Brazilian Journal of Poultry Science
Revista Brasileira de Ciência Avícola

e-ISSN: 1806-9061 2024 / v.26 / n.2 / 001-010

http://dx.doi.org/10.1590/1806-9061-2023-1788

Original Article

Growth Performance, Serum Chemistry, Cellular Immunity, and Carcass Traits of American Pekin Ducks (*Anas Platyrhynchos*) Reared Under Different Production Systems

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■Keywords

Rearing system, Pekin ducks, kitchen waste, growth rate, serum chemistry, meat cholesterol, carcass trait, cellular immunity.

Submitted: 23/March/2023
Approved: 26/July/2023

ABSTRACT

The selection of an appropriate production system plays a crucial role in ensuring the health, welfare, and productivity of American Pekin ducks. The aim of this study was to investigate the influence of various rearing production systems on the performance of American Pekin Ducks. A total of 180 straight run ducklings (10 days old) were randomly allocated into three experimental groups: intensive production system (IPS), free-range production system (FRPS), and pool with yard production system (PYPS). The distribution was carried out following a completely randomized design. We investigated the morphological parameters, growth performance, serum chemistry, meat cholesterol and triacylglycerol, cellular immunity, intestinal morphology, and carcass traits of Pekin ducks. The results indicate that PYPS birds exhibited significantly better morphometric parameters compared to IPS and FRPS ones. Ducks raised in PYPS had the highest growth rate till the 75th day as compared to those reared in IPS and FRPS. Triacylglycerol, total lipids, blood and meat fat and triacylglycerol were higher in IPS; whereas albumin, AG ratio, total proteins, glucose, and globulin were higher in PYPS. Similarly, cellular immunity (phagocytic activity, eosinophils, basophils, and monocytes) was increased in PYPS. Intestinal morphology and overall carcass traits were better in birds reared under PYPS than in those of IPS and FRPS. American Pekin ducks raised in PYPS showed improved growth, serum chemistry, cellular immunity, and carcass traits. These results suggest that the PYPS could be a promising production system for raising ducks in sub-tropical regions.

INTRODUCTION

In recent years, there has been a growing concern about the meat quality and animal welfare, as well as an increased demand for reared animals (Chen *et al.*, 2021). In the human diet, waterfowl can be used to solve (animal) protein deficiencies. Duck meat is the third most commonly produced meat globally, following the production of turkey and chicken. (Ahmed & Garnett 2011). They are different from other breeds in a few aspects: they grow rapidly, especially in early life, with excellent feed conversion efficiency. In addition, they do not require a high amount of protein in their diet, similarly to chicken. Under different climate conditions, ducks live happily and are free of common poultry diseases (e.g., infectious bronchitis, leucosis, Marek's disease, and other problems related to the respiratory system) (Erisir *et al.*, 2009; Farghly *et al.*, 2018).

The architectural design of a poultry house significantly impacts the indoor environmental conditions that influence the health and growth performance of avian stock, including ducks and chickens. Optimal environmental conditions, including temperature, humidity, ventilation, lighting, and air quality, which are crucial factors contributing to the overall well-being and productivity of poultry. Therefore, careful consideration of the poultry house design, including its layout, insulation, and materials, is vital to provide a comfortable and healthy indoor environment that promotes the growth and development of the birds. Scientific research has demonstrated that appropriate poultry house design can enhance bird welfare, reduce the incidence of diseases, and increase the overall productivity and profitability of poultry farming. Therefore, the housing used in different rearing systems has an impact on the environmental conditions. In tropical countries, the open yard housing system is seen as a beneficial housing system, because of its low cost of management, ease of construction, and simplicity in the management of heat; while in temperate regions, the controlled house is perfect for bird health and growth performance (Oloyo, 2018). In Pakistan, the poultry industry has an important role to fulfil in meeting the demand for protein. Commercial poultry farming in the country started in the 1960s, and has shown rapid growth over the decades. The poultry sector has grown rapidly due to the government's persistent attempts to increase flocks of chickens and its successful advertising campaigns (Hussain *et al.*, 2015).

The *Anas platyrhynchos domestica*, commonly referred to as the American Pekin duck, has gained worldwide recognition for its remarkable ability to grow quickly and produce meat of excellent quality (Zheng *et al.*, 2014). The meat of American Pekin ducks contains high fat contents, which improves meat flavor (Zhu *et al.*, 2015). They also have good potential regarding many productive aspects, such as growth performance (Krysiak *et al.*, 2021), carcass yield (Kwon *et al.*, 2014; Huo *et al.*, 2021), and fat contents (Liu & Churchil, 2022). Numerous studies have suggested that rearing techniques are one of the non-genomic factors that significantly affect the quality of meat and carcass characteristics. To produce high-quality duck meat, the birds need to be grown under ecological and controlled environmental conditions that confirm the quality of care (Onbaşilar & Yalcin, 2018). Moreover, the well-being of the ducks is strongly influenced by the environment and the rearing program. (Abd El-Hack *et al.*, 2022) reported that water access provided for ducks enhanced their health status, showing benefits in terms of feather and eye hygiene, as well as pad conditions. Another researcher has reported increases in duck meat production for birds that were allowed access to a free-range environment and water (Abo Ghanima *et al.*, 2020).

In closed housing systems, controlling the indoor environment can be challenging, and appropriate ventilation is necessary to regulate the temperature and other management parameters. Therefore, more research is needed to assess the production of ducks under different housing systems. Marginal and small-scale farmers face difficulties in enhancing farm productivity due to the limited resources available for farm management. In such circumstances, the use of the PYPS (Pool with yard production system) farming system can play a crucial role in increasing productivity with fewer investments. This approach involves the efficient utilization of available resources and waste recycling. Therefore, an experiment is proposed to evaluate the effects of different rearing systems on the growth and biochemical parameters of American Pekin ducks. The study aims to provide scientific evidence to support the use of appropriate housing systems and the PYPS approach to improve the productivity of duck farming.

MATERIALS AND METHODS

Location and period

The study was conducted to investigate the production of Pekin ducks under different rearing (housing) systems at the Integrated Aquaculture Research Unit (IARU), Department of Fisheries and Aquaculture, University of Veterinary and Animal Sciences (UVAS), Lahore, Pakistan. The town of Pattoki is situated in Punjab, Pakistan, and experiences a typical subtropical monsoon climate. The altitude is 199 meters above sea level, and summers in the town are characterized by high humidity, warm temperatures, and clear skies; while winters are dry, short, and clear. The annual average precipitation in the area is 500 mm. Throughout the year, temperatures in Pattoki range from 280.372 K to 313.15K, with rare instances of temperatures below 278.15K or exceeding 317.03K. The duration of the experimental study was 3 months.

Statement of animal rights

In this experimental study, all the procedures performed were in accordance with the ethical standards of the University of Veterinary and Animal Sciences, Lahore, Pakistan, and approval was granted by the Animal Ethical Review Committee.

Experimental design

A total of 180, straight-run American Pekin ducklings (10-day-old) with an average weight of 147.2 ± 4.5 (gm) were purchased from a native market, in Lahore, Pakistan. These birds were reared under three different rearing systems: Intensive production system (IPS), free-range production system (FRPS), and pool with yard production system (PYPS). They were divided into three experimental units, each consisting of three replicates, with each replicate comprising 20 birds. The research design employed for this study was a completely randomized design with factorial arrangements. Till six weeks of age, in intensive production, the stocking density was of 0.060 m^2 per bird and a nipple drinking system was used to provide water. Over time, the stocking density for the birds was progressively increased to a maximum of 0.1393 m^2 per bird. In the context of free-range production, the guidelines established by the United States Department of Agriculture were implemented. This entailed the utilization of a stationary indoor house for shelter and an outdoor area with a concrete floor, to facilitate the birds' movement. A pen measuring 3.66 × 3.05 m in the indoor area and 3.66 × 3.05 m for outside entrance was provided to 20 birds, with 0.929 m^2/bird. In the indoor area, a drinking system was provided for the birds, and supplementary drinkers and feeders were also provided in the outdoor area, with 15 birds per drinker and 10 birds per feeder. The experiment was conducted in the period between August and October, during which the rearing environment provided favorable conditions for the ducks. The temperatures ranged between 267.594 to 305.15K, creating an optimal environment for rearing. It is worth noting that the rearing environment was carefully controlled to minimize air drafts, ensuring the well-being and comfort of the ducks throughout the study. IPS, FRPS and PYPS experimental animals were respectively fed 100 % commercial feed, 50 % kitchen waste (KW) + 50% commercial feed, and 100 % kitchen waste (KW). The experimental birds were in good health at the time of purchase, and remained healthy throughout the duration of the study, with no signs of disease or health issues observed at the end of the experiment. The proximate composition of kitchen waste and feed ingredients is shown in (Table 1).

Morphometric assessment

Body length (BL), keel length (KL), wing span (WS), drumstick circumference (DC), drumstick length (DL), shank circumference (SC), shank length (SL), and wing spread (WS) were calculated. From each experimental unit, 5 birds were tagged and morphometric measurements were recorded on fortnightly basis. The measurements were carried out in accordance with the procedure established by (Kokoszyński *et al.*, 2019).

Table 1 – Proximate profile of kitchen waste and calculated composition of ingredients and nutrients of the experimental feed ration.

Proximate Analysis of Kitchen Waste (KW)			
Dry Matter %	36.7	Ether Extract %	19.01
Crude Protein %	15.9	Ash %	7.01
Moisture %	43.88		
Feed Ingredient (%)		Nutrient composition (%)	
Corn (8.5 %)	62.01	Crude Protein	21.09
Soybean Meal (30 CP%)	32.01	Dry Matter	88.2
Soybean Oil	3.02	Calcium	0.92
DCP	1.70	Metabolizable Energy (Kcal/Kg)	3020
NaCl	0.30	Lysine	2.10
Methionine	0.12	Phosphorus	0.39
Total	100	Methionine	0.45

Growth Performance

Growth parameters included WG (weight gain), WG% (weight gain), and SGR (specific growth rate). On a fortnightly basis, the body weight for each bird was recorded using an electronic weighing balance (Axis BD15S, Axis, Gdansk, Poland).

The following formulas were used to calculate WG, WG %, and SGR:

Weight gain = Final weight (g) - Initial weight (g)

Weight gain (%) = 100 × (Final Weight-Initial weight)/Initial weight

$$SGR = \frac{\ln(\text{Final BW}) - \ln(\text{Initial BW})}{\text{Number of days}} \times 100$$

Serum chemistry

A total of 27 samples (3 from each replicate) were collected from the wing vein from all treatment groups at the end of the experiment. After the collection of blood, the tubes were left in an inclined position until the serum samples were isolated by centrifugation for 15 minutes at 3000 rpm. Until the time of analysis, collected samples were preserved at -20°C in a deep freezer. Samples were then sent to CLC (Central Laboratory Complex), A block, UVAS, for evaluation of blood biochemistry parameters. Based on the glucose oxidase method, the level of glucose blood was evaluated by a ACCU-CHEK Glucometer (Roche Diagnostics GmbH, Nannheim, Germany) (D'Orazio *et al.*, 2005), Albumin was evaluated by the bromocresol green method (Doumas *et al.*, 1971; Doumas & Peters

Jr 1997), serum proteins were examined by the direct method of Biuret, cholesterol serum was evaluated by the method of enzymatic colorimetry (Allain *et al.*, 1974), serum globulin was measured by the difference between total serum albumin and protein value (Agina *et al.*, 2017), and serum alkaline phosphatase (ALP) was measured by the phenolphthalein monophosphate method (Babson *et al.*, 1966).

Cellular Immunity

A total of 27 blood samples (3 from each replicate) were collected from all treatment groups. The collected blood samples sent to the Central Laboratory complex (CLC) for analysis of phagocytic activity. Staining and microscopic examination techniques were used to assess multiple parameters, including monocytes, eosinophils, lymphocytes, basophils, and heterophiles, as well as the phagocytic index and phagocytic activity (Abo Ghanima *et al.*, 2020).

Carcass Traits

Before the birds were slaughtered, a standardized 8-hour fasting period was observed, during which the birds from each treatment group, comprising 10 birds per group, were deprived of food. Subsequently, their weights were measured and recorded. The slaughter process involved manual methods, in adherence with halal regulations, followed by the removal of internal organs and feathers through a process of degutting and de-feathering. The body parts were cut into different parts according to usual methods described by (Sarica *et al.*, 2011). Carcass parts were weighed and their percentage with their whole carcasses was calculated. The giblets (liver, gizzard, and heart) and carcasses were placed in a refrigerator for 24 hours at 4°C until further analysis.

Statistical analysis

The current research was conducted following a completely randomized design, with the experiments carried out in triplicates. Data analysis was performed using one-way analysis of variance (ANOVA) to assess the impact of different rearing systems on various treatments and their interaction. The results were presented as means ± standard deviation (SD). Statistical significance between different treatments was determined at a significance level of $p \leq 0.05$. To further determine the differences among the studied treatments, Duncan's Multiple Range test (DMR) was applied using the Statistical Analysis System (SAS) software, version 9.1.

RESULTS

Morphometric traits

Ducks reared under PYPS had the maximum body length (44.3 vs 40.19, 42.05cm), shank length (5.73 vs 4.94, 5.71cm), shank circumference (4.69 vs 3.91, 4.47cm), drumstick length (9.89 vs 8.10, 9.48 cm), drumstick circumference (5.69 vs 4.71 5.65 cm), beak length (5.04 vs 4.66, 4.92cm) and wing spread (29.21 vs 19.39, 27.99 cm) compared to IPS and FRPS. However, the results showed that the cloaca temperature did not exhibit significant differences among the various treatment groups (Table 2).

Table 2 – Morphological parameters of American Pekin ducks reared among different production systems.

Parameters	IPS	FRPS	PYPS	*p*-Value
Total body length (cm)	40.19 ± 0.72^b	42.05 ± 0.06^b	44.3 ± 0.19^a	0.0003
Shank Length (cm)	4.94 ± 0.02^b	5.71 ± 0.08^a	5.73 ± 0.01^a	0.0022
Shank Circumference (cm)	3.91 ± 0.07^b	4.47 ± 0.05^a	4.69 ± 0.02^a	0.0047
Drumstick Length (cm)	8.10 ± 0.19^b	9.48 ± 0.03^a	9.89 ± 0.04^a	0.0032
Drumstick Circumference (cm)	4.71 ± 0.03^b	5.65 ± 0.08^a	5.69 ± 0.03^a	0.0015
Beak length (cm)	4.66 ± 0.06^b	4.92 ± 0.01^a	5.04 ± 0.02^a	0.0137
Wing Spread (cm)	19.39 ± 0.35^b	27.99 ± 0.87^a	29.21 ± 0.10^a	0.0019
Cloacal Temperature (F)	105.49 ± 0.02^b	105.92 ± 0.06^b	105.51 ± 0.02^b	0.0067

Mean± Standard error; different superscripts within the same row signify significant difference ($p \leq 0.01$). Bat $p \leq 0.05$; IPS = Intensive production system (IPS), FRPS = Free-range production system (FRPS), PYPS = Pool with yard production system (PYPS).

Growth Performance

Ducks reared under PYPS exhibited better weight gain, weight gain, % and SGR followed by the birds reared under FRPS and IPS. PYPS birds had significantly higher weight gain on day 75 (P=0.0003), while lower weight gain was noted in birds under the intensive system (IPS). The weight gain % in PYPS was the highest among all treatments: until 30 days the percent value increased by about 96.8 (PYPS), which gradually decreased until 90 days. However, in the intensive rearing system, the weight gain % was higher at day 45 and declined further till day 90. In the FRPS, the weight gain % was comparatively higher than in the IPS (Table 3).

Table 3 – Growth Performance of American Pekin ducks reared under different production systems.

Parameters	Rearing system	d 15	d 30	d 45	d 60	d 75	d 90
Weight gain (g)	IPS	211.5 ± 1.5[c]	506.0 ± 3.0[c]	404.5 ± 3.5[c]	406.5 ± 6.5[c]	515.5 ± 2.5[c]	332.0 ± 1.0[c]
	FRPS	241.5 ± 1.5[b]	573.5 ± 4.5[b]	461.0 ± 4.0[b]	617.5 ± 0.5[a]	537.0 ± 5.0[b]	415.5 ± 3.5[b]
	PYPS	255.0 ± 1.0[a]	613 ± 1.0[a]	520 ± 1.0[a]	577.0 ± 1.0[b]	624.3 ± 0.5[a]	513.0 ± 6.0[a]
p-Value		0.0004	0.0004	0.0003	<.0001	0.0003	0.0002
Weight gain%	IPS	13.89 ± 0.52[b]	13.71 ± 0.0[c]	46.23 ± 0.66[c]	31.26 ± 0.04[a]	30.69 ± 0.12[a]	15.26 ± 0.07[b]
	FRPS	47.19 ± 2.82[a]	71.14 ± 2.71[b]	56.23 ± 1.55[b]	32.97 ± 0.47[a]	31.68 ± 1.11[a]	22.42 ± 0.32[a]
	PYPS	50.37 ± 5.64[a]	96.8 ± 4.5[a]	76.79 ± 1.95[a]	33.40 ± 0.72[a]	22.94 ± 0.71[b]	14.21 ± 0.5[b]
p-Value		0.0101	0.0007	0.0016	0.1065	0.0070	0.0008
SGR	IPS	0.36 ± 0.0[c]	0.61 ± 0.00[a]	0.22 ± 0.04[a]	0.26 ± 0.01[c]	0.36 ± 0.00[a]	0.08 ± 0.00[c]
	FRPS	0.42 ± 0.01[b]	0.61 ± 0.01[a]	0.18 ± 0.01[a]	0.39 ± 0.00[a]	0.22 ± 0.00[c]	0.16 ± 0.01[b]
	PYPS	0.45 ± 0.01[a]	0.62 ± 0.00[a]	0.21 ± 0.00[a]	0.32 ± 0.00[b]	0.31 ± 0.00[b]	0.19 ± 0.00[a]
p-Value		0.0021	0.2213	0.5635	0.0017	0.0002	0.0013

Mean± Standard error; different superscripts within the same column signify significant difference ($p \leq 0.01$). Bat $p \leq 0.05$; IPS = Intensive production system (IPS), FRPS = Free-range production system (FRPS), PYPS = Pool with yard production system (PYPS).

Serum chemistry

Total lipids (585.95 *vs* 533.2, 482.8 mg/Dl), triacylglycerol (133.3 *vs* 118.60, 115.5 mg/Dl), cholesterol (154.30 *vs* 130.60, 133.45 mg/Dl), meat cholesterol (143.60 *vs* 142.7, 131.7 mg/Dl) and meat triacylglycerol (133.35 *vs* 123.85, 122.75 mg/Dl) were higher in birds reared under IPS as compared to PYPS and FRPS. Albumin (2.65 *vs* 1.75, 2.5 mg/dl), AG ratio (1.75 vs 1.16, 1.30 mg/dl), total proteins (5.75 *vs* 2.60, 4.50 mg/dl), glucose (244.5 *vs* 225, 242.85 mg/dl) and globulin (5.10 *vs* 1.29, 2.93 mg/dl) were higher in birds reared under PYPS, followed by IPS and FRPS (Table 4).

Table 4 – Serum chemistry, and meat cholesterol and triacylglycerol of American Pekin ducks reared under different production systems.

Parameters	IPS	FRPS	PYPS	*p*-Value
Albumin (mg/dl)	1.75 ± 0.02[a]	2.50 ± 0.20[a]	2.65 ± 0.33[a]	0.1181
Globulin (mg/dl)	1.29 ± 0.06[c]	2.93 ± 0.05[a]	5.10 ± 0.00[b]	0.0003
AG Ratio (mg/dl)	1.16 ± 0.03[b]	1.30 ± 0.06[b]	1.75 ± 0.03[a]	0.0035
Total Protein (mg/dl)	2.60 ± 0.30[c]	4.50 ± 0.29[b]	5.75 ± 0.03[a]	0.0060
Total Lipids (mg/dl)	585.95 ± 3.95[a]	482.80 ± 4.500[b]	533.20 ± 1.00[c]	0.0006
Triacylglycerol (mg/dl)	133.25 ± 0.95[a]	115.50 ± 1.20[b]	118.30 ± 1.00[b]	0.0024
Cholesterol (mg/dl)	154.30 ± 2.00[a]	133.45 ± 1.05[b]	130.60 ± 0.20[b]	0.0019
Glucose (mg/dl)	225.00 ± 4.00[b]	242.85 ± 0.45[a]	244.50 ± 3.50[a]	0.0357
Meat cholesterol (mg/dl of extract)	143.60 ± 1.40[aa]	131.70 ± 0.70[b]	142.70 ± 0.70[a]	0.0058
Meat Triacylglycerol (mg/dl of extract)	133.35 ± 1.15[a]	122.75 ± 0.45[b]	123.85 ± 0.45[bb]	0.0039

Mean± Standard error; different superscripts within the same row signify significant difference ($p \leq 0.01$). Bat $p \leq 0.05$; IPS= Intensive production system (IPS), FRPS = Free-range production system (FRPS), PYPS= Pool with yard production system (PYPS)

Cellular immunity

The birds reared under the PYPS system exhibited higher levels of phagocytic activity, eosinophils, basophils, and monocytes when compared to birds raised under the IPS and FRPS systems. However, no significant differences in the phagocytic index, lymphocytes, and heterophiles were observed among the treatment groups (Table 5).

Table 5 – Cellular immunity of Pekin ducks reared under different production systems.

Parameters	IPS	FRPS	PYPS	*p*-Value
Phagocytic Index	1.32 ± 0.11a	1.44 ± 0.23a	1.93 ± 0.06a	0.1229
Phagocytic Activity	15.80 ± 0.40b	18.31 ± 0.49a	17.78 ± 0.33a	0.0449
Eosinophils	7.45 ± 0.11b	7.69 ± 0.07b	8.16 ± 0.01a	0.0153
Lymphocytes	33.31 ± 0.91a	33.73 ± 0.49a	34.80 ± 060a	0.4019
Heterophiles	24.50 ± 0.20b	23.21 ± 0.09b	24.82 ± 050a	0.0702
Basophiles	0.86 ± 0.05b	1.33 ± 0.01a	1.50 ± 0.07a	0.0053
Monocytes	4.49 ± 0.17b	5.37 ± 0.05a	5.45 ± 0.22a	0.0415

Different superscripts on means within row differ significantly at $p \leq 0.05$; IPS = Intensive production system (IPS), FRPS = Free-range production system (FRPS), PYPS = Pool with yard production system (PYPS).

Intestinal morphology

In comparison to other treatment groups, birds reared under the PYPS system had significantly higher values for the colon (11.95, p=0.0079), jejunum (75.05, p=0.0013), ileum (75.55, p=0.0233), duodenum (35.70, p=0.0066), caeca (34.67, p=0.0011), and total intestine (229.10, p=0.0003) (Table 6).

Table 6 – Intestinal morphology parameters of Pekin duck's reared under different production systems.

Parameters	IPS	FRPS	PYPS	*p*-value
Colon (cm)	11.10 ± 0.10^{c}	11.55 ± 0.05^{b}	11.95 ± 0.05^{a}	0.0079
Jejunum (cm)	71.25 ± 0.05^{c}	73.45 ± 0.25^{b}	75.05 ± 0.15^{a}	0.0013
Ileum (cm)	73.55 ± 0.35^{b}	74.20 ± 0.00^{b}	75.55 ± 0.25^{a}	0.0233
Duodenum (cm)	33.60 ± 0.20^{c}	34.95 ± 0.05^{b}	35.70 ± 0.20^{a}	0.0066
Caeca (cm)	30.35 ± 0.15^{c}	33.38 ± 0.18^{b}	34.67 ± 0.22^{a}	0.0011
Total intestine (cm)	224.85 ± 0.05^{c}	226.37 ± 0.03^{b}	229.10 ± 0.20^{a}	0.0003

Different superscripts on means within row differ significantly at $p \leq 0.05$; IPS = Intensive production system (IPS), FRPS = Free-range production system (FRPS), PYPS = Pool with yard production system (PYPS)

Carcass traits

The slaughtering traits of Pekin ducks were measured and are presented in (Table 7). The results showed that there were no significant differences in carcass traits among the treatment groups. However, PYPS-reared birds had the numerically highest values in all parameters of carcass traits.

DISCUSSION

As waterfowl, ducks have a different physiological structure than other poultry birds, given their high quantity of red fiber content in muscles. The rearing system or housing system is the most significant factor that can affect the different growth parameters. For assessing poultry production, growth-related parameters are the most direct indexes (Chen *et al.*, 2015). Our study examined the effect of different rearing or housing systems on various growth parameters in ducks. The results indicate that the highest weight gain was recorded in ducks reared under the PYPS (Pool with yard production system) as compared to the FRPS (Free-range production system) and IPS (Indoor production system). These results can be attributed to the natural behavior of ducks as waterfowl and the availability of a pool, which has been shown to enhance growth parameters. Furthermore, the eco-friendly environment provided by allowing ducks to access an appropriate backyard, and the minimization of energy loss due to confinement in the FRPS could be significant factors contributing to the efficient improvements in growth characteristics observed in the PYPS group. These outcomes are consistent with (Erisir *et al.*, 2009), who reported that a swimming pool efficiently improved the weight and efficiency of feed, while also enhancing the final weights of Pekin ducks. Abo Ghanima *et al.* (2020) concluded that the intensive system (closed house) showed the lowest

Table 7 – Slaughter traits of Pekin ducks reared under different production systems.

Parameters	IPS	FRPS	PYPS	*p*-Value
Live body weight (g)	1403 ± 53.0^{a}	1203 ± 57^{a}	1432.5 ± 54.5^{a}	0.1064
Blood volume (ml)	61.5 ± 1.5^{ba}	52.0 ± 5.0^{b}	71.5 ± 3.5^{a}	0.0713
Shank weight (g)	39.5 ± 1.5^{a}	34.0 ± 1.0^{a}	40.0 ± 2.0^{a}	0.1224
Feather weight (g)	251.5 ± 16.5^{b}	253.0 ± 2.0^{b}	329.5 ± 6.5^{a}	0.0202
Head weight (g)	75.0 ± 2.0^{ba}	64.5 ± 3.5^{b}	79.5 ± 1.5^{a}	0.0496
Intestine weight (g)	65.5 ± 2.5^{a}	57.5 ± 1.5^{a}	68.0 ± 3.0^{a}	0.1070
Heart weight (g)	9.5 ± 0.5^{a}	9.0 ± 1.0^{a}	9.50 ± 0.5^{a}	0.8538
Carcass weight (g)	559.5 ± 39.5^{a}	478.5 ± 21.5^{a}	583.0 ± 39.0^{a}	0.2259
Leg quarter weight (g)	130 ± 10.0^{a}	118.0 ± 8.0^{a}	131.5 ± 13.5^{a}	0.6622
Neck weight (g)	78.0 ± 3.0^{a}	62.5 ± 5.50^{a}	74.5 ± 9.50^{a}	0.3482
Breast weight (g)	156.5 ± 6.50^{ba}	133.5 ± 5.50^{b}	203.0 ± 16.5^{a}	0.0394
Ribs weight (g)	109.5 ± 4.5^{a}	92.0 ± 7.0^{a}	117.0 ± 5.0^{a}	0.1050
Ribs + Back weight (g)	250.5 ± 7.5^{a}	224.5 ± 14.5^{b}	277.50 ± 9.5^{a}	0.0911
Wings weight (g)	85.0 ± 11.0^{a}	64.5 ± 3.5^{a}	99.5 ± 9.5^{a}	0.1368
Liver weight (g)	28.5 ± 0.5^{b}	26.5 ± 0.5^{c}	31.5 ± 2.50^{a}	0.2050

Different superscripts on means within row differ significantly at $p \leq 0.05$; IPS = Intensive production system (IPS), FRPS = Free-range production system (FRPS), PYPS = Pool with yard production system (PYPS).

growth parameter as compared to other housing systems. The results showed that, given the behavior of ducks as waterfowl, permitting access to the open yard and water increased their welfare and fattening performance. El-Edel *et al.* (2015) concluded that during week 4, weight gain was found to be higher in closed housing as compared to outdoor housing of ducks. Moreover, a few authors concluded that animals raised in closed houses showed the lowest growth rate as compared to open houses (Damaziak *et al.*, 2014).

Our study revealed significant differences in morphometric parameters among the different production systems, with PYPS showing higher values compared to FRPS and IPS. Similar to our findings, Henrik *et al.* (2018) reported that the morphometric measurements in PYPS were increased more than in other treatments. They found that body weight, shank circumference, and length, body length, drumstick length and circumference, wing spread, and beak length were significantly higher in PYPS as compared to FRPS and IPS. According to Yakubu *et al.* (2011), morphometric traits like body weight, body length, leg length, and thigh circumference differed significantly among different housing systems, supporting the evidence found in this study. Altogether, previous studies showed that PYPS had positive effects on the morphometric parameters of American Pekin ducks.

Blood biochemical profiles are widely used as indicators of the metabolic and physiological status of birds, and can be affected by various factors, including rearing or housing systems (Wang *et al.*, 2015). At the end of our study, we measured the blood biochemical profile and found significant differences among the treatments. Our results are in line with the findings of previous studies, such as Qiao *et al.* (2017), who reported that rearing in a confined house can reduce cholesterol and triacylglycerol levels. Erisir *et al.* (2009) observed that raising birds in open and closed yards can lead to a reduction in the level of triacylglycerol and cholesterol due to the increased physical activity. We also found significant differences in cellular immunity among the treatments, with PYPS-reared birds exhibiting higher values for phagocytic activity, monocytes, eosinophils, and basophils. These results are consistent with the findings of Abo Ghanima *et al.* (2020).

Providing ducks with access to the yard, especially with free access to the pool, can improve their immunity. This approach can enhance the ducks' environment and encourage their natural behavior as waterfowl, which may promote efficient growth and development. However, as per El-Edel *et al.* (2015), phagocytic activity and index in intensive housing were lower than in outdoor housing, possibly due to the limited space. The morphology and health of the intestinal tract of birds are certainly affected by the conditions of the environment (Camp *et al.*, 2009). The length and diameter of the intestine varied significantly among the different treatments. PYPS had the highest value as compared to the other treatment groups. The results indicated that ducks in PYPS have better health and biochemical factors than those of the intensive and semi-intensive systems. In a previous study by Wasilewski *et al.* (2015), shorter ileum and duodenum were observed along with slightly bigger intestinal diameters, whereas Gabriel *et al.* (2008) observed that in the diet of chicken, dietary feed (whole wheat) in amounts up to 20g/kg to 40g/kg showed no impact on the comparative length of the intestine.

Our study revealed significant differences in carcass traits among the different rearing systems, with PYPS birds showing higher values in overall parameters. These results are consistent with the findings that Abo ghanima *et al.* (2020), who reported that a free-range rearing system reduced some carcass traits, as well as the percentage of dressing. Yard and swimming pool integration in duck-rearing enhances carcass traits, encouraging natural behavior, varied diets, muscle development, and cleaner birds with healthier feathers. It also aligns with ethical practices, and appeals to quality-conscious consumers. Additionally, there are improvements in the fiber muscle diameter of ducks raised in free-range systems with access to a pool, which may be attributed to increased physical activity and natural growth patterns observed in these birds after hatching.

CONCLUSIONS

It can be concluded that production systems significantly affect the growth, immune response, serum chemistry, and carcass traits of American Pekin ducks. The ducks raised in the pool with yard production system (PYPS) fed up to 100% kitchen waste had greater growth performance, morphometric parameters, serum chemistry profile, cellular immunity, and carcass traits compared to those raised in the intensive and free-range production systems. The PYPS not only increased the overall growth-related parameters, but also minimized the ecological cost and increased the farmer's income through proper utilization of natural resources.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Punjab Agriculture Research Board (PARB) for providing financial support for the development of PYPS Aquaculture Research Unit (IARU) at the Department of Fisheries and Aquaculture, University of Veterinary and Animal Sciences, Ravi Campus, Pattoki, Pakistan.

FUNDING

This manuscript is part of project sponsored by Punjab Agriculture Research Board PARB under grant No.674.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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