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Plumage cleanliness, foot health, and growth performance of Co ducks provided with different tray-based water-contact areas under semi-dry housing

Nguyen Thi My Phuong, Phan Nhan *

Faculty of Applied Biology, Tay Do University, 68 Tran Chien Street, Thanh My Area, Cai Rang Ward, Can Tho, 900000, Vietnam

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* *Corresponding author:*
Phan Nhan
Email: pnhan@tdu.edu.vn

Reviewed by:

Sabri Arda Eratalar
Poultry Science Department, Faculty of Agriculture, Bolu Abant İzzet Baysal University, Bolu, 14100, Turkey
Achikule A. Yensuk
Department of Animal Production, College of Agriculture and Veterinary Sciences, University of Nairobi, Nairobi, Kenya
Consent to publish the name of third reviewer could not be obtained

Abstract

Open water access promotes natural water-related behaviors of ducks but too much water exposure may lead to higher litter wetness and hygiene problems in semi-dry housing systems. The present study was conducted to evaluate the effects of graded water-contact areas in trays on water use behavior, floor condition, plumage cleanliness, foot health, and growth performance of Co ducks. The four treatments were defined as follows: T1 – drinking water only, with no tray-based water-contact area (0 cm^2/duck); T2 – drinking water plus a tray-based water-contact area of 25 cm^2/duck; T3 – drinking water plus a tray-based water-contact area of 50 cm^2/duck; and T4 – drinking water plus a tray-based water-contact area of 100 cm^2/duck. Water-use behavior increased with increasing tray-based water-contact area, from 13.1% in T2 to 36.9% in T4. However, floor moisture near the water area also increased from 28.4% in T1 to 53.8% in T4, and coliform counts rose from 4.18 to 5.61 $\log_{10}$ CFU/g. Ducks provided with water-contact area of 50 cm^2/duck had the lowest abdominal plumage dirtiness score (0.83), the highest body weight at 56 days (1,552.8 g/duck), and the lowest feed conversion ratio (2.84). In contrast, the 100 cm^2/duck treatment was associated with greater abdominal feather wetness (score 1.57), footpad dermatitis (score 1.31), and impaired walking (36.1%). Among the tested treatments, a tray-based water-contact area of 50 cm^2/duck showed the most favourable overall combination of water-use behavior, litter hygiene, plumage cleanliness, foot health, and growth performance under the semi-dry housing conditions evaluated.

1. Introduction

Water is an important resource in duck production because ducks are highly motivated to perform water-related behaviors such as bill dipping, head washing, preening and partial bathing. Domestic ducks use water for wet preening, head cleaning and other body-maintenance activities, but the quantity and form of water needed to meet these behavioral needs without compromising commercial management is unknown (Babington and Campbell 2022). Bathing water, litter, flooring, ventilation and space allowance have been identified as important areas of research for developing evidence-based welfare standards in duck production (Makagon and Riber 2021). These activities are not only related to the normal expression of behavior but also for maintenance of feathers, removal of dirt from the beak and nostrils, and general hygiene of the body. In recent welfare assessments of ducks, geese and quail, access to water to allow ducks to satisfy their biological needs has been considered together with floor quality, space allowance, group size and enrichment (EFSA AHAW Panel 2023). However, open water provision is often difficult in commercial and smallholder duck systems as water spillage can increase litter moisture, promote floor contamination and create adverse conditions for foot health.

The use of semi-dry housing systems is increasing as a practical compromise between the extremes of fully dry-floor rearing and wet or pond-based systems. Duck production systems have highlighted the necessity of balancing water access with housing design, flooring and management, as they are interdependent rather than independent (Rodenburg et al. 2005). Ducks are provided with drinking water and sometimes a limited space for water contact. The resting and feeding areas are maintained as dry as possible. Knierim et al. (2004) observed that in many indoor duck systems open water is limited for hygienic, technical, labor and economic reasons, but they also noted that potential negative effects on duck health should be evaluated before definitive conclusions are drawn. This is especially relevant to Co ducks, a local duck type raised under different smallholder and semi-intensive conditions in the Mekong Delta. However, the appropriate water-contact area for Co ducks under semi-dry housing has not been well established. Showers and troughs may be practical alternatives to full pond access, as they have been reported to provide welfare benefits comparable to ponds in Pekin ducks (Jones et al. 2009). In the present study, water-contact area specifically referred to the surface area of shallow water trays placed on a drained section of each pen. This tray-based provision should not be considered equivalent to open-water access in general because water systems can also differ in depth, shape, perimeter, accessibility, water volume, drainage, and splash potential. Insufficient water-contact area may result in limited natural cleaning and preening behavior, leading to dirty plumage and poor beak or nostril hygiene. In contrast, excessive tray-based water contact may increase floor moisture, litter soiling, and bacterial contamination. Wet litter can soften the footpad surface, weaken the skin barrier and increase the risk of footpad dermatitis, interdigital lesions, and impaired walking. Footpad dermatitis is well known as an important poultry welfare problem and litter moisture is one of the main predisposing factors for the development of footpad lesions (Shepherd and Fairchild 2010). Open water over a well-constructed drainage area also improved feather hygiene and body weight and reduced dirty or blocked nostrils in Pekin ducks (O'Driscoll and Broom 2011). The adverse conditions may further decrease movement, feeding activity, and growth efficiency. Behavioral responses to open water in ducks involve water-related activities associated with preening, head dipping and body maintenance, rather than drinking alone (O'Driscoll and Broom 2012). Therefore, the effects of water-contact area should be assessed not only by behavior but also by the consequences for floor condition, plumage cleanliness, foot health and productive performance.

The present study was conducted to evaluate the effects of graded tray-based water-contact areas on floor condition, water-use behavior, abdominal plumage cleanliness, head hygiene, foot health, walking ability, and growth performance in Co ducks raised under semi-dry housing. The study also examined associations among floor moisture, plumage dirtiness, footpad dermatitis, gait score, and growth performance to characterize how environmental, welfare-related, and productive variables were related under the experimental conditions. We hypothesized that an intermediate tray-based water-contact area would provide a more favourable balance between opportunities for water-related behavior and litter hygiene than either no tray-based water contact or the largest tray area evaluated.

2. Materials and Methods

2.1 Study Animals

The animal trial was conducted in Dong Phuoc commune, Can Tho City, Vietnam, for 56 days between December 2024 and February 2025. Laboratory analyses of floor and microbiological samples were completed in March 2025. A total of 480 one-day-old Co ducklings were selected for the experiment after clinical screening for normal health and activity. Six replicate pens (20 birds per pen) were randomly assigned to each of four treatments with different water-contact areas. During the experimental period, all ducks were housed in a semi-dry system and received the same diet, drinking water, lighting schedule, and general husbandry practices.

2.2 Ethical Approval

Formal ethical approval was not required for this study because the experimental procedures were limited to routine husbandry management, body-weight recording, visual welfare assessment, and environmental sampling. No invasive procedures, disease challenge, surgical intervention, blood collection, or euthanasia were performed. Plumage cleanliness, beak and nostril cleanliness, footpad condition, interdigital lesions, and gait were evaluated by visual observation and gentle handling only. Samples for moisture, pH, and coliform analyses were collected from the housing environment without causing any stress or disturbance to the ducks. All animal care, handling and management practices were carried out according to the Law on Animal Husbandry No. 32/2018/QH14 issued by the National Assembly of the Socialist Republic of Vietnam. Animal welfare was monitored throughout the experimental period, and any duck showing signs of severe illness or distress was removed from the study and treated appropriately. Because the study involved only routine husbandry procedures, non-invasive visual assessments, body-weight recording, and environmental sampling, no institutional animal ethics approval number was issued for this study.

2.3 Feed and Feeding

All ducks were fed commercial pelleted compound diets according to age. From 1 to 28 days of age, the ducks received a starter diet containing 20.0% crude protein and 2,900 kcal/kg metabolizable energy. The main ingredients included fish meal, meat meal, broken rice, rice bran, maize, soybean meal, and other minor ingredients. The calcium and phosphorus contents of the starter diet were 0.9–1.2% and 0.5–1.0%, respectively. From 29 to 56 days of age, the ducks were fed a grower diet containing 17.5% crude protein and 3,000 kcal/kg metabolizable energy. The main ingredients were fish meal, animal protein, broken rice, rice bran, corn, soybean meal and some minor ingredients. The calcium and phosphorus contents of the grower diet were 0.8–1.2% and 0.5–1.0%, respectively. The feed was provided as pellets *ad libitum* twice a day, in the morning and afternoon. Clean drinking water was available in all pens all times. To ensure any differences in plumage cleanliness, foot health and growth performance were attributable to the assigned water contact area and not diet differences, all treatment groups received the same feeding program throughout the experiment. Feed offered and refusals were recorded weekly for each pen and used to calculate feed intake and feed conversion ratio.

2.4 Experimental design

In a 56-day experiment, a completely randomized design was used to evaluate the effects of graded tray-based water-contact area on the abdominal plumage cleanliness, foot health, and growth performance of Co ducks raised under semi-dry housing conditions. A total of 480 one-day-old Co ducklings were randomly allocated to four treatments, with each treatment consisting of six replicate pens of 20 ducks each, resulting in a total of 120 ducks per treatment. Each pen had an area of 2.0 × 2.0 m (4.0 m²) and a stocking density of 5 ducks/m². The four treatments were defined as follows: T1 – drinking water only, with no tray-based water-contact area (0 cm²/duck); T2 – drinking water plus a tray-based water-contact area of 25 cm²/duck; T3 – drinking water plus a tray-based water-contact area of 50 cm²/duck; and T4 – drinking water plus a tray-based water-contact area of 100 cm²/duck. Water trays measured 25 × 20 cm, 50 × 20 cm, and 100 × 20 cm in T2, T3, and T4, respectively, corresponding to total water-surface areas of 500, 1,000, and 2,000 cm² per pen, equivalent to 25, 50, and 100 cm²/duck, respectively. Water depth was maintained at approximately 5 cm in all tray treatments throughout the experiment. The three non-zero treatments were arranged as a simple two-fold progression in tray-based water-contact area, from 25 to 50 and 100 cm²/duck, while 0 cm²/duck served as the drinking-water-only control. These levels were selected to provide clearly separated low, intermediate, and high tray-based water-contact conditions within a four-treatment design with six

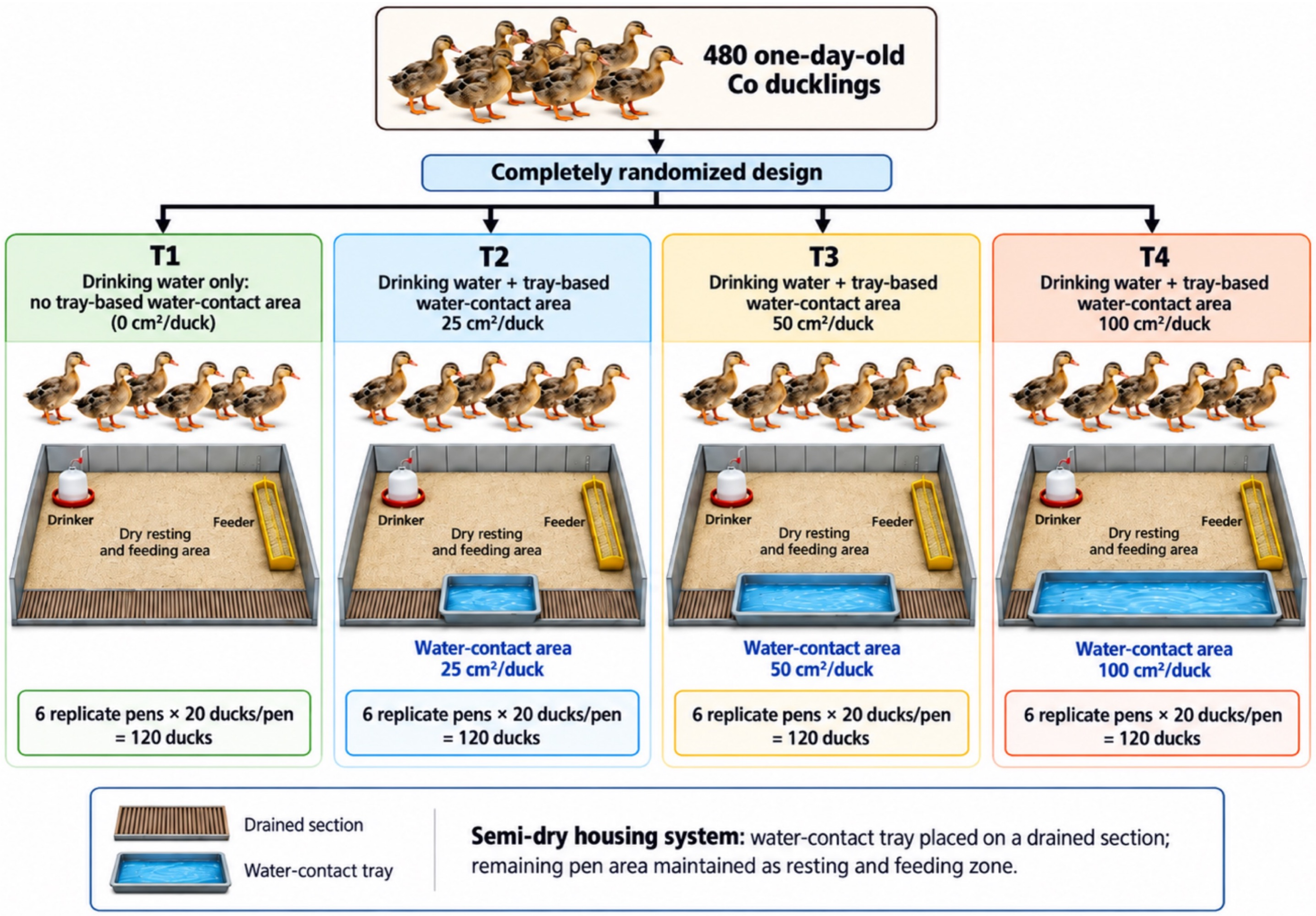

Fig. 1. *Experimental layout of tray-based water-contact area treatments in Co ducks raised under semi-dry housing*

replicate pens per treatment, rather than to estimate a fine-scale dose-response optimum. As illustrated in Fig. 1, the water-contact area in each treatment was provided through shallow water trays positioned on a drained section of the pen, while the remaining area was maintained as a semi-dry resting and feeding zone. Because tray dimensions increased across treatments, associated physical characteristics such as tray perimeter, total water volume, and simultaneous accessibility could also vary. Accordingly, the treatments were interpreted as graded tray-based water-provision conditions rather than as an isolated manipulation of water-surface area alone.

All pens were managed under the same semi-dry housing system. Feed, drinking water, lighting schedule, stocking density, litter management and general husbandry practices were the same for all treatments throughout the experiment. The experimental unit for all treatment comparisons was the pen. Individual duck measurements including body weight, abdominal plumage cleanliness, beak and nostril cleanliness, footpad dermatitis, interdigital lesions and gait score were considered as observational data and summarized at the pen level for treatment-level analysis. Data were collected throughout the experimental period according to the study objectives. Floor condition and water-use behavior were assessed periodically, while body weight was recorded at 1, 28, and 56 days of age. Plumage cleanliness and foot health indicators were evaluated repeatedly during the rearing period by direct visual scoring.

2.5 Water-tray management

Water trays were shallow and designed to allow standing in the water, bill dipping, head dipping and water-related grooming rather than swimming. All treatment pens received water from the same source as the routine drinking water. The water in the trays was static rather than flowing continuously. It was replenished during the morning and afternoon husbandry rounds, and the trays were rinsed before refilling. Water depth was kept at approximately 5 cm. At this depth, the nominal water volumes were approximately 2.5, 5.0 and 10.0 L/tray for the T2, T3 and T4, respectively. Ducks could stand in the trays with their feet in water and their bill and head submerged, but the trays were not built for swimming. Water spilled during use was allowed to drain through the designated drained section and was not returned to the trays. Visible fecal material and debris were removed during each tray-rinsing procedure before fresh water was added. Water temperature was not recorded.

2.6 Measurements

2.6.1 Effects of water-contact area on floor condition and water-use behavior

2.6.1.1 Ducks using water area (%)

This variable was recorded by direct observation at the pen level. Behavioral observations were conducted on days 14, 28, 42, and 56 of the experiment during three daily observation periods representing morning, midday, and late-afternoon activity. Each pen was observed for 10 min within each of the following time windows: 07:00–09:00, 12:00–14:00, and 16:00–18:00, providing a total of 30 min of observation per pen on each observation day. Observations were continuous during each 10-min observation period. Two trained observers conducted the observations, with pens distributed equally between observers; pen allocation and observation order were alternated among observation days to minimize systematic observer and time-of-day effects. Ducks were individually identified by numbered leg bands during behavioral observations. Ducks were considered to use the water area when they stood in the water tray, dipped the bill or head into the tray, or performed water-related grooming behavior. The percentage of ducks using the water area was calculated from the number of individually identified ducks that engaged in at least one of these activities during the observation periods relative to the number of ducks present in the pen.

2.6.1.2 Estimated water-contact time (min/duck/day)

Water-contact time was estimated from the same observation periods. The cumulative duration of water contact was recorded for each identified duck and summed across the three observation periods. The observed contact time per duck during the 30-min daily sampling period was converted to an estimated 12-h daytime value by multiplying the observed proportion of time in water contact by 720 min. Values obtained on the four observation days were averaged within each pen before statistical analysis. Before formal data collection, both observers were trained using the same behavioral definitions and jointly evaluated practice observations to standardize classification and timing procedures. For T1, these variables were not recorded because no tray-based water-contact area was provided.

2.6.1.3 Floor moisture (%) near water area and in resting area

Floor moisture was determined from litter collected in predefined locations within each pen. Sampling was conducted on days 14, 28, 42, and 56 between 07:00 and 08:00, before the morning water-tray replacement and before any routine disturbance of the litter. For the area surrounding the water tray, three subsamples were collected from the upper 0–3 cm of litter at approximately 20 cm from the tray edge and combined in equal proportions to form one composite sample per pen. In T1, subsamples were collected from the corresponding predefined front-pen locations. For the resting area, three subsamples were collected from the upper 0–3 cm at predefined points at least 50 cm from the water-contact zone and were similarly pooled. The litter was not mixed before sampling. Fresh composite samples were weighed, dried at 105 °C until constant weight, and reweighed. The four sampling-date values were averaged within each pen before treatment-level analysis.

2.6.1.4 Floor pH near water area

Floor pH was measured from litter samples collected near the water area. Fresh litter (10 g) was mixed with 90 mL distilled water, shaken well, allowed to stand, and then measured with a calibrated pH Hanna HI5222-02 meter.

2.6.1.5 Wetness/soiling score of floor (0–3)

The wetness and soiling of the floor were visually scored at pen level on a scale of 0–3: 0 = dry and friable floor; 1 = slightly moist floor; 2 = clearly moist or partly caked floor; and 3 = wet, heavily caked, or visibly soiled floor.

2.6.1.6 Coliforms near water area (log10 CFU/g)

Coliform counts were determined from fresh litter samples collected near the water-contact area. Ten grams of litter were aseptically transferred into 90 mL of sterile physiological saline and homogenized thoroughly for approximately 2 min to obtain the initial 10^{-1} suspension. Ten-fold serial dilutions were then prepared up to 10^{-5} using sterile physiological saline. MacConkey Agar without crystal violet and NaCl and containing 0.5% sodium taurocholate (M082, HiMedia Laboratories Pvt. Ltd., India) was prepared according to the manufacturer's instructions by suspending 55 g of dehydrated medium in 1 L of distilled water, heating to dissolve, autoclaving at 121 °C for 15 min, cooling to approximately 45–50°C, and pouring into sterile Petri dishes. From the 10^{-1}, 10^{-2}, and 10^{-3} dilutions, 0.1 mL was surface-plated onto duplicate agar plates using a sterile spreader. Plates were incubated aerobically at 37 °C for 24 h. Plates containing 30–300 colonies were preferentially used for enumeration. Typical lactose-fermenting colonies showing pink to red coloration, with or without surrounding bile precipitation, were counted as presumptive coliform colonies. The mean colony count from duplicate plates at the selected dilution was used to calculate colony-forming units per gram of fresh litter (CFU/g), and the results were expressed as log10 CFU/g. The analytical detection limit of the procedure was 100 CFU/g, equivalent to 2.00 log10 CFU/g.

2.6.2 Effects of water-contact area on abdominal plumage cleanliness and foot health

2.6.2.1 Welfare assessment procedure

Plumage cleanliness, abdominal feather wetness/matting, beak and nostril cleanliness, footpad dermatitis, interdigital lesions, and gait were assessed on days 28, 42, and 56. Ten ducks were randomly selected from each pen at each assessment, resulting in 60 ducks per treatment at each time point. All assessments were performed by the same trained observer using the predefined scoring criteria described below and a standardized scoring sheet throughout the experiment. Complete blinding to treatment was not possible because the water-tray treatments were visually apparent during bird handling; however, the use of a single trained observer and fixed scoring definitions was maintained to minimize observer-related variation. Because all formal welfare scoring was performed by one observer, inter-observer reliability analysis was not applicable. Scores and percentages were first calculated at the pen level for each assessment date and were subsequently averaged across the three assessment dates to obtain one pen-level value for treatment-level analysis.

2.6.2.2 Abdominal plumage dirtiness score (0–3)

The dirtiness of the abdominal plumage was scored by gently handling the selected ducks and by visual inspection of the abdominal feather area from the lower breast to the vent region. A 0-3 scale was used, where 0 = clean and dry, 1 = slightly dirty, 2 = moderately dirty and 3 = heavily dirty or matted.

2.6.2.3 Ducks with dirty abdominal plumage score ≥2 (%)

The percentage of ducks with dirty abdominal plumage was calculated as the number of ducks with abdominal plumage dirtiness score ≥2 divided by the total number of ducks assessed in the pen and multiplied by 100.

2.6.2.4 Abdominal feather wetness/matting score (0–3)

Abdominal feather wetness and matting were assessed visually using a 0–3 scale. The scoring system was as follows: 0 = dry and normally separated feathers; 1 = slight wetness or minor feather adhesion; 2 = moderate wetness or visible matting; 3 = severe wetness with extensive feather matting.

2.6.2.5 Beak and nostril cleanliness score (0–2)

Beak and nostril cleanliness was assessed by visual inspection using a 0–2 scale: 0 = clean beak and nostrils; 1 = slight dirt or material around the beak or nostrils; 2 = an obvious dirt, crusting, or material around the nostril area.

2.6.2.6 Ducks with dirty beak/nostril (%)

The percentage of ducks with dirty beak or nostrils was calculated as the number of ducks with beak and nostril cleanliness score ≥1 divided by the total number of ducks assessed in the pen and multiplied by 100.

2.6.2.7 Footpad dermatitis score (0–4)

Footpad dermatitis was assessed by examining the plantar surface of both feet of each selected duck. The more severely affected foot was used for scoring. A 0–4 scale was used: 0 = normal footpad; 1 = slight discoloration or thickening; 2 = mild lesion; 3 = clear lesion or moderate inflammation; and 4 = severe ulceration, swelling, or lesion affecting walking ability.

2.6.2.8 Ducks with footpad score ≥2 (%)

The percentage of ducks with footpad dermatitis was calculated by dividing the number of ducks with a footpad dermatitis score ≥2 by the total number of ducks scored in the pen, multiplied by 100.

2.6.2.9 Interdigital lesion score (0–2)

Interdigital lesions were assessed by visual examination of the skin between the toes. A 0-2 scale was used, where 0 = no lesion, 1 = mild redness or swelling, and 2 = an obvious lesion, swelling, or inflammation.

2.6.2.10 Gait score (0–3)

The gait score was measured by letting each selected duck walk on a flat surface for a short distance. Walking ability was scored on a scale from 0 to 3: 0 = normal walking; 1 = slightly uneven or slow walking; 2 = moderate lameness or difficulty walking; 3 = severe walking impairment or reluctance to move.

2.6.2.11 Ducks with impaired walking (%)

The percentage of ducks with impaired walking was calculated as the number of ducks with gait score ≥1 divided by the total number of ducks assessed in the pen and multiplied by 100.

2.6.3 Growth performance and associations among floor moisture, plumage cleanliness, foot health, and growth

2.6.3.1 Body weight, body-weight gain, and ADG

Body weight was individually recorded at 1 day of age using an electronic scale (Vibra Haw Japan, 30 kg capacity, 1 g readability). The same weighing procedure was repeated at 28 and 56 days of age. Individual body weights were averaged within each pen at each weighing age to obtain pen-level body-weight values. Body-weight gain from 1 to 56 days was calculated as the difference between the final and initial pen mean body weights. Average daily gain was calculated by dividing body-weight gain by the 56-day experimental period.

2.6.3.2 Feed intake (g/duck/day)

Feed intake was recorded at the pen level. Feed offered and feed refusals were weighed weekly for each pen. Average feed intake was calculated as total feed consumed divided by the number of duck-days and expressed as g/duck/day.

2.6.3.3 FCR from 1–56 days

Feed conversion ratio (FCR) was calculated at the pen level as follows:

$$\text{FCR} = \text{Total feed intake} \;/\; \text{Total body weight gain}$$

2.6.3.4 Mortality and culling rate (%)

Mortality and culling were recorded daily for each pen. The mortality and culling rate was calculated as:

$$\text{Mortality and culling rate (\%)} = [(\text{No. of dead ducks} + \text{No. of culled ducks}) \;/\; \text{Initial No. of ducks in the pen}] \times 100$$

2.7 Statistical Analysis

Data were analyzed using Minitab 16.0 software. The pen was considered the experimental unit for all treatment comparisons. For environmental, behavioral, plumage, and foot-health variables measured on more than one scheduled assessment date, observations were first summarized within each pen at each date and then averaged across assessment dates to obtain one overall pen-level value for the primary treatment comparison. Normality and homogeneity of variance of pen-level data were assessed using the Shapiro–Wilk and Levene's tests, respectively. Data satisfying these assumptions were analyzed by one-way analysis of variance, followed by Tukey's multiple-comparison test when the treatment effect was significant. Proportional outcomes expressed as percentages were arcsine square-root transformed before analysis, whereas untransformed percentages were used for presentation. Continuous variables expressed as percentages, including floor moisture, were analyzed on their original scale. Body weight measured at 1, 28, and 56 days of age was analyzed using a repeated-measures mixed model with treatment, age, and treatment × age interaction as fixed effects and pen nested within treatment as the experimental subject. Treatment comparisons within each age were adjusted using Tukey's procedure. Body-weight gain, ADG, feed intake, FCR, and mortality and culling rate were analyzed as pen-level 1–56-day outcomes using one-way analysis of variance.

Ordinal score data were summarized at the pen level. When the assumptions for parametric analysis were not satisfied, the Kruskal–Wallis test followed by adjusted pairwise comparisons was used. Associations among floor moisture, coliform counts, plumage dirtiness, footpad dermatitis, gait score, ADG, and FCR were evaluated using Spearman's rank correlation based on one summary value from each of the 24 experimental pens; repeated observations within a pen were not treated as independent observations in the correlation analysis. For treatment comparisons, results are presented as treatment means with the pooled standard error of the mean (SEM), based on six replicate pens per treatment. Statistical significance was declared at $P < 0.05$.

3. Results

3.1 Effects of water-contact area on floor condition and water-use behavior

Table 1 presents the effects of tray-based water-contact area on water-use behavior and floor condition. The percentage of ducks using the water area gradually increased from 13.1% in T2 to 24.6% in T3 and

Table 1. Floor condition and water-use behavior of Co ducks raised under semi-dry housing

Parameter	T1 (0 cm²/duck)	T2 (25 cm²/duck)	T3 (50 cm²/duck)	T4 (100 cm²/duck)	SEM	p-value
Ducks using water area (%)	—	13.10^{c}	24.60^{b}	36.90^{a}	1.25	< 0.001
Estimated water-contact time (min/duck/day)	—	7.80^{c}	15.60^{b}	27.90^{a}	1.02	< 0.001
Floor moisture near water area (%)	28.40^{d}	34.90^{c}	41.60^{b}	53.80^{a}	1.11	< 0.001
Floor moisture in resting area (%)	25.70^{c}	28.50^{bc}	31.40^{b}	38.60^{a}	0.99	< 0.001
Floor pH near water area	7.16^{c}	7.32^{bc}	7.49^{b}	7.84^{a}	0.06	< 0.001
Wetness/soiling score of floor (0–3)	0.46^{d}	0.83^{c}	1.29^{b}	2.12^{a}	0.05	< 0.001
Coliforms near water area ($\log_{10}$ CFU/g)	4.18^{c}	4.52^{c}	4.96^{b}	5.61^{a}	0.09	< 0.001

Values are treatment means with pooled standard error of the mean (SEM). For water-use variables, T1 was not included because no tray-based water-contact area was provided. The proportion of ducks using the water area was arcsine square-root transformed before analysis, whereas untransformed means are presented. Environmental and behavioral outcomes were summarized at the pen level; variables assessed repeatedly were averaged across scheduled assessment dates. Means with different superscript letters within the same row differ significantly (P < 0.05). The pen was the experimental unit (n = 6 pens per treatment)

36.9% in T4, and the differences in all three tray treatments were significant (P < 0.001). Estimated water-contact time followed the same trend, increasing from 7.8 min/duck/day in T2 to 15.6 min/duck/day in T3 and 27.9 min/duck/day in T4 (P < 0.001).

Floor condition variables also differed significantly among treatments, as shown in Table 1. Moisture near the water area increased progressively from 28.4% in T1 to 53.8% in T4, and the wetness/soiling score increased from 0.46 to 2.12, with all four treatments differing significantly from one another (P < 0.001). Resting-area moisture and floor pH were highest in T4 and lowest in T1; T2 was intermediate and did not differ significantly from either T1 or T3, whereas T3 differed from T1. Coliform counts were comparable between T1 and T2 but were significantly higher in T3 and highest in T4 (P < 0.001).

3.2 Effects of water-contact area on abdominal plumage cleanliness and foot health

Abdominal plumage cleanliness and head-hygiene outcomes are presented in Table 2. T3 had the lowest abdominal plumage dirtiness score and the lowest proportion of ducks with a dirtiness score ≥2, whereas T1 had the highest values. T2 and T4 were intermediate and not significantly different from each other for either variable (P < 0.001). Abdominal feather wetness/matting was not significantly different between T1, T2 and T3 but was significantly higher in T4 (P < 0.001). Table 2 also showed significant treatment differences in beak and nostril cleanliness. T1 had the highest beak and nostrils cleanliness score and the highest proportion of ducks with dirty beaks or nostrils, followed by T2. The T3 and T4 treatments had similarly low scores and proportions of affected ducks, with no significant difference between the two treatments (P < 0.001).

Foot-health and locomotor outcomes are summarized in Table 3. Footpad dermatitis score and the proportion of ducks with footpad score ≥2 did not differ significantly among T1, T2, and T3, whereas both outcomes were significantly greater in T4 (P < 0.001). Thus, the three lower water-contact treatments remained statistically comparable for footpad condition.

A similar pattern was observed for interdigital lesion score, gait score, and the proportion of ducks with impaired walking in Table 3. T1, T2, and T3 did not differ significantly from one another, whereas T4 had significantly higher values for all three outcomes (P < 0.001).

3.3 Growth performance and associations among floor moisture, plumage cleanliness, foot health, and growth

Growth performance differed among treatments over time, as presented in Table 4. Initial body weight was similar across treatments (P = 0.899). The group with the highest body weight at 28 days was T3, and it was significantly different from T1 and T4, whereas T2 was intermediate and did not differ significantly from either groups (P = 0.006). The same treatment pattern was observed at 56 days, with T3 again showing the highest body weight, T1 and T4 showing lower values and T2 remaining intermediate (P = 0.002). The repeated-measures analysis also revealed significant overall treatment (P = 0.0006), age (P = 0.001), and treatment × age interaction (P = 0.0008) effects.

Body-weight gain and ADG during the 1–56-day period followed the same treatment pattern, with the highest values in T3, lower values

Table 2. Abdominal plumage cleanliness and head hygiene of Co ducks raised under semi-dry housing

Parameter	T1 (0 cm²/duck)	T2 (25 cm²/duck)	T3 (50 cm²/duck)	T4 (100 cm²/duck)	SEM	p-value
Abdominal plumage dirtiness score (0–3)	1.68^{a}	1.22^{b}	0.83^{c}	1.36^{b}	0.05	< 0.001
Ducks with dirty abdominal plumage score ≥2 (%)	44.40^{a}	27.80^{b}	13.90^{c}	32.80^{b}	1.62	< 0.001
Abdominal feather wetness/matting score (0–3)	0.91^{b}	0.86^{b}	0.74^{b}	1.57^{a}	0.06	< 0.001
Beak and nostril cleanliness score (0–2)	1.14^{a}	0.79^{b}	0.51^{c}	0.47^{c}	0.06	< 0.001
Ducks with dirty beak/nostril (score ≥1) (%)	72.2^{a}	52.8^{b}	30.6^{c}	27.8^{c}	2.12	< 0.001

Values are treatment means with pooled standard error of the mean (SEM), based on six replicate pens per treatment. Ten ducks per pen were assessed on days 28, 42, and 56; scores and percentages were first calculated at the pen-date level and then averaged across the three assessment dates. Percentage data were arcsine square-root transformed before analysis, whereas untransformed percentages are presented. Means with different superscript letters within the same row differ significantly (P < 0.05). The pen was the experimental unit

Table 3. Foot health and walking ability of Co ducks raised under semi-dry housing

Parameter	T1 (0 cm²/duck)	T2 (25 cm²/duck)	T3 (50 cm²/duck)	T4 (100 cm²/duck)	SEM	p-value
Footpad dermatitis score (0–4)	0.81^{b}	0.74^{b}	0.67^{b}	1.31^{a}	0.06	< 0.001
Ducks with footpad score ≥2 (%)	12.20^{b}	10.60^{b}	8.30^{b}	25.60^{a}	1.58	< 0.001
Interdigital lesion score (0–2)	0.33^{b}	0.28^{b}	0.24^{b}	0.61^{a}	0.05	< 0.001
Gait score (0–3)	0.45^{b}	0.38^{b}	0.33^{b}	0.74^{a}	0.05	< 0.001
Ducks with impaired walking (gait score ≥1) (%)	22.2^{b}	18.9^{b}	16.7^{b}	36.1^{a}	1.54	< 0.001

Values are treatment means with pooled standard error of the mean (SEM), based on six replicate pens per treatment. Ten ducks per pen were assessed on days 28, 42, and 56; scores and percentages were first calculated at the pen-date level and then averaged across the three assessment dates. Percentage data were arcsine square-root transformed before analysis, whereas untransformed percentages are presented. Means with different superscript letters within the same row differ significantly (P < 0.05). The pen was the experimental unit

in T1 and T4, and intermediate values in T2 (P = 0.002; Table 4). Feed intake did not differ significantly among treatments (P = 0.799). In contrast, FCR differed significantly (P = 0.005), with T3 having a lower value than T1 and T4, while T2 was intermediate and did not differ significantly from either group. Mortality and culling rates were not significantly different among treatments (P = 0.542). The relationships among environmental, welfare-related, and growth variables are summarized in Table 5. There was a positive correlation between footpad dermatitis score and floor moisture near the water area (r = 0.56, P = 0.005). Coliform counts were strongly positively correlated with footpad dermatitis (r = 0.63, P < 0.001). The correlation between floor moisture and dirtiness of abdominal plumage was not statistically significant (r = -0.35, P = 0.093).

Growth-related associations in Table 5 showed that ADG was negatively correlated with abdominal plumage dirtiness (r = -0.69, P < 0.001), footpad dermatitis score (r = -0.42, P = 0.039), and gait score (r = -0.44, P = 0.034). Footpad dermatitis score was also positively correlated with FCR (r = 0.54, P = 0.006). Among the significant relationships examined, the strongest correlation was observed between abdominal plumage dirtiness and ADG (r = -0.69).

4. Discussion

The behavioral response observed in the present study indicates that Co ducks readily used the water resource when tray-based water contact was available, and greater provision was accompanied by more frequent use and longer contact. This agrees with previous evidence that water resources can modify bathing behavior and behavioral synchrony in Pekin ducks (Waitt et al. 2009). Such a response is consistent with the strong motivation of ducks to perform water-related activities, including bill dipping, head washing, preening, and partial bathing. The physical characteristics of the water source are also relevant because water depth has been shown to influence pool choice and bathing behavior in commercial Pekin ducks (Liste et al. 2012a). However, the present treatments should be interpreted as graded tray-based water-provision conditions rather than as an isolated effect of water-surface area alone. Increasing tray size also altered related physical characteristics, including perimeter, water volume, and simultaneous accessibility, and the shallow trays used here were not equivalent to unrestricted open-water systems. Accordingly, comparisons with previous open-water studies provide biological context rather than direct equivalence between water systems.

The increased opportunity for water contact was accompanied by progressively wetter and more soiled floor conditions, particularly under the largest tray treatment. Water transferred from the trays through splashing, wet plumage, and the feet could have extended moisture beyond the immediate water-contact zone and into the resting area. Variation in water use and water quality among open-water sources has previously been reported and may contribute to poorer hygienic conditions when water exposure is difficult to contain (Liste et al. 2013). The concurrent increases in floor pH and coliform counts are

Table 4. Growth performance and feed efficiency of Co ducks raised under semi-dry housing

Parameter	T1 (0 cm²/duck)	T2 (25 cm²/duck)	T3 (50 cm²/duck)	T4 (100 cm²/duck)	SEM	p-value
Initial body weight (g/duck)	43.6	43.8	43.5	43.7	0.30	0.899
Body weight at 28 days (g/duck)	648.3^{b}	674.2^{ab}	701.5^{a}	662.4^{b}	9.55	0.006
Body weight at 56 days (g/duck)	$1,428.6^{b}$	$1,486.4^{ab}$	$1,552.8^{a}$	$1,465.7^{b}$	19.93	0.002
Body weight gain 1–56 days (g/duck)	$1,385.0^{b}$	$1,442.6^{ab}$	$1,509.3^{a}$	$1,422.0^{b}$	19.86	0.002
ADG 1–56 days (g/duck/day)	24.73^{b}	25.76^{ab}	26.95^{a}	25.39^{b}	0.35	0.002
Feed intake (g/duck/day)	74.9	75.7	76.6	76.2	1.23	0.799
FCR (1–56 days)	3.03^{a}	2.94^{ab}	2.84^{b}	3.00^{a}	0.03	0.005
Mortality and culling rate (%)	3.33	2.50	1.67	4.17	1.51	0.542

Values are treatment means with pooled standard error of the mean (SEM), based on six replicate pens per treatment. Body weight at days 1, 28, and 56 was analyzed using a repeated-measures model with treatment, age, and treatment × age interaction. Overall effects were significant for treatment (P = 0.0006), age (P < 0.001), and treatment × age interaction (P = 0.0008). Treatment comparisons within each age were adjusted using Tukey's procedure. Body-weight gain, ADG, feed intake, FCR, and mortality/culling rate were analyzed as pen-level 1–56-day outcomes. Mortality/culling percentages were arcsine square-root transformed before analysis, whereas untransformed percentages are presented. Means with different superscript letters within the same row differ significantly (P < 0.05)

Table 5. Relationships among floor condition, plumage cleanliness, foot health, and growth performance

ParameterRelationship	Spearman r	P-value	Interpretation
Floor moisture near water area vs. abdominal plumage dirtiness score	-0.35	0.093	No significant monotonic association
Floor moisture near water area vs. footpad dermatitis score	0.56	0.005	Wetter floor was associated with poorer footpad condition
Coliforms near water area vs. footpad dermatitis score	0.63	< 0.001	Greater coliform contamination was associated with higher footpad dermatitis scores
Abdominal plumage dirtiness score vs. ADG	-0.69	< 0.001	Greater plumage dirtiness was associated with lower ADG
Footpad dermatitis score vs. ADG	-0.42	0.039	Higher footpad dermatitis scores were associated with lower ADG
Gait score vs. ADG	-0.44	0.034	Higher gait scores were associated with lower ADG
Footpad dermatitis score vs. FCR	0.54	0.006	Higher footpad dermatitis scores were associated with higher FCR

also compatible with greater mixing of spilled water, fecal material, and litter, which can favor organic matter degradation and microbial persistence. Water troughs provided to Pekin ducks have been associated with increased water contamination and increased grow-out mortality compared to ducks provided via pin-metered water lines, highlighting the hygienic impacts of poorly controlled open water (Schenk et al. 2016). Environmental and management factors such as humidity, litter moisture, ammonia, and water resources have also been associated with production and welfare outcomes on commercial Pekin duck farms (Jones and Dawkins 2010a).

The decrease in floor condition at the highest water-contact provision emphasizes the necessity of drainage and litter management in semi-dry systems. It has been reported that perforated plastic flooring under water lines can reduce litter moisture and improve footpad health in broiler chickens (Sonnabend et al. 2022), while wet litter is a multifactorial problem including drinker management, ventilation, manure moisture, litter characteristics, and housing design (Dunlop et al. 2016). Thus, the present response cannot be attributed solely to the presence of water. Among the tray configurations evaluated, the 50 cm²/duck treatment represented a more favourable balance than the largest tray treatment because greater opportunity for water use was achieved without the same degree of deterioration in floor condition. This finding should not be interpreted as evidence that 50 cm²/duck is a universal optimum. Evaluation of water provision in ducks should integrate productive and welfare-related outcomes rather than considering the water source alone, as previously emphasized when comparing open-water designs, nipple lines, and trough systems in Pekin ducks (Lowman et al. 2016).

Abdominal plumage and head hygiene responded differently to the graded tray-based water provision. The poorer abdominal plumage condition in ducks without a water-contact tray is consistent with reduced opportunities for water-assisted grooming. Access to water facilitates bill-dipping, head-washing, preening, and feather rearrangement. Conversely, the absence of bathing water has been found to hinder the development of the preen gland and preening behavior in Sanshui White ducks (Mi et al. 2020). In this study, the intermediate tray treatment resulted in the cleanest abdominal plumage, while the largest tray treatment did not improve on this and resulted in greater wetness and matting of the feathers. A plausible explanation is that moderate water contact facilitated grooming, while excessive wetting increased the probability that moist abdominal feathers contacted litter and fecal material. This interpretation is consistent with the observed pattern, but does not imply a single causal mechanism.

Head hygiene responded more directly to increased water provision, which is reasonable since the bill and nostril region can be immersed or washed in normal water-related behavior. Other indicators of welfare considered when misting is assessed as a commercial water-provision strategy to Pekin ducks include feather cleanliness, cleanliness of the nostrils and dermatitis of the footpads (Campbell et al. 2022). Notably, the improvement in the cleanliness of the head did not track the condition of the abdominal plumage under the largest tray treatment. A similar trade-off has been reported in grow-out Pekin ducks given semi-open water or non-water enrichment, where Pekino or preening-cup enrichments were associated with greater body weight and better nostril scores but also with dirtier feathers, poorer litter condition, greater litter moisture, and higher viable bacterial counts in water sources (Schober et al. 2025). These observations are consistent with the idea that increased opportunities for water-related behavior may be beneficial for some hygiene indicators, but at the same time increase environmental wetness and contamination when water is not adequately contained.

Another indication of this trade-off was provided by foot health. The poorer footpad, interdigital and locomotor outcomes under the largest tray treatment were consistent with the wetter and more contaminated floor environment. Research on Pekin duck flooring has previously considered environmental conditions, feather cleanliness, nostril condition, footpad quality and gait together to support a multi-indicator approach to duck welfare assessment (Karcher et al. 2013). Extended contact with wet litter can soften the skin of the plantar aspect and affect the epidermal barrier, making it more prone to irritation, inflammation and secondary contamination. However, footpad dermatitis is multifactorial and may also be affected by litter quality, body weight, diet and individual skin susceptibility (Mayne 2005). Footpad dermatitis (FPD) is more likely to develop and progress in wet litter (Taira et al. 2014) and high litter moisture alone was sufficient to cause FPD in growing turkeys (Mayne et al. 2007). The greater involvement of the interdigital areas in the highest water-contact treatment is also in keeping with the prolonged contact of the interdigital skin with damp litter and accumulated organic matter. Flooring conditions may also affect other welfare indicators, as different eye and nostril results were observed in Pekin ducks with plastic slatted flooring and pine-shaving litter in summer (Fraley et al. 2013).

The locomotor findings were in agreement with the foot health pattern. Treadmill validation of gait scoring in ducks provides biological support for the use of gait scoring, as measurable differences in walking performance were observed among Pekin ducks that differed in gait scores (Byrd et al. 2016). Impaired locomotion may reduce movement toward feeders and drinkers and increase the time spent resting on the floor and potentially increase contact with wet litter. Feather condition, nostril condition, footpad condition and gait-related measures have therefore been included as complementary animal-based indicators in on-farm welfare assessments of commercial Pekin ducks (Abdelfattah et al. 2020). Importantly, the present data do not support the conclusion that 50 cm^2/duck improved foot health relative to the 0 and 25 cm^2/duck treatments. Footpad dermatitis, interdigital lesions, gait score and impaired walking were statistically the same between T1, T2 and T3. Deterioration was seen in T4. Thus, the intermediate tray treatment was associated with the maintenance of foot-health indicators rather than a measurable improvement over the smaller water-contact conditions.

When plumage and foot outcomes are considered together, the 50 cm^2/duck treatment showed the most favourable combination among the four treatments evaluated, whereas the largest tray treatment combined improved head cleanliness with increased abdominal feather wetness and poorer foot and locomotor outcomes. Bedding condition is relevant to both welfare and productivity, as recent work in broiler ducks has jointly evaluated bedding material, growth performance, footpad dermatitis, and meat quality (Biesek et al. 2024). The present findings therefore support a trade-off between opportunities for water-related behavior and maintenance of a suitably dry floor rather than a simple assumption that increasing water-contact area continuously improves duck welfare.

Growth performance followed the same general treatment pattern as several environmental and welfare-related indicators. Different open-water sources have previously been associated with health and production responses in farmed ducks, supporting evaluation of water provision through both welfare and productive outcomes (Liste et al. 2012b). The lack of an effect of treatment on feed intake is particularly important in that it shows the differences in growth seen were not merely due to increased feed intake. Nutrition can affect water intake, excreta moisture, litter quality, and footpad dermatitis; hence, it is important to use the same diet across treatments when investigating responses to water provision (Świątkiewicz et al. 2017). Drinking and preening behavior in Pekin ducks also depend on flooring systems, indicating that water-related behavior and floor characteristics may have combined effects on duck condition (Rice et al. 2014). Commercial observations further suggest links between Pekin duck behavior, environmental conditions and body condition (Jones and Dawkins 2010b).

Higher ADG and lower FCR in T3 were accompanied by cleaner abdominal plumage, relatively better floor conditions and better foot-health outcomes compared to T4, since feed intake was not different between treatments. These concomitant responses indicate an association between housing conditions, welfare-related indicators and productive performance, but do not identify the mechanism underlying the growth response. This distinction is important since multiple pathways could simultaneously contribute, including locomotor comfort, feather condition, thermal balance and exposure to wet litter. Increased litter moisture has been associated with poorer welfare, lower technical performance and reduced carcass yield in broiler chickens (de Jong et al. 2014). Wet and matted abdominal feathers may also impair normal feather function, while foot lesions may restrict activity. Thermal conditions are relevant to duck growth because ambient temperature affects growth performance and carcass traits in growing White Pekin ducks (Sun et al. 2019). Accordingly, the poorer body-weight gain and FCR in T4 should be interpreted as occurring concurrently with the less favourable environmental and welfare-related conditions rather than as being directly caused by any single one of them.

Similar water-floor interactions have been reported in other waterfowl. Liao et al. (2021) found that swimming-pool conditions and floor type affected growth performance and footpad dermatitis of indoor-reared White Roman geese. Non-water enrichment may offer a contrast: whiffle-style balls threaded with zip-ties have been used in commercial Pekin ducks as a behavioral outlet for feather-directed activity and to reduce feather picking (Colton and Fraley 2014). Collectively, these studies indicate that behavioral enrichment and water provision might confer different benefits and have different environmental costs, highlighting the need to consider the whole housing system, rather than any single enrichment feature in isolation.

Correlation analysis also revealed associations between floor condition and plumage, foot health, and productive traits. The positive correlation between floor moisture and footpad dermatitis agrees with previous evidence that both litter moisture and footpad dermatitis vary with bedding material and litter depth (Garcês et al. 2017). The association between coliform counts and footpad lesions is also biologically plausible because prolonged contact with wet and contaminated litter can soften plantar skin, impair epidermal integrity, and increase susceptibility to irritation and secondary infection. However, bacterial contamination should be regarded as one component of the litter environment rather than as an independently demonstrated cause of lesion development in the present experiment.

Similarly, the negative associations of ADG with abdominal plumage dirtiness, footpad dermatitis, and gait score, together with the positive association between footpad dermatitis and FCR, indicate that poorer welfare-related scores tended to occur alongside poorer productive performance. These correlations are consistent with a possible pathway linking tray-based water provision, litter moisture, plumage condition, foot health, locomotor ability, and growth; however, they do not establish mediation or causality. Because the correlations were calculated across treatment groups, part of the observed relationships may also reflect differences among the experimental treatments themselves. Evidence from indoor-reared geese also indicates that swimming-pool conditions and floor types can influence physical-condition scores and behavior (Liao et al. 2022). Local ducks have likewise been reported to show changes in behavior, body condition, plumage condition, and heat-stress responses according to swimming access, which is relevant when interpreting the present responses in Co ducks (Suswoyo and Sulistyawan 2014).

Taken together, the findings indicate that the intermediate tray-based treatment provided the most favourable overall combination of water-use opportunity, plumage condition, maintenance of foot health, and productive performance among the four conditions tested. This conclusion is specific to the tray dimensions, semi-dry housing system, stocking density, genotype, location, and production cycle evaluated here and should not be generalized as a universal management optimum without validation under other production conditions.

5. Conclusions

The present study demonstrated that graded tray-based water provision affected water-use behavior, floor condition, plumage cleanliness, foot-health indicators, walking ability and growth performance in Co ducks reared under semi-dry housing. Increasing water contact with tray-based water increased beak and nostril cleanliness but progressively increased floor moisture and coliform counts, and the largest tray treatment was associated with increased abdominal feather wetness, footpad dermatitis and gait impairment. The 50 cm²/duck treatment had the most favorable combination of abdominal plumage cleanliness and growth performance of all four treatments, with foot-health indicators that were statistically similar to those observed in the 0 and 25 cm²/duck treatments. The observed correlations did not establish causality or mediation but indicated associations among litter moisture, plumage condition, foot health, locomotor ability and growth performance. The results presented here are specific to the tray-based semi-dry housing conditions explored in this experiment, and thus, further research under different locations, seasons, stocking densities and tray configurations are required before management recommendations can be broadly applied.

6. Novelty statement

This study provides new experimental evidence on the effects of graded tray-based water-contact areas on behavioral, environmental, welfare-related, and productive responses in Co ducks raised under semi-dry housing. Unlike studies that primarily compare the presence or absence of open-water access, this study evaluated three defined tray-based water-contact areas, 25, 50, and 100 cm²/duck, against a drinking-water-only control and simultaneously assessed water-use behavior, floor moisture and contamination, plumage and head cleanliness, foot health, gait, and growth performance. The findings demonstrated a clear trade-off between increasing opportunities for water-related behavior and maintaining a suitably dry and hygienic floor environment. Among the tested conditions, 50 cm²/duck showed the most favourable overall combination of abdominal plumage cleanliness and productive performance, while foot-health indicators remained comparable with those observed in the 0 and 25 cm²/duck treatments. These results provide an initial experimental basis for tray-based water provision in Co ducks under the specific semi-dry housing conditions evaluated, rather than establishing a universal optimum for water-contact area.

Declarations

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Conflict of interest: The author declare no conflicts of interest

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Data Availability: The data that support the findings of this study are available from the corresponding author upon reasonable request

Ethics approval: All animal care, handling and management practices were carried out according to the Law on Animal Husbandry No. 32/2018/QH14 issued by the National Assembly of the Socialist Republic of Vietnam. The study involved only routine husbandry procedures, non-invasive visual assessments, body-weight recording, and environmental sampling, no institutional animal ethics approval number was issued for this study

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