



Evaluation of cardiac status, ascites related factors and growth performance of five commercial strains of broiler chickens

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ABSTRACT. The aim of the current study was to evaluate cardiac status, ascites susceptibility, thyroid hormones, some hematological parameters and performance of five commercial broiler strains. Chicks were selected from strains of Cobb, Hubbard, Ross 308, Arbor Acres, and Arian (Iranian commercial broiler strain). Management and nutritional conditions were the same for all strains. Ascites related factors, and growth performance were measured. The highest and lowest, RV weight/live weight at 21 day of age were related to Arian and Ross 308 strains, respectively ($p < 0.05$). The TV weight, TV weight/live weight and the RV weight/live weight were significantly different between various strains at 49 and 54 days of age ($p < 0.05$). Strain had no effect on RV/TV. Performance, T_3 and T_4 hormones, hematological parameters, and mortalities were not significantly different among the strains ($p > 0.05$). Ascites mortalities in the Ross 308 was zero; however, it had no significant difference with other strains ($p > 0.05$). It was concluded that, based on performance and physiological status, even though considered broiler strains did not differ significantly because of the same genetic programs probably, but according to the prices and market conditions each can be selected for breeding.

Keywords: Hematological parameters; thyroid hormones; mortality; body weight gain; feed intake; feed conversion ratio.

Received on October 11, 2019.
Accepted on November 26, 2019.

Introduction

Genetic improvement and nutrition advancement have led to an increase in the rate of growth and feed efficiency in commercial broiler chickens due to increased efficiency in the use of energy and amino acids (Hassanzadeh 2010; Varmaghany, Rahimi, Karimi Torshizi, Lotfollahian, & Hassanzadeh, 2015). These improvements over the past two decades have reduced the age of slaughter of broiler chickens from 70 days to less fewer than 40 days (Olanrewaju et al., 2014). The shortening of the breeding period and the feed conversion ratio (FCR) improvement of broiler chickens along with choosing to increase the average of the productive traits has caused adverse effects on the various aspects of the physiology of these birds and has led to the occurrence of metabolic diseases (Tona et al., 2005). The causes of these adverse effects are the increase in body volume without parallel changes in the internal organs, cardiovascular and skeletal system to support of rapid growth and very large body size (Zerehdaran et al., 2005). Some of these complications, such as obesity, ascites syndrome, sudden death syndrome, and skeletal disorders have a negative effect on bird welfare.

Among metabolic abnormalities in broiler chickens, ascites syndrome has great importance due to high economic losses (Julian, 2005; Tarrant, Dey, Kinney, Anthony, & Rhoads, 2017). Today, in many countries of the world, ascites syndrome is raised as a major challenge (Ahmadpanah, Hossein-Zadeh, Shadparvar, & Pakdel, 2017; Tarrant et al., 2017). Mortality due to ascites in the broiler chickens was estimated about 5 to 8% of all over the world, which can be reached in heavy weight breeders between 20 and 30% (Baghbanzadeh & Decuyper, 2008). Among noninfectious mortality of broiler chicks, about 50% is caused by ascites (Tona et al., 2005).

In fast-growing broilers, inadequate vascular capacity for pulmonary blood flow to provide the required tissue oxygen is the primary cause of pulmonary hypertension and causes the onset of ascites syndrome (Baghbanzadeh & Decuyper, 2008). In the event of this syndrome, hematological changes is also observed in birds and packet cell volume (PCV) increase which is along with an increase in the viscosity of blood and

causes pulmonary hypertension (Pakdel, Van Arendonk, Vereijken, & Bovenhuis, 2005b). The number of secondary agents such as high sodium of diet or water may increase blood flow and increased resistance to blood flow. Therefore, an imbalance between oxygen demand and supplied oxygen occurs (Tarrant et al., 2017). The need for more oxygen supply to the tissues for any reason leads to hypoxia in the body's tissues, increased pulmonary blood pressure, increased cardiac output and ultimately leads to right ventricular (RV) hypertrophy. Right ventricular hypertrophy with cardiac valve defects leads to increased pressure in the veins of liver, resulting plasma liquid leakage into the abdominal cavity and leads to an ascites syndrome (Wideman, Rhoads, Erf, & Anthony, 2013; Tarrant et al., 2017).

Genetic, physiological, nutritional and environmental factors affect the incidence of ascites syndrome (Balog et al., 2003). The secretion and activity of thyroid hormones are also involved in the incidence of ascites (Decuypere, Hassanzadeh, Buys, & Buyse, 2005). The effect of sex and strain (Ross, Cobb and Arian) of broiler chickens showed that sex affected the parameters associated with ascites (hematocrit, thyroid hormones and lung capacity) and the incidence of ascites; however, mortality were similar in two genders (Namakparvar, Shariatmadari, & Hossieni, 2014).

In many studies, the heritability related to ascites has been reported middle to high (De Greef, Janss, Vereijken, Pit, & Gerritsen, 2001; Ahmadpanah et al., 2017). There are differences in susceptibility to ascites among commercial lines because each breeding company follows a slightly different selection program (Silversides, Lefranc Ois, & Villeneuve, 1997). Ascites prevalence in broiler chickens can be somewhat controlled by management practices such as appropriate temperature conditioning for breeding at different ages, maintaining optimal air quality, enough oxygen supply and restricting feed for limiting growth (Balog et al., 2003; Varmaghany et al., 2015). However, genetic method is the only sustainable procedure to reduce the ascites incidence. Due to the fact that there is genetic variance for ascites susceptibility within and between lines of broilers (Closter et al., 2009), the ascites susceptibility is expected to vary in different strains, as reported by Azizian, Rahimi, Kamali, Karimi Torshizi, & Zobdeh (2012). They stated that the susceptibility of different strains of broiler chickens to ascites incidence was different, so that the mortalities due to ascites in some strains were higher than other ones (Azizian et al., 2012). Olanrewaju et al. (2014) reported that rate of mortality due to ascites varied in different heavier strains of broiler chickens. It should be noted that in the study of Feizi, Bijanzad, Kaboli, & Jeyrani Moghadam (2012) the type of broiler chicken had no effect on ascites syndrome incidence. Therefore, there is a genetic correlation between growth performance and ascites, and this correlation is usually associated with complex environmental effects. Genetically, broiler chickens, especially the strains that have high growth rates and need more oxygen, are highly susceptible to ascites (Olanrewaju et al., 2014).

In physiological studies, certain symptoms have been reported as signs of ascites susceptibility. Two of the most common clinical symptoms associated with ascites include the enlargement of the RV and the accumulation of fluid in the abdominal cavity (Balog et al., 2003; Pakdel, Bijma, Ducro, & Bovenhuis, 2005a; Dey et al., 2018). Increasing ratio of RV weight to the total ventricles (TV) weight, called RV hypertrophy, has been suggested as a good indication of ascites susceptibility (Pakdel et al., 2005b). Hassanzadeh, Gilanpour, Cahrkkar, Buyse, and Decuypere (2005) showed that the relative volume of the heart in the commercial broiler lines was lower compared to the native breed of Iran. The differences in the physiological status and circulatory system of broiler strains to the ascites susceptibility have already been confirmed (Silversides et al., 1997). Silversides et al. (1997) stated that ascites parameters including heart weights and hematocrit values were different in eight strains of broiler chickens.

In addition to the differences in ascites susceptibility of different strains, there are numerous reports on performance comparisons of the strains (Abdullah, Muwalla, Maharmeh, Matarneh, & Abu Ishmais, 2010; Amoa, Ojedapo, & Sosina, 2011; Fernandes, Bortoluzzi, Froes, Garcez Neto, & Peiter, 2012; Olanrewaju et al., 2014). Production performance including live body weight, body weight gain (BWG), feed intake (FI), feed conversion ratio (FCR), and mortality in broiler strains have been different among Ross, Cobb, Hubbard, and Lohmann strains (Razuki, Mukhlis, Jasim, & Hamad, 2011). Iqbal, Mian, Ahmad, Hassan, and Khan (2012) showed that body weight of the Hubbard, Arbor Acres and Ross 308 chickens were higher than the PN chickens.

Due to the differences in the incidence of ascites in different strains of broiler chickens (Silversides et al., 1997; Azizian et al., 2012) and the efforts of the producing companies of these strains to reduce ascites susceptibility and increase the performance of commercial broiler chickens, it seems that the comparison of

production performance, heart condition during breeding period and the incidence of ascites in these strains is necessary. Therefore, the aim of this study was to compare the growth performance, cardiac characteristics, ascites related parameters, and ascites mortality in commercial strains of broiler chickens of Arbor Acres, Arian, Ross 308, Cobb and Hubbard in the similar environmental and management conditions.

Material and Methods

Experimental location

This experiment was conducted at the Poultry Research farm, Department of Animal Science, Ilam Agricultural and Natural Resources Research and Education Center (Ilam, Iran). The experiments were carried out based on protocols approved by the Animal Science Research Institute (ASRI) of Iran (Karaj, Iran).

Experimental Design, Birds and Housing

At first, hatching eggs of similar weight (62 to 65 g) were collected from the broiler breeder strains of Cobb, Hubbard, Ross 308, Arbor Acres, and Arian (Iranian commercial broiler strain). The broiler breeder strains had similar age (31 to 33 weeks). The eggs were incubated and hatched in a local hatchery at the same condition. A total of 260 one-day-old chicks were allocated to 5 experimental treatments with 4 replicates of 13 chicks each. Treatments consisted of Cobb, Hubbard, Ross 308, Arbor Acres, and Arian broiler strains. Experimental period was 54 days. The environmental and management conditions were the same for all treatments. The initial 32°C room temperature was gradually reduced to 22°C by the fifth week and remained constant until the end of the experiment. The initial lighting program was 24h light and 0h darkness until the broilers were 2-day-old, followed by 23 h light and 1 h darkness to the end of both experiments. The chickens were vaccinated against bronchitis (H-120 via spray and water drinking at 1 and 17 d respectively), infectious bursal disease (D-78, via drinking water at 12 and 28 d) and Newcastle disease (B1 via eye drop at 7 d, Lasota via drinking water at 22 d).

Diets were formulated based on maize and soybeans to meet the nutrient requirements of broilers based on the recommendations of National Research Council (NRC, 1994). Feed (as mash) and water were offered ad libitum throughout the study. Ingredients and composition of the starter (1 to 21 days of age), grower (22 to 42 days of age), and finisher (43 to 54 days of age) diets are shown in Table 1.

Cardiac status and ascites-related parameters

Postmortem examinations were performed on all dead broilers during the experiments to diagnose ascites. In order to evaluate the cardiac status of treatments on days 21, 42, 49, and 54, two birds per each replicate were randomly selected, euthanized, and used for measuring of total heart weight, RV and left ventricle weight. To measure the heart, RV and TV weights, the hearts were collected, and the pericardium, peripheral adipose tissues, and atria were trimmed. The left ventricle and RV were separated and their individual weights were measured on an analytical balance (Scaltec SBA41, Germany; precision 10–3 g), and the RV/TV was calculated (Julian, 2005). The ratio of RV weight to live weight, left ventricular weight to live weight and RV weight to TV weight were calculated.

The blood samples from 2 broilers per each pen (8 broilers per group) were randomly taken from a wing vein at the end of 21 and 42 days. PCV was determined on days 21 and 42 in whole blood samples by centrifugation of microhematocrit capillary tubes (HAEMATOKRIT 200, 24 standard capillary tubes, RPM max 13000, Rotors cat no 2076, Hettich Germany) with 12000 rpm for 10 minutes (Sturkie, 2000). At days 21 and 42, red blood cells were counted in a hemocytometer chamber using Natt and Herrick's solution to obtain a 1 to 200 blood dilution (Maxwell, Robertson, & Spence, 1986). Plasma was prepared by centrifugation (1,000 × g for 20 min) and was stored at –20°C until analysis. Plasma triiodothyronine (T₃) and thyroxine (T₄) concentrations were analyzed on day 42 by ELISA (Pishtaz Teb, Tehran, Iran). Aspartate aminotransferase (AST) enzyme activity was measured using commercial kit (Pars Azmoon, Tehran, Iran) on day 42.

Measurement of mortality and production performance

The broilers were monitored 3 times daily for total mortality and ascites-related mortality. The criteria for diagnosis of ascites syndrome were water belly and RV and TV weights. The RV and TV weights were determined in order to calculate the RV/TV weight ratio in the dead broilers. The ratio above 0.29 was

recorded as ascites mortality (Julian, 2005). Feed intake and body weight were measured weekly and cumulatively. Calculations were made for BWG, FI, FCR, and the total and ascites-related mortality rates.

Table 1. Ingredient and chemical composition of diets at starter, grower and finisher periods (g kg⁻¹, as fed basis).

Item	Experimental diets		
	Starter (1-21 d)	Grower (22-42 d)	Finisher (43-54 d)
	Ingredients (g kg ⁻¹)		
Corn grain	535.0	476.7	557.0
Soybean meal, 44% CP	307.7	286.5	222.5
Corn gluten	60.0	30.0	20.0
Wheat grain	50.0	150.0	150.0
Soybean oil	8.9	24.7	20.3
Oyster shell	12.6	13.3	13.0
Dicalcium phosphate	15.8	10.5	9.5
Sodium chloride	3.9	2.9	2.4
Minerals and vitamin premix ¹	5.0	5.0	5.0
DL – methionine, 99%	1.1	0.4	0.3
Total (g)	10000	10000	1000
	Calculated values (as fed basis) ²		
Metabolizable energy (kcal kg ⁻¹)	2900	3000	3000
Crude protein (g kg ⁻¹)	208.4	190.0	170.0
Ca (g kg ⁻¹)	9.2	8.4	7.8
Available phosphorus (g kg ⁻¹)	4.2	3.4	3.1
Na (g kg ⁻¹)	1.8	1.4	1.2
Methionine (g kg ⁻¹)	4.8	3.6	3.2
Lys vLysine (g kg ⁻¹)	10.4	9.6	8.2
Methionine + Cysteine (g kg ⁻¹)	8.4	6.8	6.2

¹Supplied per kg diet: Vit. A, 7040 IU; Vit. D3, 2000 IU; Vit. E, 8.8 IU; Vit. K3, 1.76 mg; Biotin, 0.12 mg; Thiamine, 1.2 mg; Riboflavin, 3.2 mg; Pantothenic acid, 6.4 mg; Pyridoxine, 1.97 mg; Niacin, 28 mg; Vit. B12, 0.008 mg; Choline, 320 mg; Folic acid, 0.38 mg; Mn, 60 mg; Fe, 60 mg; Zn, 51.74 mg; Cu, 4.8 mg; I, 0.69 mg; Se, 0.16 mg. ²The values were calculated from NRC (1994).

Statistical analysis

The pen was used as the experimental unit, and a one-way analysis of variance was performed using the GLM procedure with SAS software (Statistical Analysis System [SAS], 2003) in a completely randomized design. Prior to statistical analysis, conversion of all data, expressed as a percentage, was done by Arc Sin method. The comparisons of the means were done using Duncan's multiple range test ($p \leq 0.05$).

Results

Mortalities

The mean total and ascites mortalities of commercial broiler strains are presented in Table 2. The effect of strain on total and ascites mortalities was not significant ($p > 0.05$). Average total mortality of Hubbard and Ross strains were 15.38 and 5.76 percent respectively. On the other hand, the ascitic mortality was zero in Ross strain, while Arian strain had the high ascitic mortality (4.42%).

Table 2. The average of total mortality and mortality due to ascites in different strains of broiler chicken (1-7 week).

Parameter		Strain					P-value	SEM ³
		Hubbard	Cobb	Ross 308	Arian	Arbor Acres		
Total mortality (1-6)	N ¹	2.00	1.25	0.75	1.50	1.00	0.72	0.66
	% ²	15.38	9.61	5.76	12.69	7.69	0.70	5.19
Total mortality (1-7)	N ¹	200	1.50	1.00	1.50	1.25	0.87	0.68
	% ²	15.38	11.54	7.69	12.69	9.61	0.86	5.22
Ascites Mortality (1-7)	N	0.25	0.50	0.00	0.50	0.25	0.57	0.24
	%	1.92	3.84	0.00	4.42	1.92	0.54	1.95

¹No. of dead birds. ²(No. of dead birds / No. of Total birds) × 100. ³SEM: Standard error of the means.

Thyroid hormones and aspartate aminotransferase

The effect of strain on T₃ and T₄ hormones as well as AST is shown in Table 3. The effect of strain on T₃, T₄ and AST was not significant ($p > 0.05$).

Table 3. Effect of strain on T₃ and T₄ hormones and AST in broiler chickens at 42 d of age.

Parameter	Strain					P-value	SEM ¹
	Hubbard	Cobb	Ross 308	Arian	Arbor Acres		
T ₃ (ng mL ⁻¹)	3.64	4.07	3.60	3.09	3.62	0.59	0.412
T ₄ (ng mL ⁻¹)	13.92	16.69	9.08	12.78	14.09	0.30	2.376
AST (IU L ⁻¹)	55.22	53.28	40.66	58.44	57.67	0.34	6.55

¹SEM: Standard error of the means.

Cardiac status

The heart related traits including total heart weight, TV weight, RV weight, the ratio of total ventricular weight to live weight, the ratio of RV to live weight, the ratio of RV to the TV in different strains on days 21, 42, 49, and, 54 are shown in Table 4. At days 21, the effect of strain was significant on the ratio of RV to live weight (p 0.05). Accordingly, the highest ratio of RV weight to live weight was observed for Arian strain, which had not significant difference with Hubbard and Arbor Acres strains (p > 0.05), but had significant difference with Ross and Cobb strains (p < 0.05). The highest and lowest RV weight were observed in the Arian and Ross strains, respectively. It is necessary to mention that at the age of 42 days, heart related traits were not significant between strains (p > 0.05).

Table 4. Effect of strain on the heart status of broiler chicks at 21, 42, 49 and 54 day of age.

Parameter	Strain ¹					P-value	SEM ²
	Hubbard	Cobb	Ross	Arian	Arbor Acres		
21 d							
Total Heart Weight (g)	4.875	4.825	4.825	4.775	5.000	0.995	0.406
Total ventricular Weight (g)	3.450	3.600	3.450	3.765	3.425	0.873	0.263
Right ventricular weight (g)	0.700	0.637	0.575	0.700	0.675	0.479	0.055
Total ventricles/ live weight (%)	0.433	0.410	0.415	0.403	.0441	0.112	0.024
Right ventricle/ live weight (%)	0.087 ^{ab}	0.072 ^c	0.069 ^c	0.093 ^a	0.087 ^{ab}	0.024	0.005
Right ventricular/total ventricular (%)	0.202	0.176	0.167	0.186	0.198	0.114	0.009
42 d							
Total Heart Weight (g)	14.550	15.250	14.200	13.900	14.825	0.957	1.332
Total ventricular Weight (g)	10.108	8.555	8.663	9.068	9.678	0.712	0.909
Right ventricular weight (g)	1.910	2.087	1.685	1.747	1.935	0.848	0.275
Total ventricles/ live weight (%)	0.390	0.348	0.337	0.381	0.394	0.615	0.031
Right ventricle/ live weight (%)	0.074	0.084	0.065	0.073	0.079	0.740	0.010
Right ventricular/total ventricular (%)	0.185	0.235	0.190	0.192	0.210	0.477	0.021
49 d							
Total Heart Weight (g)	12.212 ^{ab}	8.537 ^c	13.606 ^a	10.202 ^{bc}	11.603 ^{ab}	0.015	0.930
Total ventricular Weight (g)	12.086 ^{ab}	8.371 ^c	13.308 ^a	10.047 ^{bc}	11.361 ^{ab}	0.016	0.920
Right ventricular weight (g)	2.271	1.438	2.316	1.786	2.034	0.118	0.245
Total ventricles/ live weight (%)	0.325 ^a	0.245 ^b	0.329 ^a	0.278 ^{ab}	0.291 ^{ab}	0.036	0.019
Right ventricle/ live weight (%)	0.061	0.042	0.057	0.050	0.052	0.259	0.006
Right ventricular/total ventricular (%)	0.189	0.171	0.172	0.183	0.174	0.888	0.014
54 d							
Total Heart Weight (g)	16.185	16.206	17.826	16.323	18.826	0.504	1.280
Total ventricular Weight (g)	10.159	9.926	10.617	10.214	11.435	0.746	0.851
Right ventricular weight (g)	2.292	2.045	1.580	2.060	2.104	0.617	0.191
Total ventricles/ live weight (%)	0.308	0.322	0.326	0.334	0.306	0.686	0.015
Right ventricle/ live weight (%)	0.070 ^{ab}	0.067 ^{ab}	0.057 ^{ab}	0.065 ^{ab}	0.056 ^{ab}	0.040	0.003
Right ventricular/total ventricular (%)	0.225	0.208	0.174	0.204	0.184	0.080	0.012

^{1a-c}Means with different superscripts in each row are significantly (p ≤ 0.05). ²SEM: Standard error of the means.

At 49 day of age, total weight of heart, total weight of ventricles and ratio of TV to live weight were significant among strains (p < 0.05). Moreover, Ross strain had the highest heart weight which significantly different from Arian and Cobb. The highest TV weight and ratio of TV weight to live weight were related to the Ross strain. At days 54, the effect of strain on RV weight to live weight was significant (p < 0.05).

Hematological parameters

The effect of strain on PCV and red blood cells count is shown in Table 5. The PCV was not significant between different strains (p > 0.05). However, red blood cell count was significant on day 21 and the highest red blood cell count was found in Ross strain (p < 0.05).

Table 5. Effect of strain on hematocrit value (HCT) and red blood cell count (RBC) in broiler chickens.

Parameter	Strain ¹					P-value	SEM ²
	Hubbard	Cobb	Ross 308	Arian	Arbor Acres		
21 d							
HCT (%)	30.73	29.88	31.30	31.64	29.11	0.497	1.207
RBC (million mm ⁻³)	2.75 ^a	2.62 ^b	2.77 ^a	2.60 ^b	2.72 ^a	0.04	0.111
42 d							
HCT (%)	32.72	29.39	32.90	31.05	30.47	0.397	1.004
RBC (million mm ⁻³)	2.67	2.90	2.90	2.77	2.80	0.07	0.193

^{1a-b}Means with different superscripts in each row are significantly ($p \leq 0.05$). ²SEM: Standard error of the means.

Production performance

The BWG, FI and FCR of five commercial broiler strains are shown in Table 6. There were no significant difference on production performance ($p > 0.05$). At overall breeding period, the BWG of five commercial broiler strains is shown in Figure 1. Numerically, the highest BWG were observed for Hubbard at weeks 1 and 2, Cobb at week 3, Ross at weeks 4 and 5, Cobb at week 6, and Hubbard at week 7.

Table 6. Effect of strain on growth performance in commercial broiler strains.

Parameter	Treatments ¹					SEM ²	P-value
	Hubbard	Cobb	Ross 308	Arian	Arbor Acres		
BWG (g bird ⁻¹ day ⁻¹)							
1-7 day	17.47 ^a	16.12 ^{ab}	16.48 ^{ab}	17.29 ^a	14.47 ^b	0.646	0.035
8-14 day	25.50	25.33	23.74	23.80	23.19	1.665	0.814
15-21 day	47.60	48.06	47.59	46.65	44.96	1.796	0.753
22-28 day	43.98	49.67	51.80	48.31	51.36	2.166	0.130
29-35 day	53.12	56.37	59.18	49.86	57.73	2.372	0.085
36-42 day	72.58	73.68	70.27	65.88	68.09	2.013	0.084
43-49 day	78.51	71.34	73.81	67.84	68.15	3.108	0.143
1-42 day	41.49	43.16	43.13	40.37	41.55	1.326	0.534
1-49 day	46.32	46.77	47.13	43.91	45.05	1.235	0.358
FI (g bird ⁻¹ day ⁻¹)							
1-7 day	16.28	15.49	16.15	16.31	14.64	0.675	0.397
8-14 day	35.70	38.29	35.09	34.39	31.25	2.291	0.341
15-21 day	80.14	80.62	77.81	87.16	77.82	4.140	0.511
22-28 day	99.47	113.02	107.39	106.80	101.45	5.092	0.391
29-35 day	106.79	118.23	131.98	117.73	136.70	7.810	0.099
36-42 day	153.52 ^{ab}	154.91 ^{ab}	173.21 ^a	145.02 ^b	173.01 ^a	6.589	0.028
43-49 day	195.63	211.28	224.9	193.50	197.78	9.540	0.156
1-42 day	77.10	82.26	85.37	79.84	84.15	1.924	0.053
1-49 day	92.63 ^b	98.83 ^{ab}	103.60 ^a	94.52 ^b	99.11 ^{ab}	2.450	0.049
FCR (g FI g ⁻¹ BWG)							
1-7 day	0.93	0.96	0.98	0.94	1.01	0.025	0.248
8-14 day	1.42	1.52	1.48	1.46	1.37	0.114	0.909
15-21 day	1.69	1.68	1.64	1.87	1.73	0.099	0.516
22-28 day	2.27	2.29	2.07	2.22	1.98	0.121	0.323
29-35 day	2.01	2.11	2.22	2.37	2.37	0.107	0.117
36-42 day	2.14	2.11	2.47	2.21	2.54	0.127	0.092
43-49 day	2.49	2.98	3.11	2.87	2.90	0.218	0.379
1-42 day	1.86	1.91	1.98	1.98	2.03	0.059	0.321
1-49 day	2.00	2.12	2.20	2.16	2.20	0.063	0.191

^{1a-b} Means with different superscripts in each row are significantly ($p \leq 0.05$). ²SEM: Standard error of the means.

Discussion

In this study, cardiac status, thyroid hormones, hematological parameters, mortalities (total and ascites), and growth performance of five commercial broiler strains were investigated. This study showed that there is no significant difference for total and ascitic mortalities of stains. These results were in accordance with those reported by Kalia et al. (2017). As pointed out by Everaert et al. (2012), mortality in resistant and susceptible broiler lines to ascites (representing two genetically different lines) were the same. Hence, considered strains in our study might be have the same breeding program, for outlining the effective selection programs to reduce ascites susceptibility. Therefore, the difference between the total mortality

and mortality due to ascites among the strains can be justified. As a whole, it has been shown that male broiler lines had the different genetic basis of ascites syndrome, which it might be comes at a cost, including a reduction in selection response for growth rate (Ahmadpanah et al., 2017). In this regard, Feizi et al. (2012) reported that there is no significant difference among various strains for ascitic mortality.

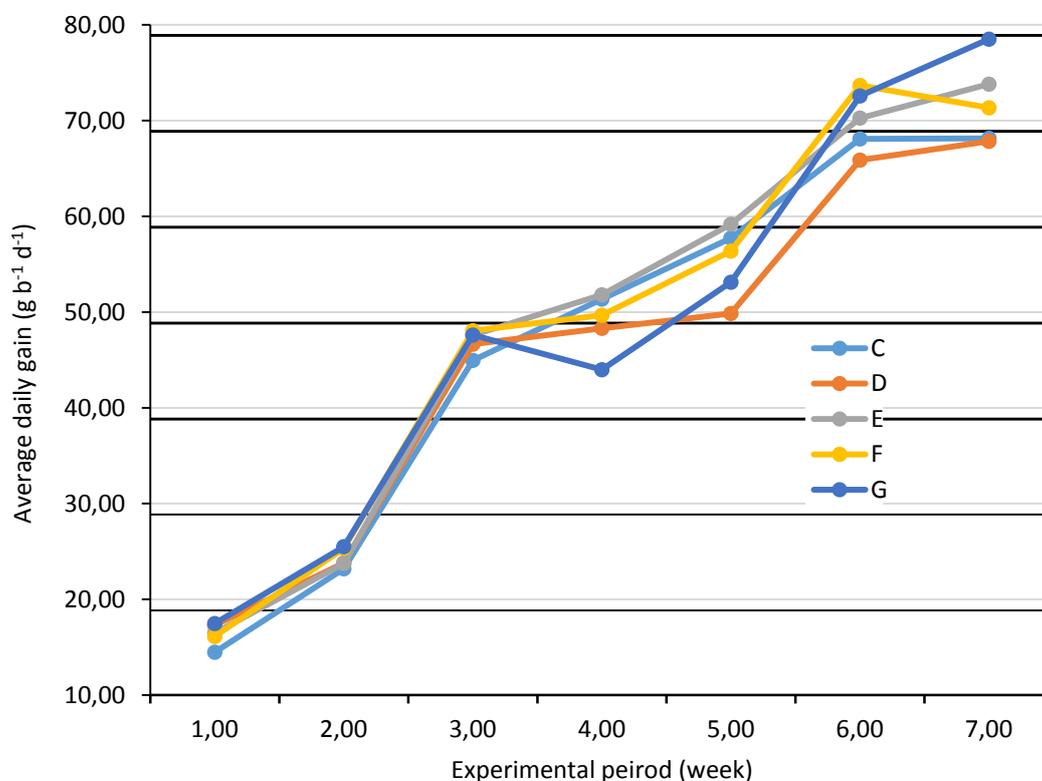


Figure 1. BWG of five commercial broiler strains at 1 to 7 weeks experimental period (C, Arbor Acres; D, Arian; E, Cobb; F, Ross; 308; G, Hubbard).

Broiler chickens resistance to ascites has been reported in induced ascites conditions (high altitude, low temperature and etc.) but present study was conducted in normal temperature and low altitude conditions. Therefore, the strains show better difference in mortality due to ascites under cold temperature conditions (Closter et al., 2009). However, broiler breeder companies consider a proper combination of traits including production, reproduction, health and behavior to improve economical traits such as the chest and thigh muscle and to reduce physiological abnormalities such as ascites and sudden death syndrome. However, in order to have an acceptable breeding system, more emphasis will be placed on health attributes (Pakdel et al., 2005b; Kalia et al., 2017). Identifying the appropriate strain of broiler chickens that can be adapted to native breeding conditions in different areas in terms of management (altitude, temperature and breeding facilities) is important to promote poultry farming (Kalia et al., 2017).

Based on the present results, T_4 and T_3 hormones as well as AST levels were the same for all strains. Thyroid hormones are good indicators for chickens that are susceptible to ascites (Hassanzadeh, Buyse, Dewil, Rahimi, & Decuypere, 1997). Whereas the metabolic rate and consequently incidence of ascites can be predicted by plasma concentration of thyroid hormones (Hassanzadeh, Bozorgmerifard, Akbari, Buyse, & Decuypere, 2000; Scheele, Van Der Klis, Kwakernaak, Buys, & Decuypere, 2003). Therefore, no significant effect of strain on T_3 and T_4 concentrations may be related to the same ascitic mortalities in the present study. Furthermore, Ozkan et al. (2006) reported that feed restriction had a negative effect on thyroid gland activity and plasma T_3 concentrations. As pointed by Luger, Shinder, Rzepakovsky, Rusal, & Yahav (2001), in dead ascitic broilers, the concentration of T_3 and T_4 hormones decreased in the last week to death. Also, by increased metabolic rate and ascites progression, plasma T_3 level is going to be reduced (Luger et al., 2001). In fact, the decrease in plasma T_4 levels can be due to the negative interaction of T_3 in the hypothalamus, which leads to reduce thyroid-stimulating hormone (Scheele et al., 2003). Regulating body temperature and stimulating growth rate are dependent on plasma T_3 level. In addition, plasma T_3 level

contributes to the improved growth rate in response to ambient temperature. Concentration of T₃ hormone is increased at low temperature and has a positive correlation with FI (Luger et al., 2001; Varmaghany et al., 2015). Azizian et al. (2012) showed that there was not significant difference among strains for T₄ (at 21 and 42 days of age) and T₃ (at 21 and 56 days of age) which was inconsistent with our results. It should be noted that, maternal hyperthyroidism is associated with a decreased incidence of cold-induced ascites in broiler chickens (Akhlaghi et al., 2012).

Hematological parameters, which can be measured on living birds, are indicator traits of ascites in broilers that represent changes in aerobic metabolism (Daneshyar, Kermanshahi, & Golian, 2007). There are a positive genetic correlation between ascites and hematocrit (De Greef et al., 2001). Pakdel et al. (2005b) reported that hematocrit value is a proper indicator for ascites syndrome. On the other hand, some researchers have reported no relation between hematocrit and ascites (Balog et al., 2003; Luger et al., 2001). Comparison of two ascites-resistant and ascites-susceptible broiler strain showed that the amount of hematocrit and red blood cell count were higher in ascites-susceptible chicken (Druyan, Shinder, Shlosberg, Cahaner, & Yahav, 2009). Increasing arterial pressure is due to the increase of red blood cell count, megalocytosis (enlargement of blood cells), or red blood cell flexibility. The main response to oxygen deficiency is to increase of red blood cells count, which increases the blood viscosity and then increases resistance to blood flow (Julian, 2000; Ozkan et al., 2006). As mentioned earlier, ascitic birds have more red blood cells, hematocrit value, alanine aminotransferase and AST than the healthy birds (Arab, Jamshidi, Rassouli, Shams, & Hassanzadeh, 2006), which is in accordance with our results. In the present study, Arian strain had the highest mortality due to ascites and AST. Feizi et al. (2012) reported that hematocrit value in the Arbor Acres and Cobb strains were higher than the Ross strain after the third weeks of age. This has also been confirmed by Azizian et al. (2012), and Luger et al. (2001) that ascitic birds had increased hematocrit value, which are consistent with responses to hypoxemia.

The most common clinical signs of ascites are RV hypertrophy and fluid accumulation in the abdominal cavity (Balog et al., 2003; Julian, 2000; Pakdel et al., 2005a; Zerehdaran et al., 2005). The ratio of right to total ventricular weight demonstrated as an indicator for ascites (Pakdel et al., 2005a). It should be noted if the ratio is greater than 29 percent, it will be considered as RV hypertrophy (Julian, 2005). In fact, the ratio of RV to the TV in ascitic birds is greater than the healthy ones (Arab et al., 2006). In the present study, at 21 days of age strain had a significant effect on the RV weight to live weight ratio. Accordingly, the highest ratio of RV to live weight was belonged to Arian strain. At 49 days of age, the effect of strain on total heart weight, TV weight and the ratio of TV weight to live weight was significant. In addition, the highest heart weight was related to Ross strain, which was significantly different from Arian and Cobb strains. The largest total weight of the ventricles was belonged to the Ross strain. Therefore, this can be used to justify the amount of ascites mortality that were zero for the Ross strain. Because in the Arian and Cobb, which had lower ratio of the TV to live weight, had greater ascites mortalities than other strains.

Druyan et al. (2009) reported the ratio of RV to TV in ascitic and healthy chicks were 0.31 and 0.235. In another study, the ratio of RV to TV in male broiler chicks (Ross 308) under standard and cold temperature conditions (10°C to 15°C from 3-5 weeks) were 0.22 and 0.31 respectively (Fathi et al., 2011). Wideman et al. (2003) also found that broiler chickens with RV fibrils had a higher partial carbon dioxide pressure in the bloodstream, less partial oxygenation in arterial blood, and higher concentrations of bicarbonate in arterial blood, partial pressure of CO₂ and partial pressure of O₂.

Hassanzadeh et al. (2000) showed that the ratio of lung weight to body weight, the relative lung and heart volume, and the volumes of the thorax cavity were lower in fast-growing commercial broiler than the layer and Iranian native chickens. In addition, relative lung weight, lung volume and thorax cavity volume were decreased by ageing in commercial broilers which made it susceptible to ascites, but these were increased in layer and native chickens (Hassanzadeh et al., 2000). As mentioned by Gaya et al. (2007), the genetic trends of absolute and relative heart weight in a male broiler line were -0.08 g and -0.004 percent per hatch-year, respectively. That is because the overall correlation between BW and RV/TV is approximately negative (Zerehdaran et al., 2005), depending on frequency of ascitic birds in the population.

Gesek et al. (2016) observed the highest number of morphological lesions on d 38, 31 and 10 of life in broilers. They found excessive growth of cardiac muscle, prolonged hypoxia and increased body weight on d 38 which are the most likely reasons for heart failure (Gesek et al., 2016). It seems that allomorphic discrepancies in heart and lung growth on the size of the bird make it susceptible to ascites. In this regard,

oxygen demand is increased, causing inconsistency of oxygen requirement and the cardiovascular ability (Decuyper et al., 2005). Therefore the prevailing sign of heart pump insufficiency is hypoxemia. That is why in fast-growing broilers, heart rate is considerably lower throughout the growth period. In the last decades, genetic variation in lung capacity of chickens has been demonstrated, and genetic susceptibility to ascites was clearly observed about lung weight or volume traits (Silversides et al., 1997). Similarities between the broilers lines considered in this study on ascites susceptibility were more pronounced than there are similar genetic selection programs, which consider production and health traits.

We showed that considered strains had no significant difference for production performance such as BWG (except from 1-7 d), FI (except from 36-42 and 1-49 d) and FCR. It seems that continuous genetic changes on different strains of broiler chickens have made it necessary to compare their performance regularly and periodically in different environmental and management conditions. There have been many published papers on evaluation of growth performance of different strains of broiler chickens (Abdullah et al., 2010; Fernandez et al., 2013; Olanrewaju et al., 2014; Amoa et al., 2011). However, in most studies (Fernandez et al., 2013; Olanrewaju et al., 2014; Amoa et al., 2011), the results showed that there were significant differences among growth performance of commercial broiler strains (Iqbal et al., 2012; Olanrewaju et al., 2014). Iqbal et al. (2012) studied the comparative performance of different economic traits of Hubbard, Arbor acres, Ross 308 and Hybro PN imported broiler strains under local conditions of Pakistan. They found that Hybro PN has less body weight, higher mortality rate and poor feed conversion ratio as compared to the others (Iqbal et al., 2012). Olanrewaju et al. (2014) showed the traits of body weight, BWG, FI, and FCR of broilers was affected by strain. On the other hands, Amoa et al. (2011) reported that growth performance such as BWG, FI, and FCR were significantly different among broiler strains which were not in agreement with our study. We showed that the FI during 1 to 49 days of age was significantly different among strains which was in agreement with the previous studies (Olanrewaju et al., 2014; Amoa et al., 2011). The FI is influenced by the breeding environment condition, the type of strain, and numerous nutritional factors such as nutrient density and dietary energy. Under normal conditions, FI has a reverse relationship with the nutrient content of the diet. Reducing the nutrient levels of the diet increases the FI and conversely. During the 1 to 49 days of age, the highest and lowest FI was observed by Ross 308 strain and Hubbard and Arian strains, respectively. The energy and protein content in the diet provides approximately 90% of the Ross 308 requirement. Moreover, increasing FI of Ross 308 strain during days 1 to 49, may be associated to decreased dietary energy, because the dietary energy of the ration for strains of Cobb, Hubbard, Arbor Acres, and Arian was more similar to the dietary energy in their catalog than Ross 308.

Fernandez et al. (2013) reported that, BWG was not significant (except 1-7 days of age) among broiler strains which is consistent with our results. It seems that inconsistency of environmental and management conditions with the companies' recommendations of strains, prevented the genetic potential for growth and performance. Feizi et al. (2012) found that the growth rate of Arbor Acres and Cobb strains were higher than that of Ross strain. It should be noted that the indirect genetic selection for high growth rate and low FCR resulted in hypothyroidism and a reduction in the ratio of T₃ to T₄ of broiler strains, resulting reduced oxygen consumption and hypoxia, increased pulmonary hypertension and RV hypertrophy, accumulation of fluid in the abdominal cavity and finally ascites (Gonzales, Buyse, Takita, Satory, & Decuyper, 1999).

Conclusion

In the current study, most parameters associated with ascites syndrome including weight heart, relative weight of heart and ventricles, ascites index (RV/TV), ascites mortality, T₃, T₄ and PCV were not significantly different among five considered strains during entire experimental period. In addition, strain had not significant effect on performance traits including BWG (except 1-7 days of age) and FCR, and mortality at all the experimental periods. It can be noted that even though considered broiler strains did not differ significantly for performance and physiological status, but according to the prices and market conditions each can be selected for breeding.

Acknowledgements

The authors are very grateful from Ilam Agricultural and Natural Resources Research and Education Center for research services.

References

- Abdullah, Y., Muwalla, M., Maharmeh, O., Matarneh, K., & Abu Ishmais, A. (2010). Effects of strain on performance and age at slaughter and duration of post-chilling aging on meat quality traits of broiler. *Journal of Animal Science*, *23*(12), 1645-1656. doi: 10.5713/ajas.2010.10045
- Ahmadpanah, J., Hossein-Zadeh, N. G., Shadparvar, A. A., & Pakdel, A. (2017). Genetic parameters of body weight and ascites in broilers: effect of different incidence rates of ascites syndrome. *British Poultry Science*, *1*, 32- 39.
- Akhlaghi, A., Zamiri, M. J., Zare Shahneh, A., Jafari Ahangari, Y., Nejati Javaremi, A., Rahimi Mianji, G., ... Zhandi, M. (2012). Maternal hyperthyroidism is associated with a decreased incidence of cold-induced ascites in broiler chickens. *Poultry Science*, *91*(5), 1165–1172. doi: 10.3382/ps.2011-02021
- Amoa, S. R., Ojedapo, L. O., & Sosina, O. A. (2011). Evaluation of growth performance traits in three strains of broiler chickens reared in derived savanna environment of Nigeria. *World Journal Young Research*, *1*(2), 28-31.
- Arab, H. A., Jamshidi, R., Rassouli, A., Shams, G., & Hassanzadeh, M. H. (2006). Generation of hydroxyl radicals during ascites experimentally induced in broilers. *British Poultry Science*, *47*(2), 216-222. doi: 10.1080/00071660600611102
- Azizian, M., Rahimi, S., Kamali, M. A., Karimi Torshizi, M. A., & Zobdeh, M. R. (2012). Comparison the susceptibility of six broiler hybrids to ascites by using hematological and pathological parameters. *Journal of Agricultural Science and Technology*, *15*(3), 517-522.
- Baghbanzadeh, A., & Decuyper, E. (2008). Ascites syndrome in broilers: physiological and nutritional perspectives. *Avian Pathology*, *37*(2), 117-126.
- Balog, J. M., Kidd, B. D., Huff, G. R., Huff, W. E., Rath, N. C., & Anthony, N. B. (2003). Effect of cold stress on broilers selected for resistance or susceptibility to ascites syndrome. *Poultry Science*, *82*(9), 1383-1387. doi: 10.1093/ps/82.9.1383
- Closter, A. M., Vav As, P., Groenen, M. A. M., Vereijken, A. L. J., Arendonk, J. A. M., & Bovenhuis, H. (2009). Genetic and phenotypic relationships between blood gas parameters and ascites-related traits in broilers. *Poultry Science*, *88*(3), 483-490. doi: 10.3382/ps.2008-00347
- Daneshyar, M., Kermanshahi, H., & Golian, A. (2007). Changes of blood gases, internal organ weights and performance of broiler chickens with cold induced ascites. *Research Journal of Biology Science*, *2*, 729-735.
- De Greef, K. H., Janss, L. L., Vereijken, A. L., Pit, R., & Gerritsen, C. L. (2001). Disease-induced variability of genetic correlations: ascites in broilers as a case study. *Journal of Animal Science*, *79*(7), 1723-1733. doi: 10.2527/2001.7971723x
- Decuyper, E., Hassanzadeh, M., Buys, B., & Buyse, J. (2005). Further insights into the susceptibility of ascites. *The veterinary Journal*, *169*(3), 319-320. doi: 10.1016/j.tvjl.2004.07.005
- Dey, S., Parveen, A., Tarrant, K. J., Licknack, T., Kong, B. C., Anthony, N. B., & Rhoads, D. D. (2018). Whole genome resequencing identifies the CPQ gene as a determinant of ascites syndrome in broilers. *PLoS One*, *13*, e0189544. doi: 10.1371/journal.pone.0189544
- Druyan, S., Shinder, D., Shlosberg, A., Cahaner, A., & Yahav, A. (2009). Physiological parameters in broiler lines divergently selected for the incidence of ascites. *Poultry Science*, *88*(9), 1984-1990. doi: 10.3382/ps.2009-00116
- Everaert, N., Willemsen, M., Debonne, M., Witters, A., Kamers, B., Darras, V. M., ... Bruggeman, V. (2012). Interaction between ascites susceptibility and CO₂ during the second half of incubation of two broiler lines: the effect on post-hatch development and ascites mortality. *British Poultry Science*, *53*(2), 262-269. doi: 10.1080/00071668.2012.669467
- Fathi, M., Nazerad, K., Ebrahiminezhad, Y., Aghdam Shahryar, H., Daneshyar, M., & Tanha, T. (2011). Antioxidant enzyme activities characterization in pulmonary hypertension syndrome (PHS) in broiler. *Research. Journal of Boil Science*, *6*(3), 118. doi: 10.3923/rjbsci.2011.118.123
- Feizi, A., Bijanzad, P., Kaboli, K., & Jeyrani Moghadam, A. R. (2012). Comparative survey of ascites syndrome incidence rate in various strains of broiler chickens. *Australian Journal of Basic and Applied Science*, *6*(13), 185.

- Fernandes, J. I. M., Bortoluzzi, C., Triques, G. E., Garcez Neto, A. F., & Peiter, D. C. (2012). Effect of strain, sex and age on carcass parameters of broilers. *Acta Scientiarum. Animal Science*, 35(1), 99-105. doi: 10.4025/actascianimsci.v35i1.13354
- Gaya, L. G., Costa, A. M. M. A., Ferraz, J. B. S., Rezende, F. M., Mattos, E. C., Eler, J. P., ... Figueiredo, L. G. G. (2007). Genetic trends of absolute and relative heart weigh in a male broiler line. *Genetic and Molecular Research*, 6(4), 1091-1096.
- Gesek, M., Otrocka-Domagala, I., Sokol, R., Pazdzior-Czapula, K., Lambert, B. D., Wisniewska, A. M., ... Korzeniowska, P. (2016). Histopathological studies of the heart in three lines of broiler chickens. *British Poultry Science*, 57(2), 219-226.
- Gonzales, E., Buyse, J. M., Takita, S. T., Satory, R. J., & Decuypere, E. (1999). Metabolic disturbances in male broilers of different strains, 1. Performance, mortality, and Right ventricular hypertrophy. *Poultry Science*, 77(11), 1646-1656. doi: 10.1093/ps/77.11.1646
- Hassanzadeh, M. (2010). Endogenous an environmental factors interactions that contribute to the development ascites in broiler chickens: A review. *International Journal of Veterinary Research*, 4(2), 117-126.
- Hassanzadeh, M., Bozorgmerifard, M. H., Akbari, A. R., Buyse, J., & Decuypere, E. (2000). Effect of intermittent lighting schedules during the natural scotoperiod on T₃-induced ascites in broiler chickens. *Avian Pathology*, 29(5), 433-439.
- Hassanzadeh, M., Buyse, N., Dewil, E., Rahimi, G., & Decuypere, E. (1997). The prophylactic effect of vitamin C supplementation on broiler ascites incidence and plasma thyroid hormone concentration. *Avian Pathology*, 26, 33-44. doi: 10.1080/03079459708419191
- Hassanzadeh, M., Gilanpour, H., Cahrkhar, S., Buyse, J., & Decuypere, E. (2005). Anatomical parameters of cardiopulmonary system in three different lines of chickens: further evidence for involvement in ascites syndrome. *Avian Pathology*, 34(3), 188-193. doi: 10.1080/03079450500096372
- Iqbal, J., Mian, A. A., Ahmad, T., Hassan, S., & Khan, S. H. (2012). Comparative performance of different economic traits of four imported broiler strains under local conditions of Pakistan. *Pakistan Journal of Agricultural Research*, 25(1), 76-82.
- Julian, R. J. (2000). Physiological, management and environmental triggers of the ascites syndrome: A review. *Avian Pathology*, 29(6), 519-527. doi: 10.1080/03079450020016751
- Julian, R. J. (2005). Production and growth related disorders and other metabolic diseases of poultry. A review. *The Veterinary Journal*, 169(3), 350-369. doi: 10.1016/j.tvjl.2004.04.015
- Kalia, S., Vijay, K. B., Gogoi, D., Giri, A., & Kumar, B. (2017). Studies on the growth performance of different broiler strains at high altitude and evaluation of probiotic effect on their survivability. *Scientific Reports*, 11(7), 46074. doi: 10.1038/srep46074
- Luger, D., Shinder, D., Rzepakovskiy, V., Rusal, M., & Yahav, S. (2001). Association between weight gain, blood parameters, and thyroid hormones and the development of ascites syndrome in broiler chickens. *Poultry Science*, 80(7), 965-971. doi: 10.1093/ps/80.7.965
- Maxwell, M. H., Robertson, G. W., & Spence, S. (1986). Studies on ascites syndrome in young broilers: 1. Haematology and pathology. *Avian Pathology*, 15, 511-524. doi: 10.1080/03079458608436312
- Namakparvar, R., Shariatmadari, F., & Hossieni, S. H. (2014). Strain and sex effects on ascites development in commercial broiler chickens. *Iranian Journal of Veterinary Research*, 15, 116-121. doi: 10.22099/IJVR.2014.2349
- National Research Council [NRC]. (1994). *Nutrient requirements of poultry* (9th rev. ed.). Washington, DC: National Academy Press.
- Olanrewaju, O. M., Miller, W. W., Maslin, W. R., Collier, S. D., Purswell, J. L., & Branton, S. L. (2014). Effects of strain and light intensity on growth performance and carcass characteristics of broilers grown to heavy weights. *Poultry Science*, 93(8), 112-116. doi: 10.3382/ps.2013-03806
- Ozkan, S., Plavnik, O., & Yahav, S. (2006). Effects of early feed restriction on performance and ascites development in broiler chickens subsequently raised at low ambient temperature. *Journal of Applied Poultry Research*, 15(1), 9-19. doi: 10.1093/japr/15.1.9
- Pakdel, A., Bijma, P., Ducro, B. J., & Bovenhuis, H. (2005a). Selection strategies for body weight and reduced ascites susceptibility in broilers. *Poultry Science*, 84(4), 528-535. doi: 10.1093/ps/84.4.528

- Pakdel, A., Van Arendonk, J. A. M., Vereijken, A. L. J., & Bovenhuis, H. (2005b). Genetic parameters of ascites-related traits in broilers: correlations with feed efficiency and carcass traits. *British Poultry Science*, *46*(1), 43-53. doi: 10.1080/00071660400023805
- Razuki, W. M., Mukhlis, S. A., Jasim, F. H., & Hamad, R. F. (2011). Productive performance of four commercial broiler genotypes reared under high ambient temperatures. *International Journal of Poultry Science*, *10*(2), 87-92. doi: 10.3923/ijps.2011.87.92
- Statistical Analysis System [SAS]. (2003). *SAS/STAT User's guide, Version 9.1*. Cary, NC: SAS Institute Inc.
- Scheele, C. W., Van Der Klis, J. D., Kwakernaak, C., Buys, N., & Decuypere, E. (2003). Haematological characteristics predicting susceptibility for ascites. 1. High carbon dioxide tensions in juvenile chickens. *British Poultry Science*, *44*(3), 476-483. doi: doi.org/10.1080/0007166030001603204
- Silversides, F. G., Lefranc Ois, M. R., & Villeneuve, P. (1997). The Effect of Strain of Broiler on Physiological Parameters Associated with the Ascites Syndrome. *Poultry Science*, *76*(5), 663-667. doi: 10.1093/ps/76.5.663
- Sturkie, P. D. (2000). *Avian physiology* (4th ed.). New York, NY: Academic Press.
- Tarrant, K. J., Dey, S., Kinney, R., Anthony, N. B., & Rhoads, D. D. (2017). Multi-generational genome wide association studies identify chromosomal regions associated with ascites phenotype. *Poultry Science*, *96*(6), 1544-1552. doi: 10.3382/ps/pew478
- Tona, K., Kemps, B., Bruggeman, V., Bamelis, F., De Smit, L., Onagbesan, O., ... Decuypere, E. (2005). Comparison of three lines of broiler breeders differing in ascites susceptibility or growth rate. 1. Relationship between acoustic resonance data and embryonic or hatching parameters. *Poultry Science*, *84*(9), 1439-1445. doi: 10.1093/ps/84.9.1439
- Varmaghany, S., Rahimi, S., Karimi Torshizi, M. A., Lotfollahian, H., & Hassanzadeh, M. (2015). The effects of increasing levels of dietary garlic bulb on growth performance, systolic blood pressure, hematology, and ascites syndrome in broiler chickens. *Poultry Science*, *94*(8), 1812-1820. doi: 10.3382/ps/pev148
- Wideman, R. F., Chamman, M., Owens, C., Devabhakhuni, M., Cavitt, L., Wang, W., & Erf, G. (2003). Broiler survivors of intravenous micro-particle injections: Evaluation of growth, livability, meat quality, and arterial blood gas values during a cyclic heat challenge. *Poultry Science*, *82*, 484-495. doi: 10.1093/ps/82.3.484
- Wideman, R. F., Rhoads, D. D., Erf, G. F., & Anthony, N. B. (2013). Pulmonary arterial hypertension (ascites syndrome) in broilers: A review. *Poultry Science*, *92*(3), 64-83. doi: 10.1093/ps/82.3.484
- Zerehdaran, S., Vereijken, A. L. J., Van Arendonk, J. A. M., Bovenhuis, H., & Van Der Waaij, E. H. (2005). Broiler Breeding Strategies Using Indirect Carcass Measurements. *Poultry Science*, *84*(8), 1214-1221. doi: 10.1093/ps/84.8.1214