Effects of stocking density and climate region on performance, immunity, carcass characteristics, blood constitutes, and economical parameters of broiler chickens

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ABSTRACT - This experiment was conducted to evaluate the effects of stocking density and climate region on performance, immunity, carcass characteristics, blood plasma, and economical parameters of the Ross strain of broiler chickens. The effects of four climates (mild and humid, semi-arid, alpine, and hot and dry) and four densities (10, 15, 17, and 20 chicks/m²) were studied as a completely randomized design with 4×4 factorial arrangement of treatments. The results showed that the density had a significant effect on feed intake and feed conversion ratio in the starter period and on body weight gain in the grower and the whole periods of the experiment. Moreover, both climate and density had a significant impact on economic performance (live weight, survival rate, production index, meat production/m², and profitability). The mild and humid climate and the density of 17 chicks/m² had the most economic benefit compared with other treatments. The climate type had a significant effect on the relative weights of the breast, wings, neck, proventriculus, and ileum. The effects of climate and density on glucose, triglyceride, very low-density lipoproteins (VLDL), high-density lipoproteins (HDL), LDL/low-density lipoproteins (HDL), total protein and globulin were significant. In addition, the effect of climate on the antibody titer against sheep red blood cells (except for immunoglobulin G on day 28) was significant.

Keywords: blood plasma, chick, climate, density, feed conversion ratio, immunity

Introduction

The world’s population is expected to reach 15.9 billion by 2050 (Costantino et al., 2018). Therefore, the increasing population size and demand for animal proteins, especially broiler chicken white meat, are such that the development of the poultry industry and improvement of the production level are necessary to provide the protein requirements (Amini et al., 2015). One of the problems in broiler breeding is the low performance of the progeny than that expected. This factor is related to nutrition and method of feeding, strain selection, stocking density, sensitivity to pathogens and metabolic disorders, appropriate slaughter age, breeding climate, and other managerial and economic aspects (Hughes, 2012; Attia and Hassan, 2017; Attia et al., 2018).

Many variables such as environmental factors (climate and stocking density) can affect nutrition efficiency (Gharaghani et al., 2015; Attia et al., 2016). Different criteria are used for stocking density in different parts of the world (FAO, 2014). The most commonly used density is 30-42 kg live weight/m² and 30 kg live weight/m² in warm climate (Qaid et al., 2016). According to Attia et al. (2016), Arbor Acres
and Hubbard strains in warm climate showed a significant increase in body weight, feed intake, feed conversion ratio, carcass performance, and meat quality. In addition, the performance of Arbor Acres chicks was better than the Hubbard strain.

The density/m² is variable based on slaughter age, access to free space, type of breed, and so on (Van Horne and Bondt, 2014), varying from 11 to 20 chicks/m² (Van Horne and Bondt, 2014). The total final body weight per area unit can be influenced by stocking density as determined by economic conditions and market demand (Imaeda, 2000). Controlling climatic conditions is costly for improving the welfare and performance of birds in different climates (Costantino et al., 2018). Awad et al. (2017) stated that feeding broiler chickens with enriched diets in controlled warm weather improved performance, the proportional weight of liver and abdominal fat, and blood parameters. In ostriches, it has been shown that warm and dry and temperate and humid climates have better effects than alpine climate on fertility (Bouyeh et al., 2017). However, egg production was not significantly different in warm and dry or temperate and humid climates.

Overall, the benefits of increasing stocking density are improved productivity, better use of limited available area, and increased income. Poultry husbandry is common in various climates, but it is unclear what climates are better for future development or what density is better in any specific climate.

Due to inadequate number of studies on the selection of suitable density in different climates or the combined effect of density and climate on the performance of broiler chickens, this study was carried out to address this problem. Our main objectives were to study growth performance, economic efficiency, carcass quality, blood parameters, and immunity of broiler chickens in four different climatic conditions with different densities and determine the most suitable density in each climate to maximize profits in different climatic conditions.

**Material and Methods**

The experimental protocol was ratified by the local Animal Ethics Committee in Tehran, Iran, and the experiment was performed with respect to the International Guidelines for research involving animals (Directive 2010/63/EU).

In this experiment, there were four stocking densities (10, 15, 17, and 20 chicks per m²) and four climates (mild and humid, semi-arid, alpine, and hot and dry) with annual rainfall categories according to Kaviani and Alijani (2001), with four replications per treatment. Rainfall of more than 400 mm/year for locations as Sari, Amol, GhaemShahr, and Babol is labeled as mild and humid climate; between 250-400 mm/year for locations as Sabzevar, Nishapur, Torbat Heydarlyeh, and Torbat-e-Jam is called alpine climate; between 150-250 mm/year for locations as Ardabil, MeshginShahr, Namin, and Niris known as semi-arid climate; and less than 150 mm/year for locations as Ardesta, Nain, Isfahan, and Shahin Shahr is defined as dry climate. A summary of geographic climates (geographical coordinates, average annual temperature (°C), average annual rainfall (mm), and altitude from the sea (m)) and the locations of study (longitude/E, latitude/N and height/m) as well as their tests are presented (Tables 1 and 2).

The area of each replicate pen was 20 m², so that each pen had a density of 10, 15, 17, and 20 containing 200, 300, 340, and 400 chicks, respectively. Thus, a total of 79,360 newly hatched Ross 308 broiler chicks were used in this experiment (200 + 300 + 340 + 400 = 1,240 chicks in the first replications and 4 × 4 × 4 × 1,240 = 79,360 overall) (Table 3).

The experimental period in all locations was six weeks (42 days), and all birds had free access to feed and water throughout the experiment. The diet was formulated according to requirements of Ross 308 (Table 4). The temperature within the pens was 31 °C in the first week and then reduced by 2 °C a week to reach a constant temperature of 25 °C. The humidity in the pens was 55%, and the lighting program was adjusted for 23 h light and 1 h darkness. The vaccination program and other management conditions were performed according to standard instructions for Ross 308 strain. Evaluation of performance characteristics was undertaken according to standard methods (Poorgashemi et al., 2013).
Weighing of chickens were performed on a weekly basis. This procedure was carried out by calculating the difference of weight between the beginning and end of each period in conjunction with wasted birds during a time range. Then, the result was divided by the bird per day. In addition, the extra weight of birds was determined for the following durations: starter (1-21 days), grower (22-42 days), and finisher (1-42 days) (Poorghasemi et al., 2013).

### Table 1 - Geographical characteristics of the four climates studied

| Climate          | Rainfall (mm/year) | Geographical coordinates | Average annual temperature (°C) | Average annual rainfall (mm) | Altitude from the sea (m) |
|------------------|--------------------|--------------------------|---------------------------------|-----------------------------|--------------------------|
| Mild and humid   | More than 400      | 53.30 31.32              | 17.9                            | 792.2                       | 48                       |
| Semi-arid        | Between 250-400    | 59.38 36.39              | 14.3                            | 250                         | 1,077                    |
| Alpine           | Between 150-250    | 48.12 38.22              | 9.2                             | 295.5                       | 1,294                    |
| Hot and dry      | Less than 150      | 51.33 32.48              | 16.3                            | 125                         | 1,600                    |

### Table 2 - Specifications of test site in 16 cities

| City             | Longitude/E         | Latitude/N          | Height (m) |
|------------------|---------------------|---------------------|------------|
| Sari             | 53° 3' 31.547"     | 36° 33' 58.023"    | 42         |
| Amol             | 52° 21' 4.471"     | 36° 28' 11.336"    | 94         |
| Ghaem Shahr      | 52° 51' 29.666"    | 36° 27' 48.835"    | 60         |
| Babol            | 52° 40' 36.427"    | 36° 32' 20.838"    | 4          |
| Sabzevar         | 57° 40' 35.339"    | 36° 12' 45.308"    | 974        |
| Nishapur         | 58° 47' 49.171"    | 36° 12' 40.683"    | 1,198      |
| Torbat Heydariyeh| 59° 13' 16.882"    | 35° 16' 56.654"    | 1,365      |
| Torbat-e-Jam     | 60° 37' 31.423"    | 35° 14' 34.453"    | 909        |
| Ardabil          | 48° 17' 39.329"    | 38° 14' 49.231"    | 1,352      |
| Meshgin Shahr    | 47° 40' 35.341"    | 38° 23' 52.545"    | 1,418      |
| Namin            | 48° 28' 56.237"    | 38° 25' 34.572"    | 1,424      |
| Nir              | 48° 0' 47.256"     | 38° 2' 9.844"      | 1,609      |
| Ardestan         | 52° 22' 52.780"    | 33° 22' 43.282"    | 1,198      |
| Nain             | 53° 4' 31.111"     | 32° 51' 17.826"    | 1,576      |
| Isfahan          | 51° 40' 17.662"    | 32° 40' 19.585"    | 1,575      |
| Shahin Shahr     | 51° 33' 11.087"    | 32° 35' 37.336"    | 1,592      |

### Table 3 - Experimental treatments (simulated climate × stocking density)

| Treatment | Climate       | Density (chicks/m²) |
|-----------|---------------|---------------------|
| 1         | Mild and humid| 10                  |
| 2         | Mild and humid| 15                  |
| 3         | Mild and humid| 17                  |
| 4         | Mild and humid| 20                  |
| 5         | Semi-arid     | 10                  |
| 6         | Semi-arid     | 15                  |
| 7         | Semi-arid     | 17                  |
| 8         | Semi-arid     | 20                  |
| 9         | Alpine        | 10                  |
| 10        | Alpine        | 15                  |
| 11        | Alpine        | 17                  |
| 12        | Alpine        | 20                  |
| 13        | Hot and dry   | 10                  |
| 14        | Hot and dry   | 15                  |
| 15        | Hot and dry   | 17                  |
| 16        | Hot and dry   | 20                  |
Bird per day = (number of duration days × number of live birds at the end of period) + number of days that wasted birds were alive during the experiment.

In addition, feed intake for each period was determined by subtracting the remaining of feed at the end of each period from the beginning of feed rationing. Furthermore, this procedure was performed for the entire period as well. It worth noting that bird per day was a basis for the calculation (Mousavi et al., 2015).

Conversion ratio at the end of each period was calculated by knowing the extra body weight and feed conversion ratio to each period as well as for the entire duration of the experiment (Poorghasemi et al., 2013).

Economic performance, including the meat production of live chick/m², feed and chick costs, total cost, income/m², profit/m², final body weight, survival rate, and production index, were measured for each separate experimental unit (pen).

Survival or immortality is calculated based on the following:

Number of live birds = number of birds at the beginning for each experiment unit – number of birds wasted and omitted

Percentage of survival or immortality = (number of live chickens/number of birds at the beginning) × 100

The price of 1 kg live weight was assumed to be $0.93 for the calculation of income. The cost of feed and one-day old chicks was also estimated as 80% of all production costs. The price of starter and grower diets was $0.37 and $0.35/kg, respectively.

Blood plasma components were measured by standard method (Jahanpour et al., 2013; Poorghasemi et al., 2017). At 42 days of age, one chick from each replicate was randomly selected. Blood sampling was performed from the wing vein, and samples were sent immediately to the laboratory to determine the values of biochemical parameters including lipids, glucose, enzyme, protein, and uric acid. To measure blood parameters, the kits of Pars Azmoun Company (Iran) were used. All mentioned measurements were carried out by the colorimetric method. Since blood serum proteins comprise the sum of albumins and globulins (fibrinogen remains in the clot and does not enter into the serum),

| Item                        | Starter period (1 to 21 d) | Grower period (22 to 42 d) |
|-----------------------------|---------------------------|----------------------------|
| Ingredient (as fed) (g/kg)  |                           |                            |
| Corn                        | 562                       | 615.7                      |
| Soybean meal                | 365                       | 308                        |
| Soybean oil                 | 25                        | 34                         |
| Dicalcium phosphate         | 17                        | 15                         |
| Calcium carbonate           | 12                        | 11                         |
| Salt                        | 3                         | 2.8                        |
| Methionine                  | 3.5                       | 2.5                        |
| Vitamin premix¹             | 5                         | 5                          |
| Mineral premix²             | 5                         | 5                          |
| Lysine                      | 2.5                       | 1                          |
| Calculated analysis         |                           |                            |
| Digestible energy (MJ/kg)   | 12.5                      | 13                         |
| Crude protein (g/kg)        | 203                       | 185                        |
| Calcium (g/kg)              | 10                        | 8.2                        |
| Phosphorus (g/kg)           | 4.8                       | 4.1                        |
| Methionine and cystine (g/kg)| 10                      | 8.3                        |
| Lysine (g/kg)               | 13                        | 10.6                       |

¹Vitamin A, 5000 IU/g; vitamin D₃, 500 IU/g; vitamin E, 3 mg/g; vitamin K₃, 1.5 mg/g; vitamin B₂, 1 mg/g  
²Calcium pantothenate, 4 mg/g; niacin, 15 mg/g; vitamin B₆, 13 mg/g; Cu, 3 mg/g; Zn, 15 mg/g; Mn, 20 mg/g; Fe, 10 mg/g; K, 0.3 mg/g.
the total globulin concentration for each serum sample was obtained by subtracting total protein and albumin concentration from the same sample.

The immunity parameters were measured by using standard methods (Shabani et al., 2015). To investigate the status of immune system, the antibody titer against the sheep red blood cell antigen (SRBC) was measured. The antibody titer changes were investigated by injection of SRBC (2%) as a non-pathogenic antigen, in two turns. At 15 and 35 days of age, two birds were selected from each experimental unit, and 0.5 mL of red blood cell suspension (2%) (prepared from Razi Institute, Karaj, Iran), which was washed three times with a physiological serum, was injected into the wing vein. Seven days after injection (at 24 and 42 days of age), blood samples were taken from the birds. In both stages of blood sampling, only one bird was used. Blood samples were kept in the laboratory for one day, and then the blood serum was isolated at 1000 rpm for 10 min. At first, serum samples were placed in an oven for 30 min at 55 °C to neutralize the complement and avoid interference with anti-SRBC antibody. Microtiter hemagglutination was used to determine the titer. When interpreting samples, the logarithm to base 2 of the last image of hemagglutination was recorded as antibody titer. To measure IgG and IgM, which components are responses to the SRBC, the sensitive antibody to mercaptoethanol that represents IgM was calculated by isolating the resistant antibody to mercaptoethanol (IgG) and deducting this amount from total response (IgM = IgG – total response).

The carcass characteristics were evaluated by using standard methods (Saraee et al., 2014). At the end of the experiment, three birds with a weight close to the average body weight of the group were selected from each pen (12 birds from each treatment) and starved for 4 h before slaughter. All chickens were weighed before slaughter. Carcass components were measured with a digital scale (0.001 precision) and the relative weight (% of body weight [BW]) of each component was recorded.

The experiment was carried out as a two-factor factorial arrangement of treatments, including four climates (mild and humid, semi-arid, alpine, and hot and dry), four densities (10, 15, 17, and 20 chicks per m$^2$), and four replicate pens per treatment in a completely randomized balanced design. Data were arranged using Excel software and analyzed using SAS software (Statistical Analysis System, version 8.2) with Proc GLM procedure. Each broiler formed the experimental unit. Means were compared using Duncan’s test at P≤0.05. The statistical model of the design was as follows:

$$X_{ijk} = \mu + A_i + B_j + A_{ij} + e_{ijk},$$

in which $X_{ijk}$ = the record of each observation, $\mu$ = the mean, $A_i$ = climate effect, $B_j$ = effect of density, $A_{ij}$ = the interaction effect of climate and density, and $e_{ijk}$= error effect.

**Results**

The effect of climate on average body weight was not significant in any of the periods (P≥0.05), whereas the effect of stocking density on average body weight was significant in the grower and whole period (P<0.05). The highest body weight gain was observed at a density of 10 chicks per m$^2$ in both the grower (22-42 d) and the entire periods (1-42 d). The interactive effect between climate and density on average body weight was not significant (P≥0.05). However, treatment with 10 chicks per m$^2$ density in alpine climate showed the highest average body weight numerically in the whole period (Table 5).

Different climates did not have any effect on feed intake in either period (P≥0.05), although the effect of stocking density on feed intake was significant in the grower period (P<0.05). The highest feed intake in the starter period was in hot and dry climate and in the grower period, it was in alpine climate. The interaction effect between climate and density on feed intake was not significant (P≥0.05). The highest feed intake was observed in mild and humid climate with 10 chicks per m$^2$ density in the whole period (P≥0.05; Table 5). The effect of climate was not significant on feed conversion ratio (P≥0.05). The effect of stocking density on feed conversion ratio was significant in both starter and grower periods (P<0.05). The best feed conversion ratio in the whole period was recorded in semi-arid and alpine climates for 10 chicks per m$^2$ density (P<0.05). The interaction effect of climate and density on feed conversion ratio was not significant (P≥0.05; Table 5).
The effect of climate on average body weight was not significant at the end of whole experimental period (P≥0.05). Birds in 10 and 20 chicks per m² densities showed the highest and the lowest body weights, respectively. Effect of stocking density on the final body weight was significant (P<0.05). The interaction effect of climate and density on average body weight at the end of experimental period was not significant (P≥0.05), but the highest body weight at the end of experiment was related to 10 chicks per m² stocking density in the alpine climate (Table 6).

The effect of climate and density on the survival rate of broiler chickens was significant (P<0.05). The lowest mortality was observed in the mild and humid climate with a density of 17 chicks per m², and the highest mortality percentage, in the hot and dry climate with 15 chicks per m² density. The interaction effect of climate and density on mortality was significant (P<0.05). The lowest and highest mortality was in mild and humid and hot and dry climates, respectively.

The effect of climate and density on production efficiency index was significant (P<0.05). The interaction effect of climate and density on production efficiency index was not significant at the end of the whole experimental period (P≥0.05). The highest production index was recorded for 15 and 17 chicks per m² densities in mild and humid climate (P<0.05; Table 6).

### Table 5 - Effect of climate and stocking density on body weight gain (BWG; g/chick/day), feed intake (FI; g/chick/day), and feed conversion ratio (FCR; g/g) of Ross 308 broilers in the starter, grower, and whole periods

| Treatment               | Starter (1 to 21 d) | Grower (22 to 42 d) | Whole (1 to 42 d) |
|-------------------------|---------------------|---------------------|-------------------|
|                         | BWG     | FI      | FCR     | BWG     | FI      | FCR     | BWG     | FI      | FCR     |
| Climate                 |         |         |         |         |         |         |         |         |         |
| Mild and humid          | 41.56   | 53.89   | 1.29    | 81.61   | 168.7   | 2.07    | 61.58   | 111.3   | 1.80    |
| Semi-arid               | 41.65   | 54.35   | 1.30    | 80.38   | 167.0   | 2.08    | 61.01   | 110.7   | 1.81    |
| Alpine                  | 41.68   | 53.98   | 1.29    | 80.52   | 167.7   | 2.09    | 61.10   | 110.8   | 1.81    |
| Hot and dry             | 41.69   | 54.49   | 1.30    | 79.91   | 166.2   | 2.08    | 60.80   | 110.3   | 1.81    |
| P-value                 | 0.97    | 0.67    | 0.87    | 0.13    | 0.13    | 0.90    | 0.13    | 0.21    | 0.90    |
| Density (chick/m²)      |         |         |         |         |         |         |         |         |         |
| 10                      | 41.58   | 55.23a  | 1.33a   | 82.81a  | 166.5   | 2.01    | 62.20a  | 110.9   | 1.78c   |
| 15                      | 41.68   | 54.18ab | 1.30ab  | 81.73ab | 167.4   | 2.05    | 61.70ab | 110.8   | 1.79bc  |
| 17                      | 41.62   | 54.04b  | 1.30ab  | 81.01b  | 168.0   | 2.07    | 61.32b  | 111.0   | 1.81b   |
| 20                      | 41.70   | 53.25b  | 1.27b   | 76.87c  | 167.7   | 2.18    | 59.29c  | 110.5   | 1.86a   |
| P-value                 | 0.98    | 0.0072  |         | <0.0001 | 0.52    | <0.0001 | <0.0001 | 0.71    | <0.0001 |
| Mild and humid          | 41.23   | 54.07   | 1.31    | 83.43   | 169.3   | 2.03    | 62.33   | 111.7   | 1.79    |
| 10                      | 41.81   | 54.15   | 1.29    | 82.66   | 166.8   | 2.02    | 62.24   | 110.5   | 1.77    |
| 15                      | 41.18   | 54.35   | 1.32    | 83.51   | 168.6   | 2.02    | 62.35   | 111.5   | 1.78    |
| 17                      | 42.01   | 52.97   | 1.26    | 76.83   | 170.1   | 2.21    | 59.42   | 111.5   | 1.87    |
| 20                      | 41.39   | 53.56   | 1.29    | 77.23   | 166.9   | 2.16    | 59.31   | 110.2   | 1.85    |
| Semi-arid               | 41.66   | 56.17   | 1.35    | 83.15   | 164.4   | 1.98    | 62.40   | 110.3   | 1.76    |
| 10                      | 41.56   | 53.66   | 1.29    | 81.38   | 168.0   | 2.06    | 61.47   | 110.8   | 1.80    |
| 15                      | 41.98   | 54.00   | 1.28    | 79.77   | 168.9   | 2.12    | 60.87   | 111.4   | 1.83    |
| 17                      | 41.76   | 55.36   | 1.29    | 77.23   | 166.9   | 2.16    | 59.31   | 110.2   | 1.85    |
| Alpine                  | 41.24   | 56.17   | 1.36    | 84.10   | 165.3   | 1.96    | 62.67   | 110.8   | 1.76    |
| 10                      | 41.76   | 54.02   | 1.29    | 81.83   | 168.5   | 2.06    | 61.80   | 111.3   | 1.80    |
| 15                      | 41.77   | 52.66   | 1.26    | 80.35   | 168.8   | 2.10    | 61.06   | 110.7   | 1.81    |
| 17                      | 41.96   | 53.07   | 1.26    | 75.81   | 168.0   | 2.22    | 58.88   | 110.6   | 1.88    |
| 20                      | 42.20   | 54.51   | 1.29    | 80.56   | 166.9   | 2.07    | 61.38   | 110.7   | 1.80    |
| Hot and dry             | 41.58   | 54.89   | 1.32    | 81.04   | 166.2   | 2.05    | 61.31   | 110.5   | 1.80    |
| 10                      | 41.55   | 55.16   | 1.33    | 80.42   | 165.7   | 2.06    | 60.99   | 110.4   | 1.81    |
| 15                      | 41.43   | 53.40   | 1.29    | 77.62   | 166.0   | 2.14    | 59.53   | 109.7   | 1.84    |
| SEM                     | 0.44    | 0.80    | 0.02    | 1.04    | 1.52    | 0.03    | 0.48    | 0.63    | 0.01    |
| P-value                 | 0.68    | 0.30    | 0.25    | 0.23    | 0.47    | 0.0472  | 0.57    | 0.78    | 0.28    |

SEM - standard error of the means.

a-c - Means within same column with different letters are significantly different (P<0.05).
The effect of climate and density on meat production based on live weight per m$^2$ was significant (P<0.05). At the end of the experiment, the interaction effect of climate and density on meat production based on live weight was not significant (P<0.05; Table 6). The analysis of variance results showed that treatments with 20 chicks per m$^2$ density in mild and humid areas had the highest meat production per m$^2$ (P<0.05).

In this study, the highest income was obtained numerically at a density of 20 chicks per m$^2$ under mild and humid climate treatments (P<0.05; Table 6).

The greatest cost caused by climate and density interaction effect was obtained in 20 chicks per m$^2$ density and mild and humid climate treatment (P<0.05; Table 6).

The highest profit was obtained in mild and humid climate (P<0.05). Besides, the effect of density on economic profit was significant, so that the highest profit was obtained in the density of 17 chicks per m$^2$ (P<0.05). The interaction effect of climate and density on meat production based on average profit of production period was not significant (P≥0.05). The highest economic profit was obtained numerically at a density of 17 chicks per m$^2$ under mild and humid climate, with a profit of $3.74 per m$^2$ (P<0.05).

From this point of view, the most suitable stocking density in mild and humid, hot and dry, and alpine climates was 17 chicks per m$^2$, whereas in semi-arid climate, it was 15 chicks per m$^2$ (P<0.05; Table 6).

### Table 6 - Effect of climate region and stocking density on economic parameters of Ross 308 broilers at 42 days of age

| Treatment          | BW (g/chick) | Survival (%) | EPI | PBW (kg/m$^2$) | Cost ($/m$^2$) | Income ($/m$^2$) | Profit ($/m$^2) |
|--------------------|--------------|--------------|-----|----------------|---------------|------------------|-----------------|
| Climate            |              |              |     |                |               |                  |                 |
| Mild and humid     | 2629.3       | 95.73a       | 332.3a | 38.91a         | 39.03a        | 41.69a           | 2.66a           |
| Semi-ard           | 2605.4       | 94.02b       | 321.9b | 37.83b         | 38.87c        | 40.53b           | 1.66b           |
| Alpine             | 2609.0       | 94.00b       | 322.6b | 37.81b         | 38.89b        | 40.52c           | 1.63c           |
| Hot and dry        | 2596.2       | 93.61c       | 319.3b | 37.13c         | 38.75d        | 40.24d           | 1.49d           |
| P-value            | 0.13         | <0.0001      | 0.0032 | <0.0001        | <0.0001       | <0.0001          | 0.05            |
| Density (chick/m$^2$) |            |              |      |                |               |                  |                 |
| 10                 | 2654.8a      | 94.35b       | 335.0a | 25.04d         | 25.11d        | 26.84d           | 1.73c           |
| 15                 | 2634.3ab     | 94.00c       | 329.0ab | 37.14c         | 37.63c        | 39.80c           | 2.16b           |
| 17                 | 2618.1b      | 94.69a       | 326.5b | 42.14b         | 42.73b        | 45.16b           | 2.43a           |
| 20                 | 2532.7c      | 94.32b       | 305.7c | 47.34a         | 50.07a        | 51.19a           | 1.12d           |
| P-value            | <0.0001      | 0.0004       | <0.0001 | <0.0001        | <0.0001       | <0.0001          | 0.05            |
| Mild and humid     |              |              |      |                |               |                  |                 |
| 10                 | 2660.4       | 95.28b       | 337.3 | 25.35          | 25.25g        | 27.16            | 1.91            |
| 15                 | 2657.0       | 95.58ab      | 341.2 | 38.09          | 37.55f        | 40.81            | 3.26            |
| 17                 | 2661.2       | 96.14a       | 341.4 | 43.49          | 42.87d        | 46.60            | 3.74            |
| 20                 | 2538.5       | 95.92ab      | 309.3 | 48.70          | 50.45a        | 52.18            | 1.73            |
| P-value            | <0.0001      | 0.0004       | <0.0001 | <0.0001        | <0.0001       | <0.0001          | 0.05            |
| Semi-ard           |              |              |      |                |               |                  |                 |
| 10                 | 2663.7       | 93.78cde     | 336.7 | 24.97          | 25.01g        | 26.76            | 1.76            |
| 15                 | 2624.8       | 93.62def     | 325.0 | 36.86          | 37.64f        | 39.49            | 1.85            |
| 17                 | 2599.5       | 94.41c       | 319.5 | 41.72          | 42.86d        | 44.70            | 1.84            |
| 20                 | 2533.7       | 94.26cd      | 306.5 | 47.76          | 49.97b        | 51.18            | 1.21            |
| Alpine             |              |              |      |                |               |                  |                 |
| 10                 | 2674.6       | 94.18bcde    | 339.7 | 25.19          | 25.10g        | 26.99            | 1.89            |
| 15                 | 2638.3       | 93.83cde     | 327.9 | 37.12          | 37.77f        | 39.78            | 2.02            |
| 17                 | 2607.2       | 94.08cd      | 322.4 | 41.69          | 42.62e        | 44.68            | 2.06            |
| 20                 | 2516.0       | 93.96cd      | 300.3 | 47.25          | 50.08b        | 50.63            | 0.54            |
| Hot and dry        |              |              |      |                |               |                  |                 |
| 10                 | 2620.3       | 94.15cd      | 326.0 | 24.67          | 25.08g        | 26.43            | 1.35            |
| 15                 | 2617.2       | 94.92f       | 321.8 | 36.50          | 37.57f        | 39.11            | 1.53            |
| 17                 | 2604.5       | 94.13cd      | 322.8 | 41.67          | 42.56e        | 44.65            | 2.10            |
| 20                 | 2542.7       | 93.20de      | 306.6 | 45.67          | 49.78c        | 50.78            | 1.01            |
| SEM                | 20.45        | 0.22         | 5.25  | 0.40           | 0.18          | 0.43             | 0.47            |
| P-value            | 0.57         | 0.0088       | 0.3321 | 0.10           | 0.03          | 0.10             | 0.64            |

BW - body weight at the 42nd day of age; EPI - European production index; PBW - produced body weight in m$^2$; SEM - standard error of the means.

a-f - Means within same column with different letters are significantly different (P<0.05).
The effect of climate on the amount of glucose, triglyceride, total cholesterol, low-density lipoproteins (LDL); high density lipoproteins (HDL) ratio, HDL, very-low-density lipoprotein (VLDL), uric acid, aspartate aminotransferase (AST), alanine aminotransferase (ALT), total protein, and globulin content of blood plasma was significant (P<0.05; Tables 7 and 8), whereas the effect of climate on albumin was not significant (P<0.05; Table 8). Stocking density significantly affected levels of glucose, triglyceride, VLDL, HDL, total protein, and globulin (P<0.05) but did not affect total cholesterol, LDL, LDL/HDL ratio, uric acid, AST, ALT, and albumin (P≥0.05; Tables 7 and 8). The interaction effect of climate and density on total cholesterol, triglyceride, VLDL, HDL, LDL/HDL ratio, and globulin were significant (P<0.05).

At 28 d of age, different climates significantly affected the levels of IgM and total antibody, whereas at 42 d of age, it affected IgG, IgM, and total antibody (P<0.05; Table 9). The highest and lowest levels of response to antibody were observed in hot and dry and mild and humid climates, respectively (P<0.05). At 28 d of age, the total amount of antibody in 20 chicks per m² treatment under semi-arid climate and at 42 d of age in 10 chicks per m² treatment under alpine and hot and dry climates was higher compared with other treatments (P<0.05).

The effect of climate on live body weight, featherless body weight, full abdomen carcass weight, empty abdomen carcass weight, breast, wings, neck, and proventriculus as a percentage of featherless body weight was significant (P<0.05; Tables 10-12). Chickens reared under hot and dry climate had the

**Table 7** - Effect of climate region and stocking density on plasma constitutes (lipids and glucose) of Ross 308 broilers at 42 days of age

| Treatment            | Glucose (mg/dL) | Total cholesterol (mg/dL) | Triglycerides (mg/dL) | VLDL (mg/dL) | HDL cholesterol (mg/dL) | LDL cholesterol (mg/dL) | LDL:HDL ratio |
|----------------------|-----------------|---------------------------|-----------------------|--------------|-------------------------|-------------------------|-----------|
| **Climate**          |                 |                           |                       |              |                         |                         |             |
| Mild and humid       | 195.1ab         | 164.8a                    | 61.18a                | 12.23a       | 73.82a                  | 82.76b                  | 1.12b      |
| Semi-arid            | 193.4bc         | 162.6b                    | 60.15a                | 12.03a       | 72.76a                  | 84.16ab                 | 1.16b      |
| Alpine               | 197.4a          | 161.0b                    | 61.79a                | 12.35a       | 68.61b                  | 85.70a                  | 1.25a      |
| Hot and dry          | 192.6c          | 161.1b                    | 56.57b                | 11.31b       | 69.46b                  | 84.38ab                 | 1.22a      |
| **Density (chick/m²)**|                 |                           |                       |              |                         |                         |             |
| 10                   | 192.9b          | 161.2                     | 59.17a                | 11.83b       | 70.29b                  | 84.03                   | 1.20       |
| 15                   | 193.8b          | 162.6                     | 58.74a                | 11.74b       | 70.43b                  | 83.37                   | 1.18       |
| 17                   | 194.7b          | 162.5                     | 59.82a                | 11.96b       | 70.43a                  | 84.75                   | 1.17       |
| 20                   | 197.1a          | 163.1                     | 61.97b                | 12.39a       | 71.60a                  | 84.85                   | 1.19       |
| **P-value**          | 0.0026          | 0.02                      | 0.0091                | 0.0091       | 0.04                    | 0.43                    | 0.58       |
| **Mild and humid**   | 190.4           | 163.9a-d                  | 61.18b-e              | 12.23b-e     | 73.19abc                | 81.61                   | 1.12d      |
| 15                   | 196.2           | 163.0a-d                  | 57.81efg              | 11.56efg     | 72.49a-d                | 82.32                   | 1.14d      |
| 17                   | 195.8           | 165.6abc                  | 63.04abc              | 12.60abc     | 75.16a                  | 83.75                   | 1.11d      |
| 20                   | 198.2           | 166.6a                    | 62.69a-d              | 12.53a-d     | 74.44ab                 | 83.35                   | 1.12d      |
| **Semi-arid**        | 193.7           | 161.9b-e                  | 58.24g                | 11.64g       | 75.32abc                | 83.80                   | 1.14d      |
| 15                   | 192.9           | 165.8ab                   | 59.56eg               | 11.91eg      | 69.90f                  | 82.92                   | 1.19bcd     |
| 17                   | 191.7           | 161.2de                   | 56.00fg               | 11.20fg      | 75.46a                  | 82.83                   | 1.09d      |
| 20                   | 195.3           | 161.6b-e                  | 66.81a                | 13.36a       | 72.18a-d                | 87.10                   | 1.21a-d     |
| **Alpine**           | 197.3           | 157.8e                    | 59.04c-g              | 11.80c-g     | 67.65ef                 | 87.26                   | 1.29a      |
| 15                   | 194.5           | 160.6de                   | 59.96c-f              | 11.99c-f     | 69.19df                 | 84.34                   | 1.22abc     |
| 17                   | 197.5           | 162.7a-e                  | 64.68ab               | 12.93ab      | 67.58ef                 | 87.26                   | 1.29a      |
| 20                   | 200.2           | 163.1a-e                  | 63.47abc              | 12.69abc     | 70.03c-f                | 83.94                   | 1.20bcd     |
| **Hot and dry**      | 190.2           | 161.4de                   | 58.21d-g              | 11.64d-g     | 66.80f                  | 83.46                   | 1.25ab     |
| 15                   | 191.5           | 161.2d                    | 57.62eg               | 11.52efg     | 70.15c-f                | 83.90                   | 1.19bcd     |
| 17                   | 193.9           | 160.5d                    | 55.56fg               | 11.11fg      | 71.15b-e                | 85.15                   | 1.19bcd     |
| 20                   | 194.9           | 161.2d                    | 54.90g                | 10.98g       | 69.75c-f                | 85.00                   | 1.22abc     |
| **SEM**              | 1.66            | 1.31                      | 1.44                  | 0.28         | 1.18                    | 1.44                    | 0.02       |
| **P-value**          | 0.30            | 0.03                      | <0.0001               | <0.0001      | 0.05                    | 0.34                    | 0.02       |

VLDL - very low-density lipoprotein; HDL - high-density lipoproteins; LDL - low-density lipoproteins; SEM - standard error of the means.

a-f - Means within same column with different letters are significantly different (P<0.05).

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highest empty abdomen carcass weight. Different densities significantly affected live body weight/empty abdomen carcass weight, thighs, and proventriculus as a percentage of featherless body weight (P<0.05). The interaction effect of climate and density on proventriculus weight was significant (P<0.05). Experimental treatments with 20 chicks per m² in semi-arid climate had the highest ratio of proventriculus weight to featherless carcass weight (P<0.05; Table 12).

**Discussion**

As the results of this study showed, the effect of outdoor climate on average body weight gain, feed intake, and daily feed conversion ratio in starter, grower, and whole periods were not significant (P≥0.05). The reason is the development and evolutions of technology in the fundamental changes in the structure and management of poultry facilities, controlling environmental conditions and improving qualitative development. In this case, having an efficient ventilation system in broiler chicken houses to remove excess moisture and heat (especially in the warm seasons), dust, and hovering particles, as well as to provide oxygen and removing toxic gases is important (Karcher, 2009).

Broiler chickens consume a certain amount of energy per day and then stop eating, even if they have not received their required protein, minerals, and vitamins (Baghoyan, 2006). So, if the management technology of poultry facilities is not optimal, this balance will not be achieved.

**Table 8 - Effect of climate region and stocking density on plasma constitutes (enzymes, proteins, and uric acid) of Ross 308 broilers at 42 days of age**

| Treatment          | Uric acid (mg/dL) | AST (U/L) | ALT (U/L) | Total protein (g/dL) | Albumin (g/dL) | Globulin (g/dL) |
|--------------------|-------------------|-----------|-----------|----------------------|----------------|-----------------|
| **Climate**        |                   |           |           |                      |                |                 |
| Mild and humid     | 4.55b             | 295.2a    | 542.9b    | 3.96ab               | 1.14           | 1.37a           |
| Semi-arid          | 4.71b             | 296.0a    | 538.6b    | 3.87b                | 1.14           | 1.30b           |
| Alpine             | 5.18a             | 293.1b    | 556.3a    | 3.99a                | 1.13           | 1.26bc          |
| Hot and dry        | 4.50b             | 293.3b    | 534.2b    | 3.90ab               | 1.15           | 1.24c           |
| **P-value**        | 0.0005            | 0.004     | <0.0001   | 0.04                 | 0.95           | <0.0001         |
| **Density (chick/m²)** |             |           |           |                      |                |                 |
| 10                 | 4.75              | 294.4     | 538.8     | 3.88b                | 1.15           | 1.25b           |
| 15                 | 4.56              | 293.1     | 541.6     | 3.89b                | 1.13           | 1.29ab          |
| 17                 | 4.71              | 294.7     | 547.8     | 4.00a                | 1.17           | 1.33a           |
| 20                 | 4.93              | 295.4     | 543.8     | 3.95ab               | 1.12           | 1.30a           |
| **P-value**        | 0.20              | 0.12      | 0.23      | 0.02                 | 0.17           | 0.05            |
| **Mild and humid** |                   |           |           |                      |                |                 |
| 10                 | 4.08              | 294.9     | 533.9     | 3.93                 | 1.15           | 1.37abc         |
| 15                 | 4.40              | 294.1     | 540.7     | 3.93                 | 1.14           | 1.38ab          |
| 17                 | 4.60              | 297.1     | 557.1     | 4.03                 | 1.20           | 1.41a           |
| 20                 | 5.13              | 294.8     | 540.0     | 3.94                 | 1.09           | 1.32ad          |
| **Semi-arid**      |                   |           |           |                      |                |                 |
| 10                 | 4.68              | 296.2     | 541.2     | 3.77                 | 1.14           | 1.26cf          |
| 15                 | 4.59              | 294.8     | 541.1     | 3.76                 | 1.15           | 1.35ad          |
| 17                 | 4.75              | 295.0     | 538.2     | 4.03                 | 1.18           | 1.35ad          |
| 20                 | 4.84              | 298.0     | 533.9     | 3.93                 | 1.10           | 1.26def         |
| **Alpine**         |                   |           |           |                      |                |                 |
| 10                 | 5.09              | 292.2     | 561.3     | 3.98                 | 1.14           | 1.20ef          |
| 15                 | 5.14              | 292.3     | 553.2     | 4.00                 | 1.10           | 1.24def         |
| 17                 | 5.22              | 294.7     | 556.9     | 4.01                 | 1.15           | 1.29be          |
| 20                 | 5.28              | 293.3     | 553.8     | 3.98                 | 1.15           | 1.33ad          |
| **Hot and dry**    |                   |           |           |                      |                |                 |
| 10                 | 5.17              | 294.3     | 518.9     | 3.85                 | 1.17           | 1.17f           |
| 15                 | 4.10              | 291.4     | 531.4     | 3.88                 | 1.13           | 1.20ef          |
| 17                 | 4.27              | 291.9     | 539.1     | 3.93                 | 1.15           | 1.28be          |
| 20                 | 4.47              | 295.5     | 547.5     | 3.96                 | 1.13           | 1.31ae          |
| **SEM**            | 0.24              | 1.35      | 6.31      | 0.06                 | 0.03           | 0.03            |
| **P-value**        | 0.06              | 0.44      | 0.07      | 0.65                 | 0.72           | 0.05            |

AST - aspartate amino transferase; ALT - alanine amino transferase; SEM - standard error of the means.

a-f - Means within same column with different letters are significantly different (P<0.05).
In a state of energy deficiency in the diet, body carbohydrates, fats, and proteins are catabolized (broken down) in body tissues, which leads to heat production (Lesson and Summers, 2008; Attia and Hassan, 2017; Attia et al., 2018). When the equipment of poultry facilities is not good, the effect of climate predominates on poultry house environment and the catabolism increases. According to the significant daily feed intake during the starter period and the increase of body weight gain during the grower and whole periods, the reason for this can be the greater floor space and feed trough allocated to each bird in 10 chicks per m\(^2\) density compared with other treatments. Increasing stocking density causes increased stress, competition for feed intake, microbial activity, and ammonia gas production, which leads to weight loss (Galobart and Moran Jr., 2005). Besides, increasing stocking density causes increases in moisture content, incidence of dermatitis in foot pads, breast wounds, and skin problems, and as a result, reduces the carcass grading in the slaughterhouse (Kjaer, 2004). The significant effect of stocking density on feed conversion ratio during the starter and whole periods affected final body weight and the profit per m\(^2\). In this study, the treatments with 17 chicks per m\(^2\) density showed the highest profit per m\(^2\).

Poultry growth is a quantitative trait influenced by the genotype, environment, and contents of diet. Differences in performance can be attributed to the above-mentioned effects and the interaction effect of genotype and environment (FAO, 2014; Attia et al., 2016).

**Table 9 - Effect of climate region and stocking density on immunity of Ross 308 broilers at 28 and 42 days of age**

| Treatment       | Climate        | 28 days                   | 42 days                   | 28 days                   | 42 days                   | 28 days                   | 42 days                   |
|-----------------|----------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
|                 |                | TSRCB (IgG)\(^1\)       | TSRCB (IgM)\(^2\)       | TSRCB (IgT)\(^3\)       | TSRCB (IgG)\(^1\)       | TSRCB (IgM)\(^2\)       | TSRCB (IgT)\(^3\)       |
| Climate         | Mild and humid| 0.92                      | 0.64b                     | 1.56b                     | 1.59b                    | 1.46c                     | 3.06c                     |
|                 | Semi-arid     | 0.92                      | 1.10a                     | 2.03a                     | 2.01a                    | 2.15b                     | 4.17b                     |
|                 | Alpine        | 0.95                      | 1.14a                     | 2.09a                     | 2.25a                    | 2.64a                     | 4.89a                     |
|                 | Hot and dry   | 0.95                      | 1.14a                     | 2.09a                     | 2.25a                    | 2.64a                     | 4.89a                     |
| P-value         | 0.98          | <0.0001                   | 0.01                      | <0.0001                   | <0.0001                   | <0.0001                   | <0.0001                   |
| Density (chick/m\(^2\)) | 10           | 1.00                      | 0.93                      | 1.93                      | 1.98                     | 2.32                      | 4.31                      |
|                 | 15            | 0.89                      | 0.96                      | 1.85                      | 2.04                     | 2.31                      | 4.35                      |
|                 | 17            | 0.90                      | 1.04                      | 1.95                      | 2.03                     | 2.14                      | 4.17                      |
|                 | 20            | 0.95                      | 1.07                      | 2.03                      | 2.04                     | 2.12                      | 4.17                      |
| P-value         | 0.75          | 0.52                      | 0.83                      | 0.94                     | 0.20                     | 0.68                      |                           |
| Mild and humid  | 10            | 0.87                      | 0.56                      | 1.43                      | 1.56                     | 1.56                      | 3.12                      |
|                 | 15            | 1.00                      | 0.62                      | 1.62                      | 1.68                     | 1.56                      | 3.25                      |
|                 | 17            | 0.93                      | 0.68                      | 1.62                      | 1.62                     | 1.43                      | 3.06                      |
|                 | 20            | 0.87                      | 0.68                      | 1.56                      | 1.50                     | 1.31                      | 2.81                      |
| Semi-arid       | 10            | 0.87                      | 0.93                      | 1.81                      | 2.00                     | 2.25                      | 4.25                      |
|                 | 15            | 0.81                      | 1.12                      | 1.93                      | 2.00                     | 2.43                      | 4.43                      |
|                 | 17            | 0.93                      | 1.12                      | 2.06                      | 2.00                     | 1.87                      | 3.87                      |
|                 | 20            | 1.06                      | 1.25                      | 2.31                      | 2.06                     | 2.06                      | 4.12                      |
| Alpine          | 10            | 1.12                      | 1.12                      | 2.25                      | 2.18                     | 2.75                      | 4.93                      |
|                 | 15            | 0.87                      | 1.06                      | 1.93                      | 2.25                     | 2.62                      | 4.87                      |
|                 | 17            | 0.87                      | 1.18                      | 2.06                      | 2.25                     | 2.62                      | 4.87                      |
|                 | 20            | 0.93                      | 1.18                      | 2.12                      | 2.31                     | 2.56                      | 4.87                      |
| Hot and dry     | 10            | 1.12                      | 1.12                      | 2.25                      | 2.18                     | 2.75                      | 4.93                      |
|                 | 15            | 0.87                      | 1.06                      | 1.93                      | 2.25                     | 2.62                      | 4.87                      |
|                 | 17            | 0.87                      | 1.18                      | 2.06                      | 2.25                     | 2.62                      | 4.87                      |
|                 | 20            | 0.93                      | 1.18                      | 2.12                      | 2.31                     | 2.56                      | 4.87                      |
| SEM             | 0.15          | 0.15                      | 0.26                      | 0.16                     | 0.17                      | 0.27                      |                           |
| P-value         | 0.90          | 0.99                      | 0.96                      | 0.99                     | 0.92                      | 0.98                      |                           |

\(^1\) Immunoglobulin G antibody against sheep red blood cell (SRBC); \(^2\) immunoglobulin M antibody against SRBC; \(^3\) total antibody against SRBC; SEM - standard error of the means.

a-c - Means within same column with different letters are significantly different (P<0.05).
Table 10 - Effect of climate region and stocking density on carcass components of Ross 308 broilers at 42 days of age

| Treatment       | LBW (g)   | DBW (g)   | FACW (g)   | EACW (g)  | EC (%)    |
|-----------------|-----------|-----------|------------|-----------|-----------|
| Climate         |           |           |            |           |           |
| Mild and humid  | 2552.3ab  | 2341.6a   | 2142.4a    | 1626.8    | 75.99b    |
| Semi-arid       | 2560.6a   | 2333.8a   | 2124.1b    | 1609.1    | 75.82b    |
| Alpine          | 2557.3a   | 2334.2a   | 2115.5b    | 1611.3    | 76.24ab   |
| Hot and dry     | 2540.3b   | 2300.9b   | 2082.4c    | 1602.3    | 77.04a    |
| P-value         | 0.04      | <0.0001   | <0.0001    | 0.09      | 0.01      |
| P-value         |           |           |            |           |           |
| Density (chick/m²) |           |           |            |           |           |
| 10              | 2545.4b   | 2323.4    | 2116.9     | 1610.8    | 76.17ab   |
| 15              | 2564.8a   | 2339.2    | 2125.0     | 1621.1    | 76.37ab   |
| 17              | 2555.7ab  | 2327.8    | 2116.8     | 1601.2    | 75.72b    |
| 20              | 2544.6b   | 2320.2    | 2105.8     | 1616.4    | 76.84a    |
| P-value         | 0.02      | 0.13      | 0.18       | 0.23      | 0.05      |
| Mild and humid  |           |           |            |           |           |
| 10              | 2545.8    | 2327.2    | 2133.5     | 1620.2    | 75.98     |
| 15              | 2556.0    | 2354.3    | 2150.5     | 1648.8    | 76.73     |
| 17              | 2535.3    | 2329.7    | 2133.6     | 1591.7    | 74.67     |
| 20              | 2533.8    | 2349.6    | 2151.8     | 1646.7    | 76.59     |
| P-value         |           |           |            | 0.23      | 0.05      |
| Semi-arid       |           |           |            |           |           |
| 10              | 2555.9    | 2326.0    | 2125.5     | 1603.2    | 75.50     |
| 15              | 2582.9    | 2342.5    | 2132.6     | 1605.0    | 75.31     |
| 17              | 2565.5    | 2350.8    | 2125.6     | 1631.4    | 76.81     |
| 20              | 2538.0    | 2316.1    | 2112.7     | 1596.8    | 76.66     |
| Alpine          |           |           |            |           |           |
| 10              | 2551.5    | 2326.5    | 2112.8     | 1612.5    | 76.39     |
| 15              | 2561.2    | 2350.9    | 2131.4     | 1626.2    | 76.37     |
| 17              | 2570.5    | 2334.1    | 2114.8     | 1586.9    | 75.13     |
| 20              | 2546.2    | 2325.2    | 2103.0     | 1619.7    | 77.07     |
| Hot and dry     |           |           |            |           |           |
| 10              | 2528.3    | 2308.3    | 2095.8     | 1607.5    | 76.79     |
| 15              | 2559.3    | 2309.1    | 2085.4     | 1604.4    | 77.05     |
| 17              | 2533.1    | 2296.3    | 2093.1     | 1594.9    | 76.28     |
| 20              | 2540.3    | 2289.9    | 2055.5     | 1602.4    | 78.04     |
| SEM             | 10.70     | 12.16     | 12.44      | 14.25     | 0.57      |
| P-value         | 0.53      | 0.63      | 0.55       | 0.11      | 0.09      |

LBW - live body weight; DBW - defeathered body weight; FACW - full abdomen carcass weight; EACW - empty abdomen carcass weight; EC - eviscerated carcass; SEM - standard error of the means.
a-c - Means within same column with different letters are significantly different (P<0.05).
Begum et al. (2009), using data envelopment analysis (DEA) to evaluate economic efficiency on a poultry farm, found that the economic efficiency was less than technical efficiency. In addition, the results of their research showed that the highest profit was obtained due to the use of all capacities and the reduction of excess inputs in the density of 17 chicks per m$^2$. In this study, the density of 20 chicks/m$^2$ in hot and dry climate should not be recommended. Moreover, the most suitable stocking density in mild and humid, alpine, and hot and dry climates was 17 chicks/m$^2$, and 15 chicks/m$^2$ in semi-arid climate.

It may seem that chicken production will have more profit in 20 kg/m$^2$ density, whereas in our research, the optimum density for maximum profit was 17 chicks/m$^2$. Due to the small body size of chicks in the starter period, the greater competition for the necessary space, and less access to feed, the effect of density on body weight gain in this period was not significant (P≥0.05). However, in this research, because the chick body size was larger in the grower period and the competition for access to feed was higher, this factor made the meat production/m$^2$ significant (P<0.05). The meat production (kg meat/m$^2$) of each chicken in 20 chicks/m$^2$ was lower than in the other treatments, the cumulative income of treatments at a density of 20 chicks/m$^2$ was less than other treatments in whole period, and the treatments at a density of 17 chicks/m$^2$ had the highest profit.

The identification of optimal density in different climates for a specific product, such as chicken meat, provides the fields of policy-making development and orientation of government supportive policies in each climate, and can be a model for other areas of the world to maximize production. The sum

| Table 11 - Effect of climate region and stocking density on relative weight of carcass components (% of defeathered weight) of Ross 308 broilers at 42 days of age |
|-----------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Treatment       | % BR        | % DR        | % WN        | % AFW       | % GZ        | % HR        | % NC        |
| Climate         | Mild and humid | 34.89a      | 31.40       | 4.31b       | 2.41        | 2.85        | 0.61        | 2.38b       |
|                 | Semi-arid   | 33.84b      | 31.18       | 4.52a       | 2.52        | 2.88        | 0.62        | 2.39b       |
|                 | Alpine      | 33.51b      | 31.37       | 4.49a       | 2.45        | 2.86        | 0.62        | 2.38b       |
|                 | Hot and dry | 34.23ab     | 31.81       | 4.54a       | 2.54        | 2.87        | 0.63        | 2.60a       |
| P-value         | 0.01        | 0.25        | <0.0001     | 0.21        | 0.95        | 0.46        | <0.0001     |
| Density (chick/m$^2$) | 10          | 34.22       | 31.77a      | 4.51        | 2.49        | 2.88        | 0.61        | 2.43        |
|                 | 15          | 33.82       | 30.92b      | 4.46        | 2.55        | 2.80        | 0.63        | 2.41        |
|                 | 17          | 34.38       | 31.57ab     | 4.45        | 2.42        | 2.90        | 0.62        | 2.49        |
|                 | 20          | 34.06       | 31.50ab     | 4.44        | 2.46        | 2.88        | 0.61        | 2.42        |
| P-value         | 0.60        | 0.05        | 0.59        | 0.27        | 0.29        | 0.54        | 0.34        |
| Mild and humid  | 10          | 34.62       | 31.94       | 4.40        | 2.45        | 2.85        | 0.60        | 2.37        |
|                 | 15          | 34.91       | 30.93       | 4.28        | 2.46        | 2.89        | 0.64        | 2.35        |
|                 | 17          | 35.89       | 31.11       | 4.28        | 2.42        | 2.81        | 0.61        | 2.47        |
|                 | 20          | 34.14       | 31.63       | 4.28        | 2.33        | 2.86        | 0.60        | 2.34        |
| P-value         | 0.60        | 0.05        | 0.59        | 0.27        | 0.29        | 0.54        | 0.34        |
| Semi-arid       | 10          | 34.41       | 31.04       | 4.57        | 2.37        | 2.98        | 0.63        | 2.35        |
|                 | 15          | 32.84       | 30.76       | 4.61        | 2.58        | 2.72        | 0.63        | 2.42        |
|                 | 17          | 33.88       | 31.31       | 4.44        | 2.50        | 2.96        | 0.62        | 2.41        |
|                 | 20          | 34.25       | 31.59       | 4.47        | 2.62        | 2.88        | 0.61        | 2.37        |
| P-value         | 0.36        | 0.41        | 0.52        | 0.58        | 0.25        | 0.84        | 0.06        |
| Alpine          | 10          | 34.06       | 32.15       | 4.54        | 2.55        | 2.87        | 0.60        | 2.44        |
|                 | 15          | 33.18       | 31.16       | 4.41        | 2.55        | 2.88        | 0.61        | 2.32        |
|                 | 17          | 33.21       | 31.25       | 4.55        | 2.33        | 2.82        | 0.62        | 2.43        |
|                 | 20          | 33.59       | 30.93       | 4.47        | 2.38        | 2.88        | 0.63        | 2.32        |
| Hot and dry     | 10          | 33.79       | 31.93       | 4.51        | 2.60        | 2.84        | 0.63        | 2.56        |
|                 | 15          | 34.36       | 30.84       | 4.56        | 2.61        | 2.72        | 0.64        | 2.55        |
|                 | 17          | 34.55       | 32.63       | 4.54        | 2.45        | 3.01        | 0.62        | 2.64        |
|                 | 20          | 34.24       | 31.83       | 4.56        | 2.50        | 2.90        | 0.62        | 2.64        |
| SEM             | 0.60        | 0.45        | 0.06        | 0.09        | 0.07        | 0.01        | 0.06        |
| P-value         | 0.46        | 0.41        | 0.52        | 0.58        | 0.25        | 0.84        | 0.06        |

BR - breast; DR - drumsticks; WN - wings; AFW - abdominal fat weight; GZ - gizzard; HR - heart; NC - neck; SEM - standard error of the means.

a-b - Means within same column with different letters are significantly different (P<0.05).
of final body weight per area unit is an effective factor in the profitability of productive unit, which, according to economic conditions and market demand, can affect the flock density per area unit decision and the average body weight for each bird (Begum et al., 2010). The results of this study showed that changing density from 10 to 17 chicks/m² will increase profit by $ 1.83 in mild and humid climate, $ 0.88 in semi-arid climate, $ 0.17 in alpine climate, and $ 0.75 in hot and dry climate. Thus, for example, under humid climate in a poultry replication with 2,000 m² area, increasing the density from 10 to 17 chicks/m² will yield $ 3,660 more profit in the whole period.

The mild and humid and hot and dry climates had the highest and lowest profitability, respectively (P<0.05). In fact, when birds are under heat stress condition, some changes occur in the blood system. The cardiovascular system involves heat removal, acid-base imbalance, increased blood pH, and respiratory alkalosis (Altan et al., 2000). It is known that stress causes disruption of leukocyte function in poultry (Ozbey et al., 2004).

Blood parameters such as triglyceride, total cholesterol, LDL:HDL, HDL, VLDL, and globulin ratios were significantly affected by climate and density (P<0.05). Moreover, chickens under alpine climate had the highest levels of blood glucose and total protein; however; chickens grown in semi-arid climate showed the lowest total protein content. These findings are consistent with the results of Zhang (2015), Attia and Hassan (2017) and Attia et al., 2018. In another report, increasing the temperature of quail breeding environment reduced the total serum protein (Ozbey et al., 2004); besides, Niu et al. (2009) indicated that high temperature weakens the immune system of broiler chickens.

Table 12 - Effect of climate region and stocking density on relative weight of carcass components (% of defeathered weight) of Ross 308 broilers at 42 days of age

| Treatment                  | Back thoracic vertebrae | Crop   | Proventriculus | Pancreas |
|----------------------------|-------------------------|--------|----------------|----------|
| Climate                    |                         |        |                |          |
| Mild and humid             | 3.01                    | 0.48   | 0.42b          | 0.29     |
| Semi-arid                  | 3.05                    | 0.49   | 0.42b          | 0.29     |
| Alpine                     | 3.07                    | 0.47   | 0.43ab         | 0.29     |
| Hot and dry                | 3.13                    | 0.47   | 0.44a          | 0.28     |
| P-value                    |                         |        |                |          |
|                          | 0.06                    | 0.46   | 0.05           | 0.77     |
| Density (chick/m²)         |                         |        |                |          |
| 10                         | 3.09                    | 0.48   | 0.43a          | 0.29     |
| 15                         | 3.08                    | 0.48   | 0.42b          | 0.29     |
| 17                         | 3.03                    | 0.49   | 0.42ab         | 0.29     |
| 20                         | 3.06                    | 0.47   | 0.43ab         | 0.28     |
| P-value                    |                         |        |                |          |
|                          | 0.59                    | 0.63   | 0.04           | 0.31     |
| Mild and humid             |                         |        |                |          |
| 10                         | 3.02                    | 0.50   | 0.44a-d        | 0.28     |
| 15                         | 3.06                    | 0.45   | 0.41de         | 0.29     |
| 17                         | 2.94                    | 0.48   | 0.41ced        | 0.30     |
| 20                         | 3.01                    | 0.49   | 0.42b-e        | 0.28     |
| Semi-arid                  |                         |        |                |          |
| 10                         | 3.05                    | 0.51   | 0.43a-e        | 0.28     |
| 15                         | 3.07                    | 0.46   | 0.40e          | 0.29     |
| 17                         | 3.03                    | 0.52   | 0.41de         | 0.29     |
| 20                         | 3.04                    | 0.48   | 0.45a          | 0.29     |
| Alpine                     |                         |        |                |          |
| 10                         | 3.14                    | 0.47   | 0.44abc        | 0.30     |
| 15                         | 3.09                    | 0.49   | 0.41ced        | 0.29     |
| 17                         | 3.02                    | 0.48   | 0.42a-e        | 0.30     |
| 20                         | 3.02                    | 0.45   | 0.42a-e        | 0.28     |
| Hot and dry                |                         |        |                |          |
| 10                         | 3.14                    | 0.44   | 0.43a-e        | 0.28     |
| 15                         | 3.09                    | 0.49   | 0.45ab         | 0.29     |
| 17                         | 3.12                    | 0.48   | 0.44a-d        | 0.28     |
| 20                         | 3.16                    | 0.47   | 0.43a-d        | 0.28     |
| SEM                        |                         |        |                |          |
|                          | 0.06                    | 0.02   | 0.01           | 0.00     |
| P-value                    |                         |        |                |          |
|                          | 0.95                    | 0.33   | 0.01           | 0.84     |

SEM - standard error of the means.

_abc - Means within same column with different letters are significantly different (P<0.05).
In the present study, the final body weight of broiler chickens in simulated hot and dry climate was lower than in other climates, which resulted in the lowest income. This may be due to the increase in temperature leading to a decrease in absorption of essential and nonessential amino acids and of protein synthesis, and increase in bird catabolism, blood glucose, and glucocorticoid levels (Gous and Morris, 2005). Some researchers have shown that stocking density causes the suppression of the immunity of broiler chickens, which can easily be determined by evaluating the weight of Bursa of Fabricius and Bursa of Fabricius weight:body weight ratio during slaughter (Heckert et al., 2002). The results of this study showed that chicks reared at a density of 20 chicks/m² had the lowest immune response at 42 days of age. In another study, stocking density changed to 18 birds/m² did not have a significant effect on antibody titer against SRBC and on IgG and IgM titers (Heckert et al., 2002), which is consistent with our findings.

Palizdar et al. (2017) reported that stocking density significantly increased the immune response, including antibody titer against SRBC, IgG, and IgM. At high densities, the antibody titer against SRBC and the IgG and IgM titers were higher compared with low densities, which is not in agreement with the findings of the present study (P<0.05). In this study, antibody titer against SRBC was significant in different climates studied (P<0.05), in which alpine as well as hot and dry climates had the highest immune response and the highest defeathered carcass weight and were in second place in terms of profitability.

The amount of blood glucose increases during heat stress (Ozbey et al., 2004). High environmental temperature weakens the immune system of broiler chickens (Niu et al., 2009). One of the major problems in tropical regions is the reduction of feed intake, growth, digestibility of amino acids and other nutrients, and changes in amino acid requirements, as well as changes in carcass composition and eventually reduced performance (Senkoylu and Altinsoy, 1999; Attia et al., 2016; Attia and Hassan, 2017).

In this experiment, the ratio of proventriculus weight to defeathered carcass weight of broiler chickens grown at a density of 20 chicks/m² in semi-arid climate was higher than in other climates. The reason is the intensity of the competition of chickens for feed, which led to an enlarged proventriculus; however, the average final body weight of this group was lower compared with other climates.

Experimental treatments under mild and humid climate showed the highest production index. In this experiment, 17 chicks/m² in mild and humid climate showed the highest profit ($ 3.74/m²) and the density of 20 chicks/m² in alpine climate showed the lowest profit ($ 0.54/m²). Therefore, according to the purpose of this experiment, to achieve maximum profit in each climate, the appropriate density should be selected.

**Conclusions**

This study showed that the maximum profit was gained in mild and humid, alpine, or hot and dry climates at a density of 17 chicks/m² and in semi-arid climate at a density of 15 chicks/m². Moreover, the most achieved profit was in the mild and humid climate at a density of 17 chicks/m² compared with other climates and densities, and this group had the lowest mortality rate and the highest production index among experimental treatments. Broiler chickens grown in hot and dry climate have the highest, while those in mild and humid climate, the lowest levels of antibody response.

**Conflict of Interest**

The authors declare no conflict of interest.

**Author Contributions**

Conceptualization: M. Gholami and A. Seidavi. Funding acquisition: M. Gholami and A. Seidavi. Investigation: M. Gholami. Methodology: M. Gholami, M. Chamani, A. Seidavi, A.A. Sadeghi and M. Aminafschar. Project administration: A. Seidavi. Resources: M. Gholami and A. Seidavi. Supervision: M.
Chamani and A. Seidavi. Validation: M. Gholami, M. Chamani, A. Seidavi, A.A. Sadeghi and M. Aminafschar. Writing-review & editing: M. Gholami, M. Chamani, A. Seidavi, A.A. Sadeghi and M. Aminafschar.

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