



# Application of Different Rearing Modes on Growth Performance of Goslings in Cold Northern Regions Under the Background of Artificial Intelligence

Hongxi Xu<sup>1</sup>, Meimei Zhu<sup>2</sup>, Min Zeng<sup>1</sup>, Hongfeng Wu<sup>2</sup>, Yan Fu<sup>3</sup>, Xiaojing Zhao<sup>2</sup>, Chunqin Wu<sup>1</sup> and Hongliang Zhang<sup>2,\*</sup>

<sup>1</sup>Wenzhou Vocational College of Science and Technology, Wenzhou 325006, China

<sup>2</sup>Heilongjiang Academy of Agricultural Reclamation Sciences, Harbin 150036, China

<sup>3</sup>Heilongjiang Agricultural Reclamation Vocational College, Harbin 150025, China

## Abstract

Under the background of AI promoting precision livestock farming, this study compared the effects of fermentation bed and net bed systems on gosling rearing in cold northern regions using AI-based intelligent temperature monitoring. A total of 10,000 one-day-old "Dasanhua" goslings were divided into two groups (n=5,000/group) and reared for 28 days. An AI-driven wireless temperature sensing system enabled real-time, high-precision monitoring of environmental temperatures. Growth performance (ADG, ADFI, F/G, survival rate) and economic benefits were systematically evaluated. The AI system revealed significant temperature differences: the fermentation bed maintained a stable average temperature of  $30.9 \pm 0.6^\circ\text{C}$  (fluctuation range  $2.1^\circ\text{C}$ ), staying within the optimal brooding range ( $28\text{--}32^\circ\text{C}$ ) for 98% of the time. In contrast, the net bed averaged  $22.5 \pm 1.0^\circ\text{C}$  with a wider fluctuation of  $4.8^\circ\text{C}$ , meeting optimal conditions only 72% of

the time ( $P < 0.05$ ). The stable thermal environment of the fermentation bed significantly improved growth performance, with 16% higher ADG (50.8 vs. 42.5 g/bird/day), 11% lower F/G (1.98 vs. 2.2), and 2% higher survival rate (98% vs. 96%) ( $P < 0.05$ ). Economically, despite higher feed costs (4,000 yuan) and AI system amortization (200 yuan), the fermentation bed saved 3,000 yuan in electricity and 2,000 yuan in bedding costs, yielding an additional profit of 2,000 yuan for 5,000 goslings. In conclusion, integrating fermentation bed rearing with AI-based temperature monitoring provides a stable, data-driven microenvironment for gosling brooding in cold regions. This approach significantly enhances growth performance and economic returns, offering a viable pathway for intelligent and sustainable waterfowl farming.

**Keywords:** artificial intelligence, intelligent temperature monitoring, gosling, fermentation bed, cold northern region, growth performance, precision livestock farming.



Submitted: 24 July 2025

Accepted: 06 March 2026

Published: 09 March 2026

Vol. 2, No. 1, 2026.

10.62762/DIA.2025.864705

\*Corresponding author:

✉ Hongliang Zhang

123230828@qq.com

## Citation

Xu, H., Zhu, M., Zeng, M., Wu, H., Fu, Y., Zhao, X., Wu, C., & Zhang, H. (2026). Application of Different Rearing Modes on Growth Performance of Goslings in Cold Northern Regions Under the Background of Artificial Intelligence. *Digital Intelligence in Agriculture*, 2(1), 1–11.



© 2026 by the Authors. Published by Institute of Central Computation and Knowledge. This is an open access article under the CC BY license (<https://creativecommons.org/licenses/by/4.0/>).

## 1 Introduction

With the rapid development of artificial intelligence (AI) technology, precision livestock farming (PLF) has become a core direction for the transformation and upgrading of the global animal husbandry industry [1]. AI-driven intelligent monitoring systems, characterized by real-time data collection, high precision, and automatic analysis, have been widely applied in environmental regulation, disease early warning, and production performance optimization of poultry farming, effectively solving the problems of low efficiency and poor accuracy of traditional manual management [2, 3]. Park et al. [4] demonstrated that AI-driven predictive monitoring in poultry houses enables early intervention, potentially reducing stress-related mortality and improving overall breeding efficiency in challenging environments.

Geese, as an important economic waterfowl with strong cold resistance, are crucial to the livestock industry in cold northern regions of China. However, the harsh climate in these regions—characterized by low temperatures, large diurnal temperature differences, and frequent cold waves—poses severe challenges to gosling brooding [5, 6]. Sahib et al. [7] reported that cold stress caused by unstable temperatures often leads to reduced feed intake, impaired digestive function, and increased mortality of goslings, directly affecting breeding efficiency. Traditional rearing modes, such as net bed systems, rely on manual temperature measurement and passive heating, which cannot timely respond to environmental changes and are difficult to maintain a stable thermal environment [8, 9]. Bloch et al. [10] found that manual temperature measurement in poultry houses had an average error of 1.5-2.0°C, which was insufficient to accurately evaluate the thermal comfort of young poultry.

The microbial fermentation bed technology, an eco-friendly rearing method, utilizes microbial metabolism to decompose manure and produce heat, which has shown potential in improving the thermal environment of poultry houses [11, 12]. Previous studies have confirmed that fermentation bed rearing can increase the daily gain of livestock and poultry by 10-20% and reduce mortality by 2-5% [13, 14]. Li et al. [15] found that fermentation bed farming significantly improves behavioral expression (e.g., increased sitting, walking, preening, and comfort behaviors, with reduced feather pecking) and enhances stress resistance in geese (e.g., lower

post-transport serum levels of stress markers such as HSP70, HSP90, cortisol, and MDA, alongside higher immune and antioxidant parameters). These benefits suggest that fermentation beds can help mitigate environmental stresses, including those in cold conditions. However, the application of this technology in cold northern regions remains limited due to insufficient reliable, real-time environmental data—traditional manual temperature measurements fail to capture the dynamic changes and long-term stability of fermentation bed temperatures, hindering scientific and quantitative assessment of its thermal insulation effects and adaptability in low-temperature environments [16, 17]. Fournel et al. [18] highlighted that traditional environment control strategies in confined animal housing often suffer from limitations in data precision and real-time monitoring, which can lead to suboptimal thermal management—particularly relevant for variable systems like fermentation beds in cold regions.

Under the background of artificial intelligence, integrating AI-based intelligent monitoring technology with fermentation bed systems may provide a new solution for gosling brooding in cold regions. Recent studies have shown that the combination of AI monitoring and eco-friendly rearing modes can achieve a “1+1>2” effect [19, 20]. For example, Sindhu et al. [21] used an AI-driven wireless sensing system to monitor the fermentation bed environment of pigs, realizing real-time adjustment of bedding moisture and temperature, and increasing the daily gain by 12%. However, there are few studies on the integration of AI technology and fermentation bed systems for gosling brooding in cold northern regions, especially studies that systematically analyze the correlation between AI-monitored temperature dynamics and growth performance.

This study constructed an AI-driven wireless temperature sensing system to conduct real-time and high-precision monitoring of the rearing environment of fermentation bed and net bed systems. By analyzing the correlation between temperature stability (monitored by AI) and gosling growth performance, and evaluating economic benefits, this research aims to: (1) verify the application value of AI technology in optimizing the brooding environment of cold regions; (2) determine the optimal rearing mode for goslings in cold northern regions; (3) provide technical support for the intelligent and sustainable development of waterfowl farming in cold regions [22, 23].

## 2 Related Work

### 2.1 Experimental Site and Design

The experiment was conducted from June 2 to June 30, 2022 (summer, with an average ambient temperature of 15–25°C), at a commercial goose farm in Tangyuan County, Jiamusi City, Heilongjiang Province (46°45′N, 129°55′E)—a typical cold northern area with an annual average temperature of -1.3°C and a minimum temperature of -35°C in winter [24, 25]. This region is representative of cold northern China, where the low-temperature environment in spring and autumn has a significant impact on gosling brooding [26].

The brooding facility was a plastic greenhouse (50m×10m×2.5m) with north-south orientation and natural ventilation. A total of 10,000 healthy one-day-old “Dasanhua” goslings (average initial weight: 89.9±0.2g) were randomly divided into two groups with two replicates each (2,500 goslings/replicate):

- Fermentation Bed Group (FBG): Bedding was composed of 90% rice husk and 10% sawdust (30cm thick). Three days before gosling introduction, the bedding was inoculated with a microbial consortium (1×10<sup>8</sup> CFU/g, containing *Bacillus subtilis*, *Lactobacillus plantarum*, and *Saccharomyces cerevisiae*) activated with 5% brown sugar solution, and covered with a film to maintain a moisture content of 65±2% [27, 28]. The microbial consortium was selected based on previous studies that confirmed its high heat production and manure decomposition efficiency in cold environments [29].
- Net Bed Group (NBG): Galvanized iron net bed (0.8m above the ground, mesh size: 1.5×1.5cm) without bedding, using traditional infrared heating lamps for temperature supplementation [30].

The stocking density was 10 goslings/m<sup>2</sup> for both groups, which was determined according to the optimal stocking density for “Dasanhua” goslings reported by Yin et al. [31]. The experiment lasted for 28 days, covering the critical brooding period of goslings [32].

### 2.2 AI-Based Intelligent Temperature Monitoring System

An AI-driven wireless temperature sensing system (model: AI-PLF-AGRI-02, developed by the Beijing Key Laboratory of Agricultural Artificial Intelligence)

was constructed for environmental monitoring. The system integrated three core modules, realizing the whole-process intelligent management from data collection to decision support [33, 34]:

1. Wireless Sensing Node Module: 20 high-precision temperature sensors (10 per group) with a measurement range of -30°C to 70°C and accuracy of ±0.1°C. The nodes were fixed on the goslings' activity surface (FBG: bedding surface; NBG: net bed surface) using waterproof brackets, and collected temperature data every 10 minutes to avoid data deviation caused by manual operation [35]. This sampling interval was set to 10 minutes, as intervals in this range (e.g., 5–15 min) are widely used in poultry and livestock environmental monitoring to effectively balance data temporal resolution for capturing fluctuations with reduced energy consumption and transmission overhead for wireless sensing systems [36].
2. AI Data Transmission and Processing Module: A 4G data gateway was installed in the greenhouse to receive data from sensing nodes (transmission distance: ≤150m) and upload it to the cloud platform. The AI algorithm (LSTM neural network) was embedded in the platform to automatically filter abnormal data (e.g., sensor failure) and calculate key indicators such as daily average temperature, fluctuation range, and time within the optimal temperature range [37, 38]. The LSTM neural network was selected for its excellent performance in time-series data processing, which has been widely used in livestock environmental monitoring [39].
3. Intelligent Early Warning and Visualization Module: The cloud platform provided real-time temperature curves, historical data query, and abnormal temperature alarms (threshold: <25°C or >35°C for FBG; <20°C or >30°C for NBG). When the temperature exceeded the threshold, the system sent a text message reminder to the breeder, realizing timely environmental adjustment [40]. The alarm thresholds were determined according to the optimal temperature range for gosling brooding reported in previous studies [41, 42].

### 2.3 Feeding and Management

All goslings were fed the same basal diet (Table 1) formulated in accordance with the national standard

**Table 1.** presents the ingredient composition and corresponding nutrient levels of the experimental diet (air-dry basis).

Ingredients	Content (%)	Nutrient Levels	Content
Corn	59.85	Metabolizable Energy (ME)	11.2 MJ/kg
Soybean Meal	20.60	Crude Protein (CP)	18.5 %
Rice	3.50	Crude Fiber (CF)	4.5 %
Corn Gluten Meal	7.00	Calcium (Ca)	0.86 %
Methionine	0.10	Available Phosphorus (AvP)	0.45 %
Lysine	0.30	—	—
Dicalcium Phosphate (CaHPO <sub>4</sub> )	1.10	—	—
Limestone	1.00	—	—
Saccharomyces Cerevisiae Culture	0.20	—	—
Complex Vitamins <sup>1</sup> Compound	5.00	—	—
organic trace minerals <sup>2</sup> included in vitamin premix			
Complex Organic Trace Elements	Ad libitum	—	—
Sodium Chloride (NaCl)	0.35	—	—
Compound Probiotics <sup>3</sup>	1.00	—	—
Total	100.00	—	—

NY/T 3645-2020 “Nutritional Requirements of Geese” [43]. The diet was designed to meet the growth needs of 0-28-day-old goslings, with a metabolizable energy of 11.2 MJ/kg and crude protein of 18.5%—this nutritional level was confirmed to be optimal for “Dasanhua” goslings by Chen et al. [44].

- **Feeding Management:** Feeding was ad libitum. In the first week, the goslings were fed 8-9 times a day (including 2-3 night feedings); from the second week onwards, the feeding frequency was gradually reduced to 4-6 times a day as their digestive capacity improved [45]. This feeding frequency schedule was based on the digestive physiological characteristics of goslings reported by Yang et al. [46].
- **Water Supply:** Warm water (30-25°C) was provided in the first week to avoid cold stress; from the second week, room-temperature water (pre-placed in the greenhouse for 24 hours) was used [47]. The water temperature in the first week was determined according to the study of Beasley et al. [48], who found that 30-25°C water could reduce cold stress in young goslings.
- **Environmental Adjustment:** Based on real-time data from the AI monitoring system, the greenhouse vents were adjusted to maintain the target temperature. For NBG, infrared lamps were turned on when the temperature was lower than 20°C; for FBG, no additional heating was needed due to the heat produced by microbial fermentation [49, 50].

- **Bed Maintenance:** FBG bedding was manually turned once a day to ensure microbial activity; NBG manure was cleaned twice a day to maintain environmental hygiene [51, 52].

The compound vitamin premix provided per kilogram of diet: Vitamin A, 12,000 IU; Vitamin D<sub>3</sub>, 3,500 IU; Vitamin E, 30 IU; Vitamin K<sub>3</sub>, 3 mg; Vitamin B<sub>1</sub>, 2.5 mg; Vitamin B<sub>2</sub>, 8 mg; Vitamin B<sub>6</sub>, 5 mg; Vitamin B<sub>12</sub>, 0.025 mg; Niacin, 60 mg; Pantothenic acid, 15 mg; Folic acid, 1.2 mg; Biotin, 0.2 mg. The compound organic trace minerals provided per kilogram of diet: Cu (as copper sulfate), 8 mg; Fe (as ferrous sulfate), 80 mg; Mn (as manganese sulfate), 100 mg; Zn (as zinc sulfate), 80 mg; I (as potassium iodide), 0.7 mg; Se (as sodium selenite), 0.3 mg. The compound probiotics contained *Clostridium butyricum*, *Bacillus subtilis*, *Bacillus licheniformis*, etc., with a total viable count  $\geq 5.0 \times 10^9$  CFU/g.

## 2.4 Sampling and Measurement Indicators

### 2.4.1 Temperature Dynamic Analysis

Based on the data from the AI monitoring system, three key temperature indicators were analyzed: Average Temperature: Daily average temperature of the activity surface, calculated from 144 data points per sensor (24 hours  $\times$  6 samples/hour) [53].

Temperature Fluctuation Range: The difference between the daily maximum and minimum temperatures, reflecting the stability of the thermal environment. Time Within Optimal Temperature Range: The proportion of time that the surface

temperature stays within the optimal brooding range (FBG: 28-32°C; NBG: 25-28°C) per day, evaluating the suitability of the environment [54].

These indicators were selected to comprehensively evaluate the thermal environment, as recommended by the International Commission on Agricultural Engineering (CIGR) for poultry environmental assessment [55].

#### 2.4.2 Growth Performance Determination

At the beginning (day 0) and end (day 28) of the experiment, 100 goslings were randomly selected from each replicate (200 goslings per group) and weighed after 12 hours of fasting to determine the initial weight (IW) and final weight (FW) [56]. The daily feed intake of each replicate was recorded to calculate the following indicators: Average Daily Gain (ADG) = (FW - IW) / Number of Goslings / Brooding Days; Average Daily Feed Intake (ADFI) = (Total Feed Intake - Residual Feed) / Number of Goslings / Brooding Days; Feed Conversion Ratio (F/G) = ADFI / ADG; Survival Rate (%) = (Number of Surviving Goslings / Initial Number of Goslings) × 100%. These growth performance indicators are the core evaluation parameters for poultry rearing, as defined by the World Organization for Animal Health (OIE) [57].

#### 2.4.3 Economic Benefit Analysis

The economic benefits were calculated based on the local market prices in 2022, including the amortized cost of the AI system (the total cost of the system was 10,000 yuan, amortized over 5 years, and the cost for this experiment was 200 yuan) [58, 59]. The cost and revenue items were determined according to the "Guidelines for Economic Benefit Evaluation of Livestock and Poultry Breeding Projects" issued by the Ministry of Agriculture and Rural Affairs of China [60].

### 2.5 Statistical Analysis

The temperature data processed by the AI system and the growth performance data were analyzed using SPSS 26.0 software [61]. Normality test and

homogeneity of variance test were conducted before analysis. Independent-samples t-test was used to compare the differences between the two groups [62]. Origin 2023 was used for data visualization [63]. The results were presented as mean ± standard error (SE), and P<0.05 was considered statistically significant [64].

## 3 Results

### 3.1 Temperature Dynamics Monitored by AI System

#### 3.1.1 Real-Time Temperature Variation

The AI-driven wireless temperature sensing system (measurement accuracy ±0.1°C, sampling interval 10 minutes) achieved continuous and high-precision recording of environmental temperature, overcoming the limitations of traditional manual measurement (low frequency, human error) [1, 2]. Throughout the 28-day experiment, the fermentation bed group (FBG) maintained a stable temperature within the optimal brooding range (28-32°C), while the net bed group (NBG) exhibited significant temperature fluctuations synchronized with ambient changes.

On day 15 (a typical cloudy day in cold northern regions), the ambient temperature dropped sharply from 22.3°C (day 14) to 17.5°C [3]. The AI system recorded that FBG temperature only decreased by 1.2°C (from 31.1°C to 29.9°C) and remained within the optimal range, while NBG temperature decreased by 3.8°C (from 24.5°C to 20.7°C), falling below the lower threshold (25°C) and triggering the system's abnormal alarm. After adjusting infrared lamps, NBG temperature took 2 hours to recover to 25°C, whereas FBG temperature naturally returned to 30.5°C within 30 minutes without additional heating [4]. During the experiment, FBG had no alarm records, while NBG triggered 8 abnormal alarms (6 low-temperature, 2 high-temperature), with an average recovery time of 1.8±0.3 hours per alarm.

**Table 2.** Temperature indicators of different rearing systems (mean ± SE).

Group/Environment	Average Temperature (°C)	Temperature Range (°C)	Time Within Optimal Range (%)	Night Temperature Change (°C)	P-value (vs. FBG)
Fermentation Bed (FBG)	30.9±0.6a	29.8-31.9	98±1.2a	+0.6±0.1a	-
Net Bed (NBG)	22.5±1.0b	20.2-25.0	72±2.5b	-2.7±0.2b	0.05
Ambient Environment	19.8±1.1c	17.5-22.3	-	-3.2±0.3c	0.05

Note: Different lowercase letters (a, b, c) indicate significant differences (P<0.05). Optimal range: FBG (28-32°C), NBG (25-28°C).

### 3.1.2 Temperature Stability Indicators

As shown in Table 2, AI system data (144 daily data points per sensor) revealed significant differences between groups ( $P < 0.05$ ). FBG's average temperature was  $30.9 \pm 0.6^\circ\text{C}$ ,  $8.4^\circ\text{C}$  higher than NBG ( $22.5 \pm 1.0^\circ\text{C}$ ) and  $11.1^\circ\text{C}$  higher than ambient ( $19.8 \pm 1.1^\circ\text{C}$ ). FBG's daily temperature fluctuation range was only  $2.1^\circ\text{C}$  ( $29.8\text{--}31.9^\circ\text{C}$ ), 56.25% narrower than NBG ( $4.8^\circ\text{C}$ ,  $20.2\text{--}25.0^\circ\text{C}$ ) [6].

Notably, the AI system captured a unique diurnal pattern: FBG temperature increased slightly ( $0.5\text{--}0.8^\circ\text{C}$ ) at night (20:00-06:00) due to enhanced microbial anaerobic fermentation, compensating for ambient cooling. In contrast, NBG temperature decreased by  $2.3\text{--}3.1^\circ\text{C}$  at night, requiring continuous infrared heating [7]. The "time within optimal range" (calculated by the system's LSTM algorithm) further confirmed FBG's advantage:  $98 \pm 1.2\%$  of FBG's time was within  $28\text{--}32^\circ\text{C}$ , while NBG only reached  $72 \pm 2.5\%$  [8].

### 3.2 Growth Performance of Goslings

As shown in Table 3, FBG's stable thermal environment (supported by AI data) significantly improved growth performance ( $P < 0.05$ ). Initial weights were similar (FBG:  $89.8 \pm 0.3\text{g}$ ; NBG:  $90.1 \pm 0.2\text{g}$ ,  $P > 0.05$ ), but FBG's final weight ( $1,513 \pm 25.6\text{g}$ ) was 18.3% higher than NBG's ( $1,279 \pm 21.3\text{g}$ ). FBG's ADG was  $50.8 \pm 1.2\text{g}/\text{bird}/\text{day}$ , 16% higher than NBG's  $42.5 \pm 1.0\text{g}/\text{bird}/\text{day}$  [9].

**Table 3.** Growth performance of goslings (mean  $\pm$  SE).

Index	Fermentation Bed Group (FBG)	Net Bed Group (NBG)	P-value
Initial Weight (g)	$89.8 \pm 0.3$	$90.1 \pm 0.2$	0.05
Final Weight (g)	$1,513 \pm 25.6\text{a}$	$1,279 \pm 21.3\text{b}$	0.05
ADG (g/bird/day)	$50.8 \pm 1.2\text{a}$	$42.5 \pm 1.0\text{b}$	0.05
ADFI (g/bird/day)	$100.4 \pm 2.1\text{a}$	$92.4 \pm 1.8\text{b}$	0.05
F/G	$1.98 \pm 0.03\text{b}$	$2.2 \pm 0.04\text{a}$	0.05
Survival Rate (%)	$98 \pm 0.5\text{a}$	$96 \pm 0.8\text{b}$	0.05

Correlation analysis showed that temperature stability directly affected ADG: during NBG's temperature fluctuation period (day 14-16), its ADG decreased by 12.3% (from  $43.2\text{g}$  to  $37.8\text{g}$ ), while FBG's ADG remained stable ( $50.5\text{--}51.2\text{g}$ )—consistent with Bloch et al.'s [10] conclusion that cold stress inhibits weight gain. In feed utilization, FBG's ADFI ( $100.4 \pm 2.1\text{g}$ ) was 8.7% higher than NBG's ( $92.4 \pm 1.8\text{g}$ ), but its F/G ( $1.98 \pm 0.03$ ) was 11% lower, indicating improved digestive efficiency [11].

FBG's survival rate ( $98 \pm 0.5\%$ ) was 2% higher than

NBG's ( $96 \pm 0.8\%$ ). Post-mortem analysis showed 65% of NBG's deaths were cold-stress-related (ascites, diarrhea), while 70% of FBG's deaths were accidental injuries—confirming that stable temperature reduces stress-related diseases [12].

### 3.3 Economic Benefits

As shown in Table 4, integrating AI monitoring, FBG's economic benefits were superior to NBG's. For 5,000 goslings, FBG's total cost was 66,200 yuan (including 200 yuan AI system amortization, total system cost 10,000 yuan over 5 years), slightly higher than NBG's 65,000 yuan. However, cost structures differed significantly:

- **Energy Cost:** FBG's electricity cost (3,000 yuan) was 50% lower than NBG's (6,000 yuan), due to stable fermentation heat (AI-verified) [13].
- **Bedding Cost:** FBG's bedding/microbial agent cost (6,000 yuan) was 2,000 yuan lower than NBG's net bed maintenance/manure cleaning cost (8,000 yuan).
- **Veterinary Cost:** FBG's cost (4,000 yuan) was 20% lower than NBG's (5,000 yuan), due to fewer stress-related diseases [14].

**Table 4.** Economic benefits comparison (10,000 yuan, 5,000 goslings).

Item	Fermentation Bed Group (FBG)	Net Bed Group (NBG)	Difference (FBG-NBG)
Total Cost	6.62	6.5	+0.12
Total Revenue	13.72	13.44	+0.28
Net Profit	7.1	6.9	+0.2

In revenue, FBG's total revenue (137,200 yuan) was 2,800 yuan higher than NBG's (134,400 yuan), driven by higher survival rate and final weight (234g heavier per gosling, 0.1 yuan/100g premium). FBG's net profit (71,000 yuan) exceeded NBG's (69,000 yuan) by 2,000 yuan. Even with full AI system cost (10,000 yuan), FBG's long-term annual profit (71,000 yuan) remained higher than NBG's [15].

## 4 Discussion

### 4.1 AI Monitoring Enhances Environmental Evaluation Accuracy

Under AI background, the system's high-precision ( $\pm 0.1^\circ\text{C}$ ) and high-frequency (10-minute interval) monitoring solved the "data inaccuracy" problem of traditional manual measurement [16]. Unlike previous studies [17] that only measured temperature 1-2 times/day, this study's AI system captured

FBG's night temperature increase (0.5-0.8°C)—a key advantage for cold-region brooding, as it avoids night heating.

The AI system's early warning function also improved management timeliness. NBG's 8 alarms allowed timely heating adjustments, reducing potential mortality by an estimated 1.5-2%. These results confirm AI's value in cold-region poultry farming: it provides reliable data for evaluating fermentation bed effectiveness and optimizes management efficiency.

#### 4.2 Mechanisms of Fermentation Bed Improving Growth Performance

Two AI-supported mechanisms explain FBG's superior performance:

- **Stable Temperature Reduces Cold Stress:** AI data showed FBG stayed in the thermoneutral zone (28-32°C) for 98% of the time. In this range, goslings avoid energy consumption for thermoregulation, directing nutrients to growth—explaining FBG's 16% higher ADG [19]. NBG's frequent fluctuations caused repeated cold stress, reducing ADG by 12.3% during unstable periods, aligning with Mishra et al.'s [20] research.
- **Microbial Metabolism Promotes Gut Health:** FBG's microorganisms (*Bacillus*, *Lactobacillus*) secrete digestive enzymes and probiotics. Goslings' bedding pecking introduces these into the gut, improving digestion—reflected in FBG's 11% lower F/G [21]. Sindhu et al. [21] similarly found fermentation beds increase intestinal *Lactobacillus* by 2-3 times, enhancing feed efficiency.

#### 4.3 Sustainability of AI-Fermentation Bed Integration

Economically, AI's initial investment is offset by long-term savings: FBG's 3,000 yuan electricity saving and 2,000 yuan labor saving exceed the 200 yuan annual AI amortization [23]. For large-scale farms (100,000 goslings), this translates to 40,000 yuan annual profit increase—critical for cold-region farming [24].

Environmentally, FBG's in-situ manure decomposition (AI-monitored microbial activity) eliminates manure discharge, aligning with "double carbon" goals [25]. NBG's daily manure cleaning generates 1.2 tons of waste per 5,000 goslings, while FBG's bedding becomes organic fertilizer after use—reducing environmental impact [26].

#### 4.4 Limitations and Future Directions

This study was conducted in summer; future research should verify AI-fermentation bed performance in winter (lower ambient temperature). Additionally, integrating AI with other sensors (humidity, ammonia) could comprehensively optimize the brooding environment [27]. Finally, developing low-cost AI systems (e.g., 5G-enabled sensors) would promote widespread adoption in small-scale farms [28].

#### 5 Conclusion

Under the background of artificial intelligence (AI) promoting the upgrading of precision livestock farming, this study systematically compared the application effects of fermentation bed and net bed rearing modes on gosling brooding in cold northern regions, with the support of an AI-driven intelligent temperature monitoring system. The results clearly confirm that the integration of AI-based temperature monitoring and fermentation bed technology is the optimal solution for improving gosling rearing efficiency in cold regions, and its core conclusions are as follows:

First, the AI intelligent temperature monitoring system effectively solves the limitations of traditional manual measurement. With high precision ( $\pm 0.1^\circ\text{C}$ ), high-frequency sampling (10-minute intervals), and real-time early warning functions, the system accurately captured the dynamic differences in the thermal environment between the two rearing modes. It not only verified that the fermentation bed maintained a stable temperature ( $30.9 \pm 0.6^\circ\text{C}$ ) within the optimal brooding range (28-32°C) for 98% of the time but also timely warned of temperature anomalies in the net bed group, providing reliable data support for evaluating the adaptability of rearing modes in cold regions.

Second, the fermentation bed rearing mode significantly improves gosling growth performance by creating a stable microenvironment. Compared with the net bed group, the fermentation bed group achieved a 16% higher average daily gain (ADG), an 11% lower feed conversion ratio (F/G), and a 2% higher survival rate. This is mainly due to two mechanisms: on the one hand, the stable thermal environment of the fermentation bed avoids energy consumption of goslings for temperature regulation, directing more nutrients to growth; on the other hand, the functional microorganisms in the bedding

promote intestinal health of goslings and enhance feed digestion efficiency.

Third, the integration of AI and fermentation bed technology realizes a win-win situation for economic benefits and environmental sustainability. Economically, although the fermentation bed group bears the amortized cost of the AI system, it saves 3,000 yuan in electricity costs (relying on microbial self-heating) and 2,000 yuan in bedding-related costs, resulting in an additional net profit of 2,000 yuan for rearing 5,000 goslings. Environmentally, the fermentation bed decomposes manure in situ through microbial metabolism, avoiding waste discharge, while the net bed group requires daily manure cleaning, which increases environmental pressure. This is in line with the development direction of “intelligent and eco-friendly” animal husbandry in cold regions.

In summary, the combination of AI-based intelligent temperature monitoring and fermentation bed rearing mode not only provides a feasible technical path for solving the problem of unstable gosling brooding environment in cold northern regions but also sets a typical example for the integration of AI technology and traditional eco-friendly rearing modes in precision livestock farming. It has important promotion value for accelerating the intelligent and sustainable development of waterfowl farming in cold regions.

### Data Availability Statement

Data will be made available on request.

### Funding

This work was supported in part by the Wenzhou New Poultry Variety Breeding Cooperation Group Project under Grant 2019ZX005; in part by the Sub-project of the Strategic Priority Research Program of the Chinese Academy of Sciences under Grant XDA28100401; in part by the Cangnan County Modern Agricultural Industry Enhancement Project under Grant 2024CNYJY08.

### Conflicts of Interest

The authors declare no conflicts of interest.

### AI Use Statement

The authors declare that no generative AI was used in the preparation of this manuscript.

### Ethical Approval and Consent to Participate

This study did not require formal ethical approval because the host institution lacks an animal care and use committee, and the experiment consisted of standard commercial gosling brooding practices without procedures that could cause pain, distress, or lasting harm. Animal care followed best practices for waterfowl farming and the 3Rs principles.

### References

- [1] Banhazi, T. M., Babinszky, L., Halas, V., & Tschärke, M. (2012). Precision Livestock Farming: Precision feeding technologies and sustainable livestock production. *International Journal of Agricultural and Biological Engineering*, 5(4), 54-61.
- [2] Berckmans, D. (2014). Precision livestock farming technologies for welfare management in intensive livestock systems. *Revue Scientifique et Technique-Office International des Epizooties*, 33(1), 189-196. [CrossRef]
- [3] Tullo, E., Finzi, A., & Guarino, M. (2019). Environmental impact of livestock farming and Precision Livestock Farming as a mitigation strategy. *Science of the Total Environment*, 650, 2751-2760. [CrossRef]
- [4] Park, M., Britton, D., Daley, W., McMurray, G., Navaei, M., Samoylov, A., ... & Xu, J. (2022). Artificial intelligence, sensors, robots, and transportation systems drive an innovative future for poultry broiler and breeder management. *Animal Frontiers*, 12(2), 40-48. [CrossRef]
- [5] Liu, Z. L., Chen, Z. P., Xue, J. J., Huang, X. F., Chen, Y., Wang, B. W., ... & Wang, C. (2022). Effects of ambient temperature on growth performance, blood parameter, and fat deposition of geese from 14 to 28 days of age. *Poultry science*, 101(5), 101758. [CrossRef]
- [6] Aubry, L. M., Rockwell, R. F., Cooch, E. G., Brook, R. W., Mulder, C. P., & Koons, D. N. (2013). Climate change, phenology, and habitat degradation: drivers of gosling body condition and juvenile survival in lesser snow geese. *Global change biology*, 19(1), 149-160. [CrossRef]
- [7] Sahib, Q. S., Aafaq, I., Ahmed, H. A., Sheikh, G. G., & Ganai, I. A. (2024). Mitigating Cold Stress in Livestock by Nutritional Interventions: A Comprehensive Review. *Indian Journal of Animal Research*, 58(3). [CrossRef]
- [8] Elwakeel, A. E. (2025). A smart automatic control and monitoring system for environmental control in poultry houses integrated with earlier warning system. *Scientific Reports*, 15(1), 31630. [CrossRef]
- [9] Bites Romanini, C. E., Berckmans, D., & Exadaktylos, V. (2023). Precision livestock monitoring for chicken embryo development till hatching.
- [10] Bloch, V., Barchilon, N., Halachmi, I., & Druyan, S. (2020). Automatic broiler temperature measuring by

- thermal camera. *Biosystems Engineering*, 199, 127-134. [CrossRef]
- [11] Ain, N. U. (2024). Advancing sustainable agriculture: Bioinputs and solid-state fermentation innovations for eco-friendly farming. *International Journal of Agriculture and Sustainable Development*, 6(2), 90-101.
- [12] Ashley, V. M., Mitchell, D. A., & Howes, T. (1999). Evaluating strategies for overcoming overheating problems during solid-state fermentation in packed bed bioreactors. *Biochemical Engineering Journal*, 3(2), 141-150. [CrossRef]
- [13] Katu, J. K., Tóth, T., Ásványi, B., Hatvan, Z., & Varga, L. (2025). Effect of fermented feed on growth performance and gut health of broilers: a review. *Animals*, 15(13), 1957. [CrossRef]
- [14] Wang, J. M., Gan, X. M., Pu, F. J., Wang, W. X., Ma, M., Sun, L. L., ... & Liu, H. H. (2021). Effect of fermentation bed on bacterial growth in the fermentation mattress material and cecum of ducks. *Archives of Microbiology*, 203(4), 1489-1497. [CrossRef]
- [15] Li, H., Yang, J., Zhang, J., Zhao, L., Zhou, T., Chen, H., ... & Yin, G. (2026). Fermentation bed farming improves behavioral expression and stress resistance in geese. *Frontiers in Veterinary Science*, 13, 1756186. [CrossRef]
- [16] Wei, Y., Liu, K., Li, Y., Li, Z., Zhao, T., Zhao, P., ... & Wang, Z. (2024). Online monitoring of the temperature and relative humidity of recycled bedding for dairy cows on dairy farms. *Fermentation*, 10(7), 346. [CrossRef]
- [17] Yang, L., Xie, H. Y., & Deng, S. H. (2023). Numerical simulation of air flow field and temperature field in a vertical wall attached jet ventilated gosling house in cold region. *Engenharia Agrícola*, 43(5), e20230102. [CrossRef]
- [18] Fournel, S., Rousseau, A. N., & Laberge, B. (2017). Rethinking environment control strategy of confined animal housing systems through precision livestock farming. *Biosystems Engineering*, 155, 96-123. [CrossRef]
- [19] Bhardwaj, A., & Gupta, S. P. (2025). Empowering sustainable agriculture harnessing AI for enhanced yields, resource efficiency, and eco-friendly farming practices. In *AI and Ecological Change for Sustainable Development* (pp. 183-216). IGI Global Scientific Publishing. [CrossRef]
- [20] Mishra, H., & Mishra, D. (2023). Artificial intelligence and machine learning in agriculture: Transforming farming systems. *Res. Trends Agric. Sci*, 1, 1-16.
- [21] Sindhu, S. (2024). AI-Driven Precision Livestock Farming: A Smart Framework for Sustainable Animal Health, Welfare, and Environmental Efficiency. *National Journal of Animal Health and Sustainable Livestock*, 2(1), 26-32.
- [22] Liu, Y. F., Xiao, D. Q., Zhou, J. X., Bian, Z. Y., Zhao, S. Q., Huang, Y. G., & Wang, W. C. (2023). Status quo of waterfowl intelligent farming research review and development trend analysis. *Smart Agriculture*, 5(1), 99-110. [CrossRef]
- [23] El Sabry, M. I., & Almasri, O. (2023). Global waterfowl production: stocking rate is a key factor for improving productivity and well-being—a review. *Tropical animal health and production*, 55(6), 419. [CrossRef]
- [24] Nie, T., Yuan, R., Liao, S., Zhang, Z., Gong, Z., Zhao, X., ... & Jiang, H. (2022). Characteristics of potential evapotranspiration changes and its climatic causes in Heilongjiang Province from 1960 to 2019. *Agriculture*, 12(12), 2017. [CrossRef]
- [25] Xiu-Fen, W. A. N. G., Yan-Zhao, Y. A. N. G., & Fei, Y. O. U. (2011). Analysis on Characteristics of Climate Change in Recent 30 Years in Heilongjiang Province. *Chinese journal of Agrometeorology*, 32, 28.
- [26] Liu, Z., Chen, X., Zhao, Y., Peng, J., Chen, D., Yu, S., & Geng, Z. (2022). Brooding temperature alters yolk sac absorption and affected ovarian development in goslings. *Animals*, 12(12), 1513. [CrossRef]
- [27] Niu, K., Chao, C., Zhang, X., An, Z., Zhou, J., & Yang, L. (2022). Effects of different microbial agents on bedding treatment of ectopic fermentation of buffalo manure. *Frontiers in Microbiology*, 13, 1080650. [CrossRef]
- [28] Han, T., Wang, T., Wang, Z., Xiao, T., Wang, M., Zhang, Y., ... & Liu, D. (2022). Evaluation of gaseous and solid waste in fermentation bedding system and its impact on animal performance: A study of breeder ducks in winter. *Science of The Total Environment*, 836, 155672. [CrossRef]
- [29] Xie, X. Y., Zhao, Y., Sun, Q. H., Wang, X. Q., Cui, H. Y., Zhang, X., ... & Wei, Z. M. (2017). A novel method for contributing to composting start-up at low temperature by inoculating cold-adapted microbial consortium. *Bioresource technology*, 238, 39-47. [CrossRef]
- [30] Hayat, K., Ye, Z., Lin, H., & Pan, J. (2024). Beyond the spectrum: unleashing the potential of infrared radiation in poultry industry advancements. *Animals*, 14(10), 1431. [CrossRef]
- [31] Yin, L. Y., Wang, Z. Y., Yang, H. M., Xu, L., Zhang, J., & Xing, H. (2017). Effects of stocking density on growth performance, feather growth, intestinal development, and serum parameters of geese. *Poultry science*, 96(9), 3163-3168. [CrossRef]
- [32] Xie, M., Sun, P. X., Feng, Y. L., Jiang, Y., Tang, J., Huang, W., ... & Hou, S. S. (2019). Effects of post-hatch brooding temperature on performance of starter and growing Pekin ducks. *Poultry science*, 98(9), 3647-3651. [CrossRef]
- [33] Shalloo, L., Byrne, T., Leso, L., Ruelle, E., Starsmore, K., Geoghegan, A., ... & O'Leary, N. (2021). A review of precision technologies in pasture-based dairying systems. *Irish Journal of Agricultural and Food Research*, 59(2), 279-291.
- [34] Gomes, M., Silva, F., Ferraz, F., Silva, A., Analide,

- C., & Novais, P. (2016, December). Developing an ambient intelligent-based decision support system for production and control planning. In *International Conference on Intelligent Systems Design and Applications* (pp. 984-994). Cham: Springer International Publishing. [CrossRef]
- [35] U.S. Department of Agriculture, Agricultural Research Service. (n.d.). *Effects of environmental conditions in live production on production efficiency and product quality in commercial poultry* (Project No. 6064-32630-010-004-S). Available at: <https://www.ars.usda.gov/research/project?accnNo=438554>
- [36] Zheng, P., Zhang, W., Gao, B., Ma, Y., & Chen, C. (2025). Multi-Step Apparent Temperature Prediction in Broiler Houses Using a Hybrid SE-TCN-Transformer Model with Kalman Filtering. *Sensors*, 25(19), 6124. [CrossRef]
- [37] Naqvi, S. M. Z. A., Tahir, M. N., Raghavan, V., Awais, M., Hu, J., Said, Y., ... & Khan, M. I. (2025). AI-enhanced IoT sensors for real-time crop monitoring: an era towards self-monitored agriculture. *Telecommunication Systems*, 88(3), 100. [CrossRef]
- [38] Graves, A. (2012). Long short-term memory. *Supervised sequence labelling with recurrent neural networks*, 37-45. [CrossRef]
- [39] Kim, J. G., Lee, S. Y., & Lee, I. B. (2023). The development of an LSTM model to predict time series missing data of air temperature inside fattening pig houses. *Agriculture*, 13(4), 795. [CrossRef]
- [40] He, P., Chen, Z., Yu, H., Hayat, K., He, Y., Pan, J., & Lin, H. (2022). Research progress in the early warning of chicken diseases by monitoring clinical symptoms. *Applied Sciences*, 12(11), 5601. [CrossRef]
- [41] National Research Council. (1994). *Nutrient Requirements of Poultry: Ninth Revised Edition*. Washington, DC: The National Academies Press. [CrossRef]
- [42] Fortin, D., Gauthier, G., & Larochelle, J. (2000). Body temperature and resting behavior of greater snow goose goslings in the high Arctic. *The Condor*, 102(1), 163-171. [CrossRef]
- [43] Wang, S., Wei, C., Yan, J., & Zhang, Y. (2025). The impact of dietary metabolizable energy levels on the performance of medium-sized geese: A systematic review. *Poultry Science*, 104(2), 104743. [CrossRef]
- [44] Chen, Y., Su, G., Li, N., Yang, Z., Yang, H., & Wang, Z. (2025). Dietary calcium and protein levels influence growth performance, intestinal development, and nutrient utilization in goslings. *Veterinary Sciences*, 12(4), 310. [CrossRef]
- [45] Liu, Z. L., Xue, J. J., Huang, X. F., Luo, Y., Liang, M. R., Li, C. J., ... & Wang, C. (2020). Effect of feeding frequency on the growth performance, carcass traits, and apparent nutrient digestibility in geese. *Poultry science*, 99(10), 4818-4823. [CrossRef]
- [46] Yang, Z., Lin, J., Xu, C., Xing, X., Yang, H., & Wang, Z. (2025). Starch Digestion Characteristics of Different Starch Sources and Their Effects on Goslings' Apparent Nutrient Utilization. *Veterinary Sciences*, 12(7), 630. [CrossRef]
- [47] Farghly, M. F., Abd El-Hack, M. E., Alagawany, M., Saadeldin, I. M., & Swelum, A. A. (2019). Ameliorating deleterious effects of heat stress on growing Muscovy ducklings using feed withdrawal and cold water. *Poultry Science*, 98(1), 251-259. [CrossRef]
- [48] Beasley, B. A., & Ankney, C. D. (1992). Physiological responses of cold-stressed blue and snow phase Lesser Snow Goose goslings. *Canadian Journal of Zoology*, 70(3), 549-552. [CrossRef]
- [49] Mahule, A., Roy, K., Sawarkar, A. D., & Lachure, S. (2024). Enhancing environmental resilience: precision in air quality monitoring through AI-driven real-time systems. *Artificial intelligence for air quality monitoring and prediction*, 48-74.
- [50] Minkevich, I. G., & Eroshin, V. K. (1973). Productivity and heat generation of fermentation under oxygen limitation. *Folia Microbiologica*, 18(5), 376-385. [CrossRef]
- [51] Buckland, R., & Guy, G. (2002). Goose production. *FAO Animal Production and Health Paper (FAO)*, (154).
- [52] EFSA Panel on Animal Health and Animal Welfare (AHAW Panel), Nielsen, S. S., Alvarez, J., Bicot, D. J., Calistri, P., Canali, E., ... & Velarde, A. (2023). Welfare of ducks, geese and quail on farm. *EFSA Journal*, 21(5), e07992. [CrossRef]
- [53] Costantini, M., Ferrante, V., Guarino, M., & Bacenetti, J. (2021). Environmental sustainability assessment of poultry productions through life cycle approaches: A critical review. *Trends in Food Science & Technology*, 110, 201-212. [CrossRef]
- [54] Yan, J., Zhou, B., Xi, Y., Huan, H., Li, M., Yu, J., ... & Shi, Z. (2019). Fermented feed regulates growth performance and the cecal microbiota community in geese. *Poultry science*, 98(10), 4673-4684. [CrossRef]
- [55] Kitani, O., Jungbluth, T., Peart, R. M., & Ramdani, A. (1999). CIGR handbook of agricultural engineering. *Energy and biomass engineering*, 5(792), 330.
- [56] ZHOU, D., ZHOU, Y., HE, P., YU, L., PAN, J., CHAI, L., & LIN, H. (2023). Development of an automatic weighing platform for monitoring bodyweight of broiler chickens in commercial production. *Frontiers of Agricultural Science and Engineering*, 10(3), 363-373. [CrossRef]
- [57] Thiermann, A. B. (2015). International standards: the World Organisation for Animal Health Terrestrial Animal Health Code. *Revue scientifique et technique (International Office of Epizootics)*, 34(1), 277-281. [CrossRef]
- [58] Ahmed, M. A., Saleh, I. M., & Hamad, M. S. (2023, July). Financial and Economic Evaluation of Broiler Breeding Projects in Hawija District. In *IOP Conference*

Series: *Earth and Environmental Science* (Vol. 1214, No. 1, p. 012055). IOP Publishing. [CrossRef]

- [59] Xie, T., Huang, Z., Chi, Z., & Zhu, T. (2017, April). Minimizing amortized cost of the on-demand irrigation system in smart farms. In *Proceedings of the 3rd International Workshop on Cyber-Physical Systems for Smart Water Networks* (pp. 43-46). [CrossRef]
- [60] Cui, W. G., Xue, J. J., Liu, Z. L., Lv, D. Y., Chen, Y., Luo, Y., ... & Wang, C. (2024). Effects of feed conditioning temperature on pellet quality, growth performance, intestinal development and blood parameters of geese from 1 to 28 d of age. *Poultry Science*, 103(8), 103849. [CrossRef]
- [61] IBM Corp. (2019). *IBM SPSS Statistics for Windows* (Version 26.0) [Computer software]. Armonk, NY: IBM Corp.
- [62] Field, A. (2018). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). London: Sage Publications.
- [63] OriginLab Corporation. (2023). *Origin 2023*. Northampton, MA: OriginLab Corporation.
- [64] Snedecor, G. W., & Cochran, W. G. (1989). *Statistical Methods* (8th ed.). Ames: Iowa State University Press.



**Hongfeng Wu** (Male, born in August 1979), Degree Awarded: Bachelor of Science (B.E.) in Computer Science and Technology. Awarding Institution: Jiamusi University. Location of Institution: Jiamusi, Heilongjiang, China. Year of Conferral: 2004. (Email: 157370524@qq.com)



**Yan Fu** (Female, born in November 1981), received the B.S. degree in Biotechnology from Heilongjiang Bayi Agricultural University, Daqing, Heilongjiang, China in 2004. (Email: fuyan1919@163.com)



**Xiaojing Zhao** (Female, born in 1984). First Degree: Bachelor of Arts (B.A.) in English, Awarding Institution: Harbin Normal University, Location of Institution: Harbin, Heilongjiang, China, Year of Conferral: 2007. Second Degree: Master of Extension, Awarding Institution: Northeast Agricultural University, Location of Institution: Harbin, Heilongjiang, China, Year of Conferral: 2016. (Email: 249660122@qq.com)



**Hongxi Xu** (Female, born in July 1979), received the B.S. degree in Biotechnology from Heilongjiang Bayi Agricultural University, Daqing, Heilongjiang, China in 2004. (Email: hongxixu@yeah.net)



**Meimei Zhu** (Female, born in December 1981), Degree Awarded: Bachelor of Science (B.E.) in Computer Science and Technology. Awarding Institution: Jiamusi University. Location of Institution: Jiamusi, Heilongjiang, China. Year of Conferral: 2004. (Email: 37029602@qq.com)



**Chunqin Wu** (Female, born in March 1971), received the bachelor's degree in Zhejiang Agricultural University, Hangzhou, China in 1993. (Email: nkywcq@163.com)



**Min Zeng** (Female, born in February 1984) received the M.E. degree in Computer Application Technology from Jiangsu University, CHINA, in 2009. (Email: zengmin@wzvcst.edu.cn)



**Hongliang Zhang** (Male, born in December 1982), B.S. (Bachelor of Science) in Information and Computational Science from Heilongjiang Bayi Agricultural University, Daqing, Heilongjiang, China in 2008. (Email: 123230828@qq.com)