Adaptive response to exercise of fast-growing and slow-growing chicken strains: Blood oxidative status and non-enzymatic antioxidant defense

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ABSTRACT The adaptation of chickens to free-range rearing systems mainly involves the locomotory behavior, which is very different in fast-growing (FG) and slow-growing (SG) strains. This study aimed to compare the effect of moderate locomotory activity (induced and prolonged) on the blood oxidative status in a slow-growing chicken strain with that in a fast-growing one. Thirty FG (Ross 308) birds and 30 SG (Hubbard) birds were divided into 2 groups for each strain and subjected to different treatments: no exercise (the control group [C]) and 1 h of walking at 4 km/h (the exercise group [E]). Daily exercise was promoted by operators, who walked behind the animals around a paddock. Blood samples were obtained weekly from both groups. For the E group, samples were obtained before exercise (E_1) and after exercise (E_2). Oxidative markers (creatine kinase [CK], reactive oxygen molecular substance [ROMS], thiobarbituric acid reactive substances [TBARS]), and antioxidant compounds (α-tocopherol [α-T], γ-tocopherol [γ-T], δ-tocopherol [δ-T], α-tocotrienol [α-T$_3$], γ-tocotrienol [γ-T$_3$], retinol, and carotenoids) were evaluated. In both strains, the CK level was higher in chickens subjected to exercise; however, its increase was greater in the FG group than in the SG one (1.56-fold vs. 1.08-fold). The antioxidant status was worse in FG strain birds subjected to exercise, whereas the status remained nearly the same in the SG strain birds. The α-T and retinol concentrations were significantly reduced by exercise, primarily in the FG group, whereas the other antioxidant compounds (α-T$_3$, γ-T$_3$, γ-T, δ-T, lutein, and zeaxanthin) were unaffected by strain or treatment. The FG and SG strains had different responses to exercise, and only the SG showed a progressive reduction in TBARS and ROMS values during the 28-day experiment. Accordingly, moderate exercise may be beneficial only when the birds have suitable behavioral characteristics (e.g., higher kinetic activity, rusticity, and explorative nature) or physical characteristics (e.g., low body weight); otherwise, exercise is highly stressful and affects physiology and well-being.

Key words: adaptation, blood antioxidants, chicken strain, exercise, oxidative stress

INTRODUCTION

Organic and free-range poultry production is increasing in the European Union and in the United States of America because of consumer expectations with regard to animal welfare, environmental impact, and qualitative characteristics of the products. However, these expectations are not entirely achieved if inadequate rearing techniques are used and largely depend on the genetic strain used (Dal Bosco et al., 2012; Castellini et al., 2016). Several studies have reported that positive results obtained in extensive rearing systems involves adequate locomotory behavior and the scavenger aptitude of the birds (Castellini et al., 2006 and 2016).

Instead, since high muscular activity reduces oxidative stability in the body and in the skeletal muscles because of the associated high production of free radicals (Alessio, 2000), it may have negative effects on meat-type birds. This selection for growth performance means that most dietary resources are addressed to muscle growth; accordingly, activities not directly connected with muscle growth (e.g., locomotory activity, reproduction, and immune response) are reduced (Siegel and Honaker, 2009). Moreover, these birds have different muscular responses to locomotory activity. Zhou et al. (2015) hypothesized that selection for breast muscle affects physiological traits (e.g., inflammatory response and oxidative stress) of these skeletal muscles. However, details on the effect of exercise on the oxidative status of domestic animals are lacking or contradictory (Bowles et al., 1991). Although antioxidants should have a role in protecting muscles from oxidative burst, their mechanism is affected by various factors.

Many vitamins (e.g., vitamins A, C, and E) and certain plant-derived bioactive compounds (e.g., carotenoids, flavonoids, and polyphenols) are natural antioxidants in as much as they prevent or eliminate oxidative damage to a target molecule in vivo (Halliwell, 2007). For instance, vitamin E is an exogenous antioxidant that comprises 8 isoforms: 4 tocopherols (α-, β-, γ-, and δ-tocopherol) and 4 tocotrienols (α-, β-, γ-, and δ-tocotrienol). Dietary supplementation of vitamin E increases its level in the membranes of animal cells and permits the scavenging of several different reactive oxygen molecular substances (**ROMS**) (El-Agamey et al., 2004).

Vitamin A and the carotenoids (pro-vitamin A compounds) are also important lipid-soluble antioxidants. Vitamin A is endogenous and abundant in animal tissues (Bendich and Olson, 1989) and is derived from the metabolism of plant carotenoids (El-Agamey et al., 2004).

To date, the effect of chronic exercise on antioxidant defense of chickens has not been investigated, to the best of our knowledge.

In view of analyzing the adaptive response to an extensive rearing system of chicken strains with different growth rates (fast-growing and slow-growing), this study aimed to assess the effect of locomotory activity on the blood oxidative status and antioxidant defense.

MATERIAL AND METHODS

The experiment was conducted at the Department of Agricultural, Environmental, and Food Science of the University of Perugia (Perugia, Italy) in January 2014. Chickens were reared using current Italian directives on animal welfare for experimental and other scientific purposes (Gazzetta Ufficiale, 1992).

Animals and Study Design

Thirty fast-growing (**FG**, Ross 308 with a growth rate about 50 g/d) chickens and 30 slow-growing (**SG**; Hubbard with a growth rate about 25 g/d) chickens were used. One-day-old chicks were purchased and handled in accordance with the standard management practices (bird density 5 birds/m^2). The animals were fed a standard starter diet for 1 to 20 d and a finisher diet beginning on d 21 for all experimental trial durations (Table 1). The average feed intake was 65.0 ± 4.2 g/d for SG chickens and 115.0 ± 6.1 g/d for FG ones. Water was provided ad libitum. The experiment lasted 28 d starting at 35 d of age, in order to mimic a locomotory activity comparable to that occurring in extensive rearing systems (Dal Bosco et al., 2010). Ten days before beginning the trial, the birds were exposed to the operators to allow them to acclimatize to the operators' presence and to avoid further stress. The animals were divided into 2 experimental groups (15 birds/strain), housed in different indoor paddocks and subjected to the following treatments:

Table 1. Formulation (%), chemical composition (% dry matter), and energetic value (MJ/kg) of the poultry diet.

	Diet	
	Starter	Finisher
Ingredients		
Maize	52.0	46.0
Full-fat soybean	30.5	12.5
Wheat	—	20.0
Soybean meal	9.0	14.0
Alfalfa meal	2.8	2.8
Gluten feed	3.0	2.0
Vitamin-mineral premix[1]	1.0	1.0
Dicalcium phosphate	1.0	1.0
Sodium bicarbonate	0.5	0.5
Sodium chloride	0.2	0.2
Chemical composition		
Dry matter	90.8	90.8
Crude protein	22.3	18.0
Ether extract	7.95	4.98
Crude fiber	4.67	4.01
Ash	5.76	5.59
Neutral detergent fiber	10.7	10.1
Acid detergent fiber	5.58	5.06
Cellulose	4.22	3.56
Acid detergent liquid	1.03	1.11
Hemicellulose	5.16	5.05
Metabolizable energy[2]	12.5	12.9

[1]Amount per kg: vitamin A, 11,000 IU; vitamin D_3, 2000 IU; vitamin B_1, 2.5 mg; vitamin B_2, 4 mg; vitamin B_6, 1.25 mg; vitamin B_{12}, 0.01 mg; α-tocopheryl acetate, 30 mg; biotin, 0.06 mg; vitamin K, 2.5 mg; niacin, 15 mg; folic acid, 0.30 mg; pantothenic acid, 10 mg; choline chloride, 600 mg; manganese, 60 mg; iron, 50 mg; zinc, 15 mg; iodine, 0.5 mg; and cobalt, 0.5 mg.
[2]Estimated by Carrè and Rozo (1990).

(1) Control (**C**, no exercise) and (2) prolonged exercise (**E**). The experimental group underwent daily moderate locomotory activity (1 h at 4 km/h on average). The operators, who walked behind the animals around the paddock, promoted the exercise of birds.

Sample Collections

Blood samples were collected weekly. They were obtained once from the C group and twice from the E group (i.e., immediately before [**E$_1$**] and after [**E$_2$**] exercise).

Two mL of blood from the brachial vein of each animal (15 chickens/group/treatment) were collected and placed in vacutainers and transported to the laboratory of the Department of Agricultural, Environmental, and Food Science at the University of Perugia (Perugia, Italy). Serum was obtained from blood samples (1 mL) and coagulated at ~25°C for 2 h; the collection tubes were then rimmed and refrigerated at 4°C for 24 h before analysis. Plasma was obtained from blood samples (1 mL), placed into EDTA-coated tubes, and centrifuged at 2500 rpm for 15 min at 4°C to determine the hematological parameters.

Traits Evaluated

Serum creatine kinase (**CK**) activity was measured spectrophotometrically using commercially available kits (EnzyChrom Creatine Kinase Assay Kit;

Table 2. Significance of the effects on the blood traits according to treatment, poultry strain, and d of exercise (n = 15 birds/strain/treatment).

	Evaluated trait[1]										
	CK	TBARS	ROMS	α-T_3	γ-T_3	α-T	γ-T	δ-T	Retinol	Lutein	Zeaxanthin
Treatments (T)	*	*	*	*	ns	*	ns	*	ns	ns	*
Strain (S)	*	*	ns	ns	ns	*	ns	ns	ns	ns	ns
Day (D)	*	*	ns	*	ns	ns	ns	*	*	ns	*
TxS	*	*	*	ns	ns	ns	ns	ns	*	ns	ns
TxD	*	ns	ns	ns	ns	*	*	*	*	ns	*
DxS	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns
R^2	19	55	65	22	17	72	15	11	52	5	40

ns: not significant.

[1]CK: Creatin kinase is expressed as *International Unit,* IU; TBARS: thiobarbituric acid reactive substances are expressed as nmol of malondialdehyde (MDA)/mL of plasma; ROMS: reactive oxygen molecular substances are expressed as nmol/mL of serum; α-, γ-T_3: α-, γ-tocotrienol are expressed as nmol/mL of plasma; α-, γ-, δ-T: α-, γ-, δ-tocopherols are expressed as nmol/mL of plasma; retinol, lutein, and zeaxanthin are expressed as nmol/mL of plasma.

*$P \leq 0.05$.

BioAssay Systems, Hayward, CA). ROMS in the blood serum were assessed using the OXY-Adsorbent kit (Diacron, Grossetto, Italy) and the d-ROMS test (Diacron) (Cesarone et al., 1999). Blood lipid peroxidation in plasma was evaluated spectrophotometrically (UV-2550, Shimadzu Corporation, Kyoto, Japan) at 532 nm for thiobarbituric acid reactive substances (**TBARS**), and a calibration curve for 1,1,3,3-tetraethoxypropane in sodium acetate buffer (pH = 3.5) (Dal Bosco et al., 2009) was plotted to quantify the nanomoles of malondialdehyde (**MDA**) per mL of plasma. The average intra- and inter-assay CV values were 0.20 and 7.47%, respectively.

Based on the method described by Schuep and Rettenmeier (1994), the plasma levels of vitamin E (α-tocopherol [α-T], $\gamma(+\beta)$-tocopherol [γ-T], and δ-tocopherol [δ-T]; α-tocotrienol [α-T_3] and γ-tocotrienol [γ-T_3]), vitamin A (retinol), and carotenoids (zeaxanthin and lutein) were assessed using HPLC (pump model PU-1580; Jasco Co., Tokyo, Japan) with an autosampler system (model AS 950–10; Jasco Co.) on a Sinergy Hydro-RP column (4 μm, 4.6 mm × 100 mm; Phenomenex, Bologna, Italy). Tocopherols and tocotrienols were identified using a FD detector (model FP-1520; Jasco Co.) set at the excitation and emission wavelengths of 295 nm and 328 nm, respectively, and were quantified using external calibration curves prepared with increasing amounts of pure standard solutions in ethanol. Retinol, lutein, and zeaxanthin were identified using a UV-VIS spectrophotometer detector (UV2075 Plus; Jasco) set at λ 325 nm for retinol and 450 nm for lutein and zeaxanthin, and quantified by comparing the sample with a pure commercial standard (Sigma-Aldrich, Steinheim, Germany) in ethanol (for retinol) or chloroform (for lutein and zeaxanthin).

Statistical Analysis

Statistical analysis was performed with a linear model (2-way with interactions) consisting of the effect of treatments (C vs. E_1 vs. E_2), and poultry strain (FG vs. SG) with the day (D) of collection as a continuous variable. Three-way interaction (T × S × D) was omitted because it was not significant. The daily trend of TBARS and ROMS also was fitted with a non-linear model (fractional polynomial procedure); fitted values were showed with 95% lower and upper confidence limits. The statistical significance was set at $P \leq 0.05$. The statistical software used was STATA (StataCorp, College Station, TX, 2015).

RESULTS

The effect of exercise was significant for most of the studied traits. However, the strains differed only in CK, TBARS, and α-T (Table 2). Two-way interactions were also significant for some traits (primarily CK, TBARS, and retinol). The effect of poultry strain and treatment (no exercise, pre-exercise, and post-exercise) is shown in Table 3. The CK level was higher in both strains of chickens subjected to exercise, but the increase was greater in the FG strain than in the SG one (1.56-fold vs. 1.08-fold increase). In the C group, the FG strain also had a higher CK level than the SG strain (3010 IU vs. 1560 IU). The FG strain chickens that were subjected to prolonged exercise had a worse antioxidant status (based on the TBARS and ROMS values), whereas the SG strain had nearly the same TBARS and ROMS values under both treatments.

Antioxidant values showed the same trend in the different strains regardless of treatment. Exercise reduced the concentrations of α-T and retinol, and this reduction was greater in the FG group. The other antioxidant compounds (α-T_3, γ-T_3, γ-T, δ-T, lutein, and zeaxanthin) were unaffected by strain or treatment. The time-dependent trend of TBARS and ROMS in both control groups was mostly stable (Figure 1). However, the SG strain generally had higher TBARS values, compared to the FG strain. The FG and SG strains had different responses to exercise: the SG strain had a progressive reduction in TBARS and ROMS during the 28-day

Table 3. Effect of poultry strain and exercise on the main blood traits (n = 15 birds/strain/treatment).

| | Treatments | | | | | | |
| | Control | | Pre-exercise | | Post-exercise | | |
Evaluated trait[2]	Slow-growing	Fast-growing	Slow-growing	Fast-growing	Slow-growing	Fast-growing	Pooled SE[1]
CK	1560[a]	3010[b]	1986[a]	3152[b]	2158[a]	4926[c]	1003
ROMS	0.19[B]	0.14[A]	0.12[A]	0.20[B]	0.18[B]	0.32[C]	0.51
TBARS	35.75[b,c]	28.67[a]	33.05[a,b]	31.95[a,b]	37.96[c]	42.59[d]	4.93
α-T$_3$	0.01	0.01	0.01	0.01	0.01	0.01	0.01
γ-T$_3$	0.08	0.07	0.02	0.02	0.05	0.05	0.58
α-T	2.02[d]	1.06[b]	1.81[c]	1.03[b]	1.83[c]	0.89[a]	0.30
γ-T	0.02	0.02	0.02	0.02	0.02	0.02	0.10
δ-T	0.23	0.21	0.20	0.18	0.25	0.27	0.15
Retinol	14.73[D]	15.10[D]	10.97[B]	12.02[C]	11.65[B,C]	8.63[A]	3.01
Lutein	0.05	0.06	0.05	0.05	0.06	0.06	0.03
Zeaxanthin	1.44	1.45	1.05	1.03	1.22	1.17	0.23

[1]SE: Standard error.

[2]CK: Creatin kinase is expressed as *International Unit*, IU; TBARS: thiobarbituric acid reactive substances are expressed as nmol of malondialdehyde (MDA)/mL of plasma; ROMS: reactive oxygen molecular substances are expressed as nmol/mL of serum; α-, γ-T$_3$: α-, γ-tocotrienol are expressed as nmol/mL of plasma; α-, γ-, δ-T: α-, γ-, δ-tocopherols are expressed as nmol/mL of plasma; retinol, lutein, and zeaxanthin are expressed as nmol/mL of plasma.

[a–d]Values within a row with different superscripts indicate a significant difference at $P \leq 0.05$.

[A–D]Values within a row with different superscripts indicate a significant difference at $P \leq 0.01$.
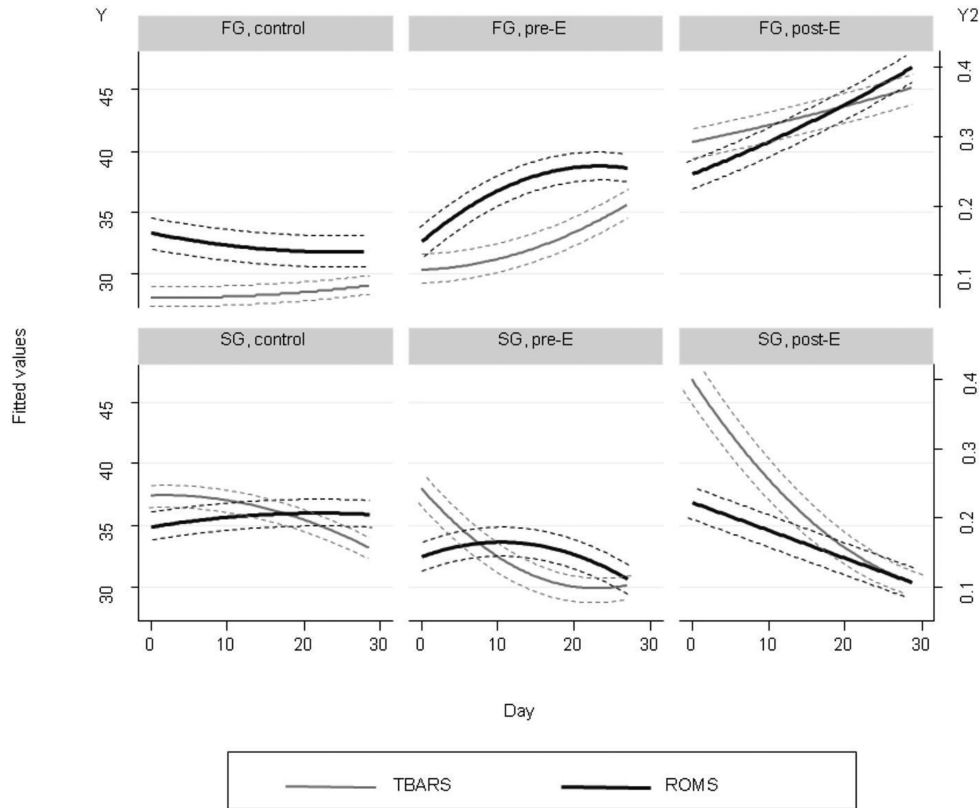

Figure 1. Time-dependent trend of TBARS (grey, Y axis) and ROMS (black, Y2 axis), using fitted values with 95% upper and lower confidence limits. Pre-E/post-E: pre-exercise/post-exercise; FG: fast-growing strain; SG: slow-growing strain; ROMS: reactive oxygen molecular substance expressed as nmol/mL of serum; TBARS: thiobarbituric acid reactive substance expressed as nmol of malondialdehyde (MDA)/mL of plasma.

experiment, whereas the FG had a progressive worsening of the oxidative status.

DISCUSSION

Several studies have compared the effect of exercise on the oxidative status of plasma and muscular tissues, and the effect of the duration of exercise (chronic or acute) in rodents (Gomez-Cabrera et al., 2006 and 2008) and in humans (Leon, 2016). To our knowledge, this is the first study to analyze the effect of chronic (moderate, induced, and prolonged) locomotory activity in chickens with different growth rates. Strenuous exercise, especially when it is sporadic, increases stress biomarkers accompanied by lipid peroxidation (Gomez-Cabrera et al., 2006) or inflammatory reactions

(Gomez-Cabrera et al., 2008). In contrast, regular physical activity is effective in preventing various types of muscle pain (reduces pain behaviors after inflammatory, non-inflammatory, and neuropathic injury; Sluka et al., 2013). However, the effects of moderate exercise remain unclear, e.g., whether a body undergoing long-term exercise has a deficiency in antioxidants and whether the antioxidant defense mechanism adjusts to meet an increased challenge.

In the present study, the increase in serum CK may be indicative of stress-associated tissue dysfunction or may reflect protein turnover, which is closely associated with muscle growth rate and activity (Berri et al., 2007). CK activity is also a specific marker of myocardial infarction, severe muscle breakdown, muscular dystrophy, and acute renal failure (Mitchell and Sandercock, 1995). CK was higher in the FG and SG strains subjected to exercise. Branciari et al. (2009) found higher serum CK values in the Leghorn (a SG strain) and Kabir (a medium-growing strain) genotypes, which are organically reared (i.e., free-range system), compared to those reared conventionally, but did not find the same trend for the FG strain. In the present study, the FG chickens had the highest CK values, compared to the control, and the greatest increase in CK after the exercise activity, compared to SG chickens (1.08-fold vs. 1.56-fold). Such apparent discrepancy is related to the fact that locomotory activity was free in the study of Branciari et al. (2009) but induced in the present study.

FG birds have low locomotory behavior and prefer to remain lying and resting (Castellini et al., 2016), compared to SG birds. This difference in behavior is associated with high body and breast weight and corroborates the general theory of resource allocation (Rendel, 1963). Meat-type birds allocate most of their resources to muscle growing with a significant reduction in all activities that expend energy (i.e., locomotory activity) (Siegel and Honaker, 2009). When FG genotypes are reared free range, they slightly change their behavior (Branciari et al., 2009; Castellini et al., 2016). However, a forced locomotory activity may expose them to severe metabolic stress.

In our experiment, the comparison between induced exercise (before and after) and no exercise (C) allows us to evaluate the progressive training of animals, which consists of acquiring an equilibrium between free radicals and antioxidant capacity of the body. In particular, the values reached after exercise represent the acute response of the body to movement, while the comparison pre-exercise vs. C shows the residual effect of the previous activity.

It should be noted that the ROMS and the main antioxidants (retinol and α-tocopherol) of the C group were statistically different in respect to the pre-exercise group. As already mentioned, this result was related to the different spontaneous locomotory activity of genetic strains, and to the response to exercise. Indeed, the SG strain, even when not subjected to chronic exercise, due to their exploratory nature, performed a higher spontaneous locomotion activity (Dal Bosco et al., 2011) and had higher ROMS and TBARS levels and lower blood antioxidants.

However, during the experimental period, the SG strain exhibited an adaptive response to exercise with a progressive improvement in the oxidative values due to the body training (low ROMS and TBARS). On the contrary, the control FG birds had a lower ROMS and TBARS, but they showed an inadequate response to the free radical production induced by locomotory activity, and the body antioxidant status progressively worsened.

This fact was in agreement with the plasma antioxidants content, which was significantly lower in the SG of pre-exercise than the control group, in correspondence to a higher TBARS value.

Conversely, these parameters did not change (α-T) or slightly change (retinol) in the FG strain.

The reduction of blood oxidative biomarkers in the SG strain was probably related to physical adaptation of these animals to exercise (Gomez-Cabrera et al., 2006). Many authors have suggested that the stress-adaptation response affected the skeletal muscle of animals through homeostatic mechanisms. One of these mechanisms could be the shift of muscle fibers (primarily the *Ileo-Tibialis lateralis)* from α-white (which are more glycolytic) to α-red fibers (which are more oxidative), as reported by Branciari et al. (2009). This shift renders the muscle more efficient and resistant to fatigue because it utilizes the substrates for adenosine triphosphate (**ATP**) production more efficiently. Another explanation could be the expression of specific contractile proteins (e.g., myosin heavy chain [**MHC**] isoforms) and the increase in muscle mitochondria (Röckl et al., 2007; Kikusato and Toyomizu, 2013), which consequently enlarges the cellular respiration rate and the oxidative capacity. However, the exact molecular mechanisms underlying this adaptation remain elusive.

Furthermore, it could not be ignored that the two blood collections from the exercise groups could possibly modify the oxidative status of chickens.

Many studies have investigated the effects of acute and chronic exercise on the amount of antioxidants in skeletal muscles, mainly focusing on endogenous molecules such as oxidative enzymes (Radak et al., 2005). Indeed, antioxidant defense in living systems involves enzymatic and non-enzymatic mechanisms (Carocho and Ferreira, 2013). Enzymes such as xanthine oxidase, superoxide dismutase (**SOD**), glutathione peroxidase (**GPX**), and catalase (**CAT**) operate as a first system; the second system is operated by exogenous antioxidant compounds such as vitamins and carotenoids (Blokhina et al., 2003).

Few studies (Bowles et al., 1991) have focused on the effect of exercise on blood exogenous antioxidant compounds, and their results have been inconsistent. For example, some studies indicated that induced exercise decreases the vitamin E concentration, whereas other

studies indicated that muscular activity does not alter vitamin E levels (Gomez-Cabrera et al., 2005 [in rodents]; Tiidus and Houston, 1995 [in humans]). In the present study, antioxidant compounds appear to be involved in the neutralization of oxidative stress.

Vitamin E is a chain-breaking antioxidant that is able to repair oxidizing radicals that prevent the chain propagation step during lipid oxidation. In the reaction between vitamin E and lipoperoxyl radicals, vitamin E donates a hydrogen ion to the radical with the consequent formation of the tocopheroxyl radical. Regeneration of the tocopheroxyl radical back to its reduced form can be achieved by vitamin C (Fryer, 1992), reduced glutathione, or coenzyme Q (Kagan et al., 2000). Carotenoids and retinol are similarly very active against lipid peroxidation (Lykkesfeldt and Svendsen, 2007). Our results showed a decrease in the main antioxidant molecules during the 28 d of trial (α-T and retinol), probably due to the depletion of these molecules by ROMS.

The reduction of oxidative stress also could have been because of cooperation between vitamins (vitamins A and E) and antioxidant enzymes (e.g., GPX and SOD, which we did not analyze), which triggered an adequate antioxidant defense. There is growing evidence that the continuous presence of low concentrations of ROMS induces the over-expression of antioxidant enzymes, DNA repair molecules, and protein-degrading enzymes, thereby decreasing the incidence of oxidative stress-related diseases (Radak et al., 2005).

Antioxidant reduction affected only some evaluated compounds (i.e., α-T and retinol). One reason could be the biochemical and metabolic nature of these molecules. α-Tocopherol is the most abundant isoform in biological systems (Charocho and Ferreira, 2013), although α-tocotrienol is the most active (Serbinova and Packer, 1994). Retinol is the vitamin produced from the breakdown of β-carotene and is very abundant in the animal body (Goodman et al., 1965). What confers its antioxidant activity is its ability to combine with peroxyl radicals before they propagate peroxidation to lipids (Carocho and Ferreira, 2013). Birds, unlike mammals, also can produce retinol from the xanthophylls (astaxanthin, zeaxanthin, and lutein). We found small but not significant differences in concentrations of zeaxanthin and lutein in the blood of chickens (Table 3).

CONCLUSIONS

The present results suggest that moderate exercise in birds with innate locomotory behavior is beneficial because it produces a lower dose of radicals that enhance non-enzymatic antioxidant defenses (vitamin E and retinol). Whereas, in FG strains, which do not have high locomotory activity and explorative nature, exercise causes high metabolic stress with a negative impact on the animal's well-being.

SG chickens showed a better oxidative status than FG and stress reduction during prolonged exercise, suggesting a stress-adaptive response. Further studies are required to clarify the relation among kinetic behavior, blood parameters, and muscle morphology/metabolism of different chicken strains.

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