 1.5% clay (ARG15) or 2% clay (ARG20). The trial involved 480 one-day-old male mulard ducklings of the MMG × PKL strain divided among 12 pens of 40 animals (density of 5 ducks/m²), with four replicates per diet. The ducks were fed a conventional two-phase diet (starting feed (pellets) with 17% CP at 2800 kcal/kg ME from D1-D21, then ARG0, ARG15 or ARG20 from D22-D80) distributed *ad libitum* from D1-D56 and then for 1 h per day from D57-D80. The length of the feed trough was 12 cm per duck. Shredded straw was used as litter throughout the trial, with no intermediate cleaning. Litter was mulched on request. Measurements were taken of the following: the animals' zootechnical performance (individual live weight and feed consumption per pen on D28, D46 and D80; weight of various cuts from 80 ducks per treatment on D80), body condition at the same ages assessed using the lookup tables developed by Litt *et al.* (2015) and the quantities of litter used and manure removed per pen.

### 3.2.2. Results

*Effect of meal frequency (one vs. two meals per day) on rationing during the growing-finishing phase*

Under these rearing conditions, with quantitative rationing (230 g/duck/day), split feeding during the growth phase (36-71 days of age) of male mulard ducks reared during sheltering has little effect on zootechnical performance (Bernadet, 2020). During the first 20 days of treatment (36-56 days of age), distributing the same daily quantity in two meals per day increased duck growth and feed-use efficiency (+116 g/duck, i.e. +3.7%, $P < 0.001$; and -0.31 FCR points) compared to ducks fed only one meal per day, confirming results obtained previously. Thigh weight differed on D72. This difference decreased and then disappeared at the end of the trial. Furthermore, feeding two meals per day did not influence the animals' body condition, as no difference was recorded between treatments. A mean of 6 kg of chopped straw per duck was used.

*Effect of decreasing the concentrations of CP (15% vs. 13.5%) and ME (3000 vs. 2800 kcal/kg) in growing-finishing diets*

The change in feed resulted in slightly lower live weight for PE- animals than for PE+ on D46 (3386 *vs.* 3418 g, i.e. +1%; $P < 0.05$), but this difference disappeared thereafter, and worse FCR from D46-D77 (+0.19 FCR points; Bijja, 2020). These observations confirm that mulard ducks can regulate energy intake during the rationing period. Body composition measured on D77 showed no significant difference between the two diets over the rearing period. The consumption of additional feed by the PE ducks generated an extra cost of €0.09 per duck, which can vary depending on the price of ingredients. No difference in footpad condition or litter quality was observed.

*Effect of adding organic acids (0%, 0.05% or 0.1% incorporation rate) to the growing-finishing feed*

Adding organic acids to the feed resulted in growth performances similar to those without supplementation. Furthermore, there were no significant differences in litter quality, which had the same water content and dry matter production, among treatments. Finally, there was no difference in footpad condition among treatments. Feed costs also did not differ among treatments.

*Effect of adding clay (0%, 1.5% or 2% incorporation rate) to the growing-finishing feed*

Adding clay to the feed at rates of 1.5% and 2% (ARG15 and ARG20) resulted in growth performances similar to those without supplementation. Adding 2% clay to duck diets appears to improve litter quality (lower water content, with no differences in manure characteristics). Adding clay to the growing-finishing feed therefore appears to be an interesting solution to be optimised, in particular by studying the effect of adding more than 2% clay to determine the threshold beyond which the cost:benefit ratio decreases.

## 3.3. Testing practices to ensure that animals adapt well to sheltering

### 3.3.1. Materials and methods

*Effects of modulating light intensity at night (no artificial lighting vs. lighting at < 20 lux) and whether or not animals have access to an outside area*

Rearing ducks during sheltering causes specific problems, including difficulties managing the strong emotional reactivity of certain batches, which is responsible for exacerbated fear behaviour on farms and certain resulting physical injuries. This is manifested by animals reacting strongly to the slightest event, creating panicked movements that can damage batches greatly (scratches, even death by suffocation). A trial was performed at the UEPFG experimental station in the Landes department to compare the combination of two practices: the intensity of night lighting and whether or not the animals had access to a protected outdoor area. These practices, chosen based on feedback from farmers, may also help limit the over-consumption of feed observed during sheltering, which was explored at the same time. The trial involved 480 animals of the MMG × PKL strain divided among 16 pens of 12 m² according to a 2 × 2 factorial design that combined two effects. There were four replicates per treatment. We compared two intensities of night lighting applied from D8-D83 (20 lux (E+) *vs.* no lighting (E-) from 22:00 to 6:00) and two accommodation arrangements (12 m² pen with no outside access (L12) *vs.* 6 m² pen with access to a 6 m² outdoor area (L6/6) from D21-D83). An intensity of 20 lux corresponds to the minimum intensity that can be considered as a daytime period in the European Union Broiler Directive. The trial was repeated over two seasons (spring/summer (S1) and autumn/winter (S2)), reversing the light conditions applied in each part of the experimental building between the two replicates. The ducks were fed a two-phase diet (starting feed (pellets) with 17.5% CP at 2800 kcal/kg ME from D1-D21, then growing-finish feed (pellets) with 14.8% CP at 2725 kcal/kg ME from D22-D80) distributed *ad libitum* from D1-D42 and then at a rate of 210 g per duck from D43-D80. The length of the feed trough was 4.2 cm per duck. The ducks were reared on wood shavings at a density of 5 ducks/m² from D1-D21 and then on slatted floors at a density of 2.5 ducks/m² from D22-D83. Measurements were taken of the following: the animals' emotional reactivity (tonic immobility tests and emergence tests on D21, D42 and D77), zootechnical performance (individual live weight and feed consumption per pen on D7, D21, D42 and D77) and body condition (assessed at the same ages using the lookup tables developed by Litt *et al.* (2015)) and behaviour (recorded by *scan sampling* the day before weighing).

#### *3.3.2. Results*

Although the differences observed were relatively small, treatment E- helped to reduce fear responses on D42 and D77 under the experimental conditions tested (Litt *et al.*, 2024). These differences were larger for L12 animals than for L6/6 animals. In contrast, treatment E- led significantly decreased live weight of the animals on D21 and D42, due to consuming too little feed. These differences were larger for L12 animals than for L6/6 animals, particularly during season S2, when feed requirements are higher due to lower temperatures. This result can be related to outdoor light shining into buildings in systems that provide access to an outdoor area in winter, but this seems to have had little effect in the trial.

These results have been published in several ways, which have increased the number of project deliverables.

## 4. Implementing tools to support farmers' choices

### 4.1. Materials and methods

#### *4.1.1. Multi-criteria evaluation*

To assess the relevance of a solution, its benefits and/or impacts need to be considered in a systemic way, considering the pillars of sustainability: environmental, economic and social. To provide the best advice to farmers and/or help them make the right choices, these three aspects need to be considered and compared to the existing production contexts. To this end, criteria and indicators developed in the S+ Durable tool, related to the Diamond method (Litt *et al.*, 2014), were selected. Initially developed for trials, this method makes it possible, using a semi-quantitative assessment that generates a scale from -1 to +1, to interpret positive, negative or neutral effects of one or more trial(s) compared to a control system, considering the pillars of sustainability. For the solutions/innovations highlighted in the context of managing the sheltering of palmipeds, 42 indicators were selected and/or adapted, and then grouped according to 15 criteria: **Economic:** economic viability, labour efficiency, efficiency and control of added value; **Environmental:** energy, water and biomass consumption, waste management, biodiversity, connection to the land; **Social:** work management, animal welfare, product quality. The associated indicators, presented in an Excel file, were designed to assess the economic viability, environmental consistency and degree of acceptability to the farmer of a structural change or a change in practices aimed at making it possible to shelter animals or managing sheltering better.

#### *4.1.2. Feasibility study of air dehumidification at building entrances*

During sheltering, litter problems may arise due to accumulation of water vapour inside the building. As outdoor weather conditions strongly influence changes in environmental conditions inside the building (Šottník, 2002), these problems area exacerbated during the periods when viruses are most likely to spread (November to March) due to these conditions. Dehumidification could help alleviate these problems. Dehumidification involves removing water from a volume of air by condensing it. There are several ways to do this, but all depend on outdoor weather conditions. A study of the feasibility of this type of system on a duck farm was performed (Laval, 2020). To this end, two case studies were defined based on the weather conditions usually encountered in south-western France as boundary conditions for dehumidifying buildings of ready-to-fatten ducks: a cold, wet winter (temperature between -5°C and 15°C and relative humidity of 80-100%) and a wet summer (temperature of 15-30°C and relative humidity of 80-100%). The target indoor conditions were defined based on feedback from the farmers (temperatures of 15°C and relative humidity of 80%).

#### *4.1.3. Developing a calculator of the rate of litter degradation as a function the type of building, weather conditions and farmer choices*

Given the difficulties that livestock farmers encounter managing litter, some of the work in the project focused on developing a calculator, using modelling, to assess a farmer's potential to manage the litter of a sheltered batch as a function of the type of building, weather conditions, animal density and mulching practices (type of litter, quantities and dates of replacement). Development of this calculator, which simulates degradation of litter during a batch, began by using farm data obtained from feedback from the farmers (from a real climate) and data acquired from the former bioclimatological facility (Institut Agro, Rennes) (from a controlled and constant climate).

### **4.2. Results**

#### *4.2.1. Multi-criteria evaluation*

Based on results of the trials performed and the feedback provided by the farmers about an innovation, structural change or change in practices, a semi-quantitative rating was developed. Based on average references, a rating from -1 to +1 was calculated according to the improvement or worsening of the indicators for each criterion compared to an initial control system. For example, multi-criteria analysis of a decrease in stocking density (

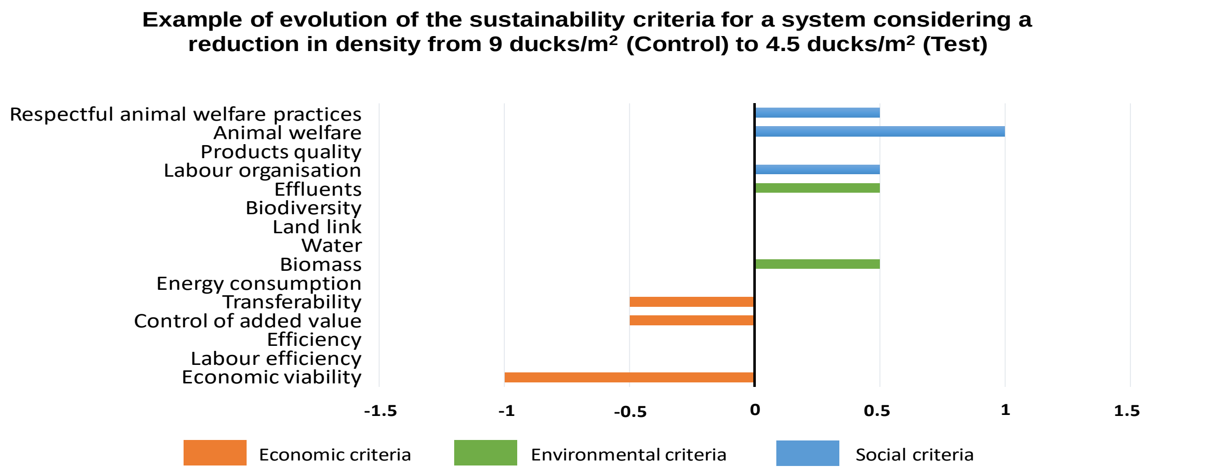


Figure 11) highlighted simulated economic losses, as well as potential improvement in animal welfare and associated reductions in waste. In this context, the main aim of this tool is to raise awareness of the stakeholders involved, mainly livestock farmers, about the need to consider systemic effects of a change to ensure that they make informed choices. The scientific accuracy of the tool remains to be seen, but its main purpose is to stimulate reflection by providing a simple, overall visualisation of the expected effects of the solutions envisioned. It is available on request from ITAVI.

### 4.2.2. Feasibility study of air dehumidification at building entrances

During a cold, wet winter, outside air contains little water. Heating the air is sufficient to achieve the desired environmental conditions inside the farm (15°C and 80% humidity). During a hot, humid summer, the incoming air must be cooled and then reheated to achieve the desired environmental conditions. The calculations show that the cooling and heating power requirements needed to dehumidify the air are 4-8 times greater than those found in livestock production for heating (Laval, 2020). As a result, it is difficult to envision this type of solution for dehumidifying the air inside buildings. Other approaches appear preferable, such as installing dynamic (motorised) ventilation.

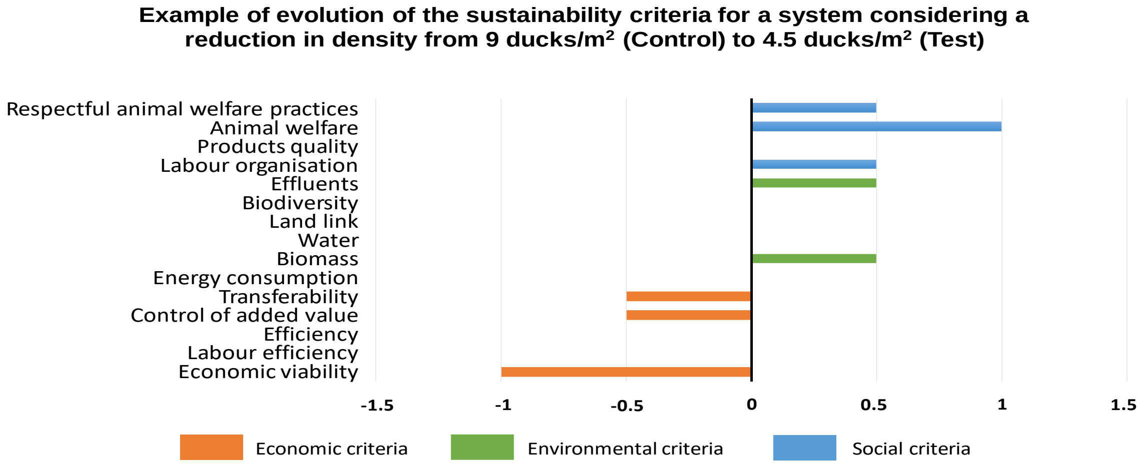


**Figure 1**: Example of multi-criteria evaluation of a decrease in the density of ducks/m². The system with fewer ducks (4.5 ducks/m²) is compared to the control (9 ducks/m²), and scores are attributed depending on the positive or negative impact of the practice on each sustainability criterion; if the two practices (control and trial) are equivalent, the score is 0.

### 4.2.3. Developing a calculator of the rate of litter degradation as a function of the type of building, weather conditions and farmer choices

The input variables (building types, types of livestock management, mulching management, animal management, management of drinking troughs) and output variables of the calculator (changes in litter water content and definition of a threshold of water content above which cleaning is recommended) were validated by the project's steering committee. Version 1 of the calculator was developed to assess whether the density chosen and the associated need for mulching are manageable depending on the type of building and the weather conditions (favourable/unfavourable) by simulating the degradation of duck litter. It meets a practical need of farmers in the management of sheltering. The calculator still needs to be validated under real farm conditions before being widely disseminated. This could not be done during the project due to difficulties in matching the project timetable with duckling supply and equipment availability. For example, the model can predict (with accuracy that remains to be validated using farm data) the water content of the litter and the quantity of manure produced for a given mulching management (Figure 2).

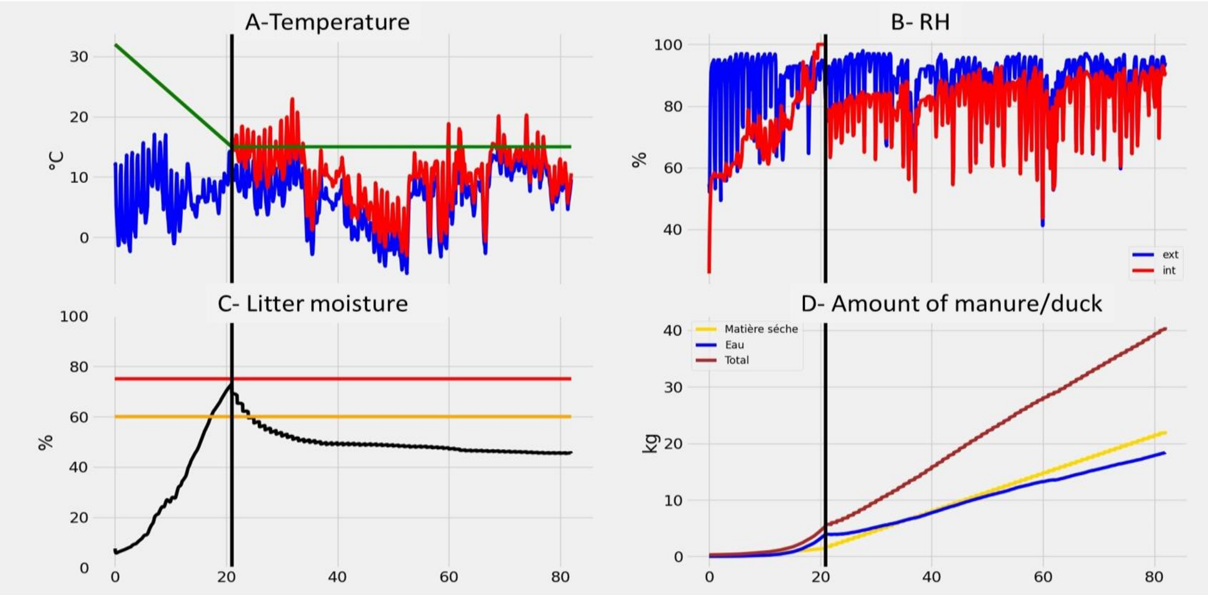


**Figure 2:** Example of model output: based on a thermodynamic balance ((A) temperature and (B) relative humidity) in the building, the calculator can predict (C) the water content of the litter associated with mulching management (in this case, daily re-mulching to maintain water content below 60% throughout the batch) and (D) the quantity of manure produced.

## 5. Conclusion

**Two types of solutions can help** farmers **overcome obstacles to sheltering:**

- **Structural**, related to the type of building available for sheltering and equipment (heating/ventilation, feeding and watering systems, mulching equipment), for which farmers have little room to manoeuvre, due in particular to the investments required;
- **Technical and organisational**, related to the choice of litter used, feed composition and distribution, and animal density at different life stages, for which farmers have more room to manoeuvre.

These solutions should be chosen on a farm-by-farm basis while considering the influence of making a change on other parameters, such as the farm's cost:benefit ratio (investments and other costs, which can vary depending on the price of raw materials and products), work (time and arduousness) and animal welfare (condition and behaviour). To help industry professionals make the best choices, **three main types of decision-making tools** were **developed to** help farmers choose their sheltering management:

- **A decision tree combined with case-study leaflets** to share feedback about different sheltering situations. They contain qualitative and quantitative information, quotes from testimonials and advice about the sheltering performed in 2020-2021 by ca. 15 farmers throughout France (west and south-west);
- **A variety of supporting materials** (technical sheets, presentation aids) that **cover the four key success factors for sheltering:** adapting the density to the type of building, controlling the water consumed and discharged (wasted) by the animals, optimising litter quality and ensuring animal performance and welfare;
- **A calculator** in the **form of a litter-degradation simulator** to assess whether the density chosen and associated need for mulching are manageable depending on the type of building and weather conditions (favourable/unfavourable). The calculator still needs to be validated under real farm conditions before it can be widely disseminated.

## Ethics

The authors declare that the experiments were performed in compliance with the applicable national regulations.

## Declaration on the availability of data and models

The data that support the results presented in this article are available on request from the corresponding author of the article.

## Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.

The authors used artificial intelligence to perform the initial translation of French to English.

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PERTUSA Marion: online surveys, multi-criteria evaluation.
GUYOT Yann: development of a simulator of litter degradation as a function of the type of building, weather conditions and farmer choices.
HAZARD Azélie, BERNADET Marie-Dominique: trial on meal splitting, participation in the multi-criteria evaluation.
BIJJA Mohamed: trials on decreasing concentrations of crude protein and metabolisable energy in diets and adding organic acids or clay to diets, participation in the multi-criteria evaluation.
LAVAL Gaétan: feasibility study of air dehumidification at building entrances.
ROBIN Paul: tests under controlled climate conditions: development of the system and improvement of the measurement chain, participation in discussions on modelling and in the feasibility study of air dehumidification at building entrances.
BLAZY Vincent, CHETOUANE Wejdene, MAZE Bernard: participation in discussions on modelling.
DO Clément: telephone and face-to-face interviews with production organisations and farmers.
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PREVOT Rafael, TESCARI Nelly: participation in online surveys, the production of deliverables and organisation of farmer feedback days.
HERAULT François: participation in the production of deliverables.
BAEZA Elisabeth: participation in discussions on feed-related trials and the production of deliverables and in the final translation of French to English of this paper.

## Declaration of interest

The authors declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

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