Growth, carcass parameters, biochemical and oxidative stress indices, and meat traits of duck breeds under different stocking densities

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ABSTRACT This investigation was aimed to inspect if there is an influence of various stocking density on growth, carcass parameters, blood indices, and meat traits of Muscovy and Mallard ducks. One hundred twenty-six 1-day-old of each Muscovy and Mallard ducks were randomly allocated into three experimental groups with different stocking density. Group one (SD1) was 5 ducks/m², while group 2 (SD2) was 7 ducks/m² and group 3 (SD3) was 9 ducks/m². The growth, carcass parameters, meat quality, blood indices were calculated. Body weight of SD1 was 18 and 4.5% heavier than SD2, while, it was 29.5 and 12% heavier than SD3 of Muscovy and Mallard duck breeds, respectively. SD3 possessed the highest levels of, H/L, ALT, AST, LDL, VLDL, and MDA with the lowest levels of lymphocyte, SOD, GSH, GPX, C3, total antioxidant capacity and IGG of both ducks' breeds. The carcass weight decreased by 40 and 15% from SD1 to SD3 in Muscovy and mallard ducks, respectively. The dressing % was highest at SD1 (84 and 83%) when compared with SD3(71and80%) of Muscovy and Mallard ducks, respectively. Cooking loss was 20 and 16% greater in group three when compared with group one in Muscovy and Mallard ducks, respectively. In conclusion ducks raised in low SD possessed the best performance with better welfare.

Key words: stocking density, muscovy duck, Mallard duck, performance, biochemical parameters

INTRODUCTION

In the last decade the duck meat (Anas platyrhynchos domestica) necessity has obviously greater than before. It is incredibly consumed in lots of countries, such as United States, Egypt, and Saudi Arabia (Wawro et al., 2004). Egypt produced around 100 to 150 million domestic ducks annually, therefore, it is considered “duck country” (Kilany et al., 2016), and it plays a chief role in the rural economy and creates employment opportunity. Ducks are characterized by rapid growth especially at the first weeks of age. Muscovy and Mullard ducks reach the slaughter age at 10 to 12 and 10 wk, respectively with weights represented 70 to 80% of adult weight (Pingel, 1999). Ducks are more tolerance to tough climates when compared with chicken, therefore, their rearing are easier for producers (Ekarius, 2007; Anonymous, 2016) due to the less likely susceptible to most common poultry diseases (i.e., Marek’s and infectious bronchitis; Oluyemi and Ologbobo, 1997).

Duck meat is considered high nutritive value and favorable meat for consumers (Taboosha, 2014). It has 1) polyunsaturated fatty acids, 2) a promising amino acid content (Woloszyn et al., 2006; Ali et al., 2007), 3) high protein and ash %, 4) low fat and water %, 5) high % of red muscle fiber in breast meat, therefore it may be called as red meat (Ali et al., 2007). Furthermore, its liver has a crucial role of income for farmers and is mostly collected from the hybrids of Pekin and Muscovy ducks (Holderread, 2011). In addition to, Mullards were mainly used for producing fattened liver, but recently used for broiler production as 35% of duck meat in France originated from Mullards (Baeza et al., 2000).

The common ducks used for meat production are Pekin, Aylesbury, Rouen, and Muscovy ducks (Crawford, 1990; Pingel, 2004). Muscovy ducks originate from domestication of the mallard duck (Anas platyrhynchos) (Cherry and Morris, 2015). Muscovy ducks were very popular based on their adaptation to rearing environment with low fat and high meat production.
(Görski and Witak, 2003). Recently, meat duck production reared under intensive system, therefore, lots of studies are required to afford appropriate animal welfare circumstances with producing high meat quality (Chen et al., 2015). The suggested stocking density of the duck farms in Egypt is 5 ducks/m² for higher growth performance (Taboosha, 2014). In the last decade consumers considered stocking density as it may be influenced animal wellbeing (Vanhonacker et al., 2008).

Stocking density (SD) is distinct as birds’ number of birds reared in specific area (Berg and Yngvesson, 2012). Fundamental intentions of worldwide poultry business are intensifying poultry meat production (kg) per m² with top-quality and to put off production losses initiated by excess numbers. Poultry high SD is mainly intended to reduce the cost interrelated with employment, gas, sheltering, and tools. However, this can lead to a negative consequence on birds wellbeing, immune status, welfare, and production traits (Shanawany, 1988; Houshmand et al., 2012). Birds are covered with feathers and do not possess sweat glands, therefore they are struggling at high temperatures especially ≤41°C and high SD that consequently may break homeostasis (Etches et al., 2008; Mello et al., 2015). Therefore, this study was aimed to explore the influence of various SD on growth traits, carcass parameters, blood indices, and meat quality of Muscovy and Mallard ducks to advocate good SD alongside cheapest coast concurrently with superior property.

MATERIALS AND METHODS

Birds and Management

The current research was done at Faculty of Veterinary Medicine Zagazig University, Egypt. One hundred twenty-six 1-day old Muscovy and Mallard ducks were randomly classified to three groups each of 6 replicates. The first one (SD1) was 5 ducks/m². The second (SD2) was 7 ducks/m². The third (SD3) was 9 ducks/m². Ducks were reared in similar pens with temperatures of 32°C for the first 7 d of age. The temperature was regularly reduced to 24°C at the age of 21 d and continued to the 10th wk. Ducks were fed ad libitum (NRC, 1994; Table 1).

Growth Traits and Blood Profile

Ducks were weighed bi-weekly for obtained, body weight, daily gain, and relative growth rate. Blood samples were collected immediately of early disturbance at the day of slaughtering (3, 4, and 5 blood samples from SD1, SD2, and SD3, respectively from each pen of each replicate). Two blood samples were smoothly obtained from the wing vein under aseptic circumstances. The first one with anticoagulant was centrifuged at 8,000 rpm for 15 min to gather the serum. Total protein, albumin, aspartate transaminase (AST), alanine transaminase (ALT), creatinine, urea, triglyceride (TG), high-density lipoprotein (HDL) cholesterol (mg/dL), low-density lipoprotein (LDL), and very low-density lipoprotein (VLDL) values were evaluated with commercial kits (Wako Pure Chemical Industries, Osaka, Japan). Superoxide dismutase (SOD) and glutathione peroxidase (GSH), malondialdehyde (MDA), and reduced glutathione (GSH) values were evaluated using commercial kits (Biomerieux, Poains, France) and a spectrophotometer (Shimadzu, Japan). Complement C and immunoglobulin G (IgG) values were evaluated using Chicken Immunoglobulin G (IgG) ELISA Kit (Cat No. MBS260043) with sensitivity up to 5 ng/mL, intra-assay precision ≤ 8% and inter-assay precision ≤ 12%. While, the second samples without anticoagulant were used to evaluate lymphocyte and heterophil.

Carcass Properties

At the 10th wk of the investigation, ducks were weighed and slaughtered. The gizzard, heart, liver, and spleen were collected, weighed. They offered as a relative weight. The carcass (breast and thigh) was weighed and the dressing % was calculated.

Meat Parameters

Ten grams of Longissimus thoracis et lumborum (LTL) muscles were collected from the chilled carcass to evaluate pH, cooking loss, drip loss, and bacteriological counts. Ultimate pH (pHu) was measured after 24 h of chilling (Korkela et al., 1986). Cooking loss was evaluated (Cyril et al., 1996). Drip loss was evaluated by the weight variation between frozen and thawing meat and blotting dry with filter paper (for more details see; Nasr et al., 2021). Total bacterial count, Enterobacteriaceae and Coliforms were counted (cfu/g) (for more details see; Nasr et al., 2021).

### Table 1. Chemical composition of basal diets.

| Ingredients (%)                      | Starter diet | Grower diet |
|--------------------------------------|--------------|-------------|
| One-day-old vs 4 wk of age           | 5–10 wk of age|
| Ground yellow corn                   | 54.14        | 65.05       |
| Soybean meal (44 %)                  | 40.10        | 29.19       |
| Soybean oil                          | 2.90         | 2.90        |
| Limestone                            | 1            | 1           |
| Di-calcium phosphate                 | 1            | 1           |
| Methionine                           | 0.11         | 0.11        |
| NaCl                                 | 0.25         | 0.25        |
| Prenmix 1                            | 0.50         | 0.50        |
| Calculated analysis                  |              |             |
| Crude protein %                      | 22.00        | 18.01       |
| Crude fiber %                        | 3.72         | 4.44        |
| Metabolizable energy, kcal           | 2.945        | 2.985       |
| Ash                                  | 7.69         | 6.17        |
| Dry matter                           | 92.50        | 93.07       |
| Ether extract                         | 3.77         | 3.36        |

1 The premix provided each kg of diet with: Vit. A: 12,000 IU, Vit. D3: 5,000 IU, Vit. E: 130 mg, Vit. K3: 3.6 mg, Vit. B1: 3 mg, Vit. B2: 8 mg, Vit. B6: 4.95 mg, Vit. B12: 0.17 mg, Niacin: 60 mg, Folic acid: 2.10 mg, d-Biotin: 200 mg, calcium d-Pantothenate: 18.3 mg, Copper: 80 mg, Iodine: 2 mg, Selenium: 150 mg, Iron: 80 mg, Manganese: 100 mg, Zinc: 80 mg, Cobalt: 500 mg.
**Statistical Analysis**

Result was statistically analyzed with SAS statistical system Package V9.1 (SAS. 2009). Kolmogorov–Smirnov test was carried out to assure the homogeneity and normality of variances among the various investigating groups. Ducklings were distributed according to a completely randomized experimental design in an ANOVA of 2 × 3 factorial arrangement. The statistical model used was:

\[ Y_{ijk} = \mu + SD_i + B_j + SDB_{ij} + e_{ijk} \]

where: \( Y_{ijk} \) = an observation, \( \mu \) = overall mean, \( SD_i \) = stocking density levels (i = 5, 7, and 9 birds), \( B_j \) = breed (j = Muscovy and Mallard), \( SDB_{ij} \) = the interaction between SD and breed and \( e_{ijk} \) = random error. The variation between means was performed with Tukey’s test. Log geometric mean was calculated for bacteriological counts. The signiﬁcant was considered at \( P < 0.05 \).

**RESULTS**

Body weight was signiﬁcantly affected by SD. The final body weight of SD1 was the highest during the whole rearing period of both ducks’ breeds. It was 18% (\( P = 0.000 \)) and 4.5% (\( P = 0.000 \)) heavier than SD2 of Muscovy and Mallard breeds, respectively. While, it was 29.5% (\( P = 0.000 \)) and 12% (\( P = 0.000 \)) heavier than SD3 of Muscovy and Mallard breeds, respectively. The average daily was the highest at SD1 of both ducks’ breeds when compared with SD2 and SD3 (Table 2). SD did not affect the levels of urea, total protein, albumin, globulin, and A/G ratio. But the variation was signiﬁcant regarding lymphocyte, heterophil, H/L ratio, ALT, and AST of both ducks’ breeds. Heterophil, H/L ratio, ALT, and AST revealed the highest values at SD3 of both breeds, while lymphocyte was the lowest (Table 3).

Cholesterol, triglyceride and HDL were not affected by different SD of Muscovy ducks, while they increased from SD1 to SD3 of Mallard ducks. SD3 possessed the highest levels of LDL, VLDL, and MDA with the lowest levels of SOD, GSH, GPX, C3, total antioxidant capacit- 3, and IGG of both ducks breeds (Table 4). Carcass traits were signiﬁcantly affected with different SD. The carcass weight decreased by 40% (\( P = 0.000 \)) and 15% (\( P = 0.000 \)) from SD1 to SD3 in Muscovy and mallard ducks, respectively. The dressing % was highest at SD1 (84 and 83%) (\( P = 0.000 \)) when compared with SD3 (71 and 80%; \( P = 0.000 \)) of Muscovy and Mallard ducks, respectively. SD1 was possessed the best breast and thigh weight of both breeds. By increasing SD, increased heart and spleen weight of both breeds (Table 5).

There was a significant effect of SD on meat quality of pectoral major muscles. Phu was the highest at SD3 of both breeds. By increasing SD, increased cooking loss of both breeds. It was 20 and 16% (\( P = 0.000 \)) greater in stocking density of group three than group one of Muscovy and Mallard ducks, respectively. However, it was 17 and 8% (\( P = 0.000 \)) higher when compared with SD2 in Muscovy and Mallard ducks, respectively. Moreover, the drip loss % was increased by increasing SD. The highest loss was recorded for SD3 in both breeds. The total bacterial counts, Enterobacteriaceae and Coliform bacteria were lowest in SD1 and SD2 of Muscovy ducks and in SD1 only in Mallard ducks (Table 6). Regarding the thigh meat quality of Muscovy ducks, it was the best in SD1 and SD2 when compared with SD3, but there was no signiﬁcant difference between SD1 and SD2. While, in Mallard ducks, the best quality was recorded for SD1 when compared with SD2 and SD3. Moreover, SD2 possessed a higher quality than that of SD4 (Table 7).

**Table 2. Growth performance of ducks reared with different stocking density.**

| Parameters                  | Muscovy breed | Mallard breed |
|-----------------------------|---------------|---------------|
| Body weight (g) at different weeks of age | SD1 | SD2 | SD3 | SEM | P-value |
| Day one                     | 51.56         | 51.90         | 51.87 | 0.09 | 0.31      | 57.32 | 57.20 | 57.31 | 0.07 | 0.75      |
| 2nd week                    | 249.20        | 240.96        | 241.94 | 0.64 | 0.002     | 255.58 | 248.34 | 247.13 | 1.01 | 0.000     |
| 4th week                    | 926.00        | 825.33        | 798.33 | 14.27 | 0.000     | 509.00 | 471.43 | 422.11 | 10.20 | 0.000     |
| 6th week                    | 2082.00       | 1869.29       | 1705.00 | 36.88 | 0.000     | 1902.00 | 1727.86 | 1453.89 | 46.62 | 0.000     |
| 8th week                    | 3029.00       | 2541.43       | 2287.22 | 76.06 | 0.000     | 3149.60 | 3017.14 | 2738.22 | 54.90 | 0.002     |
| 10th weeks                  | 3882.00       | 3197.14       | 2737.78 | 104.29 | 0.000     | 4114.00 | 3929.71 | 3631.44 | 47.55 | 0.000     |
| Average daily gain (g/d) at different weeks of age | SD1 | SD2 | SD3 | SEM | P-value |
| 0-1 week                    | 89.63         | 87.60         | 86.91 | 0.27 | 0.003     | 89.96 | 86.97 | 88.88 | 0.48 | 0.65      |
| 2-3 week                    | 123.80        | 76.89         | 100.84 | 9.85 | 0.020     | 101.66 | 104.50 | 86.45 | 1.95 | 0.000     |
| 4-5 week                    | 602.00        | 519.29        | 481.11 | 16.24 | 0.007     | 656.36 | 647.67 | 631.44 | 9.55 | 0.58      |
| 6-7 week                    | 532.00        | 353.57        | 296.11 | 28.63 | 0.001     | 580.00 | 675.71 | 776.67 | 31.65 | 0.04      |
| 8-9 week                    | 504.00        | 263.57        | 213.89 | 32.60 | 0.000     | 356.40 | 371.28 | 547.22 | 42.15 | 0.09      |
| 10-10 weeks                 | 3830.44       | 3154.24       | 2858.90 | 104.32 | 0.000     | 4056.68 | 3872.52 | 3574.13 | 47.56 | 0.000     |
| Relative growth rate (%) at different weeks of age | SD1 | SD2 | SD3 | SEM | P-value |
| 0-1 week                    | 172.68        | 168.80        | 167.57 | 0.72 | 0.010     | 156.95 | 156.79 | 155.09 | 0.92 | 0.66      |
| 2-3 week                    | 50.27         | 31.82         | 41.79 | 4.04 | 0.236     | 39.79 | 42.09 | 34.99 | 0.75 | 0.000     |
| 4-5 week                    | 65.35         | 63.28         | 60.66 | 2.03 | 0.675     | 130.49 | 138.26 | 149.95 | 3.86 | 0.12      |
| 6-7 week                    | 25.65         | 19.05         | 17.49 | 1.37 | 0.051     | 30.49 | 39.29 | 54.30 | 3.14 | 0.002     |
| 8-9 week                    | 16.95         | 9.87          | 9.42 | 1.17 | 0.000     | 11.32 | 12.33 | 20.46 | 1.92 | 0.08      |
| 9-10 week                   | 9.92          | 14.17         | 9.45 | 1.17 | 0.012     | 17.35 | 15.97 | 10.53 | 0.85 | 0.000     |

\( SD_i \): stocking density of 5 ducks/m\(^2\); \( SD_2 \): stocking density of 7 ducks/m\(^2\); \( SD_3 \): stocking density of 9 ducks/m\(^2\).

\(^{a,b,c}\): Means within the same row with different superscripts letter was different significantly.
### Table 3. Hematology, kidney, and liver parameters of ducks reared with different stocking density.

| Parameters      | Muscovy breed | Mallard breed | P-value | Muscovy breed | Mallard breed | P-value |
|-----------------|---------------|---------------|---------|---------------|---------------|---------|
|                 | SD1 | SD2 | SD3 | SEM | SD1 | SD2 | SD3 | SEM |
| Lymphocyte %    | 63.10 | 59.76 | 56.14 | 0.65 | 0.05 | 62.00 | 57.86 | 52.67 | 0.90 | 0.000 |
| Heterophil %    | 24.96 | 30.16 | 33.73 | 0.79 | 0.00 | 26.40 | 31.71 | 34.78 | 0.79 | 0.000 |
| H/L2            | 39.58 | 50.48 | 60.89 | 1.85 | 0.00 | 42.63 | 54.82 | 66.09 | 2.17 | 0.000 |
| Creatinin (mg/dL) | 1.00 | 1.09 | 0.93 | 0.03 | 0.032 | 0.93 | 0.93 | 0.95 | 0.01 | 0.78 |
| Urea (mg/dL)    | 24.56 | 24.11 | 24.23 | 0.31 | 0.869 | 12.40 | 12.31 | 11.78 | 0.20 | 0.39 |
| TP (g/dL)3      | 6.24 | 5.89 | 5.80 | 0.09 | 0.125 | 8.46 | 8.57 | 8.44 | 0.06 | 0.63 |
| Albumin (g/dL)  | 3.81 | 3.71 | 3.58 | 0.10 | 0.676 | 5.80 | 5.88 | 5.89 | 0.07 | 0.89 |
| Globulin (g/dL) | 2.43 | 2.18 | 2.22 | 0.13 | 0.765 | 2.66 | 2.69 | 2.56 | 0.09 | 0.82 |
| A/G4            | 1.77 | 1.75 | 1.82 | 0.15 | 0.982 | 2.18 | 2.24 | 2.48 | 0.15 | 0.69 |
| ALT(U/L)5       | 15.27 | 18.03 | 17.17 | 0.42 | 0.039 | 24.38 | 26.41 | 29.92 | 0.56 | 0.000 |
| AST(U/L)6       | 21.58 | 22.57 | 23.62 | 0.31 | 0.20 | 19.78 | 24.66 | 33.13 | 1.25 | 0.000 |

SD1: stocking density of 5 ducks/m²; SD2: stocking density of 7 ducks/m²; SD3: stocking density of 9 ducks/m².

### Table 4. Biochemical, oxidative stress, and immunological parameters of ducks reared with different stocking density.

| Parameters      | Muscovy breed | Mallard breed | P-value | Muscovy breed | Mallard breed | P-value |
|-----------------|---------------|---------------|---------|---------------|---------------|---------|
|                 | SD1 | SD2 | SD3 | SEM | SD1 | SD2 | SD3 | SEM |
| Cholesterol (mg/dL) | 142.00 | 137.86 | 151.78 | 3.34 | 0.179 | 292.60 | 333.14 | 384.21 | 8.51 | 0.000 |
| Triglyceride (mg/dL) | 135.60 | 134.00 | 163.44 | 7.26 | 0.146 | 60.12 | 83.57 | 154.00 | 9.33 | 0.000 |
| HDL (mg/dL)2     | 38.60 | 34.57 | 38.00 | 0.79 | 0.084 | 63.00 | 56.43 | 34.44 | 2.85 | 0.000 |
| LDL (mg/dL)3     | 68.92 | 68.74 | 114.38 | 7.01 | 0.001 | 265.08 | 283.83 | 311.24 | 4.38 | 0.000 |
| VLDL (mg/dL)4    | 25.18 | 29.44 | 42.08 | 1.93 | 0.000 | 17.08 | 22.44 | 32.96 | 1.53 | 0.000 |
| SOD (U/mL)5      | 6.76 | 6.48 | 5.23 | 0.22 | 0.003 | 5.06 | 4.84 | 4.84 | 0.86 | 0.90 |
| GSH (mmol/mL)6   | 2.71 | 2.14 | 1.70 | 0.09 | 0.000 | 7.86 | 5.01 | 3.63 | 0.38 | 0.000 |
| GPX(U/mL)7       | 137.28 | 124.29 | 124.29 | 1.25 | 0.000 | 144.20 | 124.10 | 103.49 | 3.82 | 0.000 |
| MDA(mmol/L)8     | 18.50 | 20.70 | 23.16 | 0.61 | 0.003 | 27.96 | 39.94 | 79.60 | 5.11 | 0.000 |
| Total antioxidant capacity (mM/L) | 1.60 | 1.15 | 0.63 | 0.09 | 0.000 | 6.74 | 4.18 | 2.69 | 0.37 | 0.000 |
| C3 (ug/mL)9      | 1.30 | 1.24 | 0.64 | 0.09 | 0.000 | 7.38 | 5.96 | 3.12 | 0.40 | 0.000 |
| IGG (ng/mL)10    | 3.73 | 3.42 | 2.59 | 0.13 | 0.000 | 18.67 | 11.93 | 8.43 | 0.96 | 0.000 |

SD1: stocking density of 5 ducks/m²; SD2: stocking density of 7 ducks/m²; SD3: stocking density of 9 ducks/m².

### Table 5. Carcass traits and relative organs of ducks reared with different stocking density.

| Parameters        | Muscovy breed | Mallard breed | P-value | Muscovy breed | Mallard breed | P-value |
|-------------------|---------------|---------------|---------|---------------|---------------|---------|
|                  | SD1 | SD2 | SD3 | SEM | SD1 | SD2 | SD3 | SEM | SD1 | SD2 | SD3 | SEM | P-value |
| Carcass weight (g) | 3253.60 | 2484.29 | 1958.89 | 117.84 | 0.000 | 3407.40 | 3278.01 | 2908.81 | 50.78 | 0.000 |
| Dressing %        | 83.81 | 77.62 | 71.49 | 1.18 | 0.000 | 82.82 | 83.41 | 80.09 | 0.37 | 0.000 |
| Breast weight     | 1637.96 | 1303.20 | 1081.29 | 50.32 | 0.000 | 1808.60 | 1717.06 | 1592.82 | 23.17 | 0.000 |
| Thigh weight      | 1414.40 | 1006.66 | 737.96 | 62.19 | 0.000 | 1412.80 | 1380.97 | 1155.75 | 27.46 | 0.000 |
| Liver %           | 0.72 | 0.74 | 0.80 | 0.04 | 0.000 | 0.76 | 0.77 | 0.80 | 0.01 | 0.000 |
| Heart %           | 0.15 | 0.20 | 0.26 | 0.01 | 0.000 | 0.15 | 0.15 | 0.17 | 0.001 | 0.000 |
| Gizzard %         | 0.62 | 0.68 | 0.72 | 0.08 | 0.000 | 0.50 | 0.51 | 0.50 | 0.03 | 0.80 |

SD1: stocking density of 5 ducks/m²; SD2: stocking density of 7 ducks/m²; SD3: stocking density of 9 ducks/m².

### Notes
- SD1: stocking density of 5 ducks/m²; SD2: stocking density of 7 ducks/m²; SD3: stocking density of 9 ducks/m².
- Means within the same row with different superscripts letter was differ significantly.

1SEM, standard error mean.
2H/L, Heterophil/Lymphocyte ratio.
3TP, total protein.
4A/G, albumin/globulin ratio.
5ALT, alanine transaminase.
6AST, aspartate transaminase.
**DISCUSSION**

This study explored if SDs influence on growth, carcass parameters, blood indices, and meat quality of Muscovy and Mallard duck to advocate good SD alongside cheapest coast concurrently with superior property. This study revealed that the body weight and weight gain of both duck breeds were reduced by increasing SD. These results were supported by the finding of other researchers on ducks (Xie et al., 2014; Wu et al., 2018; Zhang et al., 2018) and broilers (Nasr et al., 2021), in spite of keeping the same feeding area for each bird (Sørensen et al., 2000; Tong et al., 2012). Moreover, the meat traits decreased with increasing SD to 9 birds/m² (Xie et al., 2014). This investigation revealed that low SD (5 ducks/m²) had the best carcass traits of both duck breeds. The findings of this study were supported with researchers who stated that high SD changes the carcass parameters and lowered the carcass property (Skomorucha et al., 2009; Sekeroglu et al., 2011) decreased breast fillet, whole breast yield and thigh (Wu et al., 2018; Abo Ghanima et al., 2020). Moreover, the meat traits decreased with increasing SD to 9 birds/m² (Xie et al., 2014). This reduction and deterioration of carcass traits may be due to the high SD caused physical constraint of birds movement, consequently affect birds to reach to the feed and water (SCAHAW Scientific Committee on Animal Health and Animal Welfare, 2000). On the other hand, other researchers stated no effect of SD on carcass traits, breast, and leg weight and dressing % of Muscovy ducks (Baeza et al., 2003; Xie et al., 2014; Gupta et al., 2016), even with stoking densities of 5, 6, and 7 birds/m² (Taboosha, 2014).

Different stocking densities had no effect on gizzard and liver weight of both duck breeds which supported (Simsek et al., 2009), 7) high levels of CO2 and NH3 in the pen (Guardia et al., 2011; Petek et al., 2014; Van Staaveren et al., 2019). Moreover, high stocking densities deteriorated the duck's antioxidant ability, consequently interrupt the antioxidant defense system and finally caused oxidative stress (Simsek et al., 2009; Zhang et al., 2015). High SD interrupt the heat emission to air to help ducks for intensive growth, that influenced by the large group size even with keeping the same feeding area for each bird (Sørensen et al., 2000; Tong et al., 2012).

The carcass traits are an imperative economic aspect of the poultry business (Nasr et al., 2017, 2019). This investigation revealed that low SD (5 ducks/m²) had the best carcass traits of both duck breeds. The findings of this study were supported with researchers who stated that high SD changes the carcass parameters and lowered the carcass property (Skomorucha et al., 2009; Sekeroglu et al., 2011) decreased breast fillet, whole breast yield and thigh (Wu et al., 2018; Abo Ghanima et al., 2020). Moreover, the meat traits decreased with increasing SD to 9 birds/m² (Xie et al., 2014). This reduction and deterioration of carcass traits may be due to the high SD caused physical constraint of birds movement, consequently affect birds to reach to the feed and water (SCAHAW Scientific Committee on Animal Health and Animal Welfare, 2000). On the other hand, other researchers stated no effect of SD on carcass traits, breast, and leg weight and dressing % of Muscovy ducks (Baeza et al., 2003; Xie et al., 2014; Gupta et al., 2016), even with stoking densities of 5, 6, and 7 birds/m² (Taboosha, 2014).

**Table 6.** Meat quality of pectoral major muscle of ducks reared with different stocking density.

| Parameters                     | SD1 (Log CFU/g) | SD2 (Log CFU/g) | SD3 (Log CFU/g) | SEM | P-value |
|--------------------------------|----------------|----------------|----------------|-----|---------|
| pHu                            | 6.07           | 5.96           | 5.58           | 0.07| 0.013   |
| Cooking loss %                 | 24.98          | 25.97          | 31.24          | 0.08| 0.001   |
| Drip loss %                    | 3.96           | 4.12           | 5.48           | 0.17| 0.011   |
| Total bacterial count (Log CFU/g)* | 4.70           | 4.69           | 5.05           | 0.05| 0.0001  |
| Enterobacteriaceae (Log CFU/g)* | 3.01           | 3.00           | 3.57           | 0.06| 0.0001  |
| Coliforms bacteria (Log CFU/g)* | 2.49           | 2.50           | 3.22           | 0.09| 0.0001  |

**Table 7.** Meat quality of thigh muscle of ducks reared with different stocking density.

| Parameters                     | SD1 (Log CFU/g) | SD2 (Log CFU/g) | SD3 (Log CFU/g) | SEM | P-value |
|--------------------------------|----------------|----------------|----------------|-----|---------|
| pHu                            | 6.12           | 6.06           | 5.52           | 0.08| 0.000   |
| Cooking loss %                 | 31.30          | 32.28          | 35.32          | 0.43| 0.000   |
| Drip loss %                    | 2.024          | 2.59           | 3.38           | 0.13| 0.000   |
| Total bacterial count (Log CFU/g)* | 4.90           | 4.94           | 5.17           | 0.03| 0.000   |
| Enterobacteriaceae (Log CFU/g)* | 3.01           | 3.09           | 3.72           | 0.08| 0.000   |
| Coliforms bacteria (Log CFU/g)* | 2.59           | 2.78           | 3.82           | 0.14| 0.000   |

**SD1:** stocking density of 5 ducks/m²; **SD2:** stocking density of 7 ducks/m²; **SD3:** stocking density of 9 ducks/m².

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*a,b,c*Means within the same row with different superscripts letter was differ significantly.

*a,b,c*Results of this table were of Log transformed data.
by Bawish (2018) and confirmed by Ahaotu and Agbasu (2015) who mentioned that pekin ducks densities of 2, 4, 6, and 8 ducks/m² had no effects on giblets weight. While, our findings regarding the spleen, revealed an increase of its weight that supported by others (Chegini et al., 2018). They detected that the spleen weight was enlarged in high SD. This may be attributable to the stress that may increase the lymphoid organ to promote the immune system (Gore and Qureshi, 1997; Pope, 1991).

Blood biochemical parameters are decisive tool for predicting the metabolic diseases (Rotava et al., 2008). Stress caused an alteration of birds' blood caused by the thermoregulatory reactions (Arieli et al., 1979). High SD has a negative consequence on birds' performance and physiological traits (Cengiz et al., 2015). Corticosterone is of little useful guide chronic stress (Cunningham et al., 1988), while heterophil/lymphocyte (H/L) ratio is counted as a marker of chronic stress in birds (Gross and Siegel, 1983; Zulkifli et al., 2003) and hens welfare (Nicol et al., 2009). There were arguing conclusions on the impact of SD on ducks' H/L ratio. Several studies reported an increase of this ratio with increasing density (Hill, 1983; Stevenson and Taylor, 1988; De Jong et al., 2002; Srinongkote et al., 2004). However, other researchers did not detect any effect (Dozier et al., 2006; Turkyilmaz, 2008). The current investigation was similar to the majority of researches that detected an increase of H/L ratio as a result of increasing density. Our findings regarding Heterophil and lymphocyte were comparable with Abdel-Rahman and Mosaad (2013). Otherwise, Gupta et al. (2016) did not detect any impact of high SD on Heterophil/lymphocyte ratio.

It was no variation regarding serum total protein, albumin, globulin, and A/G ratio of both duck breeds at different stocking densities. These findings were supported by the findings of other researchers (Abu-Tabeekh, 2013; Azzam and El-Gogary, 2015; Bawish, 2018). Otherwise, it was disagreed with Srinongkote et al. (2004) and Nasr et al. (2021), who detected an increase of the serum protein with increasing density. Our values of serum total protein, albumin, and globulin were similar to that reported by Abdel-Rahman and Mosaad (2013) for Muscovy ducks.

Abo-Ghanima et al. (2020) and Park et al. (2018) reported an increase of ALT and AST with increasing the duck density from 3 to 7 ducks/m². All these results were confirmed the current findings that ALT and AST increased with high density of both duck breeds. High SD may cause heat-stressed ducks that consequently elevates the AST and ALT (Park et al., 2018). The disruptions in liver enzyme activities may be related to the disorder in body homeostasis due to high SD, accordingly birds will attempt to become accustomed themselves to the stressors through behavioral and physiological adjustments (Bueno et al., 2017). Moreover, birds’ struggle to consume more feed at high densities that will prone to muscles damage and finally increased AST and ALT in the blood.

There was no significant difference of cholesterol, triglycerides and HDL of Muscovy ducks at different densities. These findings were comparable to other researchers (Abu-Tabeekh, 2013; Bawish, 2018; Mallick et al., 2018). While, they were increased with increasing densities in Mallard ducks, which was in accordance with Wu, et al. (2018), who detected an elevation of cholesterol and triglycerides at high density of Peking ducks (9/m²). Moreover, cholesterol, triglycerides, and LDL were highest in high density (6 birds/m²) when compared with 3 and 4 birds m⁻² (Park et al., 2018).

In this study high density prompted oxidative stress, since its increased MDA level and declined the activity of serum SOD and GPx. The current finding was fortified by preponderance of studies that inspecting the destructive impact of high SD in birds (Simitzis et al., 2012; Zhang et al., 2015; Liu et al., 2016; Abo Ghanima et al., 2020). This may be owing to the overcrowding that encouraging fights between animals and initiating metabolic disorders. Moreover, prompting stress, elevated lipid peroxidation and excessive creation of ROS, raised oxidative damage and producing MDA as a result of reducing the performance of antioxidant enzymes (Droge, 2002; Yun-Zhong et al., 2002; Simsek et al., 2009).

Complement 3 and IgG reduced at high stoking density of both duck breeds that confirmed by others ( Mashaly et al., 2004; Palizdar et al., 2017). They reported high densities smooths the immunity (Zhang et al., 2015). Liberating somatostatin and adrenal corticosteroid hormones were accountable for reducing immunoglobulin synthesis (Herman et al., 2018). In contrast, there was a rise of IgG and IgM at higher densities (Li et al., 2019), while Azzam and El-Gogary (2015) did not observed any impact of SD on immunoglobulin. High densities accelerated the physiological and oxidative stress and exhilarated intestinal mucosal destruction. Thus, they were vulnerable to infectious diseases (Li et al., 2019).

Ultimate muscle pH (pHu) is an imperative guide of muscle glycolysis, meat property and muscle acidity that affect the colour, tenderness and meat storage time. Muscle lactic acid are a sign of pH and the quality of meat decreased with their high accumulations (Chen et al., 2015). Meat pHu of Muscovy and Mallard duck breeds (thigh and breast) is ranged between 5.7 and 6.17 (Wawro et al., 2004; Chen et al., 2015). Moreover, meat pH of more than 5.8 is preferable to increase meat shelf life (Ali et al., 2007). Our finding regarding pHu of both ducks breeds in breast and thigh were within this range. Also, pHu levels decreased with increasing SD. The reduction of pH accelerates the anaerobic glycolysis and lactate accumulation (Rammouz et al., 2004). A prompt decrease of pH in early postmortem stage initiates extensive protein denaturation (Huff-Lonergan and Lonergan, 2005). On contrast, there was no significant effect of stocking densities on pHu and cooking loss (Xie et al., 2014; Zhang et al., 2018).
Drip loss is a popular indirect marker of water-holding capacity, since water loss is negatively interrelated with water-holding capacity (Chen et al., 2015). The effect of high SD on cooking loss and drip loss was more obvious in Mallard ducks than Muscovy ducks. Also, with high densities they were increased and this was confirmed by Zhang et al. (2018) who reported a reduction of drip loss by increasing SD. Zhang et al. (2018) stated that the drip loss was increased with increasing density from 5 to 8 and 11 birds/m² of the ducks' breast muscle. These findings suggested that meat is further vulnerable to turn into dry, hard and may be tasteless. Omojola (2007) detected that the cooking loss was 26 to 32% for Muscovy duck gave that was comparable to our findings of Muscovy ducks. Deterioration of meat quality could be related to decrease the competence of myofibrillar protein to grasp water owned to disturb collagen and myofibrillar protein matrix. This has been carried out throughout the ageing and water pressed out from myofibrils to channels that located among muscle fiber and cell membrane. Hence the contraction at rigor mortis leads to water could leave as drip (Lawson, 2004). Low pH stimulates muscle fiber contraction, causing high drip loss (Tang et al., 2013). The more drip loss was steady with the low pH that causes inferior meat quality of ducks.

High densities are accompanying with confrontational effects on the birds’ intestinal commensal bacteria (Cengiz et al., 2015). Additionally, stress may change the leucocytes and relegated the humoral immunity, accordingly, diminish the birds immunity to overwhelmed the infections with bacteria and viruses (Mench et al., 1986). High SD revealed the greatest bacterial and infection of breast and thigh muscles of both ducks’ breed. Our outcomes regarding Enterobacteriaceae counts are within the reported range of 2.2 to 3.8 (log₁₀ cfu/g) in ducks’ breast muscle (Khalifa and Nasar, 2001). But, was lower than detected by Abdallahah (et al. 2014). They reported that Enterobacteriaceae and Coliform counts in ducks' breast muscle were 7.85 × 10² and 1.70 × 10² cfu/g, respectively while in thigh muscle were 9.13 × 10⁴ and 3.29 × 10² cfu/g, respectively. Birds' litter is a mixture of birds’ dropping and bedding stuffs, which deemed an ecological ecosystem with existence of microbial infection (Lovanh et al., 2007). Bacterial growth was increased in presence of high SD as a result of increasing the levels of ammonia and moisture in the litter, spilled water out and unsatisfactory ventilation, thus downgrading the litter quality. SD is deemed to be one of the foremost aspects affecting poultry welfare, physical performance, and product excellence. This investigation accomplished that high SD has an unfavorable consequence on ducks’ growth and welfare. High density revealed the smallest body weight, carcass traits, HDL, GPX, and IGG with great values of ALT, AST, MDA, cooking loss, drip loss of breast and thigh muscles, and bacterial count of both breeds. For that reason, this investigation suggested that the best density of Muscovy and Mallard breed is SD₁ (5 birds/m²).

ACKNOWLEDGMENTS

The authors extend their appreciation to the Taif University Researchers supporting Project number (TURSP-2020/104) Taif University, Taif, Saudi Arabia, for funding this work.

Taif University Researchers supporting Project number (TURSP-2020/104) Taif University, Taif, Saudi Arabia.

Authors’ contributions: M.N.: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Roles/Writing - original draft; Writing - review & editing. A.A. and M.R.: Data curation; Investigation; Methodology; Visualization; Roles/Writing - original draft; Writing - review & editing. A.H., R.E. and M.H.: Conceptualization; Methodology; Roles/Writing - original draft; Writing - review & editing.

Statement of animal rights: This study was authorized by the Animal Care and Welfare Committee (ZU-IACUC) of Zagzaig University, Egypt (ZU-IACUC/2/F/96/2019).

DISCLOSURES

None of the authors have any conflict of interest to declare.

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