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ANALYSIS OF HOUSING RISK FACTORS FOR ANIMAL WELFARE IN A SAMPLE OF EUROPEAN FATTENING FARMS FOR HEAVY AND LEAN PIG PRODUCTION

Scientific Disciplinary Sector: AGR/10

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Gestione Sostenibile delle Risorse Agrarie e Forestali

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ABSTRACT

Animal welfare is a major challenge that most European pig producers have been facing in recent decades to comply with EU legislation and to meet the increasing societal and market demand for pork produced in a sustainable way. Pig welfare is ruled by EU legislation in terms of minimum requirements for housing and management, but stakeholders consider that both farm-level and animal-based indicators are fundamental to monitor animal welfare. Some of the welfare issues still affecting fattening pigs are the lack of space, bedding and manipulable material and the continued practice of routine tail docking of pigs. Tail docking is applied routinely across most European countries to reduce the occurrence of severe tail biting lesions, despite its ban in the EU. Animal and non-animal-based measures are useful indicators to investigate housing risk factors for pig welfare. An observational study on 51 pig farms in seven EU countries, aimed at investigating housing risk factors for the welfare of finishing pigs, showed body weight and presence of bedded solid floored laying area (BED) identifying three clusters of farms. Farms with BED were featured by no or limited tail docking, larger availability of roughage and manipulable materials and lower number of pigs per farm and per annual work unit. Pigs in these farms were found as less affected by skin and ear lesions, compared with lean pigs in farms without BED, which were characterized by lower pig space allowance, mortality rate and medication cost. Heavy pig farms without BED were featured by more space per pig, more pigs per drinker and higher mortality rate and medication cost per pig, compared to lean pigs without BED. No statistical difference in tail lesions was found between the three farm clusters, although tail docking was performed in all farms without BED and not performed at all on most farms with BED. The outcomes of this study confirmed that the presence of BED and larger availability of space, above the minimum requirement of EU legislation, can improve welfare conditions of fattening pigs by increasing their access to optimal enrichment materials and time spent in exploring and manipulating them and by limiting the occurrence of lesions in undocked tail pigs.

Keywords: housing system; pig welfare; fattening pig; body lesion scores; bedding material; enriched environment; roughage; tail docking.

1 INTRODUCTION

1.1 Preface

Animal welfare is considered as an important pillar of sustainability in pig production because related to animal health, productivity, food safety, food quality and efficiency from a cost of production perspective (Velarde et al., 2015). Pork is the second largest global source of meat after chicken. World meat production increased by 44% from 2000 to 2019 with pork accounting for 34% in 2019. European pig farmers produce 27% of world pork production (FAO, 2021). Animal welfare is a major challenge that most European pig farmers have been facing in recent decades to comply with EU legislation and to meet the increasing societal and market demand for pork produced in a sustainable way. Although pig welfare has been governed by EU legislation since 1991 (European Commission, 1991), some major welfare issues still remain, such as the lack of space allowance, enrichment materials and bedding, and the practice of tail docking if carried out routinely (Pedersen, 2018). Tail docking is generally banned in the EU, but allowed under certain exceptional conditions. Nevertheless, the measure is still applied extensively across most European countries (De Briyne et al., 2018). For the practice of tail docking to be terminated in a way that pig welfare will be improved, changes in production systems can be suggested, provided that pork customers, along the pig supply chain, are willing to pay the increased costs (D'Eath et al., 2016).

Housing conditions are deemed by stakeholders as particularly important to safeguard animal welfare, as well as the use of animal-based and farm-level indicators to monitor the progress of animal welfare (Averós et al., 2013). Differences in the production systems should be based on overall farm management, not only on animal housing (Korent et al., 2019).

Animal-based measures were developed to directly assess the effective welfare state of the pig by measuring, for example, its behaviour, fearfulness, health, or physical condition. The Welfare Quality® scheme is a well-known protocol for assessing pig welfare, based mainly on animal-based measures and including indicators covering the Five Freedoms and 12 widely accepted criteria: Absence of prolonged hunger; Absence of prolonged thirst; Comfort around resting; Thermal comfort; Ease of movement; Absence of injuries; Absence of disease; Absence of pain induced by management procedures; Expression of social behaviours; Expression of other behaviours; Good human-animal relationship; Positive emotional state (Welfare Quality®, 2009). Nevertheless, the European legislation for the protection of pigs is based on housing and management risks which can be assessed by using resource-based measures, rather than animal-based measures (EFSA, 2012). Resource-based measures, also called non animal-based measures, are indirect measures of animal welfare because measuring the ability of the farming system (i.e. housing and management) to provide pigs with conditions to which the pigs can adapt without endangering their welfare. Monitoring resource-based measures can be useful to identify risk factors that lead or may lead to actual welfare problems in pigs, which can be measured by animal-based measures. For instance, type of floor, feeding system, stocking density, environmental temperature and pig age were found to be potential predictors of the appearance of a given welfare measure of 'good housing' on a farm (Temple et al. 2012a; Temple et al., 2012b). Therefore, monitoring both animal-based and non-animal-based measures is deemed as a promising approach to advice pig farmers to control and improve the welfare conditions of pigs.

1.2 Space allowance

Pig space allowance has been investigated and debated for decades. Restriction of space allowance in animal farming is motivated, generally, by different reasons, such as: profitability; limitations of available space for a particular facility and funds for building animal houses; need to restrict animal movement to facilitate management; human and animal health and safety (Petherick, 2007). Rest in pigs is impaired in over-crowded conditions because other individuals' step on or otherwise disturb the pigs (EFSA, 2007a). Pen design is also important to allow social relationships to minimize aggressions and competition for resources and, particularly, to establish the group hierarchy after unacquainted pigs are mixed (Pedersen, 2018). The possibility for an animal to escape and move away from one or more pen mates is needed, generally, to limit aggressive behavior (Petherick, 2007).

Minimum requirements for unobstructed floor area available to each weaner or rearing pig kept in a group, are set by Directive 2008/120/EC, by body weight bands:

- 0,2 m^2/pig for pigs weighing more than 10 kg and less than 20 kg;
- 0,3 m^2/pig for pigs weighing more than 20 kg and less than 30 kg;
- 0,4 m^2/pig for pigs weighing more than 30 kg and less than 50 kg;
- 0,55 m^2/pig for pigs weighing more than 50 kg and less than 85 kg;
- 0,65 m^2/pig for pigs weighing more than 85 kg and less than 110 kg;

- 1 m^2/pig for pigs weighing more than 110 kg.

No further indication, in terms of space allowance, is set by EU legislation for pigs heavier than 110 kg, such as the Italian heavy pigs which are slaughtered at the minimum age of 9 months and at the live weight of 160 kg ± 10%, according to the Parma ham Protected Designation of Origin (PDO) scheme (Consortium of Parma Ham, 2021).

The allometric equation $A = k \times BW^{0.67}$ (i.e. B=body weight; k = 0.030) was proposed as an alternative and more flexible option to determine similar minimum space allowance for growing and fattening pigs according to body weight, up to 110 kg, compared to the EU requirements, graduated by weight classes (Spoolder et al., 2000).

However, EFSA (2005) recommended k = 0.036 for pigs up to 110 kg of live weight and k = 0.047 above 110 kg for the allometric equation to calculate space allowance to allow all pigs to rest simultaneously in lateral lying posture (EFSA, 2005). A k value of 0.039 also was proposed for growing-finishing pigs kept on slatted floor, as resulted from through broken-line regression analysis in a meta-analytic study on quantitative relationship between space allowance, floor type and pig lying behavior, meaning that over the space allowance, calculated with this value, a further increase of the time spent lying is not expected (Averós et al. 2009); this outcome is in contrast with the k value of 0.047 which would overestimate the need for space allowance in group housed pigs, as it doesn’t consider time distribution for different behaviour patterns, different lying postures and dynamics within the group (Ekkel et al., 2003).

Separation from other pigs, sufficient contact with a cool floor, outdoor access, airflow to increase water evaporation on the pig's skin and more water to drink are considered helpful in limiting heat stress in hot weather conditions. Minimum space allowance for fattening pigs, according to EU legislation, is considered as not sufficient at the end of the finishing period, regardless of ambient temperature; furthermore, if indoor average temperature is beyond the upper limit of the pig thermal comfort zone, additional space allowance and/or cooling systems should be provided to allow pigs to increase their heat dissipation rate and limit heat stress (Spoolder et. al., 2012). In the case of low indoor temperatures, the risk of hypothermia can be reduced through thermal insulation of the floor (EFSA, 2007a).

One study showed that less stocking densities and reduced pen size can lead to more pigs laying at the same time, less pig lesions, less pen dirtiness and higher average daily gain (Vermeer at al. 2014). Another study showed more time for lying, less time for aimless exploration, higher daily growth rate and lower feed conversion ratio in heavy pigs (i.e. slaughtered at the live weight of 160 kg), kept with a space allowance of 1.3 m^2/pig, instead of 1 m^2/pig (Nannoni et al., 2019).

However, higher housing costs in well managed commercial pig system are not likely to be compensated by performance benefits from higher space allowances (Jensen et al., 2012; Vermeer et al., 2014).

The influence of group size on pig welfare is also controversial; no significant effect was proved on fattening pigs according to some authors (Spoolder at al., 1999; Turner et al. 2003; D'Eath et al. 2014; Meyer-Hamme et al. 2016), whereas an increase in group size would result into unfavourable effects on welfare and performance, according to Vermeer et al. (2014). Smaller group sizes, up to 12 pigs, were found to allow an easier establishment of the hierarchy and to reduce fights after mixing but very large group size was also found to reduce fighting, since it stimulates the creation of sub-groups of pigs (Peden et al., 2018).

1.3 Pen dirtiness

Pig dunging behaviour is affected by space allowance because different functional areas are used by pigs for resting and for dunging, unless the pigs are heat stressed or sick or the stocking density is too high or the system is poorly designed and managed (EFSA, 2007a). Excreta elimination away from the nest/laying area seems to be a pig innate behavior evolving over time in the pig life; changes in the environmental conditions were found to affect the pig's choice of the dunging area (Andersen et al., 2019). Worst hygiene conditions on solid floors were detected in the last growing phase when soiling conditions and wallowing behavior are usually more prevalent (Jensen et al., 2012). Hot climate conditions were found to negatively affect the cleanliness of straw bedded pens for fattening pigs (Battini et al., 2016). Lying and excreting behaviors in indoor housed pigs were studied in relation to high temperatures, up to 32 °C, showing higher temperatures leading pig to lay on colder area, such as the slatted floor area of partially slatted floor systems, which, being occupied, becomes not accessible to the other pigs who are forced to defecate and urinate on the solid lying area of the pen (Huynh et al., 2004; Huynh et al., 2005), contributing to increased soiling and worse hygiene conditions (Aarnink et.al., 2006). In pigs reared indoor with deep straw bedding and access to an outdoor run for rooting and wallowing, more than 75% of excreta elimination was observed outside and only 3% in the internal laying area (Olsen et al., 2001). Different levels of pen dirtiness were also investigated in relation to the type of pen partitions (i.e. open or closed), revealing dirtier conditions in pens with open partitions, compared to pens with closed partitions in which air velocity reduction was likely to provide better maintenance of pig thermal comfort (Hacker et al., 1994). Level of dirtiness in the pen is also supposed to be affected by feeding system, as liquid feeding was found to cause more pig soiling, compared to wet and dry feeding systems (Temple et al., 2012b).

1.4 Feeding and drinking system

The feeding system was shown to be a determining factor for the pig welfare status (Meyer-Hamme et al., 2016) insofar as it can cause competition between pigs for accessing to feed and consequent aggressive behavior (EFSA, 2007b; EFSA 2014). Italian heavy pigs are traditionally liquid fed during the entire growing-fattening phase, which is approximately 6 month long (Vitali et al., 2021).

Free access to water of good quality is mandatory in fattening pigs (European Commission, 2009) and needed even if liquid or wet feed is provided (EFSA, 2007a); pigs where found to benefit from the provision of fresh drinking water although the water nutritional needs could be met theoretically through liquid feeding (Nannoni et al., 2013; Vermeer et al., 2009). To this end, a maximum number of fattening pigs per functioning drinker is recommended, depending on the type of drinker (Rossi and Gastaldo, 2004): 12 pigs per nipple drinker or 15 pigs per water bowl.

1.5 Slatted floor

The type of floor was identified as a causal factor for the occurrence of severe wounds, tail biting and lameness (Temple et al., 2012b). Slatted floors are widely used for housing pigs throughout the EU countries (EFSA, 2007a), including Italian heavy pigs for national PDO productions (Vitali et al. 2021). Fully slatted floor system was estimated to be used for housing more the 80% pigs in the EU (Pedersen, 2018). Slatted floors promote pig cleanliness and hygiene by allowing the quick and effective removal of faeces and urine from the pen; however, the use of fully slatted floors is likely to hinder or limit the use of straw as bedding and manipulable material to allow pigs to perform explorative behavior. Furthermore, sharp edges in the profile of slatted floors may cause cut injuries as well as a compressive stress (EFSA, 2007a); for this reason, minimum and maximum size requirements for concrete slatted floors were set by the Council Directive 2008/120/EC (European Commission, 2009). Slatted flooring was shown to limit the time spent by pigs to root the floor as this behavior was observed as redirected to other features and pigs in the pen (Averós et al., 2010). Lower risk of abnormal gait was detected in pigs housed on solid concrete floors with deep bedding in all areas, compared to pigs kept on solid concrete floors with sparse bedding, partly-slatted floors or fully-slatted floors (Kilbride et al., 2009).

1.6 Environmental enrichment

Manipulable materials are needed to enrich the pen environment for growing and fattening pigs intensively kept, at high stocking densities, in order to meet their exploration behavioural needs and to reduce the risk of tail biting and skin lesions (EFSA, 2014). One study found decreased exploration of enrichment material with increasing live weight (Meyer-Hamme et al., 2016), so special attention should be given to providing effective enrichment as the pigs' live weight increases.

Enrichment materials are categorized as (European Union, 2016):

a) optimal materials which can be used alone because they are "edible, chewable, investigable, manipulable, of sustainable interest, accessible for oral manipulation, given in sufficient quantity, clean and hygienic";

b) suboptimal materials, possessing most of the previous characteristics but not all of them so that their use should be combined with other materials;

c) "materials of marginal interest, providing distraction for pigs which should not be considered as fulfilling their essential needs".

Straw is considered as one of the best enrichment materials, according to several studies comparing different types of enrichment for pigs, including long and chopped straw, peat, mushroom compost, wood, rubber, metal objects, rope, wood, roughage and other substrates. However, the effect of straw provision on animal-based measures is controversial. For instance, one study comparing pigs with straw on solid floor with pigs without straw on slatted floor, showed that the first ones were spending much of their time manipulating straw and had significantly lower injury scores; instead, pigs without straw were found less active and spending more time manipulating the pen facilities and other pigs. Pigs provided with straw showed no significant differences in the feed conversion rate but performed better in terms of higher feed intake and average daily gain (Lyons et al., 1995; Jensen et al., 2020).

Another study on 91 Spanish and French farms with five different housing systems found no significant difference in the prevalence of animal-based measures between pigs in straw-bedded pens and pigs in conventional systems (Temple, 2012a). Positive effects of deep litter group housing with higher space allowance was shown on pig behavior, compared to standard barren housing. The combination of increased space allowance, increased area of solid flooring, straw provided on the floor and reduced group size was found to lead to an increase in tail-directed behavior but, at the same time, to a reduction of tail damaged pigs and also to an improvement of the overall welfare conditions (Brandt et al., 2020). Provision of adequate enrichment materials, like straw, in large amounts is facilitated on solid floors, whereas it is only possible on slatted floor if solids can be removed from under the slats (EFSA, 2007a) and the use of enrichment materials of low quality, such as hanging toys, in fully slatted floor systems is considered as a risk for pig welfare, as the pig need for exploration will not be met (Barbari et al., 2017).

However, the distribution of small amounts of straw in racks in fully slatted housing systems was found as feasible without compromising the effectiveness of the manure removal system (Wallgren and Gunnarsson, 2021). Straw can also be positively integrated into the pig diet, as straw consumption between 50 and 1000 g per pig per day, compared to no or limited access to straw, was shown to play a protective role against the onset of oesophago-gastric ulcers in lean and heavy pigs with undocked tails (Di Martino et al., 2013; Herskin et al. 2016; Jensen et. al, 2017).

1.7 Stockmanship

Poor stockmanship is considered as a risk factor for the welfare of fattening pigs in relation to the skills of stockpersons and the care and time dedicated by them to inspect and handle the animals (EFSA, 2007a). In one study the risk of tail biting was found increased 1.06-fold as the number of pens per stockman increased by one (Moinard et al., 2003). Ratio of number of pigs to number of stockpersons was also proposed as a possible predictor for severe tail lesions in heavy pigs (Scollo et al. 2017).

1.8 Tail docking and pig lesions

Most pigs in Europe are tail-docked (De Briyne et al., 2018), despite the fact that the practice of routine tail docking was banned in 1994 (European Commission, 1991). Tail docking aims at reducing the frequency of tail biting and the related tail lesions, but is painful for pigs; it also can lead to neuroma formation and pyemia in different parts of the body and can be associated with lower growth rate and, in some cases, with carcass condemnation (EFSA, 2007b). It was suggested that systemic approaches are required to stop tail docking by keeping pigs with intact tail without risk for them to suffer from tail lesions due to tail biting outbreaks; as tail biting is acknowledged as a system-inherent animal welfare problem, graded actions within the farm specific context are likely to be appropriate to stop tail docking across EU Member States (Sundrum, 2020). Tail biting is deemed as an abnormal pig behavior occurring mainly, although not exclusively, in barren environments; however, it can occur in all production systems, including free-range and organic (Alban et al., 2015; Sørensen, 2016; Kongsted and Sørensen, 2017). The occurrence of tail biting has a multi-factorial origin, as it depends on a wide range of factors, such as the lack of environmental enrichment, stocking density, presence of slatted floors, microclimate discomfort, high levels of dust and noxious gases (i.e., ammonia), competition for resources, social instability and genetic, dietary and health factors (D'Eath et al. 2014; EFSA, 2007b). Additional risk factors to predict farms having severe tail lesions were identified in: pig age; live weight at slaughter; space allowance per 100 kg of live weight; number and type of drinkers; pen size; number of pigs per farm and per stockperson (EFSA, 2014; Scollo et al., 2017). Younger pigs were shown to be more likely to be severely tail bitten, than older ones (Munsterhjelm et al., 2015).

A comparison between tail docked and undocked Italian heavy pigs slaughtered at 170 kg of liveweight and reared under challenging conditions that were considered as risk factors for tail biting (e.g., male gender, high stocking density, fully slatted floor and poor health), did not demonstrate a generalized welfare endangerment directly related to tail biting in undocked pigs, which showed, however, a higher prevalence of mild tail lesions (Di Martino et al., 2015).

Particular attention should be paid by farmers keeping pigs with intact tails through frequent observation and timely intervention in case of tail-biting outbreaks, which can spread rapidly and become difficult to stop (Veit et al., 2016; De Briyne et al., 2018). Relative feed intake on the day of detected tail lesion was found to be a possible predictor of the outcome of tail biting (Munsterhjelm et al., 2015). Monitoring tail biting and tail docking, both on farm and at the slaughterhouse, and developing training materials and guidance should be part of national action plans to improve the enforcement of EU directive EC 120 /2008 (De Briyne et al., 2018).

To improve consistent assessment of tail docking and enrichment conditions on pig farms, a multi-language online training package was developed, including information on scientific basis of EU legislation (Hothersall et al., 2016).

Prevalence of physical conditions in pigs varies between herds (Kongsted and Sørensen, 2017; Dippel et al., 2014). Tail, skin, and ear lesions are used widely as animal-based measures to directly assess animal welfare of growing and fattening pigs (Welfare Quality®, 2009; EFSA, 2012). Ear and skin lesions can be assessed separately or together (i.e. as included in the animal-based measure "wound of the body" of the Welfare Quality® protocol). Skin lesions, resulting from receiving bites (i.e., bite marks), are considered as a good indicator of the severity of aggression, although differences in individual pig liveweight and between-pen should be taken into account (Turner et al., 2006).

1.9 Mortality rate

The average mortality rate of pigs on the farm is a common measure of health and welfare for pig herds. Mortality is defined as 'uncontrolled death of animals', which is distinct from culling/euthanasia. "Any animal which is found dead on the floor in the house, or out on the field is considered a mortality" (Welfare Quality®, 2009). Pigs may be culled (i.e. emergency killing) if they are injured or sick to avoid exposing them to severe pain or suffering, or if no other practical way is available to relieve the pain (EFSA, 2020). One study shows that emergency killing is more frequently implemented on piglets rather than on older pigs, such as growing and fattening pigs (Costa et al., 2019).

1.10 Aim and hypotheses of research

The overall aim of this study is to add knowledge to understand housing risk factors for welfare of finishing pigs under commercial conditions, through the assessment and the analysis of animal and non animal-based measures in commercial pig farms in different European countries, to make the pig industry more aware of animal welfare issues in pig herds and to help it into line with European legislative standards, dictated by the increasingly demand of a market concerned about sustainability of livestock farms.

An additional aim is to understand the relationship between non animal based measures, assessed though the observation of pig housing and management systems, and animal welfare measures assessed through the observation of representative samples of the farm herds.

A second additional aim is to understand the differences between housing systems and management practices across European pig farms in relation to the slaughter live weight of lean and heavy fattening pigs.

These aims were addressed by testing the following hypothesis:

- non animal-based measurements to assess the suitability of pig housing system to provide good welfare conditions to pigs do affect animal-based measurements to assess pig welfare directly through pig observation;
- housing and management systems and related welfare indicators are the same across the surveyed sample of European pig farms, in relation to the slaughter live weight of lean and heavy fattening pigs.

2 MATERIALS AND METHODS

An observational study was carried out across seven EU countries by using the Condensed protocol from the Era-Net SusAn project "SusPigSys - Sustainable pig production systems" (The SusPigSys Team, 2020).

2.1 The SusPigSys protocol

The overall aim of SusPigSys was to assess and feed-back sustainability of a pig farm in a farm specific way that helps pig farmers improve the overall sustainability of their farm in an informed and balanced way, according to four priorities: environment, economy, farm personnel wellbeing and animal health and welfare. Animal health and welfare indicators in the SusPigSys protocol were selected from ProPig (Leeb et al., 2015), Welfare Quality® (2009) and other research projects (SusPigSys, 2022). Research partners from seven European countries (i.e. Austria, Germany, Finland, Italy, Poland, Netherlands and United Kingdom) developed a protocol for assessing data on a wide range of farm types, including closed cycle farms, breeding or fattening farms. The assessment protocol was developed in two consecutive steps. The first half of the project was dedicated to the foundation of the protocol for further development. Sustainability indicators were selected from an extended list and included into a draft assessment protocol. Inclusion of indicators into the final protocol was discussed and agreed with stakeholder representatives in workshop organized across the seven participating countries. Pig farmers were found generally interested in a tool to determine the level of sustainability of pig farming through farm assessment followed by farm feedback report showing their farm better or worse than other farms (i.e. benchmarking) (Hörtenhuber et al. 2021).

Analysis of the scientific literature, national stakeholder workshops and expert consultation were performed to develop the protocol which was revised after a first round of farm visits. A mobile application, intended for both SusPigSys scientists and European pig farmers, was created to collect information about sustainability of pig production across Europe (The SusPigSys Team, 2020).

Ten farms per country were recruited in the first phase of the SusPigSys project; they were selected to represent the main types of pig housing systems (i.e. organic, extensive, free range, conventional indoor/intensive systems). SusPigSys scientists were trained to consistently apply the protocol.

The large set of collected data was then analysed to see how the protocol could be reduced and condensed to a meaningful and practical size to be feasible and useful for end users (i.e. pig farmers, advisors). This reduced and condensed assessment protocol was used afterwards, in the second stage of the project to collect data in 7 EU countries on up to 25 pig farms per country, during 2019. The following exclusion criteria were used to recruit farms for data collection:

- farms that cannot provide the data in the needed quality;
- rearing only farms (e.g. weaning farms, rearing pigs from 8 to 25 kg of liveweight);
- farms with less than 20 sows or 80 finishing places;

- teaching/research farms or farms for people with special needs (e.g. social cooperatives);
- farms producing with the current system (for organic: fully converted) shorter than since January, 1st 2018;
- farms already planning to stop producing pigs;
- farms not complying with the law or having illegal workers or are known for any other big issues.

Pig farmers' associations helped the SusPigSys partners to recruit a sufficient number of suitable pig farms, despite their involvement being limited by biosecurity measures, particularly in Poland for protecting farms against African Swine Fever (ASF).

Farms adhered to the SusPigSys data collection on a voluntary basis and were not selected for being representative of the housing systems in use in their countries.

Pig group sampling and pig number sizing in each group for collection of animal welfare data were based on Pandolfi et al. (2017). Pig groups were chosen randomly and in proportion of their stage of production: one third of the pig groups at the early fattening period but grouped at least two weeks before farm visit; one third in the middle of the fattening period; one third at the end of the fattening period. For pig groups with 100 or less pigs per group, up to 15 pig groups were assessed by observing up to 50 pigs per group. For groups larger than 100 pigs, at least 50% of pigs per group were observed up to a total of 750 pigs for all groups. Animal-based information was collected by observing the animals in their own environment from a distance of 50 cm.

Before and at the beginning of each farm visit, the farmer (i.e., person(s) to be interviewed) was informed in speech and writing about the project, including information about anonymity, why the research was being conducted, how his or her data were being used and if there were any risks associated, and were asked to return a signed informed consent before the start of data collection. Farmers were asked, before pig observation, about the number of pig houses, pig groups per pig house, pigs per group and related ages, and if no, or some, or all pigs were tail docked. Prior to the start of farm visits, training material including definitions was created and assessors were trained at a joint training occasion in order to achieve a consistent scoring, which was tested as inter-assessor agreement for inter-assessor reliability (IOR) on-farm for all measures that required scoring, using joint assessments and photo material. IOR was calculated as exact agreement between two observers and expressed as weighted Kappa, PABAK and percentage agreement.

The PhD candidate was involved in the SusPigSys, as researcher of the project partner "Fondazione CRPA Studi Ricerche", until March 2021.

His role in the project was to collaborate in:

- data collection in the first and in the second phase of the development of the assessment protocol;
- development of the SusPigSys protocol, as expert in the process of weighing and aggregating indicators for the determination of farm animal welfare scores;
- quality check for animal welfare data;

- analysis of animal welfare, productivity and economic data of fattening farms, involved in the second stage of SusPigSys.

Training to learn the use of the SusPigSys protocol was achieved by the PhD candidate by attending a training workshops organized by Wageningen University of Life Sciences, in Wageningen (NL) from 6 to 10 May, 2019.

The PhD candidate also attended regular virtual meeting, organized by the coordinator on a monthly basis, from November 2018 to August 2020.

Data input and access was carried out through both the SusPigSys application and the ShareFile platform managed by the coordinator.

2.2 Materials and methods for the observational study

Animal welfare data, together with a number of economy and productivity data, considered as relevant for animal welfare assessment, were included in this study for fattening farms or fattening units of farrow-to-finish farms involved in the SusPigSys project. For this purpose, 31 non-animal and animal-based measures were considered as animal welfare indicators for both heavy and lean pig farms in the growing and finishing phase, across fattening units of 51 pig farms in seven EU countries: 12 farms in Italy, 10 in Germany, 5 in Austria, 12 in the Netherlands, 10 in Poland, 1 in Finland and 1 in the United Kingdom. Type and description of variables are given in Tables 2.1 and 2.2.

A total of 709 pig groups from 51 pig fattening farms were assessed. Complete data from these farms were processed statistically, including:

- animal welfare measures of up to 15 pig groups observed during farm visit, except for 3 Polish farms in which 16, 17 and 18 pig groups were observed for more representativity;

- economy and productivity data of visited farms, considered as potentially relevant for pig welfare (i.e., affecting or affected by pig welfare).

Farms with uncomplete data were excluded from this study, as well as cases of observed pig groups with uncomplete or inconsistent animal welfare data for one or more variables.

Twenty-three variables of the SusPigSys protocol were taken into account for the observed pig groups (Table 2.1): 14 non animal based measures were considered as relevant for pig housing conditions, productivity and management (i.e., four continuous, seven ordinal and three dichotomous variables) together with nine animal-based measures (i.e., four continuous and five ordinal variables), as relevant for pig body weight, presence of pig lesions and pigs with shortened tails and pig behavior towards manipulable materials.

Animal welfare measures on 709 pig groups were aggregated as mean values per farm for continuous variables or median values per farm for most ordinal variables, except for the variables presence of enrichment, (EP), tail lesions (T), ear lesions (E) and skin lesion on the body (B), which were transformed from ordinal variables into continuous variables, as farm percentage of observed pens with optimal or suboptimal enrichment (EC) or with at least one pig with a mild or severe tail (T), ear (E) or body (B) lesion, respectively (Table 2.2).

Table 2.1 – Continuous, ordinal and dichotomous variables for 709 pig groups.

N.	Variable description	Acronym	Type1*	Type2**
1	Total area indoor of observed pens (m^2)	TAI	nABM	C
2	Number of pigs per observed pen (n.)	NP	nABM	C
3	Mean space allowance per pig in observed pens (m^2)	SP	nABM	C
4	Mean number of pigs per drinker in observed pens (n.)	PD	nABM	C
5	Average pig live weight in observed pens (kg)	AW	ABM	C
6	Mean space allowance per 100 kg of pig liveweight in observed pens (m^2)	SK	ABM	C
7	% of active pigs manipulating enrichment in observed pens	EMB	ABM	C
8	% of active pigs in reach of enrichment material in observed pens	PAE	ABM	C
9	Laying area dirtiness: 1=clean; 2=medium; 3=dirty	DL	nABM	O
10	Slatted Floor: 0=no; 1=partial; 2=totally slatted	SF	nABM	O
11	Liquid feeding system: 1=dry; 2=wet or mixed dry/liquid; 3=liquid	LFS	nABM	O
12	Bedding in lying area: 0=no bedding, 1=not all pigs can lie on bedded area, 2=enough in laying area; 3=all pen floor bedded	BP	nABM	O
13	Presence of roughage: 0=no roughage; 1=pellet; 2= straw; 3=hay/silage	RP	nABM	O
14	Presence of enrichment: 0=no enrichment; 1=other enrichment of marginal interest; 2=suboptimal or optimal/proper enrichment combined with other enrichment; 3=proper/optimal enrichment	EP	nABM	O
15	Tail docking: 0=no tail docked; 1=some tail docked; 2=all tail docked	TD	nABM	O
16	Short tail: 0=no pigs with tail shortened by less than 50% of the original length; 1= <=10% pigs with tails shortened by less than 50%; 2= >10% pigs with tails shortened by less than 50%	SHT	ABM	O
17	Tail stump: 0=no pigs with tail shortened by more than 50% of the original length; 1= <=10% pigs with tails shortened by more than 50%; 2= >10% pigs with tails shortened by more than 50%	STT	ABM	O
18	Tail lesions: 0=no; 1= <=10% pigs have mild damage but no pig has severe damage; 2= >10% pigs have mild damage, and/or at least 1 pig has severe damage	T	ABM	O
19	Ear lesions: 0=no; 1= <=10% pigs have mild damage but no pig has severe damage; 2= >10% pigs have mild damage, and/or at least 1 pig has severe damage	E	ABM	O
20	Body lesions: 0=no skin lesions; 1= <=20% pigs have mild skin lesions but no pig has severe damage; 2= >20% pigs have mild skin lesions, and/or at least 1 pig has severe damage	B	ABM	O
21	Feed restriction 0=no, 1=yes	FR	nABM	D
22	Outdoor access 0=no, 1=yes	OA	nABM	D
23	Organic farm 0=no, 1=yes	OR	nABM	D

*) Animal Based Measure (ABM) or non-Animal Based Measure (nABM)
**) continuous (C) or ordinal (O) or dichotomous (D) variables

Table 2.2 - Continuous, ordinal and dichotomous variables for 51 fattening farms.

N.	Variable description	Acronym	Type1*	Type2**
1	Farm mean total area indoor of observed pens (m^2)	TAI	nABM	C
2	Farm mean number of pigs in observed pens (n.)	NP	nABM	C
3	Farm mean space allowance per pig in observed pens (m^2)	SP	nABM	C
4	Farm mean number of pigs per drinker in observed pens (n.)	PD	nABM	C
5	Farm % of pens with at least 1 nipple per 12 pigs or 1 water bowl per 15 pigs	PDC	nABM	C
6	Farm % of observed pens with optimal or suboptimal enrichment	EC	nABM	C
7	Farm average number of pigs per farm in 2018 (n.)	AVP	nABM	C
8	Farm average number of pigs per Annual Work Unit in 2018 (n.)	PWU	nABM	C
9	Farm maximum pig live weight before slaughter in 2018 (kg)	LWS	nABM	C
10	Farm veterinary and medication cost per pig sold in 2018 (€)	MCP	nABM	C
11	Average pig live weight in observed pens (kg)	AW	ABM	C
12	Farm mean space allowance per 100 kg of pig live weight in observed pens (m^2)	SK	ABM	C
13	Farm Average Daily Gain in 2018 (g)	ADG	ABM	C
14	Farm average Feed Conversion Rate in 2018	FCR	ABM	C
15	Farm mean % of active pigs manipulating enrichment in observed pens	EMB	ABM	C
16	Farm mean % of active pigs in reach of enrichment material in observed pens	PAE	ABM	C
17	Average mortality rate in 2018 (%)	M	ABM	C
18	Farm % of observed pens with at least 1 tail lesion in 1 pig	T	ABM	C
19	Farm % of observed pens with at least 1 ear lesion in 1 pig	E	ABM	C
20	Farm % of observed pens with at least 1 skin lesion in the body of 1 pig	B	ABM	C
21	Tail docking: 0=no pig tail docked; 1=some pigs tail docked; 2=all pigs tail docked	TD	nABM	O
22	Farm presence of slatted floor: 0=no; 1= partially slatted; 2=totally slatted	SF	nABM	O
23	Farm presence of bedding in lying area: 0=no;1=enough bedding in laying area; 2=all pens floor bedded	BP	nABM	O
24	Farm presence of roughage: 0=no; 1=pellet; 2= straw; 3=hay/silage	RP	nABM	O
25	Farm laying area dirtiness score: 1=clean; 2=medium; 3=dirty	DL	nABM	O
26	Farm presence of liquid feeding system: 1=dry; 2=wet or mixed dry/liquid; 3=liquid	LFS	nABM	O
27	Farm presence of pigs with short tail: 0=no; 1= <=10% of pigs with short tail; 2= >10% of pigs with short tail	SHT	ABM	O
28	Farm presence of pigs with tail stump: 0=no; 1= <=10% of pigs with tail stump; 2= >10% of pigs with tail stump	STT	ABM	O
29	Feed restriction: 0=no, 1=yes	FR	nABM	D
30	Outdoor access: 0=no, 1=yes	OA	nABM	D
31	Organic farm: 0=no, 1=yes	OR	nABM	D

*) Animal Based Measure (ABM) or non-Animal Based Measure (nABM)
**) continuous (C) or ordinal (O) or dichotomous (D)

The dataset of 51 cases of fattening units was obtained, including 8 additional continuous variables (Table 2.2): mortality rate (M), not including culled pigs because sick and/or suffering, in the calendar year before farm observation (i.e., 2018), farm percentage of pig groups with at least 1 nipple drinker per 12 pigs or 1 water bowl per 15 pigs (PDC) and 6 non animal-based measures related to farm management, productivity and economy (i.e. AVP, PWU, LWS, ADG, FCR, MCP).

Management and productivity data were collected in an interview with the farm manager or the person responsible for pig care using the SusPigSys protocol (The SusPigSys Team, 2020). Data on housing conditions in the pig houses were recorded through direct observation during farm visit.

As stockperson may be full or part-time employed, the average number of pigs present on a farm (i.e., AVP) was related to the Annual Work Unit (AWU), as defined by Eurostat (2021) for a stockperson occupied in pig farming on a full-time basis; this variable is the average number of pigs present on a farm in 2018 per AWU (PWU).

Statistical analysis of all data was performed with SPSS Statistics 27, except for Principal Component Analysis (PCA), which was performed using the PLS Toolbox software (v. 8.8.1).

The datasets of 709 observed pig groups and of 51 European pig farms in which pig observations were carried out, were explored by means of PCA, in order to obtain an overview of the overall data structure, both in terms of correlations between the considered variables and of samples (farms) clustering. The loading plots were used to investigate the relationships between variables. Kendall' tau b non-parametric statistics were also calculated to investigate bivariate correlations between continuous and ordinal variables. The variables ‘total area indoor’ (TAI) and ‘number of pigs’ (NP) in the observed pens were excluded from the first PCA on 709 pig groups, because of the presence of outliers in the dataset, represented by very larger pens with much more pigs, compared to most pigs groups on farm and/or in the dataset.

PCA models were calculated on the whole datasets using autoscaling as the variable pre-processing method. Autoscaling consists of transforming each variable by subtracting its average value and then dividing it by its standard deviation. This transformation allows the data to be translated at the origin of the reference system, since each variable will have an average value equal to zero, and also makes the variability of each variable equally important in the construction of the PCA model, since each variable will have standard deviation equal to one (Wise and Gallager, 1996). Variables that are close to each other, in the loading plot, have similar properties and variables that are far apart are different from each other (Næs et al., 2010).

The score plots were used both to highlight similarities and differences between the pig farms, and for direct interpretation of the farm cases in relation to variables in the loading plots.

Non-parametric analysis (Kruskal–Wallis test) was applied to the single variables, as data were found not normally distributed (i.e. even if transformed), to further explore the differences between clusters identified by the PCA. Furthermore, pairwise comparisons were performed using the Mann–Whitney U-test, when a significant effect of the farm group was revealed.

3 RESULTS

3.1 Results from observation of pig groups

An overview of descriptive statistics of the dataset of 709 observed pig groups is given for continuous, ordinal dichotomous variables in Tables 3.1, 3.2 and 3.3.

Table 3.1 – Descriptive statistics of the dataset of 709 observed pig groups for continuous variables.

Variable	Mean	SD	Min	Q25	Mdn	Q75	Max
TAI	22.2	14.1	2.9	11.5	17.8	29.2	108.0
NP	23.1	14.5	4.0	12.0	19.0	32.0	120.0
SP	1.0	0.3	0.5	0.8	1.0	1.1	2.6
PD	10.8	6.9	0.0	7.0	10.0	13.2	38.0
AW	79.3	33.1	30.0	50.0	80.0	100.0	175.0
SK	1.4	0.6	0.6	1.0	1.2	1.8	4.4
EMB	22.0	33.9	0.0	0.0	0.0	33.3	100.0
PAE	27.9	31.3	0.0	9.1	15.0	29.3	100.0

TAI, Total area indoor; NP, pigs/pen; SP, space allowance/pig; PD, pigs/drinker; AW, average pig live weight/pen; SK, space allowance/100kg pig LW; EMB, % pigs manipulating enrich.; PAE, pigs in reach of enrich. Mean, standard deviation (SD), minimum (Min.), lower quartile (Q25), median (Mdn), upper quartile (Q75) and maximum (Max) values.

Table 3.2 – Descriptive statistics of the dataset of 709 observed pig groups for ordinal variables.

Variable	Mode	Min.	Q25	Mdn	Q75	Max.
DL	0	0	0	0	1	2
SF	1	0	1	1	2	2
LFS	2	0	0	1	2	2
BP	0	0	0	0	0	3
RP	0	0	0	0	0	3
EP	1	0	1	2	3	3
TD	2	0	2	2	2	2
SHT	0	0	0	1	2	2
STT	2	0	0	2	2	2
T	0	0	0	0	0	2
E	0	0	0	0	0	2
B	0	0	0	0	1	2

DL, dirtiness in laying area; SF, slatted floor; LFS, liquid feeding system; BP, presence of bedding; RP, presence of roughage; EP, presence of enrich.; TD, tail docked pigs; SHT, short tail; STT, tail stump; T, tail lesions; E, ear lesions; B, body lesions. Mode, minimum (Min.), lower quartile (Q25), median (Mdn), upper quartile (Q75) and maximum (Max) values.

Table 3.3 – Descriptive statistics of the dataset of 709 observed pig groups for dichotomous variables.

Variable	%
Organic farms (OR)	8.7
Outdoor access (OA)	12.8
Feed restriction (FR)	43.9

Percentage of farms (%).

Correlations between continuous and ordinal variables of the pig group dataset were calculated and shown as Kendall's tau-b non-parametric statistics (Tables 3.4, 3.5 and 3.6).

Table 3.4 – Correlation matrix between animal and non animal-based measures in the dataset of 709 observed pig groups (Kendall's tau-b).

	AW	SK	EMB	PAE	SHT	STT	T	E	B
TAI	0.032	0.065*	0.125**	-0.180**	0.177**	-0.019	0.158**	0.074*	-0.072*
NP	-0.081**	0.016	0.081**	-0.204**	0.225**	0.011	0.156**	0.129**	0.043
SP	0.265**	0.123**	0.144**	0.026	-0.051	-0.116**	0.036	-0.108**	-0.291**
PD	0.006	0.027	0.048	-0.175**	-0.052	0.074*	0.038	-0.077*	-0.147
DL	0.009	-0.082**	-0.111**	-0.053	0.175**	0.009	-0.021	0.118**	0.060
SF	0.120**	-0.152**	-0.166**	-0.348**	0.405**	0.025	0.132**	0.119**	-0.010
LFS	0.153**	-0.038	-0.033	-0.171**	-0.032	0.054	-0.091*	-0.084*	-0.199**
BP	-0.064*	0.199**	0.399**	0.483**	-0.220**	-0.460**	-0.025	-0.126**	-0.192**
RP	-0.104**	0.170**	0.245**	0.419**	-0.121**	-0.399**	-0.041	-0.093**	-0.064
EP	-0.050	0.161**	0.250**	0.304**	0.099**	-0.317**	-0.059	0.040	-0.163
TD	-0.038	-0.162**	-0.254**	-0.288**	0.195**	0.447**	0.049	0.127**	0.260**

TAI, Total area indoor of observed pens; NP, pigs/pen; SP, space allowance/pig; PD, pigs/drinker; DL, dirtiness in the laying area; SF, slatted floor; LFS, liquid feeding system; BP, presence of bedding in the laying area; RP, presence of roughage; EP, presence of enrichment; TD, tail docked pigs; AW, average pig live weight/pen; SK, space allowance/100kg pig LW; EMB, % of active pigs manipulating enrichment; PAE, % of active pigs in reach of enrichment; SHT, short tail; STT, tail stump; T, tail lesions; E, ear lesions; B, body lesions. * Correlation is significant at the 0.05 level (two-tailed). ** Correlation is significant at the 0.01 level (two-tailed).

Table 3.5 - Correlation matrix between animal-based measures in the dataset of 709 observed pig groups (Kendall's tau-b).

	AW	SK	EMB	PAE	SHT	STT	T	E	B
AW	1								
SK	-0.642**	1							
EMB	-0.028	0.100**	1						
PAE	-0.154**	0.184**	0.209**	1					
SHT	0.087**	-0.119**	-0.028	-0.190**	1				
STT	-0.060*	-0.005	-0.261**	-0.230**	-0.287**	1			
T	-0.002	0.004	0.051	-0.057	0.234**	0.013	1		
E	-0.118**	0.052	0.044	-0.137**	0.292**	-0.096**	0.005	1	
B	-0.177**	0.005	-0.098**	0.047	-0.175**	0.217**	-0.148**	0.115**	1

AW, average pig live weight/pen; SK, space allowance/100kg pig LW; EMB, % of active pigs manipulating enrichment; PAE, % of active pigs in reach of enrichment; SHT, short tail; STT, tail stump; T, tail lesions; E, ear lesions; B, body lesions. * Correlation is significant at the 0.05 level (two-tailed). ** Correlation is significant at the 0.01 level (two-tailed).

Table 3.6 – Correlation matrix between non animal-based measures in the dataset of 709 observed pig groups (Kendall's tau-b).

	TAI	NP	SP	PD	DL	SF	LFS	BP	RP	EP	TD
TAI	1										
NP	0.751**	1									
SP	0.187**	-0.077**	1								
PD	0.116**	0.125**	0.061*	1							
DL	0.023	0.087**	-0.138**	-0.093**	1						
SF	-0.014	0.020	-0.051	0.038	0.029	1					
LFS	-0.018	-0.097**	0.195**	0.039	0.044	0.317**	1				
BP	0.054	-0.027	0.206**	0.014	-0.237**	-0.476**	-0.128**	1			
RP	0.110**	0.074*	0.112**	0.035	-0.121**	-0.317**	-0.190**	0.726**	1		
EP	0.124**	0.061*	0.189**	0.100**	-0.049	-0.193**	-0.107**	0.373**	0.385**	1	
TD	-0.037	0.098**	-0.314**	-0.129**	0.269**	0.216**	-0.057	-0.697**	-0.489**	-0.352**	1

TAI, Total area indoor of observed pens; NP, pigs/pen; SP, space allowance/pig; PD, pigs/drinker; DL, dirtiness in the laying area; SF, slatted floor; LFS, liquid feeding system; BP, presence of bedding in the laying area; RP, presence of roughage; EP, presence of enrichment; TD, tail docked pigs. * Correlation is significant at the 0.05 level (two-tailed). ** Correlation is significant at the 0.01 level (two-tailed).

The PCA resulted in the first four Principal Components (PCs), selected on the basis of the scree plot, explaining 57.2% of the variance of the considered variables. The variance not captured by the model can be ascribed to statistical noise due to a number of possible factors such as the biological nature of most data, the limited sensitivity of ordinal variables and also the lack of other variables able to better explain the variance of the statistical model.

The loading plot of the first two principal components (Figure 3.1), shows that PC1, accounting for the largest data variability, is mainly influenced by the variables lying at the left and right extreme parts of the plot.

Particularly, on the right side, the following variables are shown as positively correlated with each other and with PC1: presence of bedding (BP) and roughage (RP), pig access to enrichment (PAE), pig behaviour directed to enrichment materials (EMB) and percentage of pens with optimal or suboptimal enrichment (EC). These variables are negatively correlated with those on the left side of the plot, namely tail docked pigs (TD), tail stump pigs (STT) and slatted floor (SF).

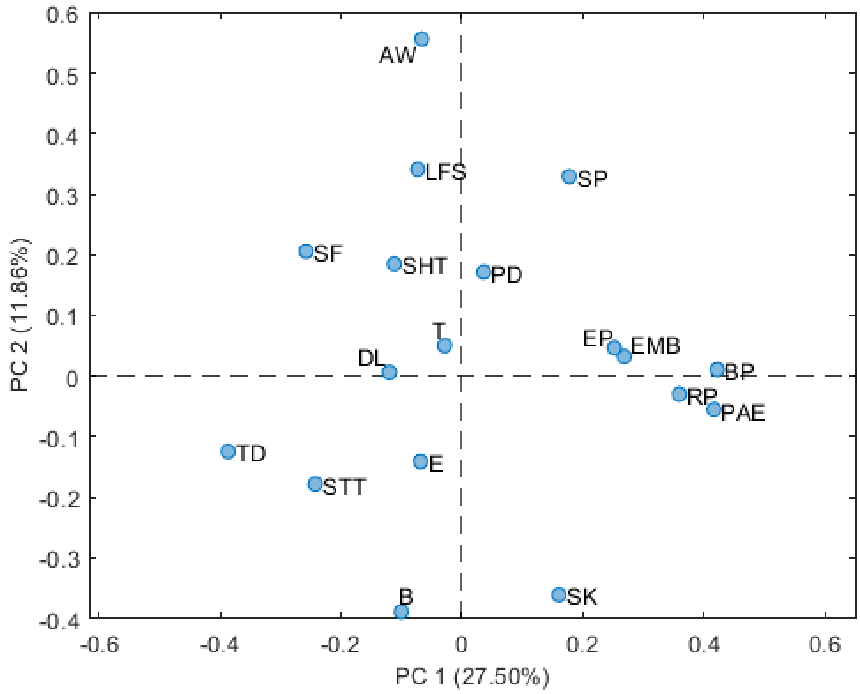

Figure 3.1 PCA of the dataset of 709 observed pig groups: loading plot of PC1 and PC2.

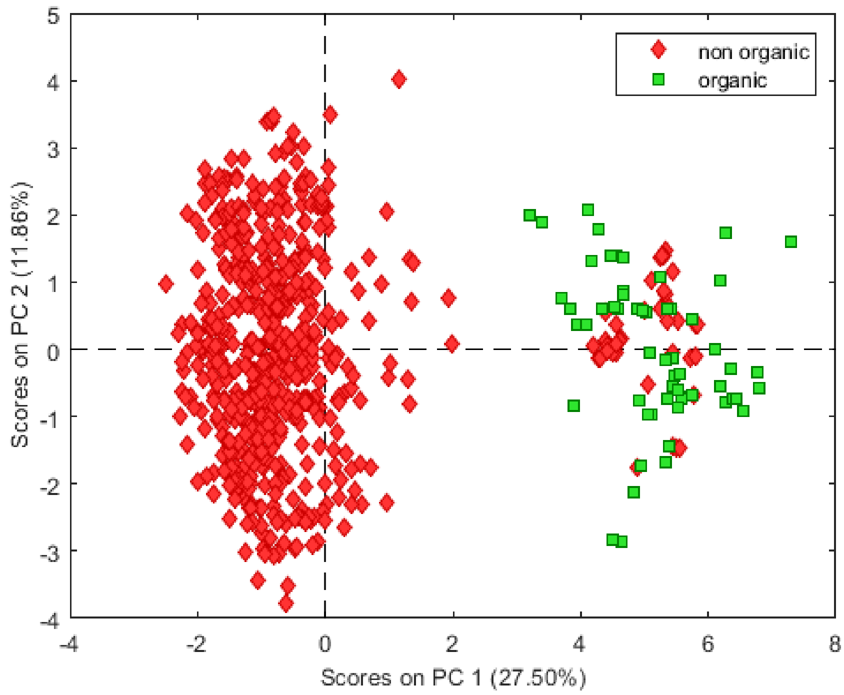

Figure 3.2 PCA of the dataset of 709 observed pig groups: score plot of PC1 and PC2, highlighting organic pig groups.

PC2 shows positive correlations between average live weight of observed pigs (AW), liquid feeding system (LFS) and space allowance (SP), in the upper part, and negative correlations between these three variables and skin lesions on the body (B) and space allowance for 100 kg of liveweight (SK), in the lower part of the plot.

The score plot of the first two principal components (Figure 3.2) shows all pig groups assessed in organic farms concentrated in the right side, where the loading plot (Figure 3.1) represents the variables bedding presence (BP), roughage presence (RP), pig access to enrichment (PAE), enrichment material behavior (EMB) and presence of optimal or suboptimal enrichment material (EP). This relationship is well explained by the compliance of organic farms to stricter bedding requirements of the Commission Regulation (EC) 889/2008 (European Commission, 2008), compared to the Council Directive 120/2008/EC (European Commission, 2009).

Nevertheless, a number of cases of pens assessed in non-organic farms are also represented in the right part of this score plot, because featured by housing systems where pigs with undocked tails are kept on solid floor with bedded laying area, roughage and enrichment materials accessible to most pigs in the pens.

The variable ear lesions (E) is better represented by the loading plot of PC1 and PC3 (Figure 3.3), in which its position in the upper part is opposed to the position of space allowance (SP), revealing a weak but statistically significant negative correlation between these variables (τ = -0.108). Weak correlation is also shown by the opposite position of the variable dirtiness in the laying area (DL) in relation space allowance (SP).

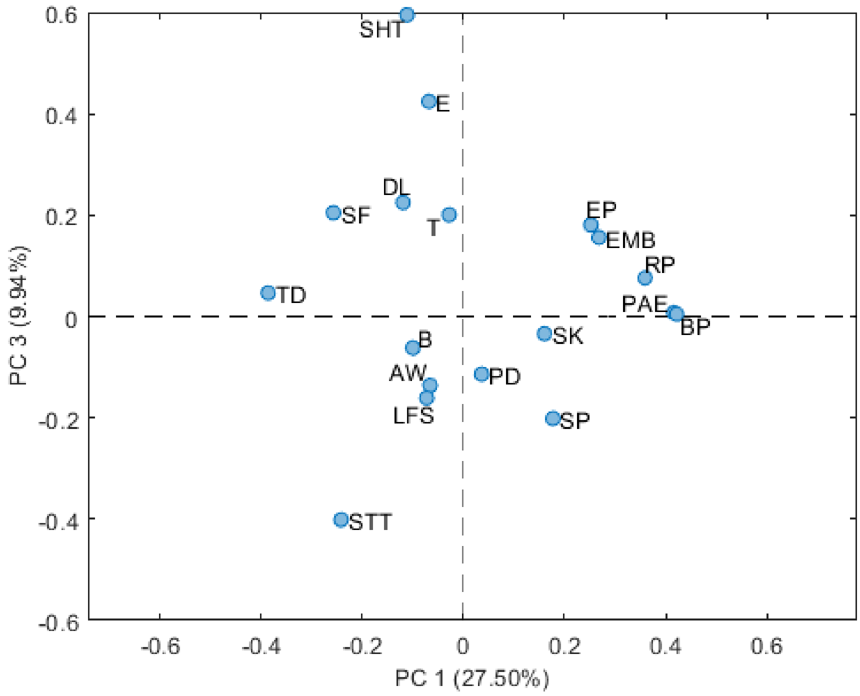

Figure 3.3 PCA of the dataset of 709 observed pig groups: loading plot of PC1 and PC3.

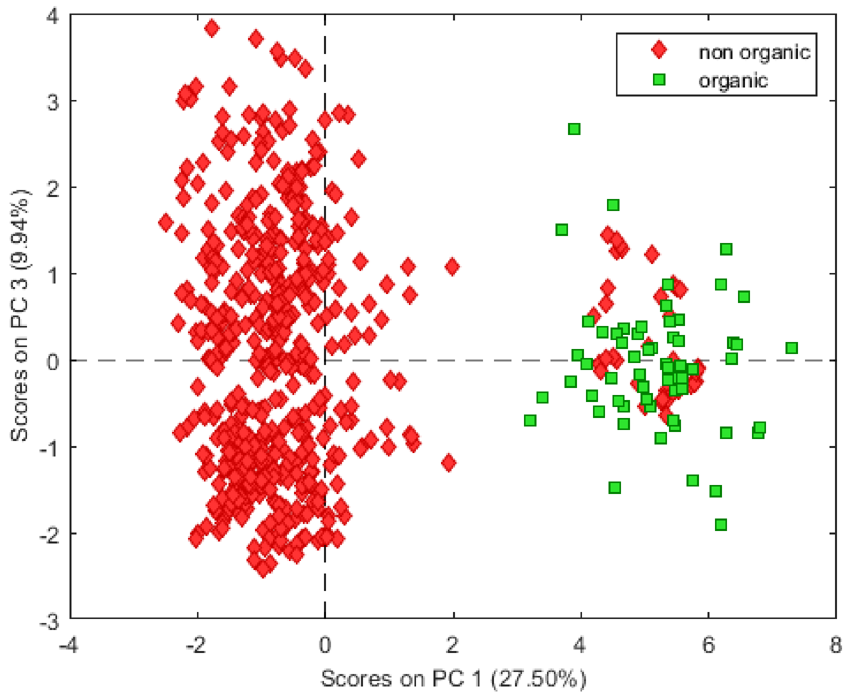

Figure 3.4 PCA of the dataset of 709 observed pig groups: score plot of PC1 and PC3 highlighting organic pig groups.

The variable tail lesions (T) is not well represented, presumably due to the limited variance of related data. However, it was found as positive correlated with the presence of tail docked pigs with tails shortened by less than 50% (SHT) (τ = 0.234), with slatted floor (SF) (τ = 0.132), total indoor area (TAI) (τ = 0.158) and number of pigs (NP) (τ = 0.156) in the observed pens (Tables 3.4 and 3.5).

Weak positive correlation was also detected between the prevalence of ear (E) lesions and both the presence of slatted floor (SF) and dirtiness in the laying area (DL) (τ = 0.119 and τ = 0.118, respectively). The score plot of PC1 and PC3 in figure 3.4 shows again that all cases of pig groups assessed in organic farms are concentrated in the right side. The score plot of PC1 and PC3 in figure 3.5 represents the countries in which the pig groups were observed.

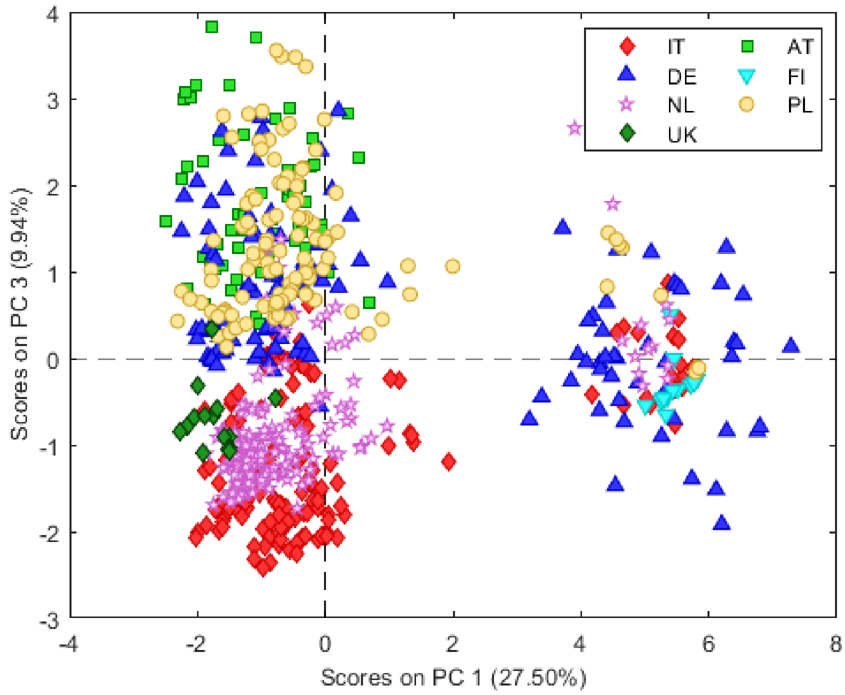

Figure 3.5 PCA of the dataset of 709 observed pig groups: Score plot of PC1 and PC3 highlighting the country in which pig groups were observed.

Most cases of pig groups observed in non-organic farms in the United Kingdom, Italy and the Netherlands are shown at the bottom left of the plot, where the related loading plot (Figure 3.3) represents the variable pig tail stump (STT) (i.e. tail shortened by more than 50% of the total length). The majority of pig groups observed in non-organic farms in Poland, Austria and Germany are positioned at the left topside of the score plot, where the related loading plot represents the variables pig shortened tail (SHT) (i.e. tails shortened by less than 50% of the total length) and ear lesions (E).

3.2 Results from pig farms

Descriptive statistics for continuous, ordinal and dichotomous variables in the dataset of 51 pig farms are shown in Tables 3.7, 3.8 and 3.9.

Correlations between continuous and ordinal variables in the dataset of 51 pig farms are given in tables 3.10, 3.11 and 3.12, as Kendall's tau non-parametric statistics.

Table 3.7 – Descriptive statistics of the dataset of 51 pig farms for continuous variables.

Variable	Mean	SD	Min	Q25	Mdn	Q75	Max
TAI	24.0	14.0	6.9	12.0	19.9	34.2	62.0
NP	24.2	13.1	7.9	14.2	19.6	35.9	59.0
SP	1.0	0.2	0.6	0.8	1.0	1.2	1.5
PD	11.1	6.9	0.0	7.6	9.8	12.5	38.0
PDC	65.1	40.7	0.0	33.3	86.7	100.0	100.0
EC	58.3	44.1	0.0	0.0	80.0	100.0	100.0
AVP	1780.7	1709.9	47.5	725.0	1298.0	2419.0	9300.0
PWU	1123.1	874.1	62.3	444.4	1038.5	1534.2	3606.4
LWS	130.3	23.3	100.0	118.8	120.8	130.0	176.0
MCP	2.1	1.8	0.0	0.8	1.6	3.3	7.7
AW	79.5	21.1	46.1	63.3	73.3	93.3	130.0
SK	1.5	0.4	0.7	1.1	1.4	1.7	2.9
ADG	822.5	103.8	643.0	746.0	809.0	859.0	1050.0
FCR	2.9	0.5	2.0	2.6	2.8	3.5	3.9
EMB	24.2	26.4	0.0	5.6	12.1	33.3	100.0
PAE	32.3	34.2	4.2	9.9	16.2	31.4	100.0
M	2.7	1.4	0.1	1.7	2.7	3.4	6.6
T	13.5	24.1	0.0	0.0	6.7	13.3	100.0
E	12.6	21.2	0.0	0.0	0.0	14.3	73.3
B	27.1	34.4	0.0	0.0	13.3	46.7	100.0

TAI, Total area indoor of observed pens; NP, pigs/pen; SP, space allowance/pig; PD, pigs/drinker; PDC, % of pens with at least 1 nipple/12 pigs or 1 water bowl/15 pigs; EC, % of pens with optimal or suboptimal enrichment; AVP, average number of pigs/farm; PWU, average number of pigs/Annual Work Unit; LWS, pig live weight at slaughter; MCP, medication cost/pig; AW, average pig live weight/pen; SK, space allowance/100kg pig LW; ADG, average daily gain; FCR, feed conversion rate; EMB, % of active pigs manipulating enrichment; PAE, % of active pigs in reach of enrichment; M, mortality rate; T, % of pens with at least one pig tail lesion; E, % of pens with at least one ear lesion; B, % of pens with at least one skin lesion. Mean, standard deviation (SD), minimum (Min.), lower quartile (Q25), median (Mdn), upper quartile (Q75) and maximum (Max) values.

Table 3.8 – Descriptive statistics of the dataset of 51 pig farms for ordinal variables.

Variable	Mode	Min.	Q25	Mdn	Q75	Max.
TD	2	0	1	2	2	2
SF	1	0	1	1	2	2
BP	0	0	0	0	0	3
RP	0	0	0	0	0	3
DL	0	0	0	0	1	2
LFS	0	0	0	1	2	2
SHT	0	0	0	1	2	2
STT	2	0	0	2	2	2

TD, tail docked pigs; SF, slatted floor; BP, presence of bedding in the laying area; RP, presence of roughage; DL, dirtiness score in the laying area; LFS, liquid feeding system; SHT, pigs with short tails; STT, pigs with tail stump. Mode, minimum (Min.), lower quartile (Q25), median (Mdn), upper quartile (Q75) and maximum (Max) values.

Table 3.9 – Descriptive statistics of the dataset of 51 pig farms for dichotomous variables.

Variable	%
Organic farms (OR)	8.7
Outdoor access (OA)	12.8
Feed restriction (FR)	43.9

Percentage of farms (%).

Table 3.10 – Correlation matrix between animal and non animal-based measures in the dataset of 51 farms (Kendall's tau-b).

	AW	SK	ADG	FCR	EMB	PAE	M	SHT	STT	T	E	B
TAI	0.009	0.054	-0.007	0.197*	0.144	-0.089	0.120	0.180	-0.078	0.079	0.098	-0.190
NP	-0.073	-0.003	0.036	0.080	0.097	-0.121	0.077	0.247*	-0.063	0.056	0.161	-0.045
SP	0.295**	0.227*	-0.047	0.357**	0.192*	0.082	0.198*	-0.134	-0.131	0.109	-0.141	-0.455**
PD	0.064	-0.028	-0.236*	0.280**	-0.009	-0.188	0.185	-0.106	0.111	0.063	-0.126	-0.215*
PDC	0.035	-0.022	0.224*	-0.150	0.064	0.221*	-0.111	0.258*	-0.251*	0.037	0.219	0.095
EC	-0.042	0.185	0.124	0.174	0.365**	0.363**	-0.023	0.157	-0.466**	0.020	0.124	-0.156
AVP	-0.028	0.081	-0.088	-0.041	-0.186	-0.301**	0.027	-0.091	0.514**	-0.017	-0.067	0.146
PWU	-0.184	0.164	-0.116	-0.008	-0.293**	-0.136	-0.062	-0.260*	0.508**	-0.076	-0.182	0.214*
LWS	0.162	0.047	-0.357**	0.508**	-0.009	-0.120	0.208*	-0.139	0.122	0.050	-0.233*	-0.375**
MCP	0.198*	-0.081	0.017	0.224*	0.114	-0.147	0.224*	0.056	-0.188	0.164	0.005	-0.232*
TD	0.001	-0.212	0.028	-0.243*	-0.284*	-0.424**	-0.092	0.251	0.512**	-0.085	0.151	0.282*
SF	0.086	-0.200	0.040	0.010	-0.131	-0.452**	-0.057	0.388**	0.125	0.200	0.302*	0.084
BP	-0.005	0.223	-0.026	0.179	0.436**	0.569**	0.075	-0.231	-0.560**	0.069	-0.220	-0.289*
RP	-0.114	0.177	-0.027	0.187	0.298**	0.485**	-0.034	-0.132	-0.555**	0.051	-0.123	-0.120
DL	-0.212	0.017	0.040	-0.214	-0.126	-0.108	-0.050	0.214	0.058	0.037	0.228	0.160
LFS	0.247*	-0.045	-0.201	0.282*	0.004	-0.258*	0.002	-0.021	0.145	-0.053	-0.009	-0.214

TAI, Total area indoor of observed pens; NP, pigs/pen; SP, space allowance/pig; PD, pigs/drinker; PDC, % of pens with at least 1 nipple/12 pigs or 1 water bowl/15 pigs; EC, % of pens with optimal or suboptimal enrichment; AVP, average number of pigs/farm; PWU, average number of pigs/Annual Work Unit; LWS, pig live weight at slaughter; MCP, medication cost/pig; TD, tail docked pigs; SF, slatted floor; BP, presence of bedding in the laying area; RP, presence of roughage; DL, dirtiness score in the laying area; LFS, liquid feeding system; AW, average pig live weight/pen; SK, space allowance/100kg pig LW; ADG, average daily gain; FCR, feed conversion rate; EMB, % of active pigs manipulating enrichment; PAE, % of active pigs in reach of enrichment; M, mortality rate; SHT, pigs with short tails; STT, pigs with tail stump; T, % of pens with at least one pig tail lesion; E, % of pens with at least one ear lesion; B, % of pens with at least one skin lesion.* Correlation is significant at the 0.05 level (two-tailed). ** Correlation is significant at the 0.01 level (two-tailed)

Table 3.11 - Correlation matrix between animal-based measures in the dataset of 51 farms (Kendall's tau-b).

	AW	SK	ADG	FCR	EMB	PAE	M	SHT	STT	T	E	B
AW	1											
SK	-0.448**	1										
ADG	-0.160	0.099	1									
FCR	0.261**	0.011	-0.412**	1								
EMB	-0.008	0.155	0.070	0.120	1							
PAE	-0.246*	0.345**	0.120	-0.063	0.280**	1						
M	0.105	0.031	-0.425**	0.294**	0.054	-0.065	1					
SHT	0.105	-0.193	0.283*	-0.079	0.039	-0.198	-0.301**	1				
STT	-0.100	0.051	-0.185	-0.093	-0.396**	-0.376**	0.108	-0.260	1			
T	0.008	0.113	0.042	0.003	0.031	-0.027	-0.013	0.233	-0.079	1		
E	-0.109	-0.011	0.211*	-0.108	0.131	-0.185	-0.127	0.426**	-0.144	0.128	1	
B	-0.354**	0.018	0.171	-0.473**	-0.125	0.006	-0.209*	-0.111	0.225	-0.214	0.198	1

AW, average pig live weight/pen; SK, space allowance/100kg pig LW; ADG, average daily gain; FCR, feed conversion rate; EMB, % of active pigs manipulating enrichment; PAE, % of active pigs in reach of enrichment; M, mortality rate; SHT, pigs with short tails; STT, pigs with tail stump; T, % of pens with at least one pig tail lesion; E, % of pens with at least one ear lesion; B, % of pens with at least one skin lesion. * Correlation is significant at the 0.05 level (two-tailed).** Correlation is significant at the 0.01 level (two-tailed)

Table 3.12 - Correlation matrix between non animal-based measures in the dataset of 51 farms (Kendall’s tau-b).

	TAI	NP	SP	PD	PDC	EC	AVP	PWU	LWS	MCP	TD	SF	BP	RP	DL	LFS
TAI	1															
NP	0.785**	1														
SP	0.244*	0.030	1													
PD	0.086	0.043	0.146	1												
PDC	-0.146	-0.092	-0.111	-0.477**	1											
EC	0.147	0.139	0.178	-0.006	0.161	1										
AVP	0.020	0.020	-0.043	-0.005	-0.244*	-0.288**	1									
PWU	-0.123	-0.113	-0.151	-0.061	-0.205*	-0.367**	0.462**	1								
LWS	0.019	-0.089	0.231*	0.284**	-0.323**	-0.090	0.139	0.147	1							
MCP	0.140	0.115	0.307**	0.264**	-0.052	0.154	-0.137	-0.324**	0.057	1						
TD	-0.080	0.015	-0.377**	-0.113	0.025	-0.420**	0.472**	0.316**	-0.075	-0.192	1					
SF	-0.045	0.008	-0.129	0.095	-0.062	-0.214	0.102	0.006	0.116	0.131	0.271*	1				
BP	0.140	0.062	0.333**	-0.013	0.106	0.463**	-0.462**	-0.328**	-0.023	0.132	-0.753**	-0.570**	1			
RP	0.167	0.145	0.187	0.026	0.065	0.499**	-0.366**	-0.290*	-0.024	0.117	-0.581**	-0.408**	0.784**	1		
DL	0.092	0.154	-0.235*	-0.184	0.007	-0.078	0.267*	0.181	-0.056	-0.263*	0.383**	0.126	-0.322*	-0.152	1	
LFS	-0.061	-0.152	0.205	0.040	-0.305*	-0.103	0.260*	0.157	0.431**	-0.053	0.095	0.370**	-0.237	-0.279*	0.104	1

TAI, Total area indoor of observed pens; NP, pigs/pen; SP, space allowance/pig; PD, pigs/drinker; PDC, % of pens with at least 1 nipple/12 pigs or 1 water bowl/15 pigs; EC, % of pens with optimal or suboptimal enrichment; AVP, average number of pigs/farm; PWU, average number of pigs/Annual Work Unit; LWS, pig live weight at slaughter; MCP, medication cost/pig; TD, tail docked pigs; SF, slatted floor; BP, presence of bedding in the laying area; RP, presence of roughage; DL, dirtiness score in the laying area; LFS, liquid feeding system.
* Correlation is significant at the 0.05 level (two-tailed). ** Correlation is significant at the 0.01 level (two-tailed)

The PCA of the dataset of 51 farms resulted in four PCs, selected on the basis of the scree plot, explaining 58.43% of total data variance. The variance not captured by the model also can be ascribed, as in the previous PCA, to statistical noise due to possible factors such as the biological nature of most data, the limited sensitivity of some variables and the lack of other variables that could better explain the variance of the model.

The loading plot of PC1 and PC2 (Figure 3.6) confirms the main outcomes of the previous PCA (Figure 3.1) in terms of positive correlations between presence of bedding and roughage (BP and RP), pig access to enrichment (PAE), enrichment material behavior (EMB) and presence of optimal or suboptimal enrichment material (EC), as well as the negative correlations between these variables and the variables tail docking (TD) and pig tail stump (STT), on the left side of the loading plot.

PC2 shows the variables pig live weight at slaughter (LWS), feed conversion rate (FCR), number of pigs per drinker (PD), presence of liquid feeding system (LFS), average live weight (AW) and mortality rate (M), as positively correlated to each other in the upper part of the plot (Figure 3.6). The opposite positions in the loading plot of the variables liquid feeding system (LFS), compared to farm percentage of pens with at least 1 nipple per 12 pigs or 1 water bowl per 15 pigs (PDC), point out the moderate negative correlation ($\tau = -0.323$) between these two non animal-based measures (Table 3.12), showing that farms with liquid feeding systems are more likely to be equipped with less drinkers, compared to farms using dry or wet feed.

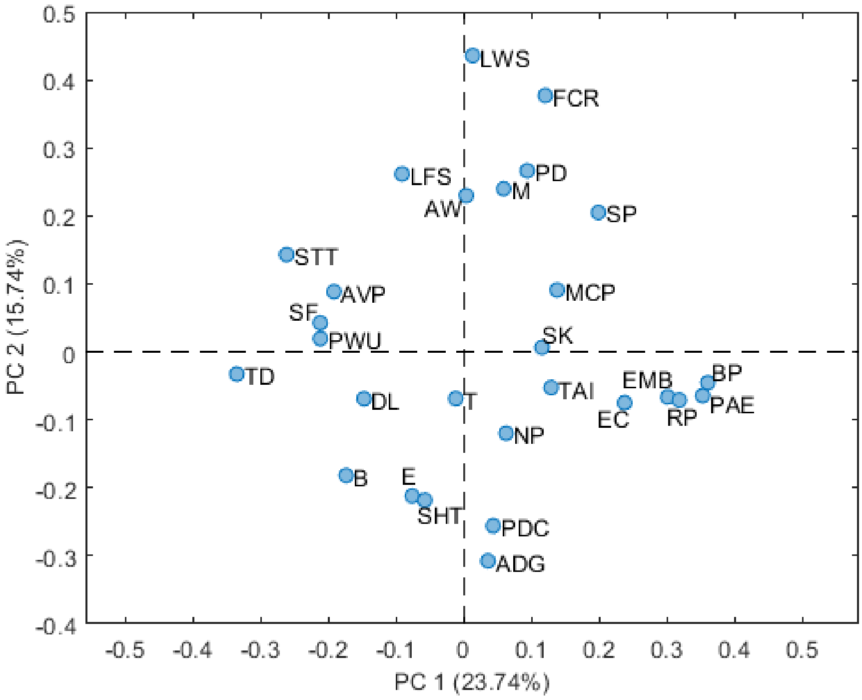

Figure 3.6 PCA of the dataset of 51 farms: loading plot of PC1 and PC2.

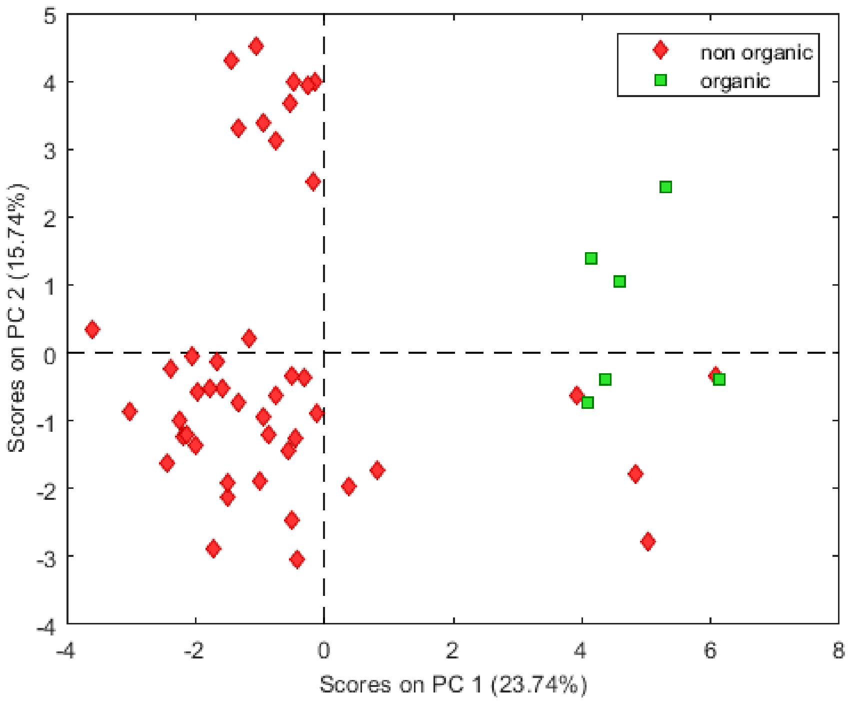

Figure 3.7 PCA of the dataset of 51 farms: score plot of PC1 and PC2 highlighting organic farms.

Mortality rate (M) is positively correlated to pig space allowance (SP) (τ = 0.198), live weight at slaughter (LWS) (τ = 0.208) and feed conversion rate (FCR) (τ = 0.294).

The variables ear (E) and skin lesions in the pig body (B), tail shortened pigs (SHT), average daily gain (ADG) and percentage of pens with at least one nipple drinker for 12 pigs or one water bowl drinker for 15 pigs (PDC) are represented in the lower part of the loading plot as negatively correlated to the variables represented in the upper part of the plot. Particularly, the variable skin lesions (B) is shown as directly correlated to the mortality rate (M) (τ = 0.209) and adversely correlated to pig average weight (AW) (τ = -0.354), live weight at slaughter (LWS) (τ = -0.375), space allowance (SP) (τ = -0.455), feed conversion rate (FCR) (τ = -0.473), whereas the variable ear lesions (E) is negatively correlated with the pig liveweight at slaughter (LWS) (τ = -0.233) and positively correlated with tail shortened pigs (SHT) (τ = 0.426) and average daily gain (ADG) (τ = 0.211).

Most of these correlations are coherent with those found in the previous PCA (i.e. Figure 3.1).

The score plot of the first two PCs clearly shows three groups of farms located on the right side, on the left topside and on the left down side, respectively (Figure 3.7). The group on the right is composed by the only six organic farms in the dataset and by four non organic farms, characterized by some welfare standards similar to the organic ones, according to Regulation (EC) 889/2008 (i.e., bedding in the resting areas, no or limited slatted floor, no or limited tail docking and high space allowance), and above the minimum requirements of Directive 120/2008/EC; this latter group is composed by two Polish, one German and one Finnish farm, as represented in the score plot of PC1 and PC2, highlighting farm nationalities (Figure 3.8).

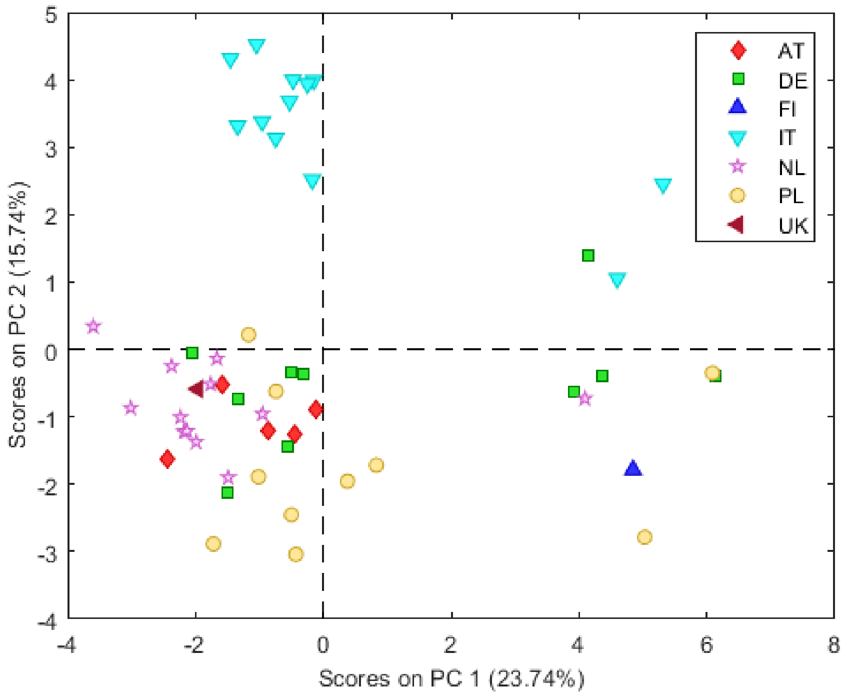

Figure 3.8 PCA of the dataset of 51 farms: score plot of PC1 and PC2 highlighting farm nationalities.

The group on the left topside consists of 10 out of the 12 Italian heavy pig farms, whose positions in the score plot, compared to the corresponding loading plot of Figure 3.6, reveal that they are characterized by higher live weight at slaughter (LWS), feed conversion ratio (FCR), mortality rate (M), number of pigs per drinker (PD) and the presence of liquid feeding system (LFS). The other two Italian heavy pig farms are organic and represented correctly on the right side of the score plot.

The loading plot of PC2 and PC3 (Figure 3.9), represents the variables live weight at slaughter (LWS), feed conversion ratio (FCR), mortality rate (M), liquid feeding system (LFS), number of pigs per drinker (PD) and the space allowance per pig (SP) grouped on the right side, confirming that they are positively correlated to each other. The average live weight of observed pigs (AW) is shown as negatively correlated with skin lesions on the pig body (B) (τ = -0.354).

The corresponding score plot of PC2 and PC3 (Figure 3.10), shows the cases of the Italian heavy pig farms located at the right side of the plot, matching with the positions of the variables space allowance per pig (SP), liquid feeding system, (LFS), number of pigs per drinker (PD), mortality rate (M), feed conversion rate (FCR) and live weight at laughter (LWS) in the related loading plot (Figure 3.9), which means that these variables characterize this type of farms in this study.

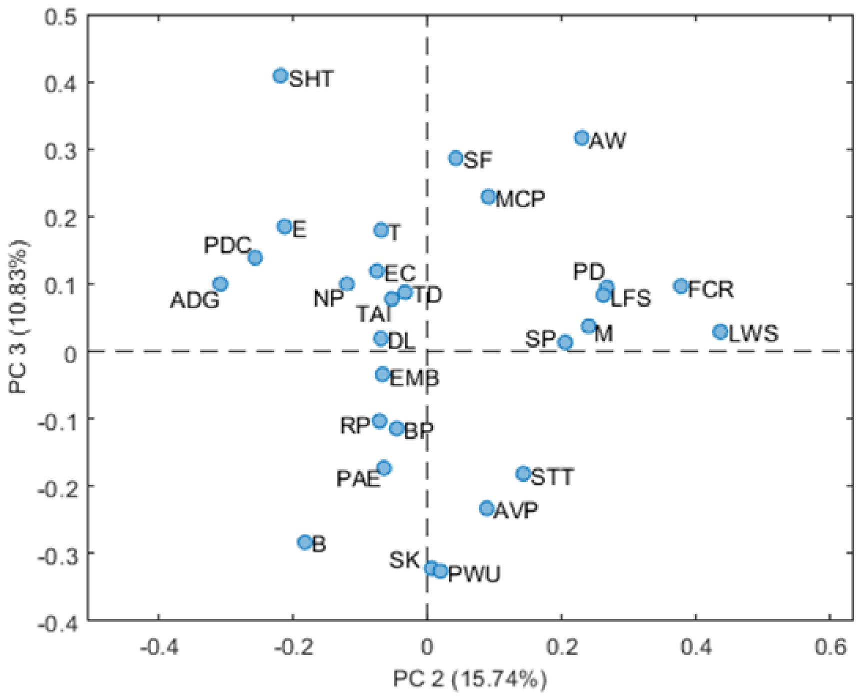

Figure 3.9 PCA of the dataset of 51 farms: loading plot of PC2 and PC3.

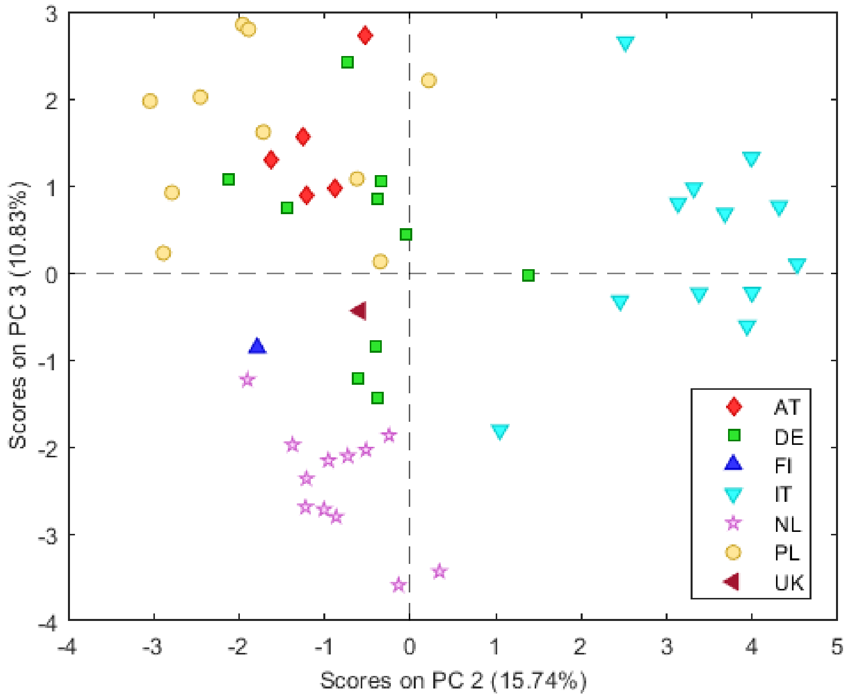

Figure 3.10 PCA of the dataset of 51 farms: score plot of PC2 and PC3 highlighting farm nationality.

Dutch farms are shown in the bottom left corner, next to the positions of the variables body lesions (B), average number of pigs per AWU (PWU) and space allowance per 100 kg of pig live weight (SK) in the load diagram, which therefore characterise these farms.

Polish and Austrian farms are mostly represented in the left upper part of the score plot, where the loading plot represents the variables shortened tail pigs (SHT) average daily gain (ADG), compliance with pig drinkers check (PDC) and ear (E) and tail (T) lesions.

Positions of German farms are less concentrated and more spread across the plot, whereas the English and the Finnish farms are represented in the left side, opposed to the position of Italian heavy pig farms, and characterized by quicker gain (ADG) and lower live weight at slaughter (LWS), space allowance (SP) and mortality (M).

The variables farm average area of observed pens (TAI) and farm mean number of pigs in observed pens (NP) are well represented in the loading plot of PC2 and PC4 (Figure 11), as strongly positively correlated to each other ($\tau = 0.785$).

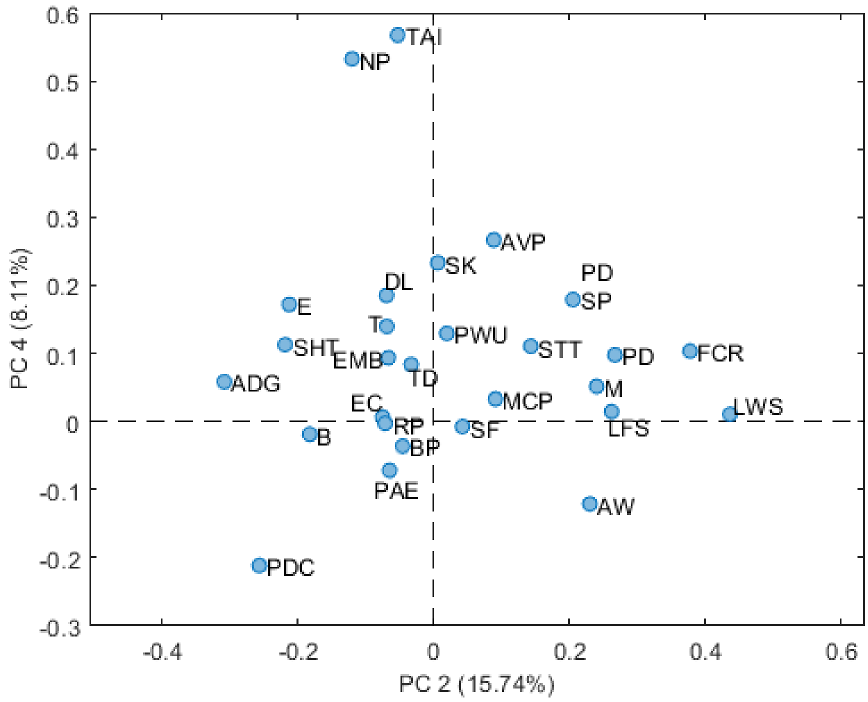

Figure 3.11 PCA of the dataset of 51 farms: loading plot of PC2 and PC4.

The correlation matrix in Table 3.12, also shows TAI as positively correlated with pig space allowance (SP) ($\tau = 0.244$) and with feed conversion rate (FCR) ($\tau = 0.197$).

Based on the results of the PCA model for the 51 farms dataset, which highlighted the presence of three separate farm clusters (Figure 3.7), the contribution of each single continuous and ordinal variable to this grouping was explored by checking for statistically significant differences between clusters (Tables 3.13 and 3.14):

1. Housing system with bedded solid floored laying area (BED);
2. Housing system with no bedded solid floored laying area for lean pigs (NBL);
3. Housing system with no bedded solid floored laying area for heavy pigs (NBH).

Farms belonging to the BED group were featured by higher presence of optimal or suboptimal enrichment (EC) ($p = 0.001$) and higher percentage of observed active pigs manipulating (EMB) and in reach (PAE) of enrichment materials ($p = 6 \times 10^{-7}$ and $p = 0.001$, respectively), compared to NBH and NBL farms.

The average number of pigs per farm (AVP) and per Annual Work Unit (PWU) in 2018, were found much lower in the BED farm group, than in the NBH and NBL farm groups ($p = 9 \times 10^{-5}$ and $p = 0.024$, respectively).

As regards the productive performances, lower average daily gain (ADG) ($p = 4 \times 10^{-4}$) and higher feed conversion rate (FCR) ($p = 4 \times 10^{-7}$) were found in NBH farms, compared to farms in the NBL and BED groups.

Higher average pig mortality rate (M) and medication cost per pig sold (MCP) were also found ($p = 0.003$ and $p = 0.046$, respectively) in NBH farms, than in the other farm groups.

Ear and skin lesions were detected more frequently in the NBL group than in the NBH and BED groups ($p = 0.023$ and $p = 2 \times 10^{-4}$, respectively).

Table 3.13 Statistics for 20 continuous variables.

Variables		NBH (10 farms)			NBL (31 farms)			BED (10 farms)			
N.	Acronym	Q25	Mdn	Q75	Q25	Mdn	Q75	Q25	Mdn	Q75	*P*-value
1	**TAI**	14.2	**20.6**	28.9	11.5	**18.2**	35.0	15.6	**21.1**	50.1	>0.05
2	**NP**	12.2	**17.3**	25.5	14.2	**21.1**	37.0	14.3	**19.3**	40.0	>0.05
3	**AW**	93.2	**110.2**^{a}	117.4	62.0	**70.0**^{b}	78.2	57.4	**75.0**^{b}	90.8	<0.01
4	**SP**	1.11	**1.15**^{a}	1.25	0.79	**0.88**^{b}	1.01	1.03	**1.20**^{a}	1.30	<0.01
5	**SK**	1.09	**1.24**	1.57	1.15	**1.40**	1.63	1.26	**1.77**	2.25	>0.05
6	**PD**	10.7	**14.5**^{a}	25.5	7.2	**8.5**^{b}	11.9	7.3	**9.4**^{ab}	17.6	<0.01
7	**PDC**	0.0	**20**^{a}	80.6	33.3	**93**^{b}	100.0	25.7	**97**^{ab}	100.0	<0.05
8	**EMB**	5.5	**6.8**^{a}	13.6	4.8	**12.1**^{a}	21.4	41.3	**72.3**^{b}	87.4	<0.01
9	**PAE**	5.9	**9.2**^{a}	11.8	10.5	**16.1**^{b}	24.5	98.7	**100**^{c}	100.0	<0.01
10	**EC**	0.0	**33**^{a}	88.3	0.0	**53**^{a}	100.0	100.0	**100**^{b}	100.0	<0.01
11	**AVP**	1571	**2169**^{a}	3226	976	**1450**^{a}	2419	191	**263**^{b}	786	<0.01
12	**PWU**	967	**1187**^{a}	1355	444	**1065**^{a}	2182	152	**460**^{b}	915	<0.05
13	**LWS**	165	**172**^{a}	175	118	**120**^{b}	122	115	**122**^{b}	140	<0.01
14	**ADG**	680	**708**^{a}	753	800	**820**^{b}	885	741	**780**^{b}	1000	<0.01
15	**FCR**	3.6	**3.7**^{a}	3.8	2.5	**2.6**^{b}	2.8	2.8	**3.0**^{c}	3.5	<0.01
16	**MCP**	1.4	**2.6**^{a}	3.4	0.5	**1.0**^{b}	2.8	1.1	**2.0**^{b}	4.9	<0.05
17	**M**	3.3	**3.8**^{a}	4.6	1.5	**2.0**^{b}	2.9	2.0	**2.7**^{b}	4.0	<0.01
18	**T**	0.0	**3.3**	6.7	0.0	**6.7**	20.0	0.0	**6.7**	21.7	>0.05
19	**E**	0.0	**0.0**^{a}	1.7	0.0	**6.7**^{b}	40.0	0.0	**0.0**^{a}	1.7	<0.05
20	**B**	0.0	**0.0**^{a}	3.3	6.7	**38.5**^{b}	73.3	0.0	**0.0**^{a}	8.3	<0.01

TAI, Total area indoor of observed pens; NP, pigs/pen; AW, average pig live weight/pen; SP, space allowance/pig; SK, space allowance/100kg pig LW; PD, pigs/drinker; PDC, % of pens with at least 1 nipple/12 pigs or 1 water bowl/15 pigs; EMB, % of active pigs manipulating enrichment; PAE, % of active pigs in reach of enrichment; EC, % of pens with optimal or suboptimal enrichment; AVP, average number of pigs/farm; PWU, average number of pigs/Annual Work Unit; LWS, pig live weight at slaughter; ADG, average daily gain; FCR, feed conversion rate; MCP, medication cost/pig; M, mortality rate; T, % of pens with at least one pig tail lesion; E, % of pens with at least one ear lesion; B, % of pens with at least one skin lesion. Median (Mdn), lower quartile (Q25) and upper quartile (Q75) values for assessed measures per housing system (i.e., BED, NBL and NBH). p = result of global Kruskal–Wallis test for housing system effect. $^{a, b, c}$ Median values with different superscripts within a row differ at $p < 0.05$ or $p < 0.01$ in a pairwise system comparison with Mann–Whitney U-test.

No statistically significant difference between the farm percentages of observed pens with at least one tail lesion (T) was found in the three farm clusters (p = 0.363), although all pigs in the NBH and NBL groups were tail docked (TD) and most pigs in the BED group (i.e., except in one farm) were tail undocked.

Pigs with tails shortened by less than 50% of the total tail length (SHT) were found more commonly in NBL farms than in NBH farms, where most pig tails were shortened by more than 50% of the total length (STT).

Evident differences are shown between the three cluster of farms in relation to the presence of bedding (BP) and roughage (RP) and to the low presence of slatted floor (SF), characterizing the BED group.

Table 3.14 Statistics for 8 ordinal variables.

Variables		NBH (10 farms)			NBL (31 farms)			BED (10 farms)			
N.	Acronym	Q25	Mdn	Q75	Q25	Mdn	Q75	Q25	Mdn	Q75	*P*-value
21	**TD**	1.8	**2.0**[a]	2.0	2.0	**2.0**[a]	2.0	0.0	**0.0**[b]	0.0	<0.01
22	**SHT**	0.0	**0.0**[a]	1.0	0.0	**2.0**[b]	2.0	0.0	**0.0**[a]	1.0	<0.01
23	**STT**	2.0	**2.0**[a]	2.0	0.0	**2.0**[a]	2.0	0.0	**0.0**[b]	0.0	<0.01
24	**SF**	1.0	**1.5**[a]	2.0	1.0	**1.0**[a]	2.0	0.0	**0.5**[b]	1.0	<0.01
25	**BP**	0.0	**0.0**[a]	0.0	0.0	**0.0**[a]	0.0	2.0	**3.0**[b]	3.0	<0.01
26	**RP**	0.0	**0.0**[a]	0.0	0.0	**0.0**[a]	0.0	2.0	**2.0**[b]	2.3	<0.01
27	**DL**	0.0	**0.0**[ab]	0.3	0.0	**1.0**[a]	1.0	0.0	**0.0**[b]	0.0	<0.01
28	**LFS**	2.0	**2.0**[a]	2.0	0.0	**0.0**[a]	2.0	0.0	**0.0**[b]	1.3	<0.01

TD, tail docked pigs; SHT, pigs with short tails; STT, pigs with tail stump; SF, slatted floor; BP, presence of bedding in the laying area; RP, presence of roughage; DL, dirtiness score in the laying area; LFS, liquid feeding system. Median (Mdn), lower quartile (Q25) and upper quartile (Q75) values for assessed measures per housing system (i.e., BED, NBL and NBH). p = result of global Kruskal–Wallis test for housing system effect. [a, b] Median values with different superscripts within a row differ at $p < 0.01$ in a pairwise system comparison with Mann–Whitney U-test.

Dirtiness in the laying area (DL) resulted statistically different ($p = 0.008$) and higher in farms of the NBL group, compared to those in the BED group.

The presence of liquid feeding (LFS) was found statistically different in the farm groups ($p = 0.001$) and less common in the BED group, compared to the other groups.

Descriptive statistics are shown in Table 3.15 for three dichotomous variables: organic farm (OR), outdoor access (OA) and feed restriction (FR) in terms of percentage of farms in the group.

Table 3.15 Statistics for 3 dichotomous variables.

N.	Variable description	Acronym	NBH % (10 farms)	NBL % (31 farms)	BED % (10 farms)
1	**Organic farm**	**OR**	0	0	60
2	**Outdoor access**	**OA**	0	3	70
3	**Feed restriction**	**FR**	90	29	30

Percentage of farms in the farm group (%)

The organic farms in the dataset are all included in the BED group. Most farms allowing pigs to access outdoors are also included in the BED farm group; only one of them belongs to the NBL group.

Feed restriction was found in 90% of the NBH farms and in only 29% and 30% of the NBL and BED farms, respectively.

4 DISCUSSION

The two PCA models, based on the datasets from 709 pig groups and from the 51 pig fattening farms in which the pig groups were observed, provided similar outputs in terms of positive and negative correlations between the 18 continuous and ordinal variables used for the first PCA and aggregated in the second PCA, meaning that the process of aggregation of data from the observed pig groups was effective in keeping and expressing the information at farm level. Greater validity of the statistical models used in this study could result from a greater availability in the future of pig farm cases in the SusPigSys database.

Loading plots of the PCA models and correlation matrices of the two datasets showed a number of statistically significant correlations between non animal-based measurements to assess the suitability of pig housing system to provide good welfare conditions to pigs (i.e. housing risk factors) and animal-based measurements to assess pig welfare directly through pig observation. Particularly, space allowance per pig (SP) was shown as positively correlated to the average liveweight of observed pigs (AW) ($\tau = 0.265$ at pig group level and $\tau = 0.295$ at farm level) and negatively correlated to the number of skin lesions on the pig body (B), at pig group level ($\tau = -0.291$) and farm level ($\tau = -0.455$). Skin lesions (B) were also found as negatively correlated with the average pig live weight (AW) at pig group ($\tau = -0.177$) and farm ($\tau = -0.354$) levels. Weaker negative correlations are shown in Table 3.4 for ear lesions (E) in relation to pig space allowance (SP) and average pig live weight (AW) at pig group level ($\tau = -0.108$ and $\tau = -0.118$, respectively).

These outcomes confirm that both space allowance and pig live weight (i.e. and related age) may play a role in the occurrence of skin lesions on the pig body, as confirmed by previous studies (EFSA, 2007b; Munsterhjelm et al., 2015; Meyer-Hamme et al., 2016).

The prevalence of tail lesions (T) was not found as strongly correlated to any housing risk (i.e. non animal-based measure) for pig welfare. However, weak positive correlation is shown in Table 3.4 between tail lesions (T) and the variables total area indoor (TAI), number of pigs (NP) and slatted floor (SF) in the observed pens (τ = 0.158, τ = 0.156 and τ = 0.132, respectively). Variance of related data is likely to be limited by the practice of tail docking in use in most farms in this study; nevertheless, the presence of pigs with tails shortened by less than 50% of the total length (SHT) was shown as positively correlated at pig group level (τ = 0.234) with the occurrence of tail lesions (T), confirming that the practice of docking tails shorter (i.e. tail stump) is effective in limiting the prevalence and the severity of tail lesion when tail biting occurs, although it is acknowledged as painful for pigs in the short and long term (EFSA, 2007b).

Tail docking (TD) was found in this study as strongly negatively correlated, at pig group level, with the presence of bedding (BP), roughage (RP) and optimal or suboptimal enrichment materials (EP) (τ = -0.697, τ = -0.489 and τ = -0.352, respectively), showing no or low provision of bedding, roughage and enrichment materials was observed on farms where tail docking is routinely practicised.

Strong negative correlation was also found between the presence of pigs with tails shortened by more than 50% of the total length (STT) and the presence of bedding

(BP), roughage (RP) and enrichment at both pig group and farm levels (Table 3.3 and 3.10), suggesting that most pigs with tail stumps were observed in farms less provided with the above mentioned materials.

More sensitive measures of pig injuries could increase the variance of these variables and better explain the effect that non animal-based measures have on them, especially in the case of tail lesions, so that the relevant frequency and severity could be better measured and represented.

Links between the non animal-based measures presence of bedding (BP), roughage (RP) and enrichment material (EP) and the animal-based measures percentage of active pigs manipulating enrichment (EMB) and percentage of active pigs in reach of enrichment material (PAE) were demonstrated, as expected, by strong and moderate positive correlations at both pig group and farm levels (Tables 3.4 and 3.10).

It's worth noting the number of pigs per Annual Work Unit (PWU) correlated with the lack of bedding, roughage and enrichment materials and with higher prevalence of skin lesions on the pig body (Table 3.10), suggesting that bedding and/or roughage and/or optimal enrichment materials are likely to be less present in farms managed with less work per pig.

Positive correlations were also found between the variables live weight at slaughter (LWS), feed conversion rate (FCR), number of pigs per drinker (PD) and liquid feeding system (LFS). These variables, together with the average weight of observed pigs (AW), pig space allowance (SP) and mortality rate (M) characterise the cluster of Italian heavy pig farms, in which the higher mortality rate can be ascribed by their higher age at slaughter (i.e. at least nine months).

Pig space allowance (SP), average liveweight of observed pigs (AW) and pig liveweight at slaughter (LWS) were found as negatively correlated, at farm level, with the animal-based measure skin lesions in the pig body (B) (τ = -0.455, τ = -0.354 and τ = -0.375, respectively), suggesting that a low prevalence of these lesions was detected in intensive heavy pig farms (NBH), which were also featured by higher feed conversion rate (FCR), and lower average daily gain (ADG), compared to pigs in the NBL and BED groups.

Links between non animal-based measures were also found, such as the negative correlation between space allowance (SP) and dirtiness in the laying area (DL); this correlation, although weak (τ = -0.138 at pig group level and τ = -0.235 at farm level, respectively) confirms the outcomes of previous studies (EFSA, 2007a). Moderate negative correlation (τ = -0.237 at pig group level) was also shown between dirtiness (DL) and the presence of bedding (BP) in the laying area, suggesting that bedding materials can improve pen cleanliness. However, the level of cleanliness in the pen floor can be affected by other factors such climate conditions and bedding management (i.e. type and amount of bedding, frequency of bedding distribution and manure removal). Obvious strong positive correlation was shown (τ = 0.751 at pig group level) between the farm mean total area indoor (TAI) and the number of pigs in the observed pens (NP); these non animal-based measures were weakly and positively correlated, at group level, with the prevalence of tail lesions (T) (τ = -0.158 and τ = -

0.156, respectively, at pig group level), confirming that an increase in group size would result into unfavourable effects on welfare (Vermeer et al. 2014).

On the basis of the above mentioned results, obtained from the statistical processing of the two datasets, it is therefore possible to accept the first hypothesis of this study according to which a number of the investigated non animal-based measurements (i.e. housing risk factors) to assess the suitability of pig housing system to provide good welfare conditions to pigs were found as significantly correlated to, and able to affect, the animal-based measurements used in this study to assess pig welfare directly through pig observation.

Instead, the second hypothesis of this study is rejected as significant differences were found according to pig slaughter weight and body weight of observed pigs in both animal and non animal-based measures, considered as relevant for housing and management risk factors for pig welfare, in the surveyed sample of heavy and lean pig fattening farms. Indeed, three well distinct clusters of fattening farms were identified in the PCA in 51 farms, according to the pig live weight and the availability of a bedded solid floored laying area.

Lower farm size (AVP) and number of pigs per Annual Work Unit (PWU) were found in farms of the BED group, compared to farms of the other two clusters, suggesting that the higher work load per pig in these farms could be related to a higher workload for the management of bedding materials, as well as to less economies of scale in place in these smaller sized farms. At the same time, a lower PWU is coherent with more work time spent per pig, including daily inspection activity and intervention in case of emergency (e.g. separation of biters in case of tail biting outbreak, emergency killing of sick and/or suffering pigs).

Farms belonging to the BED group were featured by no or limited slatted floor, presence of bedding in the laying area, presence of roughage, higher space allowance and no or limited tail docking; most pigs in these farms were observed in reach of optimal enrichment materials, according to the EC Recommendation 336/2016 (European Union, 2016), and most active pigs were manipulating them. Lower prevalence of ear and skin lesions was found in these farms, compared to lean pig farms without bedded solid floored resting area (NBL), but not compared to heavy pig farms without bedded solid floored resting area (NBH), where the higher age of the observed pigs and the higher pig space allowance could mitigate the occurrence of these lesions.

The group of heavy pig farms without bedded solid floored laying area (NBH) was characterized by the presence of fully or partially slatted floor, liquid feeding, and limited availability of drinkers, which is considered as a risk factor for pig welfare, because potentially leading to more competition between pigs to access water particularly in summertime when the water nutritional need tends to increase (EFSA, 2007a).

Higher space allowance (SP) detected in the NBH and BED groups, compared to the HBL group, can be related to pig higher live weight (AW) in NBH farms and to more space (SP) needed in BED farms to house pigs with bedded solid floored laying area. It is worth noting that the mean pig space allowance of 1.15 m^2/pig in heavy pig farms of the NBH group exceeds the minimum legal requirement of 1 m^2/pig for pigs over the live weight of 110 kg, although it is lower than the value on 1.48 m^2/pig, calculated through the allometric formula for pigs of 172 kg of live weight with k = 0.047, as recommended by EFSA (2005). However, more space allowance for heavy pigs could be further used in the next few years by heavy pig farmers attempting to house pigs with intact tails, in compliance with EU legislation.

The lower presence of roughage and bedding material in the laying area of farms in the NBH and NBL groups, compared to the BED group, can also be related to the higher prevalence of slatted floor, which is likely to limit the use of a large quantity of organic materials (e.g., straw, wood shavings) because of the inability of the most common slurry systems (e.g., vacuum system) in place in European fattening pig farms to handle and evacuate these organic materials, together with the liquid manure under the slats, as confirmed in previous studies (EFSA, 2007b; Pedersen, 2018).

Lean pig farms without bedded solid floored resting area (NBL) were featured by lower pig space allowance (SP), mortality rate (M), medication cost per pig (MCP), number of pigs per drinker (PD) and feed conversion rate (FCR) and by higher farm % of pens with at least 1 nipple per 12 pigs or 1 water bowl for 15 pigs (PDC), higher average daily gain (ADG) and prevalence of ear (E) and body (B) lesions, compared to NBH heavy pig farms.

No statistical difference was found between the farm percentages of observed pens with at least one tail lesion in one pig in the three farm groups, although tail docking was performed on all NBH and NBL farms not performed at all on most BED farms (i.e. 9 farms out of 10); this outcome suggests that the prevalence of tail biting in undocked tail pigs can be similar to docked tail pigs housed in intensive systems, if undocked tail pigs are housed with bedded solid floored laying area, plenty of manipulable material that most pigs are able to access and larger space allowance above the minimum EU legal requirements. However, additional data from farms with undocked tail pigs housed in slatted floor systems without bedding and farms with docked tail pigs provided with bedded solid floored laying area could provide more evident information to investigate the tail biting phenomenon in relation to these housing risk factors.

Low prevalence of tail lesions in the NBH group can be related also to the majority of pigs with tails shortened by more than 50% (STT), and to the higher liveweight (AW) and age of the observed pigs, confirming the outcomes of a previous study showing less severe tail lesions in older pigs, compared to younger ones (Munsterhjelm et al., 2015).

The outcomes of this study showed that most pigs with tails shortened by less than 50% of the total length were observed in intensive (i.e. non organic) Polish, Austrian and German farms, whereas most pigs with tail shortened by more than 50% (i.e. stump tails) were observed in intensive Italian, English and Dutch farms involved in this study. In any case, the above considerations cannot be extended to the countries of origin of the pig farms because of the limited number of farms involved in the study and because farms were not selected on the basis of national representativeness criteria.

The observation of more prevalent ear (E) and skin lesions on the body (B) in pigs of the NBL farm group can be ascribed to the lower space allowance at the start of the growing phase when more frequent fights may occur in recently grouped pigs to establish a hierarchy (Turner et al., 2006).

Higher pig mortality rates and medication costs per pig in NBH heavy pig farms can be explained by the longer duration of the fattening period and the higher age at slaughter of at least nine months in heavy pigs for Parma Ham PDO. However, mortality rate and medication cost per pig could also be biased by different culling rates across farms, due to a different degree of implementing this practice to reduce animal suffering and the spread of diseases on farms (EFSA, 2020).

5 CONCLUSIONS

In conclusion, the set of animal and non-animal-based measures used in this study, was found suitable and useful to assess, analyse, and compare most of the housing risk factors for pig welfare and to cluster pig fattening farms accordingly.

Both animal and non-animal-based measures provided different types of information, which are needed for routine official controls and can be suitable for use in farm assurance schemes.

Animal-based measures for pig lesions, mortality and pig behavior were used to monitor pig welfare directly and to investigate the effect that the resources and management have on the animals. The results of this research suggest that the sensitivity of animal-based measures is important to detect frequency and severity of pig lesions and to investigate their causes by analysing non animal-based measures for housing and management risk factors. Attention should also be paid to weight and age of pigs when assessing injuries and behavior, so that the results obtained from farms rearing heavy and lean pigs can be compared. As regards mortality rate, additional information about the health status of the pig herd could be obtained from monitoring the number of culled animals; separate recording for culled pigs and pigs found death are likely to be helpful to get more precise information at farm level and to make it more suitable for comparison between farms (i.e. benchmarking). Indeed, mortality rate can be biased by different culling rates across farms, due to a different degree of implementing this practice to reduce animal suffering and the spread of diseases on farms.

Higher space allowance per pigs was found to reduce the prevalence of ear and skin lesions, although the occurrence of them in this study was also affected by the body weight of observed pigs.

The availability of bedded solid floor in the laying area was shown to provide increased access of pigs to optimal enrichment materials, to better stimulate enrichment manipulation behavior and to enable the rearing of pigs with undocked tails, without significant difference in the prevalence of tail lesions, compared to pigs with docked tails, housed without bedded solid floor in the laying area. Furthermore, ear and skin lesions were found more prevalent in lean pigs of the NBL group, reared without bedded solid floor in the laying area. As a consequence, the practice of housing pigs with bedded solid floor in the laying area and limited slatted floor is likely to allow rearing pigs with intact tails, according to EU legislation, without exposing them to an increased risk of tail-biting injuries.

Housing risk factors for pig welfare, such as the lack of space allowance, bedding, and environmental enrichment, as well as the presence of fully slatted floor are likely to become more challenging for pig farmers to keep pigs intensively with long undocked tails, once the ban of routine tail docking is finally applied across all EU Member States. Changes in the pig housing systems are expected in the coming years to better comply with EU legislation and to match the market demand for more sustainable pork from pig friendly production systems. Innovative solutions to mechanically deliver straw or similar materials in pig pens and to allow manure evacuation from pits under slats will be welcome to increase pig welfare and help pig farmer to keep pigs with undocked tails.

Furthermore, additional non-animal-based measures of pig welfare could also be considered to asses pig welfare, such as those to evaluate the pig microclimate pig comfort and the presence of noxious gases and dust, as risk factors for tail biting and for overall welfare assessment. Further studies on this subject are promising to investigate casual links for these indicators in relation to other animal and non-animal measures.

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