RESEARCH ARTICLE

*J Anim Sci Technol* 2022;64(3):539-563
https://doi.org/10.5187/jast.2022.e23

JAST
*Journal of Animal Science and Technology*
pISSN 2672-0191 eISSN 2055-0391

# Correlation of animal-based parameters with environment-based parameters in an on-farm welfare assessment of growing pigs

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## Abstract

Nine pig farms were evaluated for the welfare quality in Korea using animal- and environment-based parameters (particularly air quality parameters) during the winter of 2013. The Welfare Quality® (WQ®) protocol consists of 12 criteria within four principles. The WQ® protocol classifies farms into four categories ranging from 'excellent' to 'not classified'. Each of these criteria has specific measures for calculating scores. Calculations for the welfare scores were conducted online using the calculation model in the WQ® protocol. Environment-based parameters like microclimate (i.e., temperature, relative humidity, air speed, and particulate matter), bacteria (total airborne bacteria, airborne total coliform, and airborne total *Escherichia coli*), concentration of gases (carbon dioxide, ammonia, and hydrogen sulfide) were measured to investigate the relationship between animal- and environment-based parameters. Correlations between the results of animal- and environment-based parameters were estimated using spearman correlation coefficient. The overall assessments found that five out of nine farms were 'acceptable', and four farms were 'enhanced'; no farm was 'not classified'. The average score for the four principles across the nine farms, in decreasing order, were 'good feeding' (63.13 points) > 'good housing' (59.26 points) > 'good health' (33.47 points) > 'appropriate behaviors' (25.48 points). In the result of the environment aspect, the relative humidity of farms 2 (93.4%), 3 (100%), and 9 (98%) was much higher than the recommended maximum relative humidity of 80%, and four out of the nine farms had ammonia concentrations greater than 40 ppm. Ammonia had negative correlations with 'positive social behaviors' and positive emotional states: content, enjoying, sociable, playful, lively, happy and it had positive correlations with negative emotional states: aimless, distressed. The concentration of carbon dioxide had negative correlations with positive emotional states; calm, sociable, playful, happy and it had a positive correlation with negative emotional state; aimless. Our results indicate that the control of the environment for growing pigs can help improve their welfare, particularly via good air quality (carbon dioxide, ammonia, hydrogen sulfide).

Check for updates

Received: Feb 28, 2022
Revised: Mar 22, 2022
Accepted: Apr 1, 2022

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**Competing interests**
No potential conflict of interest relevant to this article was reported.

**Funding sources**
Not applicable.

**Acknowledgements**
The authors wish to thank Professor Hong Lim Choi and Myung Sun Chun for their advice on the current paper.

**Availability of data and material**
Upon reasonable request, the datasets of this study can be available from the corresponding author.

**Authors' contributions**
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Writing - review & editing: Kang HJ, Bae S, Lee H.

**Ethics approval and consent to participate**
This article does not require IRB/IACUC approval because there are no human and animal participants.

**Keywords:** Farm animal welfare, Growing pigs, Welfare Quality®, Animal-based parameters, Environment-based parameters, Air quality parameters

# INTRODUCTION

To ensure that initiatives to improve animal welfare are acknowledged by citizens and create fair trading conditions, a scientific evaluation of animal welfare is essential. Many scientists have conducted research to evaluate animal welfare scientifically and accurately. Animal welfare is multidimensional [1]; no single measure can be used to evaluate an animal's welfare directly, so multiple measures should be used for an overall welfare assessment. There are two main types of animal welfare measures: animal- and environment-based measures [2]. Although environment-based parameters are easy and fast, they are limited in that they cannot fully represent an animal's welfare status. Nonetheless, the measurement of welfare problems based on environmental factors often serves as a good basis for solving farm animal welfare problems. Most of the Livestock Industry Act is based on environment-based parameters. On the other hand, animal-based measures assess the condition of the animal itself, using direct indicators of animal welfare [3]. Thus, animal-based parameters may overcome the limitations of indirect measures as they evaluate the actual welfare status of an animal on-farm [4]. However, recording animal-based parameters is difficult and requires considerable resources and time, and even if properly recorded, the results may be difficult to interpret; thus, they may not be suitable for the evaluation of animal welfare in practice [3]. Therefore, a combination of parameters, including both measurement types, can provide the most effective assessment of animal welfare [3].

The Welfare Quality® (WQ®) protocol is an animal-based, on-farm welfare assessment protocol designed for intensive farms. Developed in 2004 [5], it uses a multi-criteria approach based on four main principles of animal welfare: 'good feeding', 'good housing', 'good health', and 'appropriate behaviors'. During its development, the WQ® protocol for pigs mainly used direct observations, with all measurements selected from the literature, and the final monitoring protocol was tested on commercial pig farms. Moreover, all measures were evaluated in a pilot study for their independent validity, repeatability, and feasibility [6]. The WQ® protocol has been used in many studies worldwide, further confirming its validity, repeatability, and feasibility [7,8].

In Korea, although the economy and livestock industry have developed rapidly over the last few decades, public awareness of farm animal welfare has only recently begun. Animal welfare issues are receiving an increasing amount of public attention in Korea due to public campaigns by non-governmental organizations. However, few studies have assessed the welfare of pigs in Korea. Research by Renggaman et al. [9] was only conducted on two pig farms in Korea, using animal-, resource-, and management-based parameters, which is insufficient to evaluate the greater, country-wide welfare status of pigs. Therefore, the welfare assessment of growing pigs using animal- and environment-based parameters is expected to provide valuable information on the status of pig welfare in Korea.

The farm environment is a complex dynamic system that is influenced by many factors affecting the health and welfare of the animals. In fact, this is the case for many intensively reared animals in traditional, conventional livestock system. Important measurement parameters include temperature, relative humidity, ventilation, concentration of gases, airborne bacteria, and particulate matter [10–12]. Particulate matter, airborne bacteria, and gases are the most significant factors that affect pigs in the aerial environment of the pig house, and their impact depends on both animal management practices and the pig housing structure [13]. These environment-based parameters are considered as major factors influencing the welfare of pigs on commercial farms. There are many studies on


https://doi.org/10.5187/jast.2022.e23

the correlation between the results of animal-based parameters and environment-based parameters. In particular, the most important environmental determinants of pig welfare were space allowance and bedding material [14]. However, improving farm animal welfare mainly based on these two variables is difficult to achieve because most pig farms in intensive livestock production system use concrete or metal slatted floors that does not allow bedding materials to be used. Improving the space and bedding system also requires a considerable amount of financial and human recourses. Therefore, this study investigated the correlation between the results of animal- and environment-based parameters, especially air quality parameters to find out if better air quality has significant positive effect on animal-based parameters. If there is significant positive correlation between the two parameters, it might be useful to improve farm animal welfare rather quickly because improving air quality requires comparably less amount of financial and human resource and time than improving space allowance and bedding material.

## MATERIALS AND METHODS

### Study farms

The measurements in the present study were carried out in accordance with accepted ethical standards and proper hygienic maintenance. This study assessed nine intensive growing pig farms situated in three South Korean provinces during the winter of 2013 (Fig. 1). These three provinces have the largest number of pig farms in Korea: Gyeonggi-do, Gyeongsangbuk-do, and Chungcheongnam-do. According to the 2013 census of pig farms in Korean [15], there were 2,602 pig farms with 1,000–5,000 pigs. The total number of pigs raised on these farms was 5,504,409, which corresponds to 56% of all pigs in Korea. Of the nine farms evaluated in this study, eight (88%) raised between 1,000 and 5,000 pigs, and one (11%) raised fewer than 1,000 pigs, implying that the farms included in this study were representative of typical pig farm sizes in Korea. Details of the pig farms are summarized in Table 1.

Pigs were kept in pens of 10–150 animals; the mean number of pigs per pen was 43.3 ± 42.9

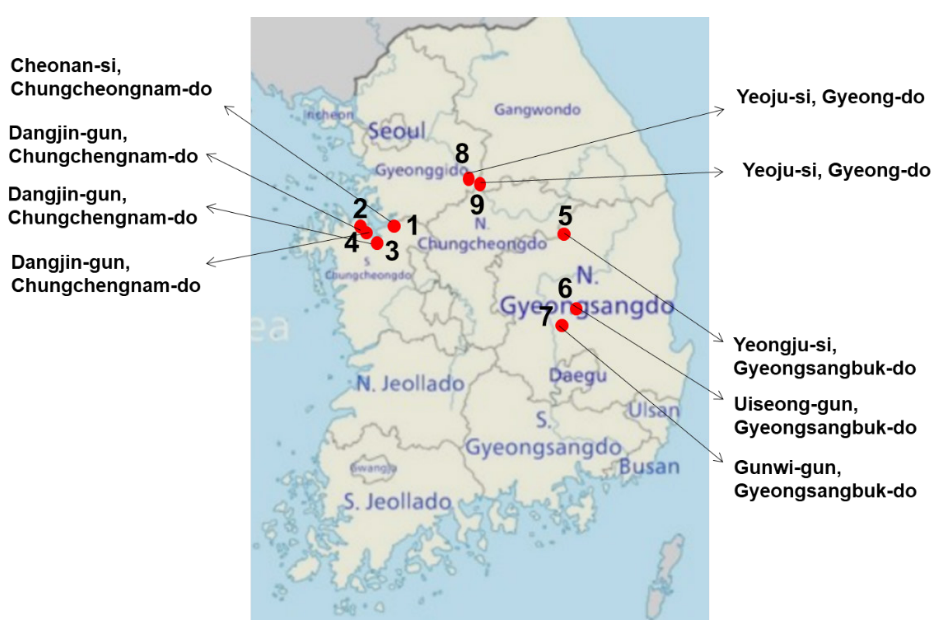



**Fig. 1. The location of pig farms assessed with Welfare Quality® protocol in Korea.**

**Table 1. The details of nine pig farms assessed in Korea**

| Farm | Floor type | Type | Number of pigs in the farm | Space allowance ($m^2$) / pig | Space allowance ($m^2$) / 100 kg | Number of pigs / pen | Average weight (kg) | Average ages (days) |
|---|---|---|---|---|---|---|---|---|
| 1 | Partly slatted concrete floors | Breeder-fatteners | 3,500 | 0.8 | 1.3 | 18 | 60 | 81 |
| 2 | Partly slatted concrete floors | Breeder-fatteners | 5,000 | 0.4 | 0.7 | 150 | 60 | 80 |
| 3 | Partly slatted concrete floors | Breeder-fatteners | 2,000 | 0.4 | 1.8 | 13 | 25 | 42 |
| 4 | Partly slatted concrete floors | Fatteners | 450 | 1.0 | 2.1 | 10 | 45 | 66 |
| 5 | Fully slatted concrete floors | Breeder-fatteners | 1,500 | 1.1 | 2.2 | 30 | 50 | 70 |
| 6 | Partly slatted concrete floors | Breeder-fatteners | 2,900 | 0.7 | 1.8 | 40 | 40 | 62 |
| 7 | Sawdust | Fatteners | 2,000 | 1.8 | 4.0 | 30 | 45 | 63 |
| 8 | Partly slatted concrete floors | Breeder-fatteners | 4,000 | 0.4 | 1.1 | 40 | 40 | 60 |
| 9 | Sawdust | Breeder-fatteners | 2,000 | 0.7 | 1.5 | 60 | 45 | 65 |

pigs (30.1 ± 16.6 pigs when excluding the farm with 150 pigs). The average space allowance in the pen ranged from 0.7 to 4 $m^2$/100 kg (mean ± SD = 1.82±0.95 $m^2$/100 kg) or from 0.42 to 1.8 $m^2$/individual (mean ± SD = 0.81 ± 0.44 $m^2$/individual). The age of the pigs within a single pen ranged from 42 to 81 days (mean ±SD = 65.4 ± 10.7 days) and the body weight in a pen ranged from 25 to 60 kg (mean ± SD = 45.56 ± 19.97 kg). For six out of the nine farms, the space allowance was above 0.45 $m^2$; this is above the Requirements for permission and registration of livestock industry in the Enforcement Decree of the Livestock Industry Act [16]. Four of nine pig farms had a mechanical ventilation system and five had a natural ventilation system. During the assessment, because of the cold weather, there were no fans operating in the pig houses with mechanical ventilation systems. The houses with natural ventilation systems were covered with thick, heavy curtains. Seven pig farms had slatted concrete floors without bedding materials (six farms were partially slatted and one farm was fully slatted) and two farms had sawdust floors. Prior access permissions were obtained from farm owners, and they allowed post-visit contact for questions regarding the farm operations.

## Animal-based parameters

The WQ® protocol was assessed by two observers. The two observers had identical training prior to the assessment to minimize any differences between observers. Observers obtained prior access permissions from farm owners. The two observers ensured that there was no previous contact with the pigs for at least 48 h prior to the assessment. The WQ® protocol [5] was used to evaluate the welfare status of the nine growing pig farms using animal-based parameters. The WQ® protocol consists of an assessment using 12 criteria within four main principles: 'good feeding', 'good housing', 'good health', and 'appropriate behaviors'. Each of these criteria has specific measures for calculating scores (Table 2). Table 3 describes the respective scoring scale and description of each measure used in the welfare assessment. The order of recorded measures, sample size, location, and time required are shown in Table 4.

### *Overall assessment*

After the animals were observed at six observation points per farm, an overall assessment was carried out at the farm level. Four criteria were combined into an overall assessment to indicate the level of welfare on the pig farms. Based on the final score, an overall assessment of the WQ® protocol can be made under four categories as follows: 'excellent' (80.1–100): the welfare of the animals is of the highest level; 'enhanced' (60.1–80): the welfare of the animals is good; 'acceptable' (20.1–60): the welfare of the animals is above or meets minimal requirements; and 'not classified'

 https://doi.org/10.5187/jast.2022.e23

**Table 2.** The principles and criteria of Welfare Quality® assessment protocols

| Principle | Criteria | Measures |
|---|---|---|
| Good feeding | 1 Absence of prolonged hunger<br>2 Absence of prolonged thirst | Body condition score<br>Water supply |
| Good housing | 3 Comfort around resting<br>4 Thermal comfort<br>5 Ease of movement | Bursitis, absence of manure on the body<br>Shivering, panting, huddling<br>Space allowance |
| Good health | 6 Absence of injuries<br>7 Absence of disease<br>8 Absence of pain induced by management procedures | Lameness, wounds on body, tail biting<br>Mortality, coughing, sneezing, pumping, twisted snouts, rectal prolapse, scouring, skin condition, ruptures and hernias<br>Castration, tail docking |
| Appropriate behaviors | 9 Expression of social behaviors<br>10 Expression of other behaviors<br>11 Good human-animal relationship<br>12 Positive emotional state | Social behaviors<br>Exploratory<br>Fear of humans<br>Qualitative behaviors assessment (QBA) |

(0–20): the welfare of the animals is low and considered unacceptable.

### *Good feeding, good housing, and good health*

In this protocol, the welfare status of the pigs is assessed via direct observation, except for the criteria 'absence of prolonged thirst' and 'ease of movement'. Ten pens located evenly across the room were selected and assessed (Table 4). As much as possible, all rooms on the farm were assessed; the hospital pen was not assessed. The welfare parameters were scored for each individual pig at the pen level using a three-point scale: 0 for good welfare, 1 for compromised welfare, and 2 for poor welfare. For each parameter, the number of pigs that received a score of 1 or 2 was recorded. In some cases, the parameters were recorded using a binary scale: 0 for absent, 2 for present (Table 3). Pigs were individually scored for body condition, bursitis, manure on the body, lameness, wounds on the body, tail biting, pumping, twisted snouts, rectal prolapse, skin condition, ruptures, and hernias. Huddling, panting, shivering, coughing, and sneezing were observed from outside the pens; all other measures were assessed inside the pens to enable careful observation of the pig's bodies. Manure on the body, skin condition, bursitis, and wounds on the body were scored only on one side of each pig, as there are no significant differences in scores between the left and right sides of pigs [17].

### *Appropriate behaviors*

Two different measures were used for the assessment of 'appropriate behaviors': quantitative behavioral assessment and qualitative behavioral assessment (QBA). Quantitative behavior assessment includes social and exploratory behaviors and the human-animal relationship (HAR). Social and exploratory behaviors were assessed via scan sampling at three different observation points [17], with approximately 50–60 pigs observed at each observation point (Table 4). Before beginning the scan, the observer clapped to make all pigs stand up, then, after 5 min, started the scan from outside the pen. Each pen was observed five consecutive times with an interval of 2.5 min between scans [17]. The HAR was evaluated using the fear of human test [17], in which 10 randomly selected pens were assessed throughout the farm. Any pen with more than 60% of the pigs showing panic toward the human was recorded, where panic was defined as an animal facing away from the observer or huddling in the corner of the pen. QBA uses descriptive terms with an expressive connotation to reflect animals' experiences of a situation [18]. A rating scale was used to score pigs at the group level at six observation points per farm, based on 20 different terms: active, relaxed, fearful, agitated, calm, content, tense, enjoying, frustrated, sociable, bored, playful, positively occupied, listless, lively, indifferent, irritable, aimless, happy, and distressed.

**Table 3.** Measures with their respective scoring scale and description used in the welfare assessment [5]

| Measures | Score | Description |
|---|---|---|
| Body condition | 0 | Animal with a good body condition |
| | 2 | Poor body condition: Animal with visible spine, hip and pin bones |
| Water supply | 0 | Number of drinking places are enough/ Function correctly and clean |
| | 2 | Number of drinking places are not enough/ Do not function properly / dirty |
| Bursitis | 0 | No evidence of bursa / swelling |
| | 1 | Moderate bursitis: One or several small bursae (1.5-2.0 cm) on the same leg or one large bursa (3.0-5.0 cm) |
| | 2 | Severe bursitis: Several large bursae on the same leg, or extremely large bursa (5.0-7.0 cm) or any bursas that are eroded |
| Manure on the body | 0 | Less than 20% of one side of the body is soiled |
| | 1 | Moderately soiled body: More than 20% but less than 50% of one side of the body surface is soiled with faeces |
| | 2 | Severely soiled body: Over 50% of one side of the body surface is soiled with faeces |
| Shivering | 0 | No vibration of any body part |
| | 2 | Slow and irregular vibration of any body part, or the body as a whole |
| Panting | 0 | Normal breathing. |
| | 2 | Rapid breath in short gasps |
| Huddling | 0 | Pig lying with less than half of its body lying on top of another pig |
| | 2 | Pigs lying with more than half of its body lying on top of another pig |
| Space allowance | | Space allowance expresses in $m^2$ / 100 kg animal |
| Lameness | 0 | Normal gait or slight difficulty but using all 4 legs; swagger of caudal body while walking; shortened stride |
| | 1 | Severely lame, minimum weight-bearing on the affected limb |
| | 2 | No weight-bearing on the affected limb, or not able to walk |
| Wounds on body | 0 | If all regions of the animal's body have up to 9 lesoins in one side of the body |
| | 2 | Severely wounded: when more than 10 lesions are observed on at least two zones of one side of the body or if any zone has more than 15 lesions |
| Tail biting | 0 | No evidence of tail biting or superficial biting along the length of the tail, but no fresh blood or any swelling missing and presence of scabs |
| | 2 | Bleeding tail and / or swollen infected tail lesion and / or part of tail tissue |
| Mortality | % | Percentage mortality during the previous 12 months |
| Coughing | | Average frequency of coughing per animal per 5 minutes |
| Sneezing | | Average frequency of sneezing per animal per 5 minutes |
| Pumping | 0 | No evidence of laboured breathing |
| | 2 | Evidence of laboured breathing |
| Twisted snouts | 0 | No evidence of twisted snouts |
| | 2 | Evidence of twisted snouts |
| Rectal prolapse | 0 | No evidence of rectal prolapse |
| | 2 | Evidence of rectal prolapse |
| Scouring | 0 | No liquid manure visible in the pen |
| | 1 | Areas in the pen with some liquid manure visible |
| | 2 | All faeces visible inside the pen is liquid manure |
| Skin condition | 0 | No evidence of skin inflammation or discoloration |
| | 1 | Localized skin condition: More than zero, but less than 10% of the skin is inflamed, discoloured or spotted |
| | 2 | Widespread skin conditoin: More than 10% of the skin has an abnormal colour or texture |
| Ruptures and hernias | 0 | No hernias / ruptures |
| | 1 | Hernias or ruptures present, but the affected area not bleeding, not touching the floor and not affecting locomotion |
| | 2 | Bleeding lesions, hernias / ruptures and they are touching the floor |
| Castration | 0 | No castration done |
| | 1 | Castration with use of anesthetics |
| | 2 | Castration without use of anesthetics |
| Tail docking | 0 | No tail docking done |
| | 1 | Tail docking with use of anesthetics |
| | 2 | Tail docking without use of anesthetics |
| Hernias | 0 | 0 No hernia/rupture |
| | 2 | 2 Hernias/ruptures with bleeding lesion or touching the floor |
| Social behaviors | % | Negative social behavior: Aggressive behavior, including biting or any social behavior with a response from the disturbed animal |
| | % | Positive social behavior: Sniffing, nosing, licking and moving gently away from the animal without an aggressive or flight reaction from this individual |
| Explorative behavior | % | Sniffing, nosing, licking all features of the pen or paddock. Exploration towards straw or other suitable enrichment material. |
| Fear of human | 0 | No panic response to human presence |
| | 2 | Panic response: More than 60% of the animals fleeing, facing away from the observer or huddled in the corner of the pen |
| Qualitative behavioral assessment (QBA) | Rating scale | Active, relaxed, fearful, agitated, calm, content, tense, enjoying, frustrated, sociable, bored, playful, positively occupied, listless, lively, indifferent, irritable, aimless, happy, distressed |

 https://doi.org/10.5187/jast.2022.e23

**Table 4.** Order of recorded measures, sample size, place and time required

| Information collected | Sample size | Place | Time required (min) |
|---|---|---|---|
| Management-based measures | - | Animal unit manager | 10 |
| Qualitative behavior assessment (QBA) | 2 to 8 Points of observation | PENS C | 20 |
| Coughing | 6 Points of observation: minimum 2 pens | PENS A or B | 15 |
| Sneezing | | | |
| Social behavior | 3 Points of observation<br>50–60 animals/point | PENS A | 30 |
| Exploratory behavior | | | |
| Outside the pen: | 150 pigs from 10 different pens/groups (15 pigs per pen/group).<br>When > 15 animals per pen/group, 15 animals per pen/group will be randomly chosen and marked before assessment.<br>If there are less than 10 pens/groups, the number of pigs inspected inside each pen/group should be increased until reaching a total of 150 animals | PENS B | 60 |
| Huddling | | | |
| Shivering | | | |
| Panting | | | |
| Inside the pen: | | | |
| Fear of humans | | | |
| Body condition | | | |
| Bursitis | | | |
| Absence of manure on the body | | | |
| Wound on the body | | | |
| Tail biting | | | |
| Lameness | | | |
| Pumping | | | |
| Twisted snouts | | | |
| Rectal prolapse | | | |
| Scouring | | | |
| Skin condition | | | |
| Ruptures and hernias | | | |
| Water supply | - | | |
| Space allowance | - | | |

Data from Welfare Quality [5].

## Environment-based parameters

### *Microclimate*

All measurements were conducted in triplicate. Temperature, relative humidity, and air speed were measured at nine points inside the pig house at 60 cm above the floor (Fig. 2), which corresponds to the nose height of growing pigs [19]. Air temperature and relative humidity were measured with a hygrothermograph (SK-110TRH, SATO, Tokyo, Japan) and air speed was measured with an anemometer (model 6112, KANOMAX, Osaka, Japan).

### *Particulate matter concentrations*

Particulate matter concentrations were measured at three points along the aisles (Fig. 2), as it would be difficult to keep the instrument (aerosol mass monitor, GT-331, SIBATA, Saitama, Japan) safe from the pigs if it were inside the pen. The mass concentrations of $PM_{10}$ (PM average aerodynamic diameter #10 mm), $PM_{7.5}$ (PM mean aerodynamic diameter #7.5 mm), $PM_{2.5}$ (PM mean aerodynamic diameter #2.5 mm), $PM_1$ (PM mean aerodynamic diameter #1 mm), and total suspended particulate matters (TSP) were obtained simultaneously.

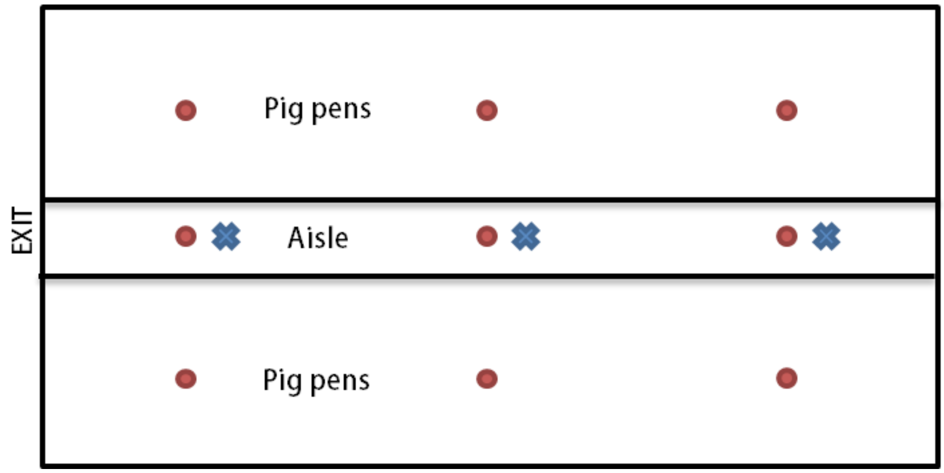



**Fig. 2. Sampling points for the environmental parameters.** O, sampling points for temperature, relative humidity, and air speed; X, sampling points for concentration of particulate matter, airborne bacterial, and gases ($CO_2$, $NH_3$, $H_2S$).

#### *Airborne bacteria*

Airborne bacterial counts were measured at three points along the aisles (Fig. 2) using the settle plate method; this is a direct method for assessing the likely number of microorganisms depositing onto a product or surface in a given time. The method is based on the fact that, in the absence of any kind of influence, airborne microorganisms, typically attached to larger particles, will deposit onto open culture plates. Tryptic soy agar (Merck, Darmstadt, Germany) was used for enumeration of total airborne bacteria, and Chromocult Coliformen agar (Merck) was used for airborne total coliforms and airborne total *Escherichia coli*. After sampling, the plates were incubated at 37℃ for 48 h, and the colonies were counted and calculated as colony-forming units.

#### *Concentrations of carbon dioxide, ammonia, and hydrogen sulfide*

Concentrations of carbon dioxide, ammonia, and hydrogen sulfide were measured using a gas detection device (Model 801, Gastec, Kanagawa, Japan). A Gastec was used because it is simple to handle and requires only a short time to measure several types of gases. Gases from the growing pig houses were measured at three points along the aisle (Fig. 2). Concentrations were expressed in ppm.

### Statistical analysis

Calculations for the welfare scores were conducted online using the calculation model in the WQ® protocol [5]. The final score of each criterion ranged from 0 to 100. Farms were classified according to four categories based on the final score in each criterion. The statistical evaluation was carried out using SPSS. 25 (SPSS, Chicago, IL, USA). Correlations between the results of animal- and environment-based parameters were estimated using spearman correlation coefficient with significance level of 0.05.

## RESULTS

### Animal-based parameters

The results of the WQ® protocol are summarized in Table 5. Although none of the farms were

**Table 5. The result of the Welfare Quality® protocol at the level of overall assessment, principle and criterion on 9 pig farms**

| Indicator | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Overall Assessment | A | A | A | E | E | E | A | A | E | - | - |
| Good feeding | 57.3 | 42.5 | 100.0 | 56.8 | 82.4 | 57.3 | 57.3 | 57.3 | 57.3 | 63.1 | 17.2 |
| Absence of prolonged hunger | 100.0 | 100.0 | 100.0 | 90.0 | 75.5 | 100.0 | 100.0 | 100.0 | 100.0 | 96.2 | 8.4 |
| Absence of prolonged thirst | 55.0 | 40.0 | 100.0 | 55.0 | 100.0 | 55.0 | 55.0 | 55.0 | 55.0 | 63.3 | 21.4 |
| Good housing | 22.4 | 73.9 | 36.7 | 81.3 | 82.7 | 65.3 | 42.7 | 47.1 | 81.2 | 59.3 | 22.5 |
| Comfort around resting | 16.1 | 69.8 | 24.1 | 76.1 | 80.5 | 57.2 | 28.3 | 40.5 | 84.8 | 53.0 | 26.4 |
| Thermal comfort | 26.0 | 100.0 | 100.0 | 46.0 | 100.0 | 100.0 | 26.0 | 100.0 | 100.0 | 77.6 | 34.2 |
| Ease of movement | 41.5 | 86.0 | 74.2 | 96.8 | 88.9 | 89.6 | 86.1 | 66.9 | 80.0 | 78.9 | 16.6 |
| Good health | 22.5 | 31.9 | 24.8 | 35.4 | 32.2 | 54.2 | 25.6 | 38.5 | 36.1 | 33.5 | 9.5 |
| Absence of injuries | 70.2 | 93.4 | 73 | 89.7 | 100 | 62.8 | 93.9 | 100.0 | 96.4 | 86.6 | 14.1 |
| Absence of disease | 52.3 | 84.0 | 60.6 | 100.0 | 84 | 74.1 | 60.6 | 100.0 | 100.0 | 79.5 | 18.7 |
| Absence of pain induced by management procedures | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 47.0 | 8.0 | 8.0 | 8.0 | 12.3 | 13.0 |
| Appropriate behaviors | 14.9 | 25.2 | 14.0 | 19.2 | 30.5 | 33.1 | 32.6 | 31.2 | 28.6 | 25.5 | 7.6 |
| Expression of social behaviors | 26.6 | 49.9 | 28.5 | 14.7 | 55.9 | 1000 | 77.6 | 79.7 | 100.0. | 59.2 | 32.0 |
| Expression of other behaviors | 7.1 | 22.3 | 5.9 | 23.9 | 27.5 | 22.3 | 28.7 | 22.2 | 11.1 | 19.0 | 8.7 |
| Good human relationship | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 |
| Positive emotional state | 17.9 | 17.5 | 16.0 | 21.9 | 22.7 | 17.2 | 18.7 | 20.2 | 17.9 | 18.9 | 2.3 |

A, acceptable; E, enhanced.

classified as 'excellent' or 'not classified', four out of the nine farms were classified as 'enhanced' and five were classified as 'acceptable' according to the overall assessment. The average score for the four principles across the nine farms, in decreasing order, were 'good feeding' (63.13 points) > 'good housing' (59.26 points) > 'good health' (33.47 points) > 'appropriate behaviors' (25.48 points). The percentage of farms per category in terms of the WQ® protocol criteria is shown in Fig. 3.

### *Good feeding*

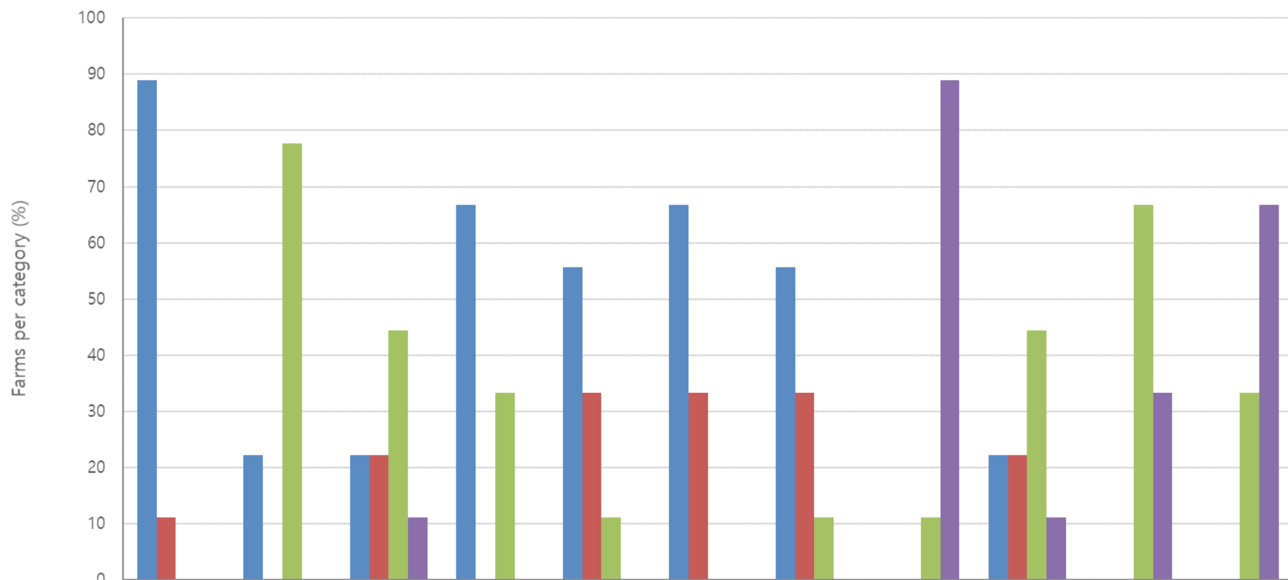
In eight out of nine farms, the criterion 'absence of prolonged hunger' scored above 90 points (farm 5 scored 75 points). Two farms (farm 3 and 5) scored 100 points for the criterion 'absence of prolonged thirst', but the remaining seven farms scored below 55 points because of poor drinker functionality (Table 5). The average number of pigs per drinker was 10.8, with a range of 4.5 to 15 pigs per drinker.

### *Good housing*

Among the three criteria within the principle 'good housing', the criterion 'comfort around resting' scored the lowest (53.04 points; Table 5) because of a high prevalence of bursitis and soiled body (Table 6). For this criterion, farm 1 scored as 'not classified', which means that its welfare status was unacceptable. For the criterion 'thermal comfort', 33.3% of the farms were classified as 'acceptable' and 66.7% were classified as 'excellent', as can also be seen in Fig. 3.

### *Good health*

Within the principle 'good health', low scores were recorded for all farms because of a general low score from the criterion 'absence of pain induced by management procedures' (mean = 12.33 points). All nine farms performed castration without anesthesia, and eight farms performed tail docking. One farm (farm 6) that did not practice tail docking scored 46 points, whereas all the




| | 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 | Positive emotional state |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Excellent | 88.9 | 22.2 | 22.2 | 66.7 | 55.6 | 66.7 | 55.6 | 0 | 22.2 | 0 | 0 |
| Enhanced | 11.1 | 0 | 22.2 | 0 | 33.3 | 33.3 | 33.3 | 0 | 22.2 | 0 | 0 |
| Acceptable | 0 | 77.7 | 44.4 | 33.3 | 11.1 | 0 | 11.1 | 11.1 | 44.4 | 66.7 | 33.3 |
| Not classified | 0 | 0 | 11.1 | 0 | 0 | 0 | 0 | 88.9 | 11.1 | 33.3 | 66.7 |

**Fig. 3. Percentage of farms per category in the criteria of the Welfare Quality® protocol.** Good human-animal relationship is not shown in the graph since 100% of the farms classified as excellent category.

other farms scored 8 points, which means that their welfare status was not acceptable (Table 5). All nine farms were above the 'enhanced' level (over 60 points) for the criterion 'absence of injuries'. For the criterion 'absence of disease', eight farms were above 'enhanced' while one farm (farm 1) was 'acceptable'.

### *Appropriate behaviors*

Among all the principles, 'appropriate behaviors' scored the lowest. Even though the mean score for the criterion 'good human relationship' was 100 points, the criteria 'expression of other behaviors' (mean = 19 points) and 'positive emotional state' (mean = 18.89 points) were the lowest levels within the principle 'appropriate behaviors' (Table 5). In terms of the criterion 'expression of other behaviors', 66.7% of the farms reached the acceptable level whereas 33.3% of the farms failed to reach the minimum score for acceptability. In terms of the criterion 'positive emotional state', 33.3% of the farms fell within the acceptable level; the remaining 66.7% of the farms did not reach the minimum score for acceptability (Fig. 3).

## Environment-based parameters

Results for temperature, relative humidity, air speed, and particulate matter concentration are presented in Table 7. Temperature, relative humidity, air speed and particulate matter concentrate ranged from 9.15 to 26.29℃ (mean ± SD = 18.62 ± 5.76℃), 39.61 to 100% (mean ± SD = 75.24 ± 21.04%), 0 to 0.04 m/s (mean ± SD = 0.021±0.03 m/s), 192.33 to 1,397.25 $\mu g/m^3$ (mean ± SD = 696.34 ± 466.2 $\mu g/m^3$) for $PM_{10}$, 101.72 to 1112.83 $\mu g/m^3$ (mean ± SD = 409.27 ± 320.43 μg/

 https://doi.org/10.5187/jast.2022.e23

**Table 6.** The results of the indicators of the Welfare Quality® assessment protocol on 9 pig farms

| Indicators of the Welfare Quality® protocol | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | Min | Max | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % Lean pigs | 0.0 | 1.3 | 0.0 | 1.4 | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 3.8 | 1.3 |
| No. of pigs/pen | 150.0 | 13.0 | 18.0 | 30.0 | 10.0 | 30.0 | 400 | 40.0. | 60.0 | 43.4 | 10.0 | 150.0 | 42.9 |
| Average weight | 60.0 | 25.0 | 60.0 | 45.0 | 45.0 | 50.0 | 40.0 | 40.0 | 45.0 | 45.56 | 25.0 | 60.0 | 10.7 |
| Floor area | 63.0 | 5.8 | 13.7 | 54.0 | 9.5 | 33.6 | 28.5 | 17.5 | 39.2 | 29.4 | 5.8 | 63.0 | 20.0 |
| Pigs/drinking | 15.0 | 13.0 | 4.5 | 15.0 | 5.0 | 6.0 | 6.7 | 20.0 | 12.0 | 10.8 | 4.5 | 15.0 | 5.5 |
| Number of drinking places | 10.0 | 1.0 | 4.0 | 2.0 | 2.0 | 5.0 | 6.0 | 2.0 | 5.0 | 4.1 | 10.0 | 1.0 | 2.8 |
| Fonctionning of drinkers | 0.0 | 0.0 | 2.0 | 0.0 | 2.0 | 2.0 | 2.0 | 0.0 | 0.0 | 2.0 | 0.0 | 2.0 | 0.0 |
| Cleanliness of drinkers | 0.0 | 0.0 | 0.0 | 00 | 0.0. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| % Pigs with bursae score 0 | 82.7 | 69.3 | 79.2 | 86.5 | 77.1 | 43.2 | 61.2 | 80.1 | 96.7 | 75.12 | 43.2 | 96.7 | 15.6 |
| % Pigs with bursae score 1 | 17.3 | 24.0 | 18.1 | 10.6 | 21.4 | 52.7 | 38.8 | 13.7 | 2.7 | 22.1 | 2.7 | 52.7 | 15.2 |
| % Pigs with bursae score 2 | 0.0 | 6.7 | 2.8 | 2.8 | 1.5 | 4.1 | 0.0 | 6.2 | 0.7 | 2.7 | 0.0 | 6.7 | 2.5 |
| % Pigs with manure score 0 | 0.0 | 83.3 | 9.0 | 82.3 | 96.2 | 89.2 | 24.2 | 66.4 | 86.7 | 59.7 | 0.0 | 96.2 | 37.8 |
| % Pigs with manure score 1 | 36.7 | 16.7 | 45.8 | 14.9 | 3.8 | 10.1 | 37.0 | 5.5 | 12.7 | 20.4 | 3.8 | 45.8 | 15.4 |
| % Pigs with manure score 2 | 63.3 | 0.0 | 45.1 | 2.8 | 0.0 | 0.7 | 38.8 | 28.1 | 0.7 | 20.0 | 0.0 | 63.3 | 24.4 |
| Shivering | 2.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 | 0.6 | 0.0 | 2.0 | 0.9 |
| Panting | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Huddling | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| % Animals affected with lameness score 1 | 6.7 | 1.3 | 4.2 | 1.4 | 0.0 | 1.4 | 1.2 | 0.0 | 0.7 | 1.9 | 0.0 | 6.7 | 2.2 |
| % Animals affected with lameness score 2 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.7 | 0.3 |
| % Pigs with wounds scored 1 | 4.7 | 0.7 | 1.4 | 6.4 | 0.0 | 0.7 | 0.6 | 0.0 | 0.0 | 1.6 | 0.0 | 4.7 | 2.3 |
| % Pigs with wounds scored 2 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.7 | 0.2 |
| % Pigs with tail severely bitten | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 10.8 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 10.8 | 3.6 |
| Frequency of coughing per pig per 5 min | 1.5 | 0.0 | 0.0 | 1.3 | 1.3 | 1.2 | 0.7 | 0.8 | 0.7 | 0.8 | 0.0 | 1.5 | 0.6 |
| Frequency of sneezing per pig per 5 min | 1.8 | 0.0 | 1.8 | 0.6 | 1.0 | 2.2 | 1.4 | 1.1 | 1.3 | 1.2 | 0.0 | 2.2 | 0.7 |
| % Pigs with labored breathing | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 1.0 | 0.3 |
| % Pigs with thirsted snout | 0.0 | 0.0. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| % Pigs with rectal prolapse | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Aspect of manure in the pen | 2.0 | 0.0 | 2.0 | 1.0 | 0.0 | 0.0 | 2.0 | 0.0. | 1.0 | 0.9 | 0.0 | 2.0 | 0.9 |
| % Pigs with more than 10% abnormal skin | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 2.0 | 0.77 |
| % Pigs with hernia score 1 | 6.0 | 2.0 | 4.0 | 1.4 | 3.3 | 0.7 | 2.4 | 0.0 | 0.0 | 2.2 | 0.0 | 6.0 | 2.0 |
| % Pigs with hernia score 2 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.7 | 0.2 |
| % Pigs dead on the farm during the last 12 months | 0.5 | 1.0 | 0.5 | 1.0 | 1.0 | 6.0 | 1.0 | 1.0 | 1.0 | 1.4 | 0.5 | 6.0 | 1.7 |
| Castration | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 0.0 |
| Tail-docking | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 0.0 | 20 | 2.0. | 2.0 | 1.8 | 0.0 | 2.0 | 0.7 |
| % Sample points with social behavior out of sample points when pigs were active | 1.4 | 3.2 | 6.0 | 2.3 | 3.6 | 1.2 | 2.7 | 9.1 | 0.3 | 3.3 | 0.3 | 9.1 | 2.7 |
| % Sample points with negative social behavior out of sample points when pigs were active | 1.0 | 1.1 | 4.1 | 2.0 | 1.0 | 0.0 | 0.3 | 0.9 | 0.0 | 1.2 | 0.0 | 4.1 | 1.3 |
| % Sample points when exploration of pen features was observed out of sample points | 6.7 | 23.5 | 5.5 | 25.0 | 30.4 | 23.6 | 32.1 | 23.4 | 10.8 | 20.1 | 5.5 | 32.1 | 9.9 |
| % Sample points when exploration of enrichment material was observed out of sample point | 0.0 | 0.0 | 0.0 | 0.3 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| % Pens with panic score 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Tendency to be active | 4.9 | 7.0 | 7.1 | 9.6 | 9.4 | 4.6 | 7.8 | 6.9 | 7.2 | 7.2 | 4.6 | 9.6 | 1.7 |
| Tendency to be relaxed | 5.2 | 5.3 | 1.2 | 9.0 | 9.7 | 6.2 | 4.3 | 5.3 | 2.4 | 5.4 | 1.2 | 9.7 | 2.7 |
| Tendency to be fearful | 2.3 | 0.2 | 1.2 | 0.2 | 0.8 | 0.5 | 0.5 | 0.2 | 0.8 | 0.7 | 0.2 | 2.3 | 0.7 |
| Tendency to be agitated | 2.0 | 1.6 | 7.3 | 0.1 | 0.2 | 0.5 | 4.8 | 0.2 | 1.4 | 2.0 | 0.1 | 7.3 | 2.5 |
| Tendency to be calm | 5.6 | 4.3 | 0.9 | 7.6 | 9.6 | 7.0 | 1.7 | 4.3 | 2.9 | 4.9 | 0.9 | 9.6 | 2.9 |
| Tendency to be content | 2.4 | 4.3 | 1.2 | 7.8 | 10.1 | 3.1 | 5.5 | 7.0 | 3.4 | 5.0 | 1.2 | 10.1 | 2.9 |
| Tendency to be tense | 1.0 | 0.9 | 4.9 | 0.1 | 0.0 | 0.0 | 1.3 | 0.2 | 1.0 | 1.0 | 0.0 | 4.9 | 1.5 |
| Tendency to be enjoying | 0.5 | 4.6 | 0.7 | 8.7 | 10.1 | 2.6 | 4.0 | 6.5 | 1.4 | 4.3 | 0.5 | 10.1 | 3.5 |
| Tendency to be frustrated | 1.8 | 1.8 | 6.9 | 0.1 | 0.1 | 0.2 | 3.5 | 0.3 | 2.4 | 1.9 | 0.1 | 6.9 | 2.2 |
| Tendency to be bored | 5.2 | 2.8 | 2.3 | 0.0 | 0.3 | 6.2 | 0.9 | 3.3 | 4.9 | 2.9 | 0.0 | 6.2 | 2.2 |
| Tendency to be playful | 2.5 | 6.2 | 4.1 | 7.4 | 8.1 | 0.6 | 4.7 | 6.5 | 1.5 | 4.6 | 0.6 | 8.1 | 2.7 |
| Tendency to be positively occupied | 2.5 | 2.6 | 3.6 | 9.1 | 8.9 | 1.8 | 4.2 | 6.6 | 3.1 | 4.7 | 2.5 | 9.1 | 2.8 |
| Tendency to be listless | 8.9 | 2.2 | 2.1 | 0.5 | 0.1 | 8.8 | 0.8 | 0.2 | 1.1 | 2.7 | 0.1 | 8.9 | 3.5 |
| Tendency to be lively | 3.7 | 7.0 | 5.5 | 8.9 | 9.6 | 1.0 | 6.3 | 6.4 | 4.9 | 5.9 | 1.0 | 9.6 | 2.6 |
| Tendency to be indifferent | 1.8 | 4.3 | 2.5 | 0.2 | 0.1 | 1.7 | 1.3 | 0.5 | 0.9 | 1.5 | 0.1 | 4.3 | 1.3 |
| Tendency to be irritable | 1.9 | 2.1 | 8.7 | 0.1 | 0.0 | 0.8 | 1.7 | 0.7 | 0.8 | 1.9 | 0.1 | 8.7 | 2.7 |
| Tendency to be aimless | 1.0 | 0.8 | 2.8 | 0.3 | 0.2 | 3.3 | 1.6 | 0.4 | 1.0 | 1.3 | 0.2 | 3.3 | 1.1 |
| Tendency to be happy | 3.3 | 4.3 | 1.0 | 8.0 | 10.2 | 3.0 | 5.5 | 7.4 | 3.1 | 5.1 | 1.0 | 10.2 | 2.9 |
| Tendency to be distressed | 1.7 | 1.2 | 7.5 | 0.1 | 0.0 | 1.3 | 1.1 | 0.0 | 2.0 | 1.7 | 0.0 | 7.5 | 2.3 |
| Tendency to be sociable | 2.5 | 6.9 | 1.3 | 8.7 | 9.3 | 2.4 | 4.0 | 5.2 | 3.6 | 4.9 | 1.3 | 9.3 | 2.9 |

**Table 7.** Microclimate parameters and the concentration of particulate matters in 9 pig farms

| Item | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEM | 16.45 | 16.55 | 19.28 | 9.15 | 11.71 | 25.21 | 26.29 | 21.06 | 21.83 | 18.62 | 5.76 |
| RH | 100.00 | 48.26 | 92.02 | 75.30 | 39.61 | 67.80 | 73.63 | 81.93 | 98.60 | 75.24 | 21.04 |
| AS | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.02 | 0.02 | 0.04 | 0.02 | 0.021 | 0.03 |
| $PM_{10}$ | 1,249.47 | 207.87 | 214.03 | 297.80 | 825.82 | 1,216.65 | 192.33 | 1,397.25 | 665.88 | 696.34 | 496.20 |
| $PM_7$ | 1,112.83 | 118.50 | 209.40 | 173.25 | 384.63 | 599.72 | 101.72 | 515.82 | 467.58 | 409.27 | 320.43 |
| $PM_{2.5}$ | 209.22 | 42.75 | 105.53 | 36.75 | 34.83 | 45.65 | 39.18 | 103.73 | 233.02 | 94.52 | 77.11 |
| $PM_1$ | 16.72 | 28.68 | 49.08 | 19.75 | 10.23 | 9.20 | 24.72 | 66.45 | 94.22 | 35.45 | 28.90 |
| $TSP^5$ | 1,292.68 | 701.57 | 226.75 | 590.65 | 1,892.20 | 2307.00 | 444.58 | 3,997.17 | 1,020.77 | 1,385.93 | 1,193.52 |

TEM, temperature (℃); RH, relative humidity (%); AS, air speed (m/s); PM, particulate matters (μg/$m^3$); TSP, total suspended particulate matters (μg /$m^3$).

$m^3$) for $PM_7$, 34.83 to 233.02 μg/$m^3$ (mean ± SD = 94.52 ± 77.11 μg/$m^3$) for $PM_{2.5}$, 9.2 to 94.22 μg/$m^3$ (mean ± SD = 35.45 ± 28.9 μg/$m^3$) for $PM_1$ and 226.75 to 3,997.17 μg/$m^3$ (mean ± SD = 1,385.93 ± 1193.52 μg/$m^3$) for TSP across the nine pig farms, respectively. The concentrations of total airborne bacteria, airborne total coliform, and airborne total E. coli ranged from 3.33 to 4.36 CFU/$m^3$ (mean ± SD = 4.08 ± 0.29 CFU/$m^3$), 1.87 to 3.82 CFU/$m^3$ (mean ± SD = 2.89 ± 0.66 CFU/$m^3$), and 0 to 3.49 CFU/$m^3$ (mean ± SD = 2.28±1.05 CFU/$m^3$) across the nine pig farms, respectively (Table 8). The concentrations of hydrogen sulfide, ammonia, and carbon dioxide ranged from 0 to 1.23 ppm (mean ± SD = 0.41 ± 0.42 ppm), 3.69 to 68.17 ppm (mean ± SD = 30.05 ± 26.21 ppm), 955 to 5,583.75 ppm (mean ± SD = 2,945.09 ± 1,648.04 ppm) across the nine pig farms, respectively (Table 9).

## Correlations between animal- and environment-based parameters

The significant correlation between the results of indicators of the WQ® protocol and environment-based parameters is shown in Table 10. Coefficients with significance ($p < 0.05$) are presented in Table 10 and the original table with all the coefficients is presented in Table 11. Temperature had a negative correlation with 'abnormal skin' and relative humidity had a negative correlation with 'coughing'. Air speed in the pig house had negative effects ($p < 0.05$) on 'manure score 1', 'lameness score 1', 'hernia score 1', and negative emotional states namely 'listless', 'indifferent', and 'irritable'. PM did not have effect on any indicator of this protocol. Total airborne bacteria had a positive correlation with 'coughing' and negative correlations with negative emotional states- 'indifferent' and 'irritable' ($p < 0.05$). Airborne total coliform had a positive effect on 'sneezing' and airborne

**Table 8.** Concentration of airborne bacteria in 9 pig farms

| Bacteria | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TAB | 3.33 | 4.24 | 3.99 | 4.36 | 4.02 | 4.15 | 4.24 | 4.14 | 4.24 | 4.08 | 0.30 |
| TC | 2.84 | 3.56 | 1.87 | 2.69 | 3.39 | 3.34 | 1.92 | 3.82 | 2.55 | 2.89 | 0.70 |
| TE | 2.62 | 3.27 | 0.00 | 1.29 | 2.98 | 2.84 | 1.61 | 3.49 | 2.44 | 2.28 | 1.12 |

TAB, total airborne bacteria (CFU/$m^3$); TC, airborne total coliform (CFU/$m^3$); TE, airborne total *Escherichia coli* (CFU/$m^3$).

**Table 9.** Concentration (ppm) of hydrogen sulfide ($H_2S$), ammonia ($NH_3$), and carbon dioxide ($CO_2$) in 9 pig farms

| Gases | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2S$ | 1.23 | 0.00 | 0.75 | 0.27 | 0.16 | 0.74 | 0.45 | 0.00 | 0.13 | 0.41 | 0.42 |
| $NH_3$ | 41.67 | 9.60 | 57.60 | 11.83 | 3.69 | 59.07 | 11.30 | 7.50 | 68.17 | 30.05 | 26.21 |
| $CO_2$ | 1,400 | 2,686.24 | 5583.75 | 955.00 | 1,014.13 | 4,766.67 | 4,040.00 | 2,816.67 | 3,243.33 | 2,945.09 | 1,648.04 |


https://doi.org/10.5187/jast.2022.e23

**Table 10.** Correlation between the results of the indicators of the Welfare Quality® protocol and environmental-based parameters

| Indicators of the Welfare Quality® Protocol | TEM | RH | AS | TAB | AC | AE | $H_2S$ | NH3 | $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Manure score 1 | | | −0.681* | | | | | | |
| Manure score 2 | | | | | | 0.689* | | | |
| Lameness score1 | | | −0.781* | | | | 0.789* | | |
| Lameness score 2 | | | | | | | | | 0.725* |
| Coughing | | −0.692* | | 0.730* | | | | | |
| Sneezing | | | | | 0.683* | 0.700* | 0.778* | | |
| Abnormal skin | −0.730* | | | | | | | | |
| Hernia score 1 | | | −0.718* | | | | | | |
| Positive social behavior | | | | | | | | −0.717* | |
| Fearful | | | | | | | 0.687* | | |
| Calm | | | | | | | | | −0.728* |
| Content | | | | | | | | −0.733* | |
| Enjoying | | | | | | | | −0.750* | |
| Sociable | | | | | | | | −0.767* | −0.800** |
| Playful | | | | | | | | −0.867** | −0.667* |
| Listless | | | −0.766* | | | | | | |
| Lively | | | | | | | | −0.800** | |
| Indifferent | | | −0.843** | −0.746* | | | | | |
| Irritable | | | −0.795* | −0.698* | | | | | |
| Aimless | | | | | | | | 0.711* | 0.879** |
| Happy | | | | | | | | −0.817** | −0.783* |
| Distressed | | | | | | | | 0.845** | |

*$p < 0.05$ (2-tailed), **$p < 0.001$ (2-tailed).

TEM, temperature (℃); RH, relative humidity (%); AS, air speed (m/s); TAB, total airborne bacteria (CFU/$m^3$); AC, airborne total coliform (CFU/$m^3$); AE, airborne total *Escherichia coli* (CFU/$m^3$).

total *E. coli* had positive effects on 'manure score 2' and 'sneezing' ($p$ <0 .05). Results showed that the concentration of gases in the pig house had a significant influence on the emotional states of pigs. The concentration of ammonia had negative correlations with the positive emotional states: 'content', 'enjoying', 'sociable', 'playful', 'lively', and 'happy', and had positive correlations with the negative emotional states: 'aimless' and 'distressed' ($p < 0.05$). The concentration of carbon dioxide had negative correlations with the positive emotional states: 'calm', 'sociable', 'playful', and 'happy' and had a positive correlation with the negative emotional state: 'aimless' and the concentration of hydrogen sulfide had a positive correlation with the negative emotional state: 'fearful' ($p < 0.05$).

# DISCUSSION

## Animal-based parameters

### *Good feeding*

The percentage of lean pigs is the only parameter for the criterion 'absence of prolonged hunger' in the WQ® protocol, which often results in low assessment sensitivity for body condition when using the WQ® protocol. This is because pigs in intensive farming systems are generally fed *ad lithium* to grow quickly [20], which makes the prevalence of poor body condition very low. The results of this study (0.73%) were higher than that (0.4%) of Temple et al. [21], who conducted assessments on 91 growing pig farms from 2007 to 2009 in France and Spain, and that (0.2%) of Meyer-Hamme

**Table 11. Correlation between the results of the indicators of the Welfare Quality® protocol and environment-based parameters (full version)**

| Indicators | TEM | RH | AS | TAB | AC | AE | $H_2S$ | $NH_3$ | $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Bursae score 0 | 0.433 | 0.367 | 0.392 | 0.458 | −0.150 | 0.000 | −0.109 | 0.233 | −0.417 |
| Bursae score1 | −0.467 | −0.433 | −0.511 | −0.407 | 0.133 | −0.017 | 0.234 | −0.167 | 0.383 |
| Bursae score2 | −0.151 | 0.269 | 0.004 | −0.598 | −0.176 | −0.168 | −0.532 | −0.235 | 0.050 |
| Manure score 1 | 0.267 | 0.133 | −0.681* | −0.441 | −0.083 | 0.033 | 0.536 | 0.333 | 0.367 |
| Manure score 2 | 0.210 | −0.143 | −0.253 | −0.145 | 0.597 | 0.689* | 0.662 | 0.261 | 0.269 |
| Lameness score1 | −0.084 | −0.252 | −0.781* | −0.316 | 0.050 | 0.160 | 0.789* | 0.538 | 0.151 |
| Lameness score 2 | −0.518 | 0.000 | −0.423 | −0.632 | 0.207 | 0.207 | 0.520 | 0.518 | 0.725* |
| Woundsscored1 | 0.128 | −0.272 | −0.635 | −0.199 | −0.136 | −0.017 | 0.611 | 0.298 | −0.153 |
| Frequency of coughing | −0.127 | −0.692* | 0.190 | 0.730* | 0.329 | 0.262 | 0.318 | −0.127 | −0.633 |
| Frequency of sneezing | −0.350 | −0.417 | −0.315 | −0.186 | 0.683* | 0.700* | 0.778* | 0.617 | 0.633 |
| Aspect of manure | 0.321 | 0.009 | −0.355 | 0.018 | 0.125 | 0.232 | 0.680* | 0.410 | 0.232 |
| Abnormal skin | −0.730* | −0.365 | 0.082 | 0.279 | 0.068 | −0.160 | 0.069 | −0.183 | −0.068 |
| Hernia score 1 | −0.393 | −0.117 | −0.718* | 0.043 | 0.050 | −0.092 | 0.660 | −0.142 | −0.092 |
| Positive social Behavior | −0.183 | 0.417 | 0.043 | −0.322 | 0.150 | 0.000 | −0.276 | −0.717* | 0.000 |
| Negative social Behavior | 0.128 | −0.272 | −0.635 | −0.199 | −0.136 | −0.017 | 0.611 | 0.298 | −0.153 |
| Fearful | −0.479 | 0.026 | −0.371 | 0.209 | 0.256 | 0.180 | 0.687* | 0.410 | 0.231 |
| Calm | −0.276 | −0.527 | 0.188 | 0.579 | −0.084 | −0.201 | −0.059 | −0.326 | −0.728* |
| Content | 0.267 | −0.083 | 0.655 | 0.542 | −0.250 | −0.350 | −0.603 | −0.733* | −0.650 |
| Enjoying | 0.117 | −0.017 | 0.536 | 0.322 | −0.317 | −0.433 | −0.628 | −0.750* | −0.567 |
| Sociable | 0.233 | 0.017 | 0.451 | 0.525 | −0.450 | −0.550 | −0.644 | −0.767* | −0.800** |
| Playful | 0.133 | 0.167 | 0.332 | 0.322 | −0.283 | −0.417 | −0.460 | −0.867** | −0.667* |
| Listless | −0.217 | −0.250 | −0.766* | −0.424 | 0.117 | 0.217 | 0.527 | 0.617 | 0.350 |
| Lively | 0.167 | 0.283 | 0.315 | 0.288 | −0.500 | −0.617 | −0.561 | −0.800** | −0.633 |
| Indifferent | −0.183 | 0.133 | −0.843** | −0.746* | −0.017 | 0.050 | 0.301 | 0.350 | 0.500 |
| Irritable | −0.075 | 0.259 | −0.795* | −0.698* | 0.000 | 0.075 | 0.361 | 0.360 | 0.552 |
| Aimless | −0.159 | −0.151 | −0.487 | −0.596 | 0.326 | 0.418 | 0.580 | 0.711* | 0.879** |
| Happy | 0.250 | −0.167 | 0.519 | 0.610 | −0.150 | −0.267 | −0.469 | −0.817** | −0.783* |
| Distressed | −0.126 | 0.259 | −0.551 | −0.383 | −0.059 | 0.075 | 0.517 | 0.845** | 0.577 |

*$p < 0.05$ (2-tailed), **$p < 0.001$ (2-tailed).

TEM, temperature (˚C); RH, relative humidity (%); AS, air speed (m/s); TAB, total airborne bacteria count (CFU/$m^3$); AC, airborne total coliform (CFU/$m^3$); AE, airborne total *Escherichia coli* (CFU/$m^3$).

et al. [22], who conducted assessments on 60 fattening pig farms from 2013 to 2014 in Germany. Many farms scored low on the criterion 'absence of thirst' because of faulty water nipples. Reaseon could have been due to low illuminance in the pig house making it difficult for fault water nipples to be detected, the high stocking density of the pigs, and/or the high work intensity of the farmer. In the present study, there were less than two water nipples in the pen for four out of nine farms. This would have undermined the welfare of the pigs under the criterion 'absence of thirst', had one or more of the nipples not worked properly.

### *Good housing*

A bursa is a fluid filled sac that arises in the subcutaneous connective tissue due to the exudation of fluid from traumatized capillaries and lymphatic vessels after pressure over a bony prominence [23,24]. Moderate and severe bursitis are indicators of discomfort around resting; as such, this is an animal-based parameter for evaluating comfort around resting [21]. In the present study,

 https://doi.org/10.5187/jast.2022.e23

moderate bursitis was present at a prevalence of 22.14% (Table 6), which was the most prevalent animal-based indicator. This value is lower than that which Meyer-Hamme et al. [22] and Temple et al. [21] observed on conventional pig farms (35% and 43.5%, respectively). Bursitis is highly related to the pig's age [25], which could explain the higher results of Meyer-Hamme's study [22] on fattening pigs than that of our present study on growing pigs. As pigs spend about 80% of their time lying [26,27], the type of flooring in the pig house is very important for their welfare, especially in terms of comfort around resting. According to studies reporting on the positive effects of straw on pig welfare, bedding is said to improve the physical comfort of the hard floor [28,29]. In our study, 'Bursitis 0' (no evidence of bursa on the legs) was very high with sawdust flooring (farm 7 and 9) and 'Bursitis 1' (moderate bursitis: one or several small bursae on the same leg or one large bursa) higher with concrete slat flooring. According to Gillman et al. [29], solid concrete flooring is a risk factor of bursitis. Mouttotou et al. [24] also found that deep bedding was the most important factor for reducing bursitis. In addition, Lyons et al. [30] found that the prevalence of bursitis was four times higher with concrete and slatted floors than deep-straw floors.

The prevalence of moderately soiled bodies (20.35%) noted in the present study (Table 6) is similar to that reported by Temple et al. [20], who conducted assessments on 30 intensive growing pig farms in Spain (16.6%), and the report by Meyer et al. [22] in Germany (15.5%). In contrast, the prevalence of a severely soiled body (19.95%) in this study was much higher than the values of 3.7% and 6.2% reported by Temple et al. [20] and Meyer et al. [22], respectively. In conventional farming systems, multiple factors, including environmental factors [20,31], lead to soiled bodies. e.g., seasonal effects, cleanliness of the pen and the type of flooring [14]. Temple et al. [20] also found that moderately soiled body measurements appeared to be sensitive to differences between intensive farming systems. In this study, the relative humidity in the pig house was generally very high, which could dilute the manure on the floor, making it easy for pigs to get dirty. Two of the pig farms had sawdust floors in this study and in those farms with the all-in-all-out system, the sawdust was wet and dirty, leading to even higher dirtiness scores. Therefore, on farms with sawdust floors, a certain portion of sawdust should be regularly changed (e.g., once every two weeks), and on farms with slatted concrete floors, new bedding should be provided at regular intervals. Above all, to meet the criterion 'comfort around rest', stocking density should be kept lower than the current standard on conventional pig farms.

### *Good health*

The principle 'good health' was the second lowest scored principle after 'appropriate behaviors'; attributable mainly to the low score from the criterion 'absence of pain induced by management practice'. Tail docking was performed on eight farms (except farm 6) and additional castration was carried out on all farms. None of the farms used anesthetics or analgesics when performing tail docking and castration. Therefore, alleviating pain associated with tail docking and castration would significantly improve the scores for the principle 'good health'. Nonetheless, farm 6, even without tail docking, had the lowest score for the criterion 'absence of injuries'. Pigs tend to bite their penmates when stocking density is high and barren housing environments do not allow them to express their species-specific behaviors. Therefore, providing pigs with an environment conducive to positive behavior would be a prerequisite to manage tail biting. The prevalence of moderately wounded pigs in this study (1.6%) was much lower than the levels (10.5%) observed by Meyer et al. [22]. In general, 'wounds on the body' are more frequent as pigs get older. This could explain the relatively higher numbers reported in Meyer et al.'s study [22] which assessed fattening pigs that are older in age compared to the growing pigs in this study. Meyer et al. [22] also noted that farmers who manage the whole production cycle are specialized compared to farmers who only raise pigs during the fattening stage. All the farms in the present study were relatively small, with less than 5,000 pigs; small farms normally employ a limited number of employees to save labor costs, devoting relatively little time and effort to growing/fattening pigs compared to sows.

### *Appropriate behaviors*

Animal behavior is a sensitive indicator of environmental changes. Changes in behavior often represent the first level of response to an environment that stresses animals. Behavior is a clear indicator of poor welfare, especially when associated with physical pain. As such, it is the most commonly used parameter for assessing animal pain [32]. Modern intensive farming systems severely limit animals to perform their species-specific behaviors which was also demonstrated in this present study with the lowest score achieved for the principle 'appropriate behaviors'. Behavioral assessment is more subjective than the other three principles [33], but both psychological and physiological parameters are essential to evaluating farm animal welfare [34]. In the present study, 'appropriate behavior' scored the lowest among the four principles, with three out of nine farms (farm 1, 3, and 4) scoring below 'acceptable' (Table 5). The criteria 'expression of other behavior' and 'positive emotional state' had a determining effect on the overall score. Providing pigs in barren housing environments with enrichment in the form of straw, peat, or extra space can have a positive effect on pig behavior. However, this is difficult to realise in practice in the current conventional livestock industry because of production costs, incompatibility with slatted floors and liquid manure treatment systems, additional costs for straw and labor, and concerns about increased health risks [25].

The score for the 'expression of other behaviors' (mean score = 19) was much lower than that for the 'expression of social behavior' (mean score = 59.2 points; Table 5). This result is also reported by Petersen et al. [35] who obserbed that a decrease in exploratory behavior in intensive environments was associated with an increase in negative social behavior. In fact, behavior among penmates becomes more frequent when there is no spare space or object to explore. Pigs that fail to express their natural behavior of rooting substrate may use pen fixtures as an alternative [36]. Pen fixtures may serve as temporary targets for their nature behavior, but objects are not suitable for root-seeking and chewing [37]. Therefore, penmates are often targeted as an alternative to express a higher level of harmful social behavior in barren environments [35,38–40]. The pigs on all the farms (7 farms with slatted concrete floors and 2 farms with saw-dust floors; no addition or replacement of sawdust) evaluated in our study had nothing to play with that would encourage their natural behaviors and curiosities. According to Temple et al. [20], social behavior is also affected by the management status of the farm, as well as environmental factors. Because the growing phase is a stable period within the pig production cycle, farmers do not have to spend much time and effort caring for their pigs; in particular, as the number of growing pig houses increase, the stress between pigs increases because farmers do not pay attention to their growing pigs. According to Battini et al. [41], under a high workload, farmers are less likely to spend time attending to their animals and are unable to identify important animal signals. The provision of larger space is an important factor in providing comfort and enrichment to growing and fattening pigs [42]. However, producing fattening pigs in large groups has advantages for producers in terms of the efficient use of resources (e.g., space, pen divisions, feeders, and drinkers) and ease of management. Producers thus tend to raise pigs at larger scale (i.e., maintaining groups of more than 50 pigs in a pen) [43]. In the present study, as the pens got larger, more pigs were being raised in them (Table 1), leading to overcrowding that could result in aggression and competition [9]. Velarde and Geers [31] also noted that less space can hinder behavior, and lead to social stress and reduced physiological functioning. They also found that larger pens provide more space, but some negative effects can occur as group sizes increase. For example, as the size of the group increases, the pig's social unrest and aggression

 https://doi.org/10.5187/jast.2022.e23

increases, which can negatively affect their health. Baxter [44] suggested that, to maintain social stability, all the pigs in the group must be able to recognize all the other pigs, and we know that pigs can recognize 20 to 30 pigs [39]. This suggests that if the size of the group is larger than the number proposed by Baxter [44], there will be chronic aggression associated with permanent social instability. In the present study, 150, 40, 40, and 60 pigs were raised in a single pen on farms 2, 6, 8, and 9, respectively, which is greater than the number suggested by Baxter.

No panic response was observed on any of the farms in the present study. This may reflect a good relationship between the farmers and their pigs. Other factors also affect the HAR, such as genetics, growth stages, breeding materials, feeding system, stocking density, and group size [20,22,45,46]. In fact, the results may be biased by the fact that pigs in a small pen cannot as easily escape from the observer as those in a large pen. In addition, the animal's curiosity can also affect their responses to humans [47]. These factors can be pronounced under more intensive conditions.

QBA is an animal-based parameter whereby observers judge animal behavioral expressions by integrating signals with perceived behavioral details using qualitative descriptors (e.g., relaxed, fearful, and playful) that reflect the emotional state of the animal [18]. QBA allows scientific evidence to be applied to the expression of the animal's emotional states in specific behavioral expressions [48]. In terms of the criterion 'positive emotional state', six of the nine farms (66.7%) were 'not classified' (Fig. 3). Assessments of emotional states are highly dependent on the observers and subjective since it is difficult to evaluate the exact state of emotions in animals. While QBA is susceptible to the contextual bias of observers, Wemelsfelder et al. [49] notes that it does not undermine the basic reliability of the assessment. Wemelsfelder et al. [50] also observed that the behavioral expressions of pigs raised in an unenriched environment (with a small pen and bare concrete floor) differed from those raised in an enriched environment (half-filled with straw and containing objects like fresh branches, car tires, and metal chains).

### Correlation between animal- and environment-based parameters

The negative correlation between temperature and 'abnormal skin' is expected because it is well known that low temperature has significant negative effects on the health and well-being of animals. Four (farm 1, 2, 4, and 5) out of nine pig farms had lower room temperature than the recommended temperature of growing pigs, which is around 18℃ to 26.7℃ [51]. Under low temperature, pigs have poor feed conversion rates, and decreased immune response. Cargill and Byrt [52] showed that the incidence of scouring increased in neonatal pigs and the mortality rate increased, when the temperature in the pig house was lowered. Similarly, Le Dividich [53] found that lowering the temperature every day during the first week after weaning decreased the growth rate of piglets by 10% and significantly increased post-weaning diarrhea. Scheepens et al. [54] observed increases in diarrhea, coughing, sneezing, and hemorrhagic ear lesions in pigs exposed to low temperatures. 'Abnormal skin', which is skin inflammation or discoloration, may indicate a disease localized to the skin or a systemic disease. Skin condition is an unspecified measure that can be a symptom of a various health problems, and is affected by a variety of diseases, parasites, and disorders [55]. As the temperature remains below the low critical temperature in winter in the pig house, the stress on pig increases, and the animal's ability to respond to the health problems decreases [52,54,56]. Therefore, pigs with poor ability to respond to health problems are inevitably vulnerable to skin-related diseases.

In the present study, as the relative humidity increased, the frequency of coughing significantly increased ($p < 0.05$). The average humidity of the farms in this study was high at 75.5%, which was because the farmers were using water sprinklers in the pig house to prevent respiratory diseases during the dry winter environment. Even the relative humidity of farms 2 (93.4%), 3 (100%), and 9

(98%) was much higher than the recommended maximum relative humidity of 80% [51]. The most common cause of coughing is respiratory infection caused by a virus or bacteria [56]. In the growing pig houses where water sprinklers were used, higher humidity could have increased the amounts of microbes deposited on surfaces and increased the viability of viruses in droplets on surfaces. This could have encouraged contact transmission with pathogens that cause coughing such as influenza and respiratory syncytial virus [57].

In winter, there is little air flow in the growing pig houses, be it with a mechanical or a natural ventilation system. Nonetheless, our results indicate that air speed decreased 'manure score 1', 'lameness score 1', and 'hernia score 1', significantly (Table 10). The 'manure score 2' of growing pigs had positive correlation with the concentration of airborne total *E. coli* in the pig houses ($p < 0.05$). So far, there have been no studies on air quality parameters that affect 'manure score 1' and 'manure score 2' separately. However, Temple et al. [21] indicated that 'manure score 1' had a moderate positive correlation with 'manure score 2', but this correlation was not strong enough for these indicators to be analyzed independently. According to their study [21], 'manure score 2' was more sensitive to differences between production systems (intensive system vs extensive system) than 'manure score 1', and when studying the dirtiness of pigs between intensive farming systems [21], a 'manure score 1' could be distinguished better than a 'manure score 2'. Manure could be diluted in the growing pig houses with high relative humidity (average 75% in the present study), and the higher the air speed, the faster the manure on the floor and pig body dries. This could help reduce the prevalence of 'manure score 1'. Pigs prefer to separate their lying and dunging areas. However, stocking density in the intensive farming system is very high, forcing pigs to lie in their dunging area. In addition to its impact on pig welfare, since excrete can cause infection, pigs' dunging area should be separated from their lying area. This could be also explained by the positive correlation between severely soiled body and airborne total E. coli in this study ($p < 0.05$). The environment-based parameters affecting each of the 'manure score 1' and 'manure score 2' need further research.

'Lameness' is considered a reliable indicator of animal health if pigs are evaluated individually as they walk out into the passage. However, because such an evaluation was not possible under commercial conditions, pigs were only evaluated inside their pens. Moderate lameness therefore not considered in this WQ® protocol [21]. Therefore, 'lameness 1' means severe lameness minimum weight-bearing on the affected limb, and 'lameness 2' means no weight-bearing on the affected limb, or not able to walk. The evaluation of 'lameness' is an insensitive indicator because it is unlikely to be feasible. In addition, since hospital pens were not included in the sample for the WQ® protocol, the prevalence of 'lameness' may have been low in the present study. Mismanagement of hospital pens or insufficient availability of pens may increase the prevalence of 'lameness.' The type of the floor is a major factor influencing lameness and reducing the manure on the floor may help to reduce lameness of the growing pigs [58]. In this study, the prevalence of 'lameness 1' could have been lower because diluted manure, a cause of slippery floors, were reduced due to airflow. Also, as the concentration of $H_2S$ and $CO_2$ in the air increased, the direct cause could not be found for the increased prevalence of 'lameness.' However, the average prevalence of 'lameness 2' was very low at 0.15%, and the more manure on the floor, the higher the concentrations of $H_2S$ and $CO_2$, which can roughly explain this correlation. Further research is needed to elucidate the cause. In addition, air speed decreased negative emotional states; 'listless', 'indifferent', and 'irritable', significantly (Table 10). According to Vitali et al. [59], the QBA results were more positive for growing pigs in the houses equipped with a mechanical ventilation system with high ventilation performance, i.e., good indoor air velocity.

Many of the intensive pig houses are poorly managed due to the high cost and lack of expertise. In addition, open pig houses are also operated under unsanitary conditions and poor economic

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conditions [60]. As a result, airborne bacteria generated in pig buildings can adversely affect pig health, cause environmental problems such as odors, and spread infectious diseases [61]. In Korea, there have been studies to measure the concentration of airborne bacteria in the pig houses. A study conducted from 2008 to 2009 by Yao et al. [10] revealed that the concentration of total airborne bacteria count, airborne total coliform, and airborne total *E. coli* in the pig houses were 2.13–4.30, 2.08–2.43, and 1.36–3.04 CFU/$m^3$, respectively. Yao et al. [10] and Kim et al. [60] reported that similar concentrations of total airborne bacteria (4.04 and 4.13 CFU/$m^3$, respectively) were detected in the pig houses. The present study found that the concentration of airborne bacteria in growing pig house can negatively affect the pig health. The 'manure score 2' of growing pigs had as positive correlation with the concentration of *E-coli* in the pig houses ($p < 0.05$). Pigs prefer to separate their lying and dunging areas. However, when stocking density is high, as it is in the intensive farming system, pigs are forced to lie in their dunging area. This not only has an impact on pig welfare but also increases the risk of infections as could be observed by the positive correlation between severely soiled body and airborne total *E. coli* in this study. The frequency of sneezing was affected by airborne total coliform and airborne total *E. coli* ($p < 0.05$). This can be expected because suspended microbial pathogens can cause infectious and allergic diseases such as pneumonia, asthma, and rhinitis in pigs. Studies have shown that the concentrations of airborne bacteria in the pig houses are higher than those in industrial, residential, or outdoor environments [61,62]. The concentration of airborne bacteria can be minimized through the control of dust, humidity, and ventilation rates.

The present study found that the concentration of gases is significantly correlated with many of the terms to describe the emotional state of pigs (Table 10). The concentration of ammonia decreased the pigs' positive emotions of 'content', 'enjoying', 'sociable', 'playful', 'lively', and 'happy' and increased the negative emotions of 'aimless' and 'distressed'. According to Wathes et al. [63] the main air pollutants in pig houses are ammonia, carbon dioxide, particles in the air, and microorganisms. Ammonia is a highly irritating, colorless gas and accumulation in a pig house is an indicator of ventilation failure. As such, ammonia is used to evaluate the environment in pig houses because it can be easily analyzed on-site. Hayes et al. [64] noted that the concentrations of ammonia in growing pig house were 10.8 ± 0.06 ppm. Similarly, Kim et al. [65] found that the concentration of ammonia in growing pig house was 12.59 ± 1.83 ppm. Based on our current study, the mean ammonia concentrations were higher than the threshold limit value, ranging from 3.69 to 68.17 ppm [66]. Ammonia concentration > 20 ppm can affect the aggressiveness of pigs and are associated with stress [67]. Pigs actively avoid environments with airborne ammonia concentrations at 10 to 20 ppm, if given the freedom to choose [68–71]. Chronic exposure to ammonia at concentrations of 20 ppm during the rearing period can cause physiological problems in pigs, and can also act as a source of great stress, which can have a detrimental effect on positive behavioral experiences and potentially compromise their welfare [72]. In addition, chronic exposure to ammonia and dim light has been found to have detrimental effects on social behavior in pigs [67]. According to the National Pork Board US [73], the concentration of ammonia should not exceed 50 ppm. In our results, the average concentration of ammonia was 30.05 ppm (Table 9), but four out of the nine farms had ammonia concentrations greater than 40 ppm.

In addition, the concentration of carbon dioxide was negatively correlated with the pigs' positive emotions of 'calm', 'sociable', 'playful', and 'happy' and positively correlated with the negative emotion of 'aimless.' In pig houses, carbon dioxide is mainly generated via the respiration of animals, and a negligible amount as a byproduct of bacterial waste decomposition [74]. The mean concentration of carbon dioxide in Canadian pig farming buildings was 2,632 ppm [75], whereas the mean concentration of carbon dioxide in the present study was 2,945 ppm, ranging from 955 to 5,584 ppm. There have been studies on the concentration of carbon dioxide used to stun pigs in slaughterhouses, but there have been no studies on carbon dioxide and the emotional state of pigs so far. A high concentration of carbon dioxide proves that the pigs are intensively raised, and the ventilation is poor, which could result in negative behaviors and emotions in the pigs. The concentrations of ammonia and carbon dioxide in this study was high because the farmers did not provide ventilation in the pig houses. Duchaine et al. [76] compared the concentrations of ammonia and carbon dioxide in terms of seasonality, noting that winter concentrations were higher than summer concentrations.

To reduce civil complaints, the Ministry of Environment of the Korean government restricts the concentration of odors along the border of pig farms, with ammonia at 1.0 ppm and hydrogen sulfide at 0.02 ppm [77]. In the future, an animal welfare-oriented odor restriction system needs to be established as there are currently no such restrictions for the welfare of animals. To design a reasonable odor-regulating system, it will be very useful to have data on animals' behavioral response to the different concentrations of odor-producing gases, reflecting the emotional state of pigs. The criterion 'positive emotional state' can be improved if gas concentrations ($CO_2$, $NH_3$, $H_2$) are managed.

Korea has a continental, temperate climate with four distinct seasons and is affected by the East Asian monsoon. Winter temperatures are higher along the southern coast and considerably lower in the mountainous interior. Summer is hot and humid, with temperatures exceeding 30℃ throughout the country. Because of the climate difference between summer and winter in Korea, the welfare of pigs should be evaluated in both seasons. However, since farmer did not allow visits during the summer due to poor farm conditions and concerns over disease outbreaks, the first limitation of this study is that it was only conducted in the winter. Secondly, at the time of the study, it was very difficult to acquire permission to assess pig farms because of an on-going foot-and-mouth disease outbreak. Therefore, we were only able to assess nine pig farms. The nine farms involved in this study do not necessarily represent the situation across all regions of Korea, but this study still provides useful insight into the welfare on pig farms in Korea and can serve as a foundation for future studies to improve farm animal welfare. The farms assessed in this study constitute the first pig farms to participate in an independently observed, animal-based welfare assessment study in Korea.

## CONCLUSION

None of the farms in this study were classified as 'excellent' or 'not classified' in Korea. The lowest scores among the 12 criteria in this study were related to 1) the criterion 'absence of pain induced by management procedures', and 2) the criteria 'positive emotional state' and 'expression of other behaviors'. To improve the criterion 'absence of pain induced by management procedures', legal restrictions on routine tail docking or the use of anesthetics during tail docking and castration are required. In addition, the score for the criterion 'absence of injuries' could be low even when tail docking is performed. Thus, environmental improvements such as decreasing the stocking density or providing enrichment are essential. Lastly, the criteria 'positive emotional state' and 'expression of other behaviors' can be improved by controlling air quality (concentration of $CO_2$, $NH_3$, $H_2$).

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