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Assessment of Stocking Rate and Housing System on Performance, Carcass Traits, Blood Indices, and Meat Quality of French Pekin Ducks

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Abstract: Commercial practice in poultry production management has been susceptible to increased problems, driven by concerns about safety of food and animal welfare. Thus, the main proposal of the present study was to evaluate the influence of different stocking densities on performance, blood, and carcass traits of Pekin ducklings reared on two different floor types (wood shaving litter, WSL or plastic slatted floor, PLS). A total of 450 one-day-old ducklings were randomly allocated into six equal experimental groups stocking density (nine, 15 and 21 birds/m^2 during the first 14 d and three, five and seven birds/m^2 until 49 days) reared on two floor types (WSL and PLS), five replicate pens each. Increased stocking density reduced body weight (BW), weight gain (WG), and feed conversion ratio (FCR) values and increased feed intake (FI) in both floor types at 14 days old. At 49 days old, reared ducklings on PLS type verified higher BW and WG and reduced FCR values. Moreover, increasing stocking density in both floor types significantly reduced the breast, thigh, and left fillet percentages. Conversely, reared birds floored on PLS system decreased the triglycerides (TG) and increased the total cholesterol (TC) serum content. Furthermore, the meat contents of TG and TC were decreased in birds reared on higher stocking density but not affected by floor type. Further, serum antioxidant indices were reduced in PLS birds on low stocking densities. In conclusion, housing Pekin ducklings on PLS improved their growth performance, carcass traits, meat cholesterol, and antioxidant status, particularly at stocking density of three and five birds/m^2.

Keywords: antioxidant enzymes; performances; floor type; Pekin ducks; stocking density

1. Introduction

Over the past 20 years, the growth of the duck industry has substantially increased, where about 1.15 billion ducks were kept worldwide in 2017 [1]. Egypt is the most abundant duck producer in Africa, with production rate increased from 67% in 2000 to 77% in 2013 [1]. This elevation was achieved to meet the growing demand for duck meat by using intensive production systems. The intensive production of Pekin ducks has been transited from conventional free-range and open water outdoors to confinement and environmentally controlled production that allows for higher stocking density.

Although increasing the number of birds per unit area results in higher economic returns, it may reduce the well-being, health, and performance of birds. Several investigations have been reported the effect of stocking density on broilers [2–4]. However, the information concerned that its effect on duck production is sparse and has not been renewed [5–7]. Simsek et al. [8] investigated that the high stocking density reduced performance as a result of numerous factors, such as high temperature stress of the birds per unit, insufficient air exchange, high ammonia levels, and lower the palatability for feed and consumption of water. Several studies reviewed the effects of a high stocking density on reduced performance and a high occurrence of footpad dermatitis, scratches, bruising, low feathering, and condemnations on broilers [9]. Besides, Zhang et al. [10] illustrated that a high stocking density suppressed the immune response and induced atrophy on the spleen of Pekin ducks. The maximum stocking density of seven-week-old Pekin ducks recommended in the European production systems ranged from six to eight duckling s/m^2 [11] while the maximum recommendations of FASS [12] for two and seven-week-old growing ducks in litter floor and wire floor were 21.6 and 22.8, and 5.4 and 6.2 bird s/m^2, respectively. Consequently, Osman [13] reported that stocking density significantly affected growth performance, carcass traits and meat quality of Pekin ducks and recommended stocking density of four duckling s/m^2 from five to ten weeks of age. Also, Rodenburg et al. [11] found that higher growth performance and carcass quality achieved by seven and nine birds/m^2 and recommended stocking density ranging from five to 15 duck s/m^2 based on marketing age, management level and flooring types. Meanwhile, Xie et al. [5] noticed a significant reduction in the final body weight of ducks when stocking density elevated to nine bird s/m^2. Furthermore, the recommended stocking density in the duck industry in Egypt is set as five bird s/m^2 to obtain higher growth performance without any noticeable alterations in ducks' behavioral traits [14]. In addition, several investigations revealed that high stocking density can lower carcass traits [15,16], growth performance [3,4,16–18], antioxidative activity [3], and immunity status [19,20] in broiler and meat quality in male Pekin ducks [13]. It can also elevate serum corticosterone levels in laying hens [21] and help in the occurrence of footpad and skin lesions in broiler chickens [15,17,18]. Moreover; in ducks, a high stocking density affected the liver proteomics such as serum MDA, lipid metabolism, serum low-density lipoprotein cholesterol (LDL-C), acyl-CoA synthetase, and catalase in ducks [22].

Appropriate flooring type must be considered to meet the requirements for birds' welfare, particularly on high stocking density that are used in the intensive production of ducks. In the United Kingdom, commercial farms typically have solid flooring with straw as bedding. In contrast, in Egypt and the United States, the predominant commercial flooring systems are solid floors with wood shavings litter, plastic/wire slatted floor, or a combination of both systems. The floor type could negatively or positively affect the environment, welfare, and performance of commercial ducks as each floor type has some advantages and disadvantages.

The ducks reared on wood shaving litter are highly susceptible to respiratory and enteric diseases and have impaired nostril and eye scores because of the prevalence of dust and direct contact with manure and wet litter. Moreover, the conventional litter materials are rapidly cumulative on the conditions of high stocking density, besides increasing the potential of leg abnormalities and lower carcasses quality in addition to their contribution to raising the ambient temperature, relative humidity and concentrations of CO_2 and NH_3 within the shed [23–25]. On the other hand, the plastic-slatted floors resolve all problems of wood shaving litter because there is no litter to be used and the convenience of cleaning and disinfection operations improves ammonia management and footpad scores. Furthermore, the plastic–slatted floors are very durable, easy to install and clean, cost-effective, and do not deteriorate or need rapid replacement. However, it needs high initial investment costs and may worsen bird welfare [26,27]. Therefore, the main objective of the present study is to assess the optimum stocking densities and its interactive effects with typical flooring type used in commercial French Pekin duck production in Egypt on growth performance, carcass traits, meat cholesterol, and antioxidative status.

2. Materials and Methods

The bird management followed the regulations of the Animal Care and Ethics Committee at Animal Husbandry and Animal Wealth Development Department, Faculty of Veterinary Medicine, Damanhour, University, Egypt (DMU/VetMed-2019-/0145).

2.1. Experimental Design and Birds Management

Four hundred and fifty one-day-old French Pekin ducklings from a commercial hatchery were randomly assigned into six equal experimental groups with five replicate pens (three m^2 size each). Firstly, at initial duck placement, all birds were brooded on one-third of pen size through the first 14 days of age, making the stocking density during this period nine, 15 and 21 birds/m^2. Then, the ducklings were allocated into the all pen size to obtain three different stocking densities (three, five and seven birds/m^2 from 15 days of age till the end of the experiment as described by Bai et al. [28]), each group were reared in two flooring types (wood shaving litter, WSL and plastic slatted floor, PLS). The depth of wood shaving litter was 7.5 cm, while plastic slatted floor dimensions were (50 × 50 cm) consisted of holes (15 × 10 mm) and bridges (steel bars covered with plastic; width 3.5 mm). During the entire experimental period, the excreta were stored at a depth of approximately 20 cm on the slatted floor. Birds were housed in open-sided houses naturally ventilated, and pens of WSL and PLS were separated with net walls one m height not to interfere with air movement. All birds had free access to water and feed using supplemental feeders and drinkers. Commercial duckling diets were formulated to meet the recommendations of NRC [29] (Table 1). Ducklings were subjected to the same vaccination program, exposed to continuous (24 h a day) illumination program and brooded at 33 °C at the birds' level during the first three days of age. Then the temperature was gradually reduced until it was attained after the room temperature (24 °C) at 14 days of age.

2.2. Growth Performance Traits

Body weights (BW), weight gain (WG), and feed intake (FI) were recorded at 14 and 49 days of age in early morning before receiving any feed. FCR was also calculated as described by Arif et al. [30]. On 49 days, after 12 h of feed deprivation, five birds per group, one bird/replicate/group, were randomly selected, weighed, slaughtered, scalded, wet-plucked, and eviscerated. Hot carcass, liver, heart, and abdominal fat were individually weighed and proportioned to pre-slaughter weight. The blood, limbs, head, neck, lungs, and viscera were termed as the offal and discarded. The carcass was cut onto separate parts including breast (muscles with the sternum), thigh (average of two thighs weight), shoulder (average of two shoulders weight), and left filet (the de-skinned left pectoral muscle) and each was weighed and proportioned to the pre-slaughter weight [31]. Pectoral major muscle samples were immediately collected and stored at −20 °C until the analysis of cholesterol and triglycerides contents.

2.3. Blood Biochemistry and Tissue Cholesterol Content

Blood samples were collected during slaughtering from one bird/replicate/group in labeled test tubes. Blood samples were kept to clot, then centrifuged at 3,500× *g* for 12 min, and sera were separated and preserved at −25 °C until the biochemical analysis. Serum concentrations of alanine aminotransferase (ALT), aspartate aminotransferase (AST), uric acid, creatinine, triglycerides (TG), total cholesterol (TC), and total lipids (TL) were determined spectrophotometrically (Spectronic 1201, Milton Roy, Ivyland, PA, USA) using commercial kits of Bio-diagnostic Co., Egypt according to the manufacturer's instructions [32]. Serum malondialdehyde (MDA) content and glutathione peroxidase (GPx), catalase, and superoxide dismutase (SOD) activities were estimated using ELISA Kit of QuantiChrom™ (Hayward, CA, USA), BioAssay Systems (Hayward, CA, USA) and Cayman Chemical Company (Hayward, CA, USA) [33]. Total cholesterol and triglycerides contents in breast muscle samples were estimated according to the modified method of Dinh et al. [34].

Table 1. Ingredients and calculated chemical composition of the basal diets.

Ingredients	Starter (%)	Grower (%)
Yellow corn	54.14	65.05
Soybean meal (44% CP)	40.10	29.19
Soya bean oil	2.90	2.90
Limestone	1.00	1.00
Di-calcium phosphate	1.00	1.00
DL-methionine	0.11	0.11
NaCl	0.25	0.25
Vitamin-mineral Premix [1]	0.50	0.50
Chemical analysis (%) [2]		
Crude protein	22.00	18.01
ME (kcal/kg)	2945	2985
Crude fiber	3.72	4.44
Ash	7.69	6.17
Dry matter	92.50	93.07
Ether extract	3.77	3.36

[1] Provides each kg of diet: Vit. A: 12000 IU, Vit. D_3: 5000 IU, Vit. E: 130.0 mg, Vit. K_3: 3.605 mg, Vit. B_1: 3.0 mg, Vit. B_2: 8.0 mg, Vit. B_6: 4.95 mg, Vit. B_{12}: 0.17 mg, Niacin: 60.0 mg, Folic acid: 2.083 mg, D-Biotin: 200.0 mg, calcium D-Pantothenate: 18.333 mg, Copper: 80 mg, Iodine: 2.0 mg, Selenium: 150.0 mg, Iron: 80.0 mg, Manganese: 100.0 mg, Zinc: 80.0 mg, Cobalt: 500.0 mg. [2] Calculated according to NRC [29].

2.4. Statistical Analysis

Collected data were subjected to two-way ANOVA with the General Linear Models using SPSS software, Version 18.0 to examine the effects of floor types (plastic slatted floor vs wood shaving litter), stocking density (nine, 15 and 21 birds/m^2 during the first 14 days and three, five and seven birds/m^2 for the remaining period) and their interaction. The experimental unit for growth performance traits was the replicate pen, while individual birds were considered as the experimental unit for the rest of the parameters. To test the normal distribution of data and homogeneity of variance, Shapiro-Wilk and Levene's tests were performed. When a significance between floor types, stocking densities, or their interaction, means of treatments were separated using Tukey's multiple range test at a significance level of $p < 0.05$.

3. Results

3.1. Growth Performance

The impacts of different stocking densities and flooring types on growth performance are presented in Table 2. Body weight (BW) and WG were significantly reduced ($p < 0.001$) in both flooring systems with the increase in stocking density at 14 days of age, however they were not affected by flooring type. At 49 days of age, ducklings reared on PLS recorded higher BW and WG than those raised on WSL at the same stocking density. However, BW and WG of Pekin ducks were not affected by the interaction between stocking density and type of floor. Daily feed intake of birds housed on WSL was reduced during the period from 1–14 d ($p = 0.001$) while it has not differed from those reared on PLS during the periods from 15–49 days and 1–49 days (Table 2). However, during these periods, FI was increased in both flooring types by increasing stocking density.

Moreover, at a stocking density of three birds/m^2, birds reared on WSL consumed a lower amount of feed than those reared on PLS during the overall experimental period. FCR was compromised by increasing stocking density when birds were housed on either WSL or PLS flooring materials during all experimental periods except during 1–14 days for littered birds.

Furthermore, overall, FCR was improved when birds floored on PLS and impaired when ducklings housed at a stocking density of five and seven birds/m^2.

Table 2. Effects of stocking density (STD) and flooring type (FT) on body weight, weight gain, feed intake and feed conversion ratio of Pekin ducks.

FT	STD (bird/m^2)		BW (g/bird)			WG (g/bird/day)			FI (g/bird/day)			FCR (g/g)		
			Period in days											
			Day old	14	49	1–14	15–49	1–49	1–14	15–49	1–49	1–14	15–49	1–49
	14 day	49 day												
WSL	9	3	43.40	605 ^{a}	3385 ^{b}	40.14 ^{a}	79.44 ^{ab}	68.21 ^{ab}	87.29 ^{a}	216.7 ^{d}	179.7 ^{c}	2.18 ^{b}	2.73 ^{cd}	2.64 ^{d}
	15	5	43.20	591 ^{ab}	3316 ^{c}	39.13 ^{b}	77.87 ^{b}	66.80 ^{b}	84.59 ^{cd}	224.3 ^{ab}	184.4 ^{a}	2.16 ^{b}	2.88 ^{a}	2.76 ^{b}
	21	7	43.20	571 ^{bc}	3281 ^{d}	37.71 ^{c}	77.43 ^{b}	66.09 ^{b}	83.99 ^{d}	225.6 ^{a}	185.2 ^{a}	2.23 ^{ab}	2.91 ^{a}	2.80 ^{a}
PLS	9	3	43.40	604 ^{a}	3461 ^{a}	40.04 ^{a}	81.63 ^{a}	69.75 ^{a}	86.51 ^{ab}	220.3 ^{c}	182.1 ^{b}	2.16 ^{b}	2.70 ^{d}	2.61 ^{d}
	15	5	43.60	581 ^{b}	3401 ^{ab}	38.43 ^{bc}	80.57 ^{ab}	68.53 ^{ab}	86.47 ^{ab}	223.1 ^{ab}	184.1 ^{ab}	2.25 ^{a}	2.77 ^{bc}	2.67 ^{c}
	21	7	43.20	567 ^{c}	3352 ^{bc}	37.41 ^{c}	79.57 ^{b}	67.53 ^{b}	85.79 ^{bc}	222.0 ^{bc}	183.1 ^{ab}	2.29 ^{a}	2.79 ^{b}	2.71 ^{c}
SEM			0.205	3.25	1.85	0.23	0.31	0.24	0.28	0.64	0.42	0.01	0.02	0.01
Two-Way ANOVA (*p*-Value)														
FT			0.786	0.201	<0.001	0.182	<0.001	<0.001	0.018	0.589	0.967	0.026	<0.001	<0.001
STD			0.915	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.003	<0.001	<0.001
STD × FT			0.916	0.688	0.850	0.651	0.759	0.858	0.013	0.003	0.011	0.104	0.016	0.041

BW, body weight; WG, weight gain; FI, feed intake; FCR, feed conversion ratio; FT, Floor type; WSL, Wood shaving litter; PLS, Plastic slatted floor; STD, stocking density. SEM: Standard error of mean. Means in the same column bearing different superscript letters are significantly different ($p < 0.05$).

3.2. Carcass Characteristics

Regardless of floor type, the dressing percentage of Pekin ducklings was reduced ($p < 0.001$) by increasing stocking density from three to five birds/m^2 but not significantly differed between five and seven birds/m^2 (Table 3). Birds floored on PLS recorded higher ($p = 0.012$) dressing percentage than those reared on WSL. Abdominal fat was not affected by stocking density while decreased ($p = 0.012$) when ducklings floored on PLS. The relative weight of thigh was reduced ($p < 0.001$) when ducks were housed at seven birds/m^2, while left fillet relative weight was decreased in birds reared on WSL compared to those of PLS and also at higher stocking densities. Relative weights of liver, heart, breast and shoulder were not affected by floor type or stocking density. All carcass traits were not affected by the interaction between floor type and stocking density.

Table 3. Effects of stocking density (STD) and flooring type (FT) on carcass traits of Pekin ducks at 49 days of age.

FT	STD (bird/m^2)	Dressing %	Liver %	Heart %	Abdominal Fat %	Breast %	Thigh %	Shoulder %	Left Filet %
WSL	3	61.2 ^{a}	4.03	1.16	2.46 ^{a}	28.8	12.4 ^{ab}	7.20	12.1 ^{a}
	5	59.0 ^{b}	5.17	1.13	2.52 ^{a}	28.8	12.2 ^{b}	7.21	11.8 ^{ab}
	7	58.4 ^{c}	3.96	1.06	2.36 ^{ab}	28.4	11.8 ^{c}	7.10	11.5 ^{b}
PLS	3	62.2 ^{a}	4.03	1.15	2.20 ^{c}	29.4	12.9 ^{a}	7.32	12.2 ^{a}
	5	60.4 ^{ab}	4.00	1.07	2.19 ^{c}	29.1	12.6 ^{a}	7.22	12.1 ^{a}
	7	59.6 ^{b}	3.96	1.11	2.26 ^{b}	28.5	12.1 ^{b}	7.14	11.9 ^{ab}
SEM		0.31	0.21	0.01	0.05	0.14	0.09	0.03	0.05
Two-Way ANOVA (*p*-Value)									
FT		0.012	0.336	0.671	0.012	0.353	0.005	0.254	0.002
STD		<0.001	0.389	0.059	0.910	0.137	<0.001	0.074	<0.001
STD × FT		0.934	0.397	0.157	0.534	0.726	0.779	0.637	0.216

FT, Floor type; WSL, Wood shaving litter; PLS, Plastic slatted floor; STD, stocking density. SEM: Standard error of the mean. Means in the same column bearing different superscript letters are significantly different ($p < 0.05$).

3.3. Blood Metabolites and Meat Cholesterol

Serum concentrations of uric acid, creatinine and total lipids were not altered either by stocking density, floor type or their interaction (Table 4). Serum AST and ALT activities were increased ($p = 0.036$ and $p < 0.001$) in birds housed in a stocking density of seven birds/m2, while only ALT was reduced ($p = 0.006$) in birds reared on PLS. The serum level of TG was reduced ($p = 0.001$) in birds floored on PLS while TC was elevated ($p = 0.019$) in the same birds. Nevertheless, the meat contents of TG and TC were reduced ($p = 0.004$ and $p = 0.005$) in birds reared on higher stocking density but not affected by floor type. Serum TL was not influenced by the main factors or their interaction. All the parameters as mentioned above were not affected by the interaction between floor type and stocking density except TC of meat, which was reduced in birds reared on WSL and PLS at five and seven birds/m^2, respectively.

Table 4. Effects of stocking density (STD) and flooring type (FT) on blood biochemistry and meat cholesterol of Pekin ducks at 49 days of age.

FT	STD (bird/m^2)	ALT (g/dL)	AST (g/dL)	Uric acid (mg/dL)	Creatinine (mg/dL)	Serum (mg/dL)			Meat (mg/dL)	
						TG	TC	Total lipids	TG	TC
WSL	3	30.0 ^{b}	70.2 ^{d}	5.06	2.84	155 ^{a}	135.1	568.4	138.4 ^{b}	131.0 ^{a}
	5	32.6 ^{a}	73.4 ^{c}	5.18	1.09	145 ^{ab}	131.6	544.9	134.8 ^{bc}	129.6 ^{ab}
	7	33.0 ^{a}	75.4 ^{b}	5.30	1.16	155 ^{a}	135.8	567.4	128.6 ^{d}	126.2 ^{c}
PLS	3	28.4 ^{c}	70.8 ^{d}	5.10	1.03	143 ^{b}	153.1	571.8	142.0 ^{a}	131.2 ^{a}
	5	30.4 ^{b}	76.0 ^{ab}	5.02	1.06	129 ^{c}	144.7	530.0	132.6 ^{c}	127.4 ^{bc}
	7	31.8 ^{ab}	79.4 ^{a}	5.00	1.09	129 ^{c}	146.7	529.4	134.2 ^{bc}	129.2 ^{ab}
SEM		0.39	1.11	0.07	0.29	2.92	2.91	3.92	1.19	0.49
Two-Way ANOVA (p-Value)										
FT		0.006	0.253	0.325	0.293	0.001	0.019	0.307	0.252	0.680
STD		<0.001	0.036	0.915	0.420	0.156	0.691	0.249	0.004	0.005
STD × FT		0.759	0.795	0.611	0.388	0.483	0.868	0.570	0.270	0.049

FT, Floor type; WSL, Wood shaving litter; PLS, Plastic slatted floor; STD, stocking density. SEM: Standard error of the mean; ALT: alanine aminotransferase; AST: aspartate aminotransferase; TG: triglycerides; TC: total cholesterol. Means in the same column bearing different superscript letters are significantly different ($p < 0.05$).

3.4. Anti-Oxidative Activity

Regardless of the stocking density, serum MDA content and SOD and catalase activities were reduced in birds housed on the PLS floor compared to those housed on WSL (Table 5). Malondialdehyde level was reduced ($p < 0.001$) in the serum of ducks reared on stocking density of five and seven birds/m^2. In contrast, at the same stocking density, the SOD, GPx and catalase activities were increased ($p < 0.001$). None of those, as mentioned earlier, parameters were affected by the interaction between stocking density and floor type.

Table 5. Effects of stocking density (STD) and flooring type (FT) on anti-oxidative activity of Pekin ducks at 49 days of age.

FT	STD (bird/m^2)	MDA (nmoles/mL)	SOD (U/gHb)	GPx (U/gHb)	Catalase (U/gHb)
WSL	3	10.1 ^{c}	60.2 ^{c}	22.2 ^{bc}	1.89 ^{c}
	5	10.3 ^{ab}	63.1 ^{bc}	24.4 ^{b}	2.26 ^{ab}
	7	10.8 ^{a}	67.8 ^{a}	29.2 ^{a}	2.42 ^{a}
PLS	3	10.1 ^{c}	58.2 ^{d}	21.6 ^{c}	1.78 ^{d}
	5	10.2 ^{b}	61.8 ^{bc}	25.4 ^{b}	1.96 ^{bc}
	7	10.4 ^{ab}	64.1 ^{b}	28.1 ^{a}	2.15 ^{b}
SEM		0.06	0.74	0.58	0.05
Two-Way ANOVA (p-Value)					
FT		0.028	0.039	0.640	0.002
STD		<0.001	<0.001	<0.001	<0.001
STD × FT		0.204	0.602	0.277	0.444

FT, Floor type; WSL, Wood shaving litter; PLS, Plastic slatted floor; STD, stocking density. SEM: Standard error of the mean; MDA: malondialdehyde; SOD: superoxide dismutase; GPx: glutathione peroxidase. Means in the same column bearing different superscript letters are significantly different ($p < 0.05$).

4. Discussion

Few investigations have studied the effect of stocking density on the growth performance of waterfowl, although it has been intensively investigated on broilers [2,3] and laying hens [35,36]. Generally, it has been reported that high stocking density can adversely affect growth performance, even when the same feeding space was maintained for each bird [4,5,37]. In the present study, we adhered to the prescribed maximum limits, and its effect on different flooring materials were tested. According to our study results, increasing stocking density depressed BW, WG, and FCR in both flooring types at 14 and 49 days, however, at the end of fattening period ducklings recorded better BW, WG, and FCR when reared on PLS than those of WSL at the same stocking density. Daily FI of WSL ducks was reduced but not affected in PLS ones during the period from 1–14 days while from 1–49 and 15–49 days, it was increased in both floor type by increasing stocking density.

These findings are in agreement with those obtained by Zhang et al. [38] who noticed WG and FCR of ducks were significantly compromised when reared on stocking density of eight and 11 birds/m^2 in comparison with that of five birds/m^2. Xie et al. [5] reported a significant reduction in WG of White Pekin ducks at STD of nine birds/m^2 compared with the lower stocking density. However, the authors did not find a significant effect on FCR. The reduction in growth performance of ducks reared on high stocking density could be explained by the deterioration in the antioxidant capacity of ducks, as described below, which disturb the antioxidant defense system and lead to the oxidative stress [39,40]. Though, the variations in growth performance of ducks reared on various flooring types may be due to the ability of birds to swap their body heat with the ground underneath, the air, and bedding floor materials [41].

Moreover, the possible reason for the enhancement in the growth performance of Pekin ducks housed on PLS was their lack of direct contact with feces, which maintains better environmental hygiene and thus reduces the incidence of diseases. In line with our findings, Çavuşoğlu et al. [26] and Chuppava et al. [42] reported that broilers brooded on PLS observed higher BW than those reared on WSL. Nevertheless, in a study conducted by Almeida et al. [43], the authors noticed insignificant alterations in BW of broiler chickens reared either on PLS or WSL. These discrepancies in results could be attributed to the differences in ambient temperature, season, strain, or sex [44,45].

The obtained results concerning the carcass traits are following the results of El-Deek and Al-Harthi [46], Osman [13], and Cravener et al. [47] who reported significant reductions in carcass weight, dressing percentage and breast meat yields of broilers and Pekin ducks by increasing stocking density. Similarly, recent researches revealed significant depression in absolute and relative weights of breast fillet with the increase in stocking density [15,22]. Moreover, Şimşek et al. [48] and Bahreiny et al. [49] noticed a significant elevation in the breast weight of caged birds than floored birds. Contrarily, other researchers observed non-significant effect of stocking density or floor type on carcass characteristics of Pekin and Muscovy ducks [5,50], and broilers [43,51–53]. Reared ducks on higher stocking density induced higher mortality rates, leg problems, bluishness of carcass, and resting behaviors was increasingly disturbed [54]. Also, Taboosha [14] reported that percentages of the carcass, total edible parts, and bone of ducks significantly increased with rising stocking density.

The finding of the present study revealed significant elevations in hepatic enzyme activities by increasing stocking density, while the remaining blood biochemical parameters were not affected. These results are in line with those of Park et al. [55], who stated that AST and ALT were elevated in heat-stressed ducks housed in high stocking density. These disturbances in hepatic enzyme activities might be due to the disturbance in body homeostasis as a response to the stress of higher stocking density and in such situations, the birds will try to adapt themselves to the stressors by developing response mechanisms including behavioral and physiological adjustments [56]. The elevation in serum AST and ALT levels could be considered an indication of the potential hepatic or muscular disorder [57,58]. However, hepatic and renal function biomarkers were not significantly affected by floor type. The same observations were reported by Sogunle et al. [59], who noticed no alterations in blood biochemistry between caged and litter reared birds.

Moreover, the reduction in TG and TC of breast meat in the current study is in agreement with the findings of Nasoetion et al. [60], who demonstrated that increasing stocking density to 16 broiler chicks/m^2 decreased carcass contents of cholesterol and low-density lipoprotein cholesterol. Simitzis et al. [3] observed a significant decline in the content of intramuscular fat (IMF) of breast muscle and NADP-malate (MDH), and NADP-isocitrate (ICDH) dehydrogenases activities of broiler chickens brooded at high stocking density. To date, the precise reason for the reduction in TC and TG in the meat of birds housed in high stocking density remains unclear. However, high stocking density has been widely considered as a stressor to birds that trigger the lipid peroxidation process that increase MDA production, which in turn may increase cholesterol oxidation [40,61]. Furthermore, Rabasa and Dickson [62] reported that stress might increase lipolysis, thereby reducing fatness. On the same basis, stress-induced by high STD may stimulate lipolysis and reduce muscle fat and cholesterol.

The previous finding of Simitzis et al. [3] supports this hypothesis as the reduced activities of MDH and ICDH in crowded birds suggesting that these birds compensated their energy needs by lipolysis of their muscular and hepatic lipids.

Regarding the effect of floor type on serum and meat cholesterol, the present results revealed a significant decrease in serum TG and an increase in TC while their content in breast meat was not affected. To our knowledge, limited studies investigated the effect of floor type on serum and muscle cholesterol content in ducks. Nevertheless, despite the lack of literature, it is evident that floor type seems to affect meat quality, as demonstrated by Manohar et al. [63] who stated that cholesterol level in the thigh and breast meat was higher in litter reared broilers than those caged irrespective of the stocking densities and age. This decrease in meat cholesterol content meets the market's need as this feature recently favored by health-conscious consumers [64].

Crowding conditions could impair the antioxidative capacity of Pekin ducks and lead to oxidative stress, which elevates serum MDA and disturb the activities of antioxidant defense enzymes [39,40]. In the present study, serum MDA and SOD levels were increased in ducks reared at stocking density of seven birds/m^2 while GPx and catalase activities were increased in those housed at 5 and 7 birds/m^2. Similarly, high stocking density decreased glutathione (GSH) concentration and the ratio between glutathione and oxidized glutathione [3]. In contrast, although Wu et al. [22] found a significant elevation in serum MDA of crowded ducks, they noticed a reduction in the total antioxidant capacity of their pectoral muscle. The authors, in proteomic analysis, found a decrease in catalase and regucalcin expression in the high stocking density group.

Moreover, liver antioxidants, including catalase, SOD, and GSH, have previously found to be decreased on high stocking density [65]. Simsek et al. [40] revealed that crowding increased the serum level of MDA and reduced GPx but did not affect catalase and GSH levels. The conflict of results related to antioxidant enzyme activities could be due to the differences in stocking density used in the current and the previous studies. In the present study, the highest stocking density was approximately 23.1 kg BW/m^2 while in the study of Simsek et al. [40], Simitzis et al. [3] and Wu et al. [22] it was 47.3, 27.2, and 28.4 kg BW/m^2, respectively. This indicates that the effect of stocking density on oxidative stress and potential cellular damage was not the same in all studies, so the response of the antioxidant defense system might be varied. We suppose that the increase in antioxidant enzyme activities in the present study might be a physiological response to protect living cells against oxidative stress during the period of non-damaging exercise [66–68]. Another possible reason for the different results of antioxidant enzyme activities may be due to several factors else affected the birds such as heat stress [3]. Regardless of the effect of stocking density, serum MDA content and SOD and catalase activities were reduced in birds housed on PLS compared to those housed on WSL while GPx was not affected. These elevations in the aforementioned parameters in WSL ducks might be attributed to the high susceptibility of these birds to enteric and respiratory diseases because the incidence of dust and direct contact with manure and wet litter which in turn suppress the antioxidant defense system. These results are agreed with those of Zhao et al. [69] who reported that serum MDA was significantly reduced in birds reared on PLS in comparison with those of wire netting birds; however, GPx activity was not altered. Contrarily, Şimşek et al. [48] noticed significant increase in serum levels of catalase and MDA in caged birds compared with those reared on a litter floor in summer season. The authors attributed the increase in MDA content to the high susceptibility of caged birds to heat stress that subsequently stimulate corticosterone synthesis [48].

5. Conclusions

Increasing the stocking density of Pekin ducks from five to seven birds/m^2 suppressed the growth performance traits, dressing percentage, and relative weights of the thigh and left fillet. Moreover, high stocking density adversely affected the hepatic function and the antioxidative activity, meanwhile, TC and TG of breast meat were reduced in ducklings housed on WSL at seven birds/m^2 and on PLS at five and seven birds/m^2. In general, the use of PLS was better than WSL on the stress of high stocking density. Consequently, stocking density of Pekin ducks reared on WSL from 14 to 49 days of age should be five birds/m^2 and can be increased to seven birds/m^2 if PLS is used.

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