Evaluation of growth performance and muscle marker genes expression in four different broiler strains in Jordan

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ABSTRACT
This study investigates the expression of the muscle growth factors Myostatin (MSTN) and Insulin-like growth hormone type I (IGF-I) and muscle marker genes MyoD and MyoG in relation to growth performance and meat characteristics in four different commercial broiler strains. Eight hundred, one-day-old chicks of Hubbard Classic (HC), Cobb500 (Cobb), Ross308 (Ross) and Indian River (IR) strains were randomly distributed in a completely randomised design into four groups for 28 days. At the end of the growth trial, 10 birds from each strain were weighed and slaughtered. A sample of Pectoral muscle was taken and kept in RNA solution for mRNA expression level measurements. Gene expression in the pectoral muscle at 20 days revealed that MSTN expression was higher for Ross than HC and IR. IGF-I expression was highest in IR and lowest in HC. MyoD expression was lowest in HC but higher in Ross and Cobb, while MyoG expression was similar. At the end of the experiment, IR gained the highest (p <.0001) body weight, while Ross the lowest, yet still with no significant differences in body weight gain among the four strains. HC scored the lowest (p =.01) efficiency in feed consumption (1.60 ± 0.03 kg/kg). Hot and cold carcase weights of IR were significantly heavier (p <.0001) than the other strains, with no significant difference in dressing percentages. Cooking loss was the highest (p =.058) for Cobb, IR, HC, and Ross, in decreasing order. The meat-tenderness value was highest for Ross, while differences in pH, colour and water holding capacities were insignificant among the strains.

HIGHLIGHTS
- IGF-I and MyoG genes can be used in Broiler artificial selection programmes for improving body weight and carcase cuts.
- Indian River strain gained the highest in body, and hot and cold carcase weights.

INTRODUCTION
Several commercial broiler chicken strains (Arbor Acres, Cobb, Hubbard, Indian River, Lohman, Ross) are reared in the Mediterranean environment. Although many studies attempted to investigate the effect of strain on growth performance, carcase characteristics, and meat quality in broiler chickens worldwide (Dransfield and Sosnicki 1999; Young et al. 2001; Santiago et al. 2005; Berri et al. 2006), only few of them focussed on the molecular investigation of gene expression of muscle marker genes (Weintraub 1993; Oustanina et al. 2004) and muscle growth factors (Adams and McCue 1998; Adams et al. 1999; Halevy et al. 2004). Chicken body weights have increased twice at about half the time compared to five decades ago (Barbut et al. 2008); improvements were mainly due to the high heritability of body composition and body weight during breeding (Le Bihan-Duval et al. 2003). Furthermore, genetic selection and enhancement of chickens produced heritable changes in their genetic capacity and muscle tissue characteristics by imposing stress on the growing birds (Barbut et al. 2008) and altering the majority of chicken growth processes and their relevant environmental
requirements. The expression of the genes that control these quantitative traits in chicken is affected by both environmental and genetic factors (Falconer and Mackay 1996). Therefore, only an optimal environment would allow the expression of their genetic potential. Several genes have been identified with differing effects on growth performance in broiler chickens (Zhou et al. 2005; Bhattacharya et al. 2016); differences in gene expression, and body and breast muscle weights have been observed and correlated among birds within the same strain (Xiao et al. 2017). Another study showed how upregulation of muscle marker and growth factor genes induced the improvement of body weight of chickens near and at market age (Al-Zghoul et al. 2016). Candidate genes involved in growth and meat production traits include IGFs that regulate and control body and muscle growth in chickens (Duclos et al. 1999; Kadlec et al. 2011).

Insulin-like Growth Factor I (Igf-I) is another factor that stimulates proliferation, differentiation and metabolism of myogenic cell lines in different species (Florini et al. 1996). Meanwhile, Myostatin (MSTN) has a negative regulatory effect on muscle growth determining both muscle fibre number and size (Carnac et al. 2007). Additionally, muscle regulatory factors (MRFs) such as Myogenic Differentiation Antigen (MyoD) and Myogenin (MyoG) play important roles in muscle growth and development (Te Pas and Soumillon 2001). During the last few decades, the inflating global population and the consumer’s perception of the health benefits of chicken meat has led to an increasing demand for poultry meat (FAO 2008; López et al. 2011), in addition to a shift of consumer’s preferences towards the consumption of cuts (particularly breast fillets) and processed products instead of whole chickens (McKee and Sams 1998; Mehaffey et al. 2006; Abdullah et al. 2010). This growing demand has resulted in pressure on nutritionists, breeders and livestock keepers to enhance growth performance and meat quality of birds (Petracci and Cavani 2012). Therefore, poultry breeding companies have focussed more on many commercial broiler breeds with superior traits and higher growth performance capabilities (Scheuermann et al. 2003; Havenstein et al. 2003).

The objectives of this study were to investigate the gene expression of muscle growth factors (MSTN and IGF-1) and muscle marker genes (MyoD and MyoG) in relation to the growth performance and meat characteristics of four different commercial broiler strains reared in the Mediterranean area. The results generated from this study will aid in marker-assisted selection for improved broiler production satisfying both consumers and producers, in addition, to increase knowledge of poultry breed performance in the Middle East.

### Materials and methods

All procedures and experiments were approved by the Animal Care and Use Committee (ACUC) of Jordan University of Science and Technology.

A total number of 800, one-day-old chicks from a commercial hatchery were randomly distributed by a completely randomised design to four equal groups, with 10 replicates (pens) per treatment and 20 birds per pen, representing the four broiler strains; Ross 308 (Ross), Indian River (IR), Cobb500 (Cobb) and Hubbard Classic (HC) strains. The chicks were transferred to the animal house at Jordan University of Science and Technology, where the field experiment was conducted.

All birds were fed a well-balanced commercial corn-soybean meal diet as recommended by the National Research Council (NRC 1994) shown in Table 1. Feed and water were present ad libitum for the duration of the experiment which lasted 28 days. Birds were kept in cages (1.00 × 1.00 m), with a stocking density of 20 birds/m² (<36 kg/m²). Body Weight (BW) and feed consumption measurements were recorded on a weekly basis. Average daily gain, average daily feed intake (ADFI), and feed:gain ratio was calculated subsequently. At the end of the growth performance trial of 28 days, 10 birds from each strain were weighed.

### Table 1. Composition of the experimental diets.

| Ingredient, % as fed | Starter diet 1 to 21 d | Grower diet 22 to 28 d |
|----------------------|------------------------|------------------------|
| Corn                 | 57.00                  | 64.00                  |
| Soybean meal         | 32.00                  | 25.00                  |
| Concentrate          | 6.00                   | 5.50                   |
| Soybean oil          | 1.00                   | 2.00                   |
| Dicalcium phosphate  | 1.10                   | 0.90                   |
| Limestone            | 1.50                   | 1.50                   |
| Mineral-vitamin premix | 0.75              | 0.50                   |
| Salt (NaCl)          | 0.25                   | 0.25                   |
| DL-Methionine        | 0.23                   | 0.21                   |
| L-Lysine HCl         | 0.17                   | 0.14                   |
| Soybean meal         | 32.00                  | 25.00                  |
| Corn                 | 57.00                  | 64.00                  |
| Calculated nutritive value, g kg⁻¹ DM⁻¹ |
| AMEn, kcal kg⁻¹c | 3120.00 | 3185.00 |
| Crude protein, DM % | 22.30 | 19.20 |
| Ether extract, DM % | 4.90 | 7.80 |

*Provided the following per kilogram of diet: vitamin A: 11,166 U; cholecalciferol: 2500 U; vitamin E: 80 mg; menadione: 2.50 mg; vitamin B₁₂: 0.02 mg; folic acid: 1.17 mg; choline: 379 mg; D-pantothenic acid: 12.50 mg; riboflavin: 7.0 mg; niacin: 41.67 mg; thiamine: 2.17 mg; D-biotin: 0.18 mg; pyridoxine: 4.0 mg; ethoxyquin: 0.09 mg; Mn (MnO₄): 73 mg; Zn (ZnO): 55 mg; Fe (FeSO₄): 45 mg; Cu (CuSO₄): 20 mg; I (CaI₂O₆): 0.62 mg; and Se (Na₂SeO₃): 0.3 mg.

cDM stands for dry matter content.

cAMEn stands for Apparent metabolisable energy.
and slaughtered following the procedure described by Merkley et al. (1980) on post-hatch day 28. Fasting live weight was recorded, and after scalding (58 to 60 °C, 45 s), the carcasses were de-feathered and manually eviscerated. Carcasses were then chilled for 6 h at 5 °C, and carcass cold weight, and cuts weight and percentage eviscerated. Carcasses were then chilled for 6 h at 5 °C. The pH values were determined in duplicate homogenised muscle samples using the iScript cDNA Synthesis Kit (Biorad, California, USA), after which the cDNA was amplified using semi-quantitative RT-PCR with Advanced TM SYBR Green Supermix kit (Biorad, California, USA). Briefly, 10 µL of master mix, 2 µL forward primer (10 pmol), 2 µL reverse primer (10 pmol), 2 µL sample cDNA and 4 µL of nuclease-free water were amplified using Biorad CFX96 (BioRad, Hercules, CA, USA) with the thermal cycling conditions of 50 °C for 2 min, 95 °C for 15 min for denaturation, and 40 cycles of 95 °C for 10 s denaturation, followed by 30 s at 55 °C for annealing and 72 °C for 10 s for extension with final melting at 95 °C for 20 s. Duplicates from each cDNA were analysed, fluorescence emission was detected, and using the relative comparative threshold method, values were automatically calculated using CFX manager TM software V3.1 (BioRad, Hercules, CA, USA).

Data were analysed as a completely randomised design using General Linear Model procedure of SAS 9.1 (SAS Institute Inc 2004). Means were considered to be significantly different at p < .05. Body weight, relative expression of mRNA levels of MyoD, MyoG, IGF-I and MSTN were expressed as means ± standard error (SE). One-way analysis of variance, followed by all-pairs Bonferroni test, was used to compare different parameters among treatment groups. Simple correlations between body weight and gene expression data were calculated using Pearsons correlations (PROC CORR in SAS 9.1).

### Results

Body weights (g/chick/week) of the four commercial broiler strains are shown in Table 3. Day 7 onwards, IR had the heaviest body weight at both 7 d (166.34 g) and 21 d (1030.51 g), while Ross was the lightest (p ≤ .05) at 14 d (429.92 g) and 21 d (816.42 g). At the end of the experiment (28 d), IR gained the highest

### Table 2. Oligonucleotides used for expression analysis of chicken genes and the annealing temperatures (AT).

| Gene    | Primer sequences | Annealing temperature |
|---------|------------------|-----------------------|
| cMyoD   | F) 5’TACCCACGTCGGAGCAGA3’ | 57 °C |
|         | R) 5’GCTTGAGCTGGGCTGAACT3’ | |
| cMyoG   | F) 5’AGACGGCTCAACAGCAGA3’ | 58 °C |
|         | R) 5’TCTGCGTGATCCGCTCAAG3’ | |
| cMSTN   | F) 5’TCTGGACACCCGCGCAATGAT3’ | 52 °C |
|         | R) 5’CTTGCAGCAACCGTGGCTGAGA3’ | |
| cIGF-I  | F) 5’CGTGACACCCGCGCAATGAT3’ | 55 °C |
|         | R) 5’CGTACAGAGGCGTGACAGA3’ | |
| cGAPDH  | F) 5’GGTGGCCTACATGA3’ | 52 °C |
|         | R) 5’CAGTGTTGCTTAAGACCC-3’ | |

The left side muscle was used for the evaluation of the ultimate pH and water holding capacity. While the muscles from the right side were weighed, placed in plastic bags and cooked at 85 °C, muscles from the right side were weighed, placed in the ultimate pH and water holding capacity. While the

Pectoral muscle samples (100 µg) were collected from 10 chicks from each treatment group per day, on days 1, 14, 21 and 28. Total RNA was extracted from homogenised muscle tissue samples using the DirectZol/chloroform/isopropanol method with DirectZol® (Zymo Research) reagent according to manufacturer’s instructions, and DNA was removed using DNase I kit (Ambion, Austin, TX). Furthermore, RNA samples were checked for concentration and purity (260:280 nm absorbency) using Elisa reader (BioTek PowerWave HT microplate Spectrophotometer). Next, 2 µg of RNA was reverse transcribed to cDNA using iScript cDNA Synthesis Kit (Biorad, California, USA), after which the cDNA was amplified using semi-quantitative RT-PCR with Advanced TM SYBR Green Supermix kit (Biorad, California, USA). Briefly, 10 µL of master mix, 2 µL forward primer (10 pmol), 2 µL reverse primer (10 pmol), 2 µL sample cDNA and 4 µL of nuclease-free water were amplified using Biorad CFX96 (BioRad, Hercules, CA, USA) with the thermal cycling conditions of 50 °C for 2 min, 95 °C for 15 min for denaturation, and 40 cycles of 95 °C for 10 s denaturation, followed by 30 s at 55 °C for annealing and 72 °C for 10 s for extension with final melting at 95 °C for 20 s. Duplicates from each cDNA were analysed, fluorescence emission was detected, and using the relative comparative threshold method, values were automatically calculated using CFX manager TM software V3.1 (BioRad, Hercules, CA, USA).

Data were analysed as a completely randomised design using General Linear Model procedure of SAS 9.1 (SAS Institute Inc 2004). Means were considered to be significantly different at p < .05. Body weight, relative expression of mRNA levels of MyoD, MyoG, IGF-I and MSTN were expressed as means ± standard error (SE). One-way analysis of variance, followed by all-pairs Bonferroni test, was used to compare different parameters among treatment groups. Simple correlations between body weight and gene expression data were calculated using Pearsons correlations (PROC CORR in SAS 9.1).
and hot and cold carcase weights are shown in body weight gain among all strains at 28 d. Dressing percentage had no significant difference (1293.28 g) and Ross (1285.73 g). Dressing percentage had a significantly higher cold carcase weight with no (1460.66 g), among the four strains. Only IR (1489.25 g) was the significantly lowest, while IR hot significantly different. Cobb final body weight between Ross (1688.51 g) and HC (1678.73 g) was not significantly different. Cobb final body weight (1588.15 g) was the significantly lowest, while IR hot carcase weight was the significantly highest (1460.66 g), among the four strains. Only IR (1489.25 g) had a significantly higher cold carcase weight with no significant differences among HC (1367.17 g), Cobb (1392.28 g) and Ross (1328.73 g). Dressing percentage had no significant difference (p > .1) among all strains with values ranging between 75–80% at 28 d. Table 3 shows the cumulative feed consumption (kg feed/kg gain), where no significant differences (p > .1) were observed among all strains at 7 d (p = .39) and 14 d (p = .37). Whereas at 21 d, Ross had the highest (1.50 ± 0.05 kg/kg) and at 28 d HC the lowest (p = .01) feed conversion ratio (1.60 ± 0.03 kg/kg). At 21 d; IR, HC and Cobb scored the lowest (p = .04) cumulative feed consumption and were more efficient in feed conversion than Ross (1.25 ± 0.04, 1.32 ± 0.04 and 1.38 ± 0.04 kg/kg vs. 1.50 ± 0.05 kg/kg, respectively). At 28 d, HC had the lowest (p = .01) efficiency in feed consumption (1.60 ± 0.03 kg/kg).

Table 3. Least squares mean for broiler initial body, final body, hot carcase and cold carcase weights and dressing percentages as affected by strain.

| Strain     | Initial body weight, g ± SE | Final body weight at 28 days, g ± SE | Hot carcase weight, g ± SE | Cold carcase weight, g ± SE | Dressing percentage, %±SE |
|------------|-----------------------------|-------------------------------------|-----------------------------|-----------------------------|---------------------------|
| Cobb       | 48.620 ± 0.760              | 1588.150 ± 25.900                  | 1275.060 ± 33.670          | 1293.280 ± 32.820          | 80.310 ± 1.260            |
| Hubbard    | 49.620 ± 0.760              | 1678.730 ± 28.430                  | 1327.340 ± 36.950          | 1367.170 ± 36.010          | 79.080 ± 1.390            |
| Indian River | 50.080 ± 0.760            | 1878.470 ± 30.850                  | 1460.660 ± 40.100          | 1489.250 ± 39.080          | 77.850 ± 1.510            |
| Ross       | 38.500 ± 0.760              | 1688.510 ± 48.670                  | 1278.010 ± 63.270          | 1285.730 ± 61.660          | 75.370 ± 2.380            |

Means followed by different superscripts within the same column are significantly different at (p ≤ .05).

(p < .0001) body weight (1573.62 g) compared to HC and Cobb (1499.03 and 1459.06 g, respectively), while Ross remained the lowest (1355.16 g).

Body weight gain for IR was significantly greater (p = .0084) than the other strains (525.16 g/chick/week) at 14 d, while there were no significant differences among Cobb, HC and Ross at 21 d, neither (p > .1) in body weight gain among all strains at 28 d.

Initial and final body weights, dressing percentages, and hot and cold carcase weights are shown in Table 3. Final body weight was significantly heavier (p < .0001) for IR (1878.46 g), while final body weight between Ross (1688.51 g) and HC (1678.73 g) was not significantly different.

Table 4 indicates that, at slaughter (28 d), Cobb had the significantly (p < .01) lowest value of breast percentage, while HC had the lowest (p = .04) value of leg percentage. Back percentages were significantly (p = .13) higher for HC (19.96%) and IR (19.13%) as opposed to Ross (17.91%) and Cobb (17.94%). Cobb had the highest (p < .0001) abdominal fat percentage (1.48%) among all strains with the lowest significant value for IR (0.57%), followed by Ross with a moderate percentage of 0.93%. Wing, neck and breast fillets were not affected by broiler strain since there were no significant differences among the strains.

Table 5 shows the non-carcase components with a significant difference (p = .05) in Gizzard % among the different strains. Ross (1.73%) and HC (1.44%) had greater percentages. There were no significant differences in proventriculus, liver and heart percentages expressed as part of cold carcase weights among all

| Strain       | Breast, % | Leg, % | Wing, % | Back, % | Neck, % | Abdominal fat, % | Breast fillet, % |
|--------------|-----------|--------|---------|---------|---------|------------------|------------------|
| Cobb         | 34.470    | 26.410 | 8.240   | 17.940  | 5.630   | 1.480            | 23.540           |
| Hubbard      | 36.900    | 24.610 | 8.580   | 19.960  | 6.350   | 0.730            | 26.190           |
| Italian River | 37.510   | 25.570 | 8.550   | 19.130  | 5.860   | 0.570            | 24.280           |
| Ross         | 37.530    | 26.630 | 8.600   | 19.710  | 5.940   | 0.930            | 25.600           |
| SEM          | 0.680     | 0.530  | 0.190   | 0.710   | 0.310   | 0.070            | 1.190            |

Means followed by different superscripts within the same column are significantly different at (p ≤ .05).
strains. Gizzard percentage in HC tended to be significantly different ($p \leq .06$) between Cobb and Ross.

Table 6 illustrates meat quality parameters; there was a significant ($p = .0468$) difference in yellowness among the strains with the lowest value assigned to IR(1465.28). Cooking loss was significantly the highest ($p = .0583$) for Cobb (29.37). Shear force values indicated that meat from the Ross strain carcases were significantly ($p = .0397$) more tender (2.23 kg/cm$^2$) than other strains. There were no significant differences in pH, Lightness ($L^*$), Redness ($a^*$) and water holding capacity (WHC) among all strains.

As shown in Figure 1, feed consumption at 7 d was significantly the highest ($p = .0004$) for IR (165.209 ± 4.92 g/week), while Ross (127.74 ± 5.87 g/week) was the lowest ($p = .0004$). At 14 d ($p = .0070$) and 21 d ($p = .0037$), HC and IR had the highest feed consumption values (at 21 d: 1225.00 ± 13.10 and 1241.10 ± 13.68 g/week, respectively). At 28 d, Ross (2063.57 ± 46.20 g/week) and Cobb (2135.57 ± 29.34 g/week) had the lowest ($p = .0112$) feed consumption.

Figure 1 highlights a highly significant difference in IGF-I expression. IR had the highest ($p < .05$) expression of IGF-I gene that was about 35% higher than Ross, one fold higher than Cobb, and more than two folds higher ($p < .05$) than HC. Multiple comparisons show that IGF-I expression in Ross is higher ($p < .05$) by 40% to Cobb and 60% to HC. Cobb had an IGF-I expression level about 45% greater than HC. There was no significant difference in MYO-D gene expression between Ross and Cobb, although it was higher ($p < .05$) than IR by about 20%, while HC had the lowest value with nearly one fold lower than Cobb and Ross, whereas IR’s was about 30% folds higher ($p < .05$) than HC. There were significant differences ($p < .05$) in Myo-G expression among the four strains. IR and Ross had the greatest values of Myo-G among the four strains with about 20%, 35% and 110% higher ($p < .05$) expression in IR than in Ross, HC and Cobb, respectively. Meanwhile, Myo-G levels in Ross was about 30% higher ($p < .05$) than HC and 110% than Cobb with HC 35% higher ($p < .05$) than Cobb. Ross had the highest ($p < .05$) MSTN expression levels but it was not significantly different than Cobb. Whereas IR and HC had 20% lower ($p < .05$) expression levels than Ross. Notwithstanding, MSTN showed no significant ($p > .05$) differences among all breeds.

Furthermore, correlation analysis between body weight and the various muscle marker genes showed a negative correlation between BW and MSTN ($r = −0.76$), a positive correlation of 0.547 with both MyoD and MyoG, and 0.50 with IGF-I; indicating that MyoD, MyoG or IGF-I can be used as effective selection markers for weight variations.

**Discussion**

In this study, we measured growth performance, and carcase and meat quality, in relation to the expression levels of muscle marker genes of four commercial broiler strains reared in Jordan. Hristakieva et al. (2014) showed that the weight of hatchlings differed significantly according to genotype between one-day-old Cobb 500 which were heavier than Ross 308 broilers; differences are possibly attributed to the variation in the weight of eggs at incubation. Further, López et al. (2011) found significant differences in average weight per bird at 3 week and 6 week of age between two commercial broiler strains.

Furthermore, variations in body weight gain in the present study are consistent with the findings of Sarkar et al. (2001) who reported that body weight gain was significantly higher in ISA Vedette than Arbor Acres and Hybro; the three different fast-growing broiler strains from day-old to 6 weeks. Amão et al. (2011) confirmed that the significant differences in body weight, average daily gain, and average feed intake could be attributed to variations in genetic makeup, as in several other studies where genotype affected initially, weekly average and final body weights, feed consumption, and feed conversion ratio among different commercial strains at different ages (Yakubu et al. 2010; Siaga et al. 2017). Abdullah et al. (2010) reported a significant strain effect on the

| Strain     | pH          | Lightness ($L^*$) | Redness ($a^*$) | Yellowness ($b^*$) | Cooking loss, % | Water holding capacity, % | Shear force, kg/cm$^2$ |
|------------|-------------|------------------|----------------|-------------------|----------------|---------------------------|------------------------|
| Cobb       | 6.012       | 4348.300         | 297.000        | 1846.000*         | 29.370         | 35.910                    | 2.790*                 |
| Hubbard    | 6.036       | 4295.800         | 317.100        | 1784.500*         | 27.480         | 37.500                    | 2.490*                 |
| Indian River | 5.776      | 4080.110         | 496.110        | 1465.280*         | 28.650         | 34.710                    | 3.020*                 |
| Ross       | 6.042       | 4383.100         | 304.800        | 1684.300*         | 26.520         | 35.500                    | 2.230*                 |
| SEM        |             | .354             | .813           | .270              | .047           | .058                      | .773                   |

*Means followed by different superscripts within the same column are significantly different at ($p \leq .05$) (Honikel 1998).

% cooking loss: [(raw weight – cooked weight)/(raw weight)] × 100.
weight gain of broilers at 7–21 and 28–42 days of age. Difference in feed efficiency among modern broiler strains is attributed to physical activity and genotype which can affect the growth performance of broiler chicken strains (Agaviezor 2005).

In addition, the present study shows differences in feed consumption among the studied strains that were consistent with Ravindran et al. (1999), where nutrient utilisation between breeds could be attributed to differences in the structure of the digestive tract and absorptive capacity, changes in digestive enzyme output, and passage rate of digesta. Latshaw and Moritz (2009) suggested that increasing feed efficiency for the modern strain could be related to lower maintenance requirements because maintenance energy requirements decreased with rapid growth. In fact, digestive function or nutrient uptake per unit of gut mass was not influenced by selection, but increased gut size was responsible for increased digestive and absorptive capacity in modern broilers (Jackson and Diamond 1996). Additionally, Gonzales et al. (1998) reported that weight gain and FCR were affected by strain; Ross broilers achieved higher weight gain compared to other strains (Arbor Acres, Avian Farms, Cobb-500, Hubbard-Peterson, ISA and Naked Neck). Similarly, Smith et al. (1998) reported that strain had an effect on feed intake and FCR when they compared strain crosses (Ross x Ross208) and fast-growing strains (Peterson x Arbor Acres). Rondelli et al. (2003) concluded that the Ross line showed higher final weight and weight gain, and better intake and feed conversion rate than the AVIAN farm line through weeks 2–4. However, Farran et al. (2000) reported that there were no significant differences in live body weight and feed to gain ratio among Ross, Arbor acres and Lohman broilers from day 0 to 21. Yet still, several reports (Taha et al. 2011; Udeh et al. 2015) showed that genotype does affect body weight, body weight gain, feed intake, and feed conversion ratio of broiler chickens.

Altogether, it would be reasonable to argue that the differences observed in growth performance traits among the studied strains may be attributed to differences in the genetic potential of each strain.

In this study, genotype showed a decisive influence on the relative fastest body weight and carcass weight (%) of broilers, with greater weights recorded for Arbor Acres. Genotype had a significant effect on the carcass yields and some cut parts (neck, wing, and back relative weights %) of the birds. These differences in breast percentage are consistent with the results presented by Reddish and Libburn (2004) who showed that these could be related to the differences in breast muscle dimensions and muscle fibre number.

![Figure 1. Growth and consumption parameters of tested broiler strains during four weeks of experimentation. Data presented as LSMeans ± SE. Means without a common superscript differ significantly (p ≤ .05); *means differ significantly (p < .05, see text).](image)
and size. Similarly, several studies (Johnson and Asmundson 1957; Havenstein et al. 1994; Zuidhof et al. 2014) suggested a high positive correlation between pectoral weight and body weight due to emphasis on genetic improvement and body weight selection.

The significant differences in abdominal and carcase fat calculated in our study were in agreement with the findings reported by Chambers et al. (1981). They compared commercial and experimental strains of broilers and reported that selection for heavier body weight increases abdominal fat in selected birds, and part of the increased fat deposition could be due to genetic differences in feed conversion. Furthermore, Abeni and Bergoglio (2001) and Gonzales et al. (1998) showed that the percentage of abdominal fat differed among broiler strains, while Nestor et al. (1988) showed line differences in the relative weight of drumstick muscles; both findings are in accordance with our reported results. However, Siaga et al. (2017) found no significant differences in carcase, breast, back, thigh, wing, drumstick, heart, gizzard, liver, and abdominal fat among different strains. Differences in gizzard weights (expressed as a percentage of cold carcase weight) are supported by the findings of Maisonnier et al. (2001); they reported that absolute gizzard weight was significantly greater in broilers (Le Bihan-Duval et al. 1999), turkeys (Sante et al. 1991), and ducks (Baæza et al. 1997) showing a significant decrease in colour intensity or an increase in lightness in rapidly growing or high-yield strains compared to those less selected. Meat colour differed in redness due to a difference in the amount of myoglobin in meat. They also reported that selection had an influence on breast meat colour development during storage.

Water holding capacity values in the present study are similar to the findings of Abdullah and Matarneh (2010). They observed that water-holding capacity percentage was not significantly affected by differences in carcase weight. This result could be explained by the lack of difference in muscle pH values among carcase weights. Our results are also supported by the findings of Hamm (1986) who explained that post-mortem drop in pH resulted in changes in muscle protein electronic charge to reach isoelectric point that weakens the bond between actin and myosin resulting in expelling water outside, therefore reducing water holding capacity.

Mehaffey et al. (2006) stated that variation among strains, particularly in tenderness, could be attributed to slower rates of rigour mortis development in some broiler lines than others, resulting in increased breast meat toughness. Shear force values are consistent with the results of Abdullah and Matarneh (2010) that suggest that differences in tenderness could be associated with differences in bird age, size, strain and fat content in the breast muscle. Meat tenderness is influenced by the quantity and quality of connective tissue and by the contractile state of muscle fibres and bundles (Kooohmaraie et al. 2002). Results of cooking loss percentage reported by López et al. (2011), consistent with our results, indicated no significant differences in cooking loss percentage between two commercial broiler strains.

The levels of IGF-I expression for IR were consistent with the findings of Lalani et al. (2000) who reported that IGF-I had a positive regulatory effect on muscle differentiation and growth. In addition, IR had the highest final body weight compared to the other studied strain. MyoD and MyoG levels obtained from the current study are partly (slightly) consistent with
the findings of previous researches that found MSTN functions as an inhibitory factor for myogenic differentiation by downregulating the expression of myogenic regulators such as MyoD, MyoG, and Myf-5 (Langley et al. 2002; Ríos et al. 2002; Joulia et al. 2003). Furthermore, differences in MyoD and MyoG expression among strains could be attributed to long-term genetic selection or type of production (Zhang et al. 2018). Other factors such as physiological and environmental conditions (Yin et al. 2014), different genetic origins, skeletal muscle contents (Li et al. 2014), and polymorphisms (Zhu et al. 2010) could also be involved in gene expression differences among strains. Results of MSTN expression in the present study are in agreement with the findings of several previous studies that showed a negative association between MSTN levels and increase in size and number of skeletal muscle fibres or muscle mass (Grobet et al. 1997; Kambadur et al. 1997; McPherron et al. 1997; McPherron and Lee 1997; Lee 2004), and the results of final body weights of the four strains in the current study support these findings. Similarly, Kocamis and Killefer (2002) reported that high expression levels of MSTN may be to prevent excessive muscle growth. Differences in MSTN expression among strains could be attributed to the inhibitory effect of propeptide on the biological activity of the MSTN (Lee and McPherron 2001; Thies et al. 2001).

From the expression levels (Figure 2) of the studied genes, it can be concluded that body weight (Figure 1) of IND and HUB were the highest compared to Ross and Cobb, in fact, associated with elevated IGF-I and MYO-G genes expression, with similar expression in the Myostatin gene for all studied strains.

Our reported results and the findings of previous studies that investigated IGF-I expression levels may explain the superiority of IR to the other strains in growth performance and breast muscle percentages. Gene expression levels of IR and Ross could explain the relationship between MSTN and the other MRFs. As MSTN expression decreased, the expression of the other genes (MyoD, MyoG and IGF-I) increased and vice versa; that proves the theory proposed about MSTN acting as a regulatory factor for MRFs (Xiao et al. 2017). It is important to note that although the surrounding environmental conditions were the same for all strains, they may have been more suitable for the IR and Ross strains, possibly negatively impacting the mRNA expression of the IGF-I gene.

Conclusions

This study shows a physiological variation among several commercial broiler strains reared in Jordan. It also shows the superiority of the Indian River to the other strains regarding growth performance and carcass characteristics. Additionally, a small variation in carcass cuts was observed among the different strains. Further support for the Indian River strain’s superiority is demonstrated by its highest expression levels of IGF-I and MyoG, while IGF-I and MyoD were the lowest in the Hubbard strain. Moreover, IGF-I and MYO-G genes may play an important role in enhancing the growth of the IND and HUB strains. Hence, the IGF-I gene can be used as a promising marker for selecting Broiler types with a higher growth rate.

In order to gain more profitability, Indian River should be used in farmer’s fields because of its high
growth performance. Marker-assisted selections, such as IGF-1, should be considered for choosing Broilers with the best performance. Nonetheless, more studies need to be completed on gene expressions and their role in affecting growth performance, and meat quality and characteristics of these strains and other strains in order to build a more comprehensive selection or screening process.

Disclosure statement

No potential conflict of interest was reported by the authors.

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