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ANIMAL AND HUMAN PHYSIOLOGY

The Effect of Seasons on Total Antioxidant Capacity (TAC), Total Oxidant Capacity (TOC) and OSI (Oxidative Stress Index) Levels in Free-Living Blackbirds (*Turdus merula*) in Nature

Evrim Sonmez[a, *], Arzu Gursoy-Ergen[b], A. Cemal Ozsemir[c], Sena Cenesiz[d], Metin Cenesiz[d], and Ayris Salt-Gokceoglu[d]

[a] *Department of Mathematics and Science Education, Education Faculty, Sinop University, Sinop, Turkey*
[b] *Department of Biology, Faculty of Science, Ankara University, Ankara, 06100 Turkey*
[c] *Bafra Vocational School, Ondokuz Mayıs University, Bafra/Samsun, 55400 Turkey*
[d] *Veterinary Faculty, Ondokuz Mayıs University, Atakum/Samsun, 55200 Turkey*
**e-mail: esonmez@sinop.edu.tr*

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Abstract—The oxidative stress level of organisms is one of the best indicators of whether they are healthy or not. The increase in oxidative stress level in the cell can affect the longevity of the organism as well as cause some immune diseases. In this study, wing, tail, tarsus lengths, weights, muscle and fat scores, Total Antioxidant Capacity (TAC), Total Oxidant Capacity (TOC) and Oxidative Stress Index (OSI) levels of Blackbirds living in Sinop, Sarıkum Nature Protection Area were examined during all four seasons. A total of 55 Blackbirds were caught in autumn, winter, spring and summer. The highest weight was detected in females and males in autumn, and the lowest in summer. Although there was no statistical difference between the wing and tail lengths, they were slightly higher in the Spring. Total antioxidant levels were highest in both sexes in spring. TAC levels were statistically different only in males, and OSI levels in both sex. The season with the highest OSI levels for both sexes is autumn. This situation was closely related to seasonal conditions and whether they were in the breeding period or not. This study shows that total antioxdant levels and oxidative stress index can easily change in Blackbirds.

Keywords: bird physiology, stress, captivity, reproduction, tarsus

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INTRODUCTION

The Common Blackbird is a medium-sized passerine widespread throughout Eurasia. The blackbird is 23 to 29 cm long (including a 9–10 cm tail) and have a wingspan of 34 to 38 cm. Weight ranges from 80 to 125 g). Each sex is easily distinguishable due to sexual dimorphism in colouration (Cramp, 1988). The male is entirely glossy black with brown-black legs and has a yellow eye-ring and a bright orange to yellow bill. The female is dark grey-brown with mottled light grey-brown underparts, a paler chin and dull brownish-yellow bill (Collar, 2005). Juveniles are similar in appearance to females, but lighter brown with more mottled upper parts. Blackbirds occupy an estimated global area of 10,000,000 km^2. Spreading from Europe to Central Asia and North Africa, this bird species is one of the most abundant passerines in Turkey (Roselaar, 1995; Kirwan et al., 2008; Birdlife, 2016). Blackbirds are generalist omnivores. They mostly forage on the ground amongst leaf litter or on lawns, eating a wide variety of foods such as ground invertebrates, flying insects, earthworms, snails, spiders, molluscs, frogs, tadpoles, small reptiles and vegetable matter. Blackbirds also feed arboreally on fruits such as cherries, peaches, nectarines, figs, olives, berries (Tracey et al., 2007). The blackbirds successfully use a range of habitats such as forest, woodland, grassland, urban, orchard, buildings (Kentish et al., 1995).

Birds living in the wild, like all other organisms, are highly affected by variables such as temperature, humidity and light in the environment. In particular, factors such as temperatures above or below seasonal normals, excessive precipitation and humidity are among the factors affecting the survival and reproductive success of birds. Any change in these environmental factors can affect their metabolism and physiology. Reproduction and breeding in birds are the most important activities that require energy. Situations such as starvation during the breeding season, being away from the nest for too long in search of food, protecting the embryos of female birds from predation and providing an environment for safe embryo development, and lack of adequate food reserves of females are the problems that affect their reproductive success. Such environmental changes and problems cause extra stress in all aerobic organisms and all living organisms suffer from oxidative stress (Finkel and Holbrook, 2000; Guh et al., 2019). And this situation can change the oxidant and antioxidant balance in organisms. The increase of oxidative stress at the cellular level can affect the longevity of organisms, besides this can cause some immune diseases (Bize et al., 2014; Costantini et al., 2010; Cram et al., 2015; Vágási et al., 2019; Cram, 2022). The best way to evaluate organisms as healthy is to determine the individual oxidative stress level. Disruption of the balance between oxidant and antioxidant is defined as oxidative stress and affects the physiology of organisms (Constantini et al., 2006). The definition of antioxidant is the name given to substances that have the ability to capture and stabilize free radicals (Şahin et al., 2015). They have an important role in preventing the initiation of oxidation reactions by keeping the oxygen in the cell. However, when free radicals exceed physiological levels in the cell, they cannot be destroyed by antioxidants and oxidative stress occurs in the cell. Free radicals cause lipid peroxidation. As a result, phospholipids in the membrane are oxidized and membrane permeability increases. The functions of membrane-bound surface receptors and the ion balance in the cell are disrupted and they cannot fulfill many biochemical functions (Mis et al., 2018).

Organisms in the wild are extremely sensitive to environmental changes. Changes in their environment cause important physiological events and they may respond differently. As a result of these responses, the animal devotes its available resources predominantly to survival. This brings extra physiological costs to the organism (Skrip and McWilliams, 2016). Understanding the response and adaptation mechanisms of birds to these changing environmental conditions is very important for conservation biology (Fischer and Romero, 2018). In this study, Total Antioxidant Capacity (TAC), Total Oxidant Capacity (TOC) and Oxidative Stress Index (OSI) levels of Blackbirds living in Sarıkum Nature Reserve will be examined during all four seasons. The effects of seasons, activities such as breeding and food seeking on cellular oxidative stress levels of Blackbirds will be interpreted. The expected hypothesis in this study is that TAC, TOC and OSI levels will vary according to the seasons, based on similar studies. But this study will try to answer the questions of when, to what extent and why.

MATHERIALS AND METHODS

Study Site

Sarıkum Nature Reserve is located at the western part of Black Sea region on Sinop peninsula in Turkey, at 42°00′00″–42°02′42″ N and 34°54′46″–34°58′22″ E. Habitats of Sarıkum Nature Reserve are sand dunes, reedbeds, pastures, lake, agricultural areas, sea and flooded forest. The size of the area is approximately 785 ha. Because of habitat richness and complex ecosystems Sarıkum Nature Reserve is a very important feeding, breeding, wintering and stopover area for many bird species. It is also one of the most important areas for migrating birds to rest before crossing the Black Sea (Yılmaz, 2005).

Capture and Identification of Birds

In this study, Blackbirds were caught in 4 seasons (3 month periods). In autumn (September, October, November) 9 females and 9 males, in winter (December, January, February) 6 females and 7 males, in spring 6 females and 6 males (March, April, May) and summer (June, July, August) 6 females and 6 males, in total 55 Blackbirds were caught. Blackbirds were caught with 7 and 12 meters long, 5-shelf, black mist nets. The Blackbirds were removed from the nets as soon as they were caugth. To minimize the stress factors, the birds kept under dark conditions for at least 15 minutes after trapping. Then blood samples were taken from the rested birds within the first 5 minutes. Birds that could not be bled within the first 5 minutes were released back to nature. Ringing and measurements were performed after taking blood samples. On the left tarsus of the birds, 4.2 mm diameter aluminum-magnesium rings with a feedback address under the pseudonym Turkey were attached. Species and sex determinations of the captured birds were made according to Busse, 1984; Jonsson, 1992; Svensson, 1992; Heinzel et al., 1995; Mullarney et al., 1999. The wing, tail, tarsus lengths of each bird were measured, respectively. All measurements were made with a 30 cm (1 mm precision) caliper in accordance with SEEN standards. Weight was measured with an electronic scale with an accuracy of 0.1 g.

Taking Blood Samples

Blood was collected from each individual to the microcapillaries by bleeding the wing vein. The collected blood samples were transferred to EDTA tubes (BD vacutainer, K_2 EDTA) and samples were separated into plasma by centrifugation (Electro-mag M815 M) for 10 minutes at 4500 rpm in the field. Plasma samples were transported to the laboratory at the end of the day with a blood/vaccine carrying bag. They were stored in a deep freezer (Profilo 6600) at –20°C until analysis.

Performing Blood TAC (Total Antioxidant Capacity) and TOC (Total Oxidant Capacity) Analysis

TAC and TOC measurements (Rel Assay Diagnostics, Total Oxidant Status Assay Kit–Total Antioxidant Status Assay Kit) were performed with colorimetric test kits according to the recommended procedure.

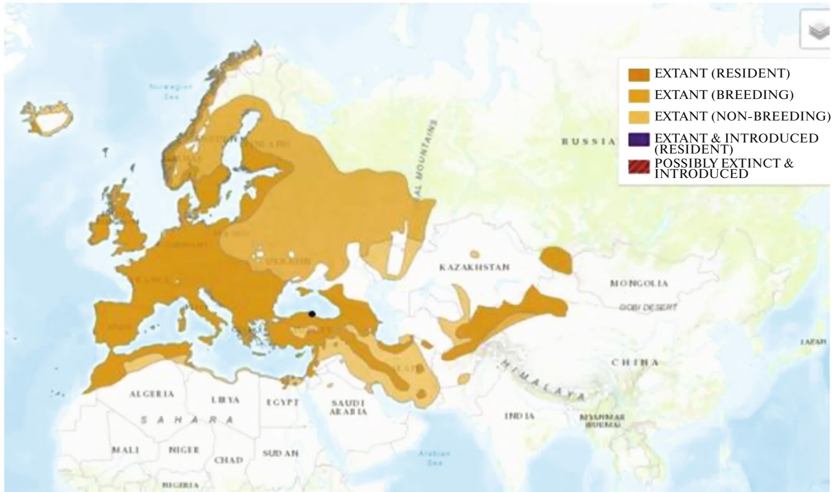

Fig. 1. The range of the species and the study site (black dot) (Birdlife, 2016).

TAC Analysis

Measurement of plasma total antioxidant capacity is determined based on the reduction of the dark blue-green colored prochromogen 2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical in the sample to its colorless ABTS form. Based on this principle, it was studied and calculated in accordance with the procedure in commercial test kits. This analysis was calibrated with Trolox and expressed as Trolox equivalent (mmol Trolox Equiv/L).

TOC Analysis

Measuring the total oxidant capacity of the plasma is measured by the ferric ion forming a colored complex with the chromogen in an acidic medium, forming a color intensity depending on the ratio of oxidants in the medium, and determining this spectrophotometrically. Principle; It is based on the oxidation of oxidants present in the plasma to iron ions with the iron ion-chelate complex. Based on this principle, it was studied and calculated in accordance with the procedure in commercial test kits. This analysis was calibrated with H_2O_2 and expressed as H_2O_2 equivalent (μmol H_2O_2 Equiv/L).

Calculation of Oxidative Stress Index (OSI)

To calculate OSI, an indicator of the degree of oxidative stress, the TOC value was divided by the TAC value and multiplied by 100.

$$\mathrm{OSI} = \frac{\mathrm{TOC}}{\mathrm{TAC}} \times 100.$$

Data Analysis

Data analysis was used using the SPSS 21 program. Normality tests of the data were performed. According to the Shapiro–Wilk test, the data were normally distributed, and since the sample numbers of the groups were not equal, whether there was a difference between the groups was determined according to the Kruskal–Wallis test. Since there was no difference in the comparison of autumn TAC Female (capital letters), autumn TAC Female-Male and TOC Female-Male (lowercase letters), no other test was applied to these groups. Since there was a difference in all other groups, the difference between which groups was determined by the Mann–Whitney test. The $p < 0.05$ value was taken as basis in all groups.

RESULTS

As seen in Table 1, Autumn TAC female (capital letters, Chi-square: 7.504, df: 3, $p = 0.057$) and TAC female-male comparison (lowercase letters, Chi-Square: 3.872, df: 1, $p = 0.052$, Chi-Square: 1.653, df: 1, $p = 0.199$, Chi-Square: 0.103, df: 1, $p = 0.749$, Chi-Square: 1.641, df: 1, $p = 0.200$) levels are statistically insignificant. Therefore, these groups were not tested other than the Kruskal–Wallis test. In TAC male groups, only the levels in the autumn group differed from the other groups ($U = 5.000$, $p = 0.005$). The differences in all seasons of TOC female groups were statistically significant (capital letters, for autumn $U = 1.000$, $p = 0.002$; for winter $U = 3.000$, $p = 0.005$; for spring $U = 9.000$, $p = 0.034$, and for summer, $U = 0.000$, $p = 0.004$). In TOC male groups, only the summer group differed from the others ($U = 0.000$, $p = 0.004$). In the TOS female-to-male comparison, no difference was found only in autumn male-female comparison ($U = 21.000$, $p = 0.085$), the differences

Table 1. TAC, TOC and OSI levels of the Blackbirds caught according to the seasons

	Seasons			
	Autumn	Winter	Spring	Summer
	TAC* Mean ± S.E. (mmol Trolox Equv/L)			
Female	1.278 ± 0.139 Aa	1.324 ± 0.105 Aa	1.676 ± 0.113 Aa	1.573 ± 0.052 Aa
Male	0.928 ± 0.107 Aa	1.560 ± 0.117 Ba	1.726 ± 0.087 Ba	1.665 ± 0.019 Ba
	TOC* Mean ± S.E. (μmol H_2O_2 Equv/L)			
Female	603.033 ± 114.514 Aa	58.975 ± 15.800 Ba	146.394 ± 38.709 Ca	293.869 ± 40.305 Da
Male	887.344 ± 107.160 Aa	542.450 ± 263.176 Ab	765.135 ± 100.773 Ab	154.853 ± 6.609 Bb
	OSI* Mean ± S.E. (Arbitrary Unit)			
Female	47.18 ± 12.12 Aa	4.54 ± 0.98 BEa	8.73 ± 3.57 CEa	18.96 ± 2.86 Da
Male	95.91 ± 26.47 Aa	33.77 ± 15.37 BEb	44.32 ± 5.49 CEb	9.30 ± 0.34 Db

* There is no statistical difference between the data shown with the same capital letters in the same row.
* There is no statistical difference between the data shown with the same lowercase letters in the same column.
* TAC: Total Antioxidant Capacity, TOC: Total Oxidant Capacity, OSI: Oxidative Stress Index, S.E.: Standartd Error.

between male-female comparisons in all other seasons were statistically significant (lowercase letters for winter $U = 4.000$, $p = 0.015$, for spring and summer $U = 0.000$, $p = 0.004$).

DISCUSSION

In this study, wing, tail, tarsus lengths, weights, muscle and fat score, TAC, TOC and OSI levels of blackbirds caught in 4 different seasons were evaluated. When the data obtained were compared in terms of weight, the highest weight was found in females and males in autumn, and the lowest in summer. This may have been caused by the fact that they spent their reserves as much as possible after a successful breeding in the summer and with the increase in air temperature and metabolism. In autumn, their weight was high as they filled their storage reserves in preparation for the approaching winter. In the spring, it is a very normal and expected result that the females have low fat scores due to their activities such as carrying eggs, brood care, and foraging for food, consuming more energy and spending their storage reserves (Fig. 4).

Wing, tail and tarsus lengths and weights may differ significantly according to sex. Males have longer wings and tails than females (Figs. 2 and 3). In some studies, it has been suggested that the wing and tarsus length and temperature are directly proportional (Hamilton, 1961; Sun et al., 2017). The main factor here is actually finding enough high-calorie foods. If birds can be fed with foods with high nutritional value during development, their development will be in their normal course. The calorie values of the fruits that the blackbirds are fed increase with the season and temperature. In the present study, a similarity was found especially in terms of wing and tarsus values. Looking at Figs. 2 and 3, it has been determined that the wing and tarsus lengths are partially high, especially in spring and summer. Although these data may suggest that wing and tarsus length are directly proportional to temperature and food, more detailed studies with larger numbers of individuals are needed.

Birds living in temperate regions respond to seasonally fluctuating temperatures by adjusting their physiology to match the thermogenic requirements of their environment. Climate change increases the frequency of temperature fluctuations. This is predicted to increase the likelihood of birds facing environmental incompatibility (Jimenez et al., 2020). Seasonally changing temperatures cause important physiological changes in birds as well as in all organisms. In addition, the reproductive period, egg formation, ovulation, mating, brood care, molting, short daylight in winter, migration are important factors that change the oxidative balance of birds. For birds, dietary antioxidants during the migration period and autumn have a very important role. Spring probably represents significant oxidative challenges as it is the reproductive and migration period in the life history of female birds (Frawley et al., 2021). Migratory birds make two endurance flights per year to their breeding field in the summer and to their wintering field in the winter. These endurance flights cause oxidative results. These results may differ between autumn and spring migration, or especially in the spring, as females prepare for breeding and ovulation (Cooper-Mullin and McWilliams, 2022). In a study with *Sturnus vulgaris*, they found that oxidative damage was lower in females before flight compared to autumn. It had been found females increased enzymatic and non-enzymatic

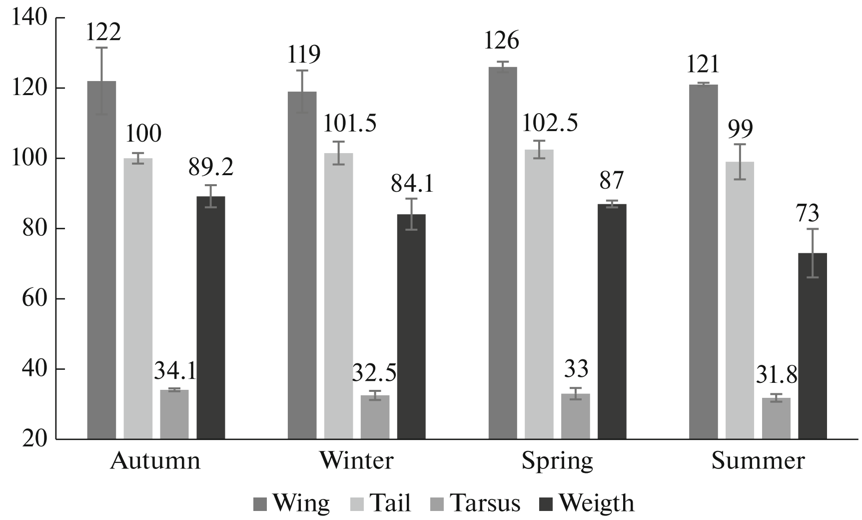

Fig. 2. Wing (mm), tail (mm), tarsus (mm) lengths and weights (gr) of Female Blackbirds. The differences between the wing, tail, tarsus lengths and weights of the captured Female Blackbirds were not statistically significant (Mann–Whitney U, $p > 0.05$).

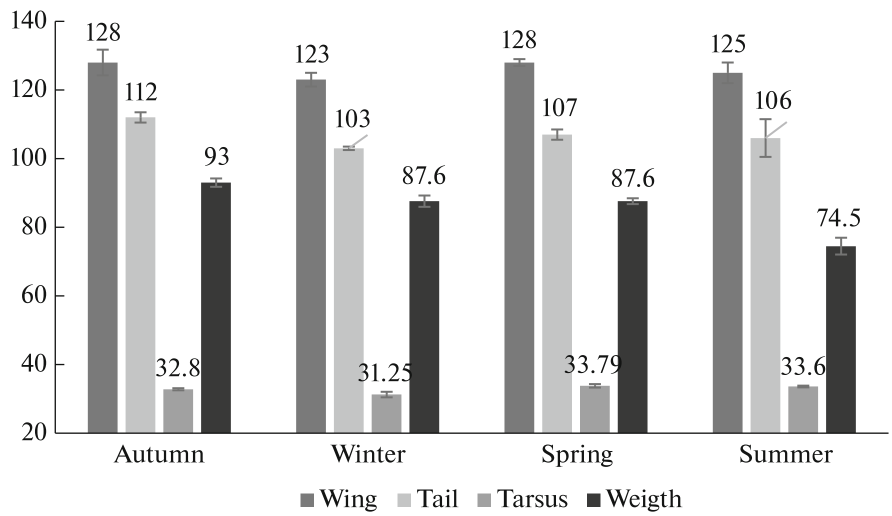

Fig. 3. Wing (mm), tail (mm), tarsus (mm) lengths and weights (gr) of Male Blackbirds. The differences between the wing, tail, tarsus lengths and weights of the captured Male Blackbirds were not statistically significant (Mann–Whitney U, $p > 0.05$).

endogenous antioxidants in the spring (Frawley et al., 2021). When we look at our current findings, it has been determined that the total antioxidant levels of females and males are at the highest level in the spring (Table 1). There is no statistical difference between total antioxidant levels in male and female individuals in spring compared to other seasons. On the other hand, the amount tends to be slightly higher. The reason for this may be that Blackbirds were fed with antioxidant-rich plants or fruits and increased their total antioxidant level. While these antioxidants produced by plants provide a defense for themselves, they are a reward for consumers. Birds use carbohydrates and fats as their primary energy source, and free radicals appear as a result of fat metabolism. While the increase in the amount of this antioxidant is a protection for plants and the birds that consume them, it can also provide a protection for the free radicals that the consumer will face as a result of fat metabolism too (Bolser et al., 2013). At the same time, Blackbirds often migrate at close distances. It can be argued that this is due to the increase in metabolism resulting from a preparation for close-range migration or the breeding season. Here, we think that it is mostly caused by reproductive behaviors and nutritional sources. Reproductive effort may result in reduced antioxidant defenses in birds (Alonso-Alvarez et al., 2004; Wiersma et al., 2004; Casagrande et al., 2011). In the current study, the highest TAC levels were found in the spring. TAC levels may have increased due to the

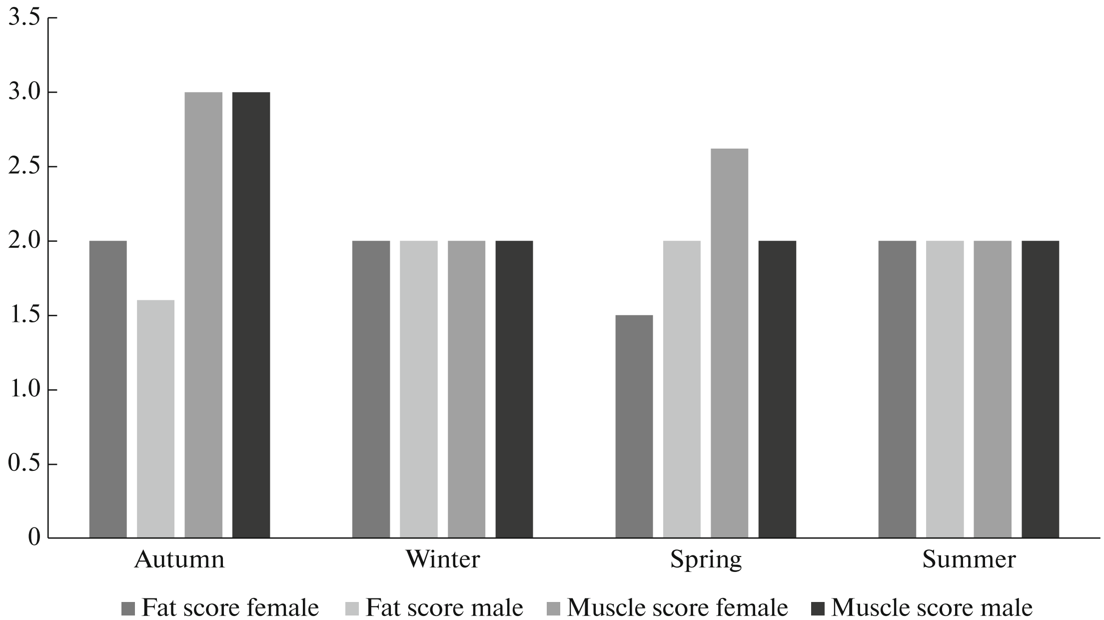

Fig. 4. Muscle and fat scores of Female and Male Blackbirds. The differences between the muscle and fat scores of the captured female and male Blackbirds were not statistically significant (Mann–Whitney U, $p > 0.05$).

abundance of their diets with the arrival of spring. In addition, Blackbirds are fed with lower calorie foods due to the difficulties they experience in finding food during the winter months. In the other three seasons, they have a richer diet because of the abundance of fruits and their rich calorie content and the increase in the amount of insects and other invertebrates.

Casagrande et al., (2011) reported in a study conducted with *Falco tinnunculus tinnunculus* in the wild and in captivity, that more oxidative damage was observed in wild than in captivity. In a study of pigeons in captivity, they reported a slightly greater increase in oxidative damage in pigeons that lost more body mass. (Costantini et al., 2010). High physical activity can result in increased metabolic activity and the production of pro-oxidants. The hormonal status of breeding birds can also regulate the plasma oxidative state. Testosterone, in particular, is found at high levels during the breeding season in wild males and can increase metabolic rate. Depending on this, it can change the balance between reactive chemicals and antioxidants (Chainy et al., 1997).

Jimenez et al., (2020), in a study with conducted *Poecile atricapillus* and *Columba livia*, found that heat stress did not change oxidative stress in both species and tissues. However, the highest peroxyl scavenging capacity in the muscles was determined in autumn, while the hydroxyl scavenging capacity was found to be high in both species in autumn and summer. In the brain, they found that the scavenging capacity of hydroxyl radicals for rock pigeons was highest in autumn and summer, whereas for *P. atricapillus* it only increased in summer. Findings showed that the oxidative stress system changes slowly seasonally (Jimenez et al., 2020). In the current study, the season in which OSI levels tend to be highest in both sex is autumn (Table 1).

Costantini and Dell'Omo, (2006) suggested in a study they conducted with *F. tinnunculus* that OXY (total serum antioxidant level) was more affected by environmental components, and the changes in OXY were caused by the antioxidants they received with food. Costantini et al. (2006, 2007), in a study conducted with *F. tinnunculus* lives freely in nature, found that stress levels increased due to decreased access to food in more sibling rivalries.

The metabolic rate also increases as a result of illness or injury. This causes the production of abundant reactive oxygen species, which is a by-product. These reactive oxygen species cause oxidative damage to biomolecules and accumulation of damage. As a result, the homeostasis regulation mechanism is destroyed and can lead to shortened longevity or death of the animal (Costantini and Verhulst, 2009; Yaprakçı et al., 2016). At the same time, the assessment of oxidative stress levels can be a scale for assessing immune status and whether the bird is healthy (Cram et al., 2015). If oxidative stress generation is not prevented reactive oxygen species can damage DNA, lipids and proteins. This can increase the rate of aging and reduce cellular function. Breeding is generally associated with higher metabolic rates, which, if not increased antioxidant protection of the animal, can increase reactive oxygen species production and lead to oxidative damage. Therefore, reproduction may be a mechanism that creates oxidative stress in the organism (Lin et al., 2022).

It is known that free radicals and oxidative stress in cells cause many disorders such as premature aging, reproductive capacity, arthritis, cardiovascular diseases, and allergic reactions. Many things can also cause increased oxidative stress in wildlife. Environmental variables (food, temperature, humidity, light, etc.) (Costantini and Dell'Omo, 2006; Wang et al., 2021), predator and human pressure, poachers (Yaprakçı et al., 2016), chemical contamination of food, food and water resources, radiation (Fernie and Bird, 2001; Fernie and Reynolds, 2005; Bonisoli-Alquati et al., 2010; Espín et al., 2014; Abbasi et al., 2017), even whether the animal is in the migration period (Arnold et al., 2010), brood and nest size (number of chicks) (Costantini et al., 2006), free radicals are the reasons that cause the increase of free radicals and oxidative stress index in animals. In recent years, studies on oxidative stress, which directly affects health and life capacity by being affected by many factors, are gaining importance in wildlife (Casagrande et al., 2011; Bize et al., 2014).

CONCLUSIONS

Blackbirds react very quickly to any stressor in their environment. Environmental temperature, humidity and light levels, predator and human pressure, scarcity of food can cause stress in Blackbirds. According to the results of this study, the oxidative stress index was highest in both sex in autumn. This could be due to the relative decrease in temperatures compared to summer, the preparation for the coming winter and the fact that the food was not as abundant and varied as before. The highest TAC levels were detected in the spring. It may be due to the abundance and enrichment of their habitats in terms of nutrients and the fact that they fed with rich fruits showing oxidant properties. At the same time, breeding and mating behaviors may have caused high levels of total antioxidants and oxidative stress index, as female birds protect their chicks from predators and provide an environment for their development. This study is important because it is the first study that reflects TAC, TOC and OSI levels of Blackbirds living freely in nature during all four seasons. However, studies with larger numbers of birds are needed to reach more conclusive results.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The authors declare that they have no conflicts of interest.

Statement on the welfare of animals. Studies were performed by licensed researchers and were approved by the Erciyes University Local Ethics Committee for Animal Experiments (13.03.2017/17-031) and the Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks (Permit no. 17.05.2017/72784983-488.04.109303).

REFERENCES

Abbasi, N.A., Arukwe, A., Jaspers, V.L.B., Eulaers, I., Mennilod, E., Ibor, O.R., Frantz, A., Covaci, A., and Malik, R.N., Oxidative stress responses in relationship to persistent organic pollutant levels in feathers and blood of two predatory bird species from Pakistan, *Sci. Total. Environ.*, 2017, vol. 580, pp. 26–33. https://doi.org/10.1016/j.scitotenv.2016.11.197

Alonso-Alvarez, C., Bertrand, S., Devevey, G., Gaillard, M., Prost, J., Faivre, B., and Sorci, G., An experimental test of the dose-dependent effect of carotenoids and immune activation on sexual signals and antioxidant activity, *Am. Nat.,* 2004, vol. 164, pp. 651–659. https://doi.org/10.1086/424971

Arnold, K.E., Larcombe, S.D., Ducaroir, L., and Alexander, L., Antioxidant status, flight performance and sexual signalling in wild-type parrots, *Behav. Ecol. Sociobiol.,* 2010, vol. 64, pp. 1857–1866. https://doi.org/10.1007/s00265-010-0997-x

BirdLife International. *Turdus merula*. The IUCN Red List of Threatened Species 2016, e.T103888106A87871094. Downloaded on December 20, 2019. https://doi.org/10.2305/IUCN.UK.2016-3.RLTS.T103888-106A87871094.en

Bize, P., Cotting, S., Devevey, G., Rooyen, J., Lalubin, F., Glaizot, O., and Christe, P., Senescence in cell oxidative status in two bird species with contrasting life expectancy, *Oecologia*, 2014, vol. 174, pp. 1097–1105. https://doi.org/10.1007/s00442-013-2840-3

Bolser, A.J., Alan, R.R., Smith, A.D., Li, L., Seeram, N.P., and McWilliams, S.R., Birds select fruits with more anthocyanins and phenolic compounds during autumn migration, *Wilson J. Ornithol.*, 2013, vol. 125, no. 1, pp. 97–108.

Bonisoli-Alquati, A., Mousseau, T.A., Møller, A.P., Caprioli, M., and Saino, N., Increased oxidative stress in barn swallows from the Chernobyl region, *Comp. Biochem. Physiol., Part A: Mol. Integr. Physiol.*, 2010, vol. 155, pp. 205–210. https://doi.org/10.1016/j.cbpa.2009.10.041

Busse, P., *Key to Sexing and Ageing of European Passerines*, Betr. Naturkd. Niedersachs Sonderheft, 1984, pp. 1–224.

Casagrande, S., Dell'Omo, G., Costantini, D., Tagliavini, J., and Groothuis, T., Variation of a carotenoid-based trait in relation to oxidative stress and endocrine status during the breeding season in the Eurasian kestrel: A multi-factorial study, *Comp. Biochem. Physiol., Part A: Mol. Integr. Physiol.*, 2011, vol. 160, pp. 16–26. https://doi.org/10.1016/j.cbpa.2011.04.011

Chainy, G.B.N., Samantaray, S., and Samanta, L., Testosterone-induced changes in testicular antioxidant system, *Andrologia*, 1997, vol. 29, pp. 343–349.

Collar, N., Common Blackbird (*Turdus merula*), in *Handbook of the Birds of the World Alive*, del Hoyo, J., Elliott, A., Sargatal, J., Christie, D.A., and de Juana, E., Eds., Barcelona: Lynx Edicions, 2015.

Cooper-Mullin, C. and McWilliams, S.R., Fat stores and antioxidant capacity affect stopover decisions in three of four species of migratory passerines with different migration strategies: an experimental approach, *Front. Ecol. Evol.*, 2022, vol. 10, pp. 1–20.
https://doi.org/10.3389/fevo.2022.762146

Costantini, D. and Dell'Omo, G., Environmental and genetic components of oxidative stress in wild kestrel nestlings (*Falco tinnunculus*), *J. Comp. Physiol., Part B: Biochem. Mol. Biol.*, 2006, vol. 176, pp. 575–579.
https://doi.org/10.1007/s00360-006-0080-0

Costantini, D. and Verhulst, S., Does high antioxidant capacity indicate low oxidative stress?, *Funct. Ecol.*, 2009, vol. 23, pp. 506–509.
https://doi.org/10.1111/j.1365-2435.2009.01546.x

Costantini, D., Casagrande, S., Filippis, S., Brambilla, G., Fanfani, A., Tagliavini, J., and Dell'Omo, G., Correlates of oxidative stress in wild kestrel nestlings (*Falco tinnunculus*), *J Comp. Physiol., Part B: Biochem. Mol. Biol.*, 2006, vol. 176, pp. 329–337.
https://doi.org/10.1007/s00360-005-0055-6

Costantini, D., Coluzza, C., Fanfani, A., and Dell'Omo, G., Effects of carotenoid supplementation on colour expression, oxidative stress and body mass in rehabilitated captive adult kestrels (*Falco tinnunculus*), *J Comp. Physiol., Part B: Biochem. Mol. Biol.*, 2007, vol. 177, pp. 723–731.
https://doi.org/10.1007/s00360-007-0169-0

Costantini, D., Rowe, M., Butler, M.W., and McGraw, K.J., From molecules to living systems: historical and contemporary issues in oxidative stress and antioxidant ecology, *Funct. Ecol.*, 2010, vol. 24, pp. 950–959.
https://doi.org/10.1111/j.1365-2435.2010.01746.x

Cram, D.L., Blount, J.D., York, J.E., and Young, A.J., Immune response in a wild bird is predicted by oxidative status, but does not cause oxidative stress, *PLoS One*, 2015, pp. 1–10.
https://doi.org/10.1371/journal.pone.0122421

Cram, D.L., Oxidative stress and cognition in ecology, *J. Zool.,* 2022, Print ISSN 0952-8369.

Cramp, S., *Handbook of the Birds of Europe, the Middle East and North Africa: the Birds of the Western Palearctic*, New York: Oxford University Press, 1988, p. 1084. ISBN-13: 978-0198575078.

Espín, S., Martínez-López, E., Jiménez, P., María-Mojica, P., and García-Fernández, A.J., Effects of heavy metals on biomarkers for oxidative stress in Griffon vulture (*Gyps fulvus*), *Environ. Res.*, 2014, vol. 129, pp. 59–68.
https://doi.org/10.1016/j.envres.2013.11.008

Fernie, K.J. and Bird, D.M., Evidence of oxidative stress in American Kestrels exposed to electromagnetic fields, *Environ. Res, Sect. A*, 2001, vol. 86, pp. 198–207.
https://doi.org/10.1006/enrs.2001.4263

Fernie, K.J. and Reynolds, S.J., The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: a review, *J. Toxicol. Environ. Health, Part B*, 2005, vol. 8, no. 2, pp. 127–140.
https://doi.org/10.1080/10937400590909022

Finkel, T. and Holbrook, N.J., Oxidants, oxidative stress and the biology of ageing, *Nature*, 2000, vol. 408, pp. 239–247.
https://doi.org/10.1038/35041687

Fischer C.P. and Romero L.M., Chronic captivity stress in wild animals is highly species-specific, *Conserv. Physiol.*, 2018, vol. 7, pp. 1–38.
https://doi.org/10.1093/conphys/coz093

Frawley, A.E., DeMoranville, K.J., Carbeck, K.M., Trost, L., Bryła, A., Dzialo, M., Sadowska, E.T., Bauchinger, U., Pierce, B.J., and McWilliams, S.R., Season, anthocyanin supplementation, and flight training have mixed effects on the antioxidant system of migratory European Starlings, *Ornithology*, 2021, vol. 138, pp. 1–16.
https://doi.org/10.1093/ornithology/ukab023

Guh, Y., Tamai, T.K., and Yoshimura, T., The underlying mechanisms of vertebrate seasonal reproduction, *Proc. Jpn. Acad., Ser. B: Phys. Biol. Sci.*, 2019, vol. 95, no. 7, pp. 343–357.
https://doi.org/10.2183/pjab.95.025

Hamilton. T.H., The adaptive significances of intraspecific trends of variation in wing length and body size among bird species, *Evolution*, 1961, vol. 15, pp. 180–195.

Heinzel, H., Fitter, R., and Parslow, J., Türkiye ve Avrupa'nın Kuşları, İstanbul, Türkiye: Doğal Hayatı Koruma Derneği, 1995.

Jimenez, A.G., Tobin, K.J., Anderson, K.N., McCann, M.K.E., and Briggs, C.W., Differences in oxidative stress across seasons and ability to cope with environmental mismatch in muscle and brain of black-capped chickadees *Poecile atricapillus* and rock pigeons *Columba livia, J. Avian Biol.*, 2020, vol. 51, no. 5, pp. 1–11.
https://doi.org/10.1111/jav.02417

Jonsson, L. *Birds of Europe with North Africa and the Middle East*, New Jersey: Princtone University Press, 1992, p. 416. ISBN-13: 978-0691026480.

Kentish, B.J., Dann, P., and Lowe, K.W., Breeding biology of the common Blackbird *Turdus merula* in Australia, *J. Emu.—Aust. Ornithol.*, 1995, vol. 95, pp. 233–244.
https://doi.org/10.1071/MU9950233

Kirwan, G.M., Boyla, K.A., Castell, P., Demirci, B., Özen, M., Welch, H., and Marlow, T., *The Birds of Turkey*, London: Christopher Helm Publishers Ltd., 2008, 1st ed., p. 512. ISBN: 9781408104750.

Lin, Y., Patterson, A.N., Jimenez, A.G., and Elliott, K., Altered oxidative status as a cost of reproduction in a seabird with high reproductive costs, *Physiol. Biochem. Zool.*, 2022, vol. 95, no. 1, pp. 35–53.
https://doi.org/10.1086/717916

Mis, L., Mert, H., Comba, A., Comba, B., Söğütlü, İ.D., Irak, K., and Mert, N., Some mineral substance, oxidative stress and total antioxidant levels in Norduz and Morkaraman sheep, *Van Vet. J.*, 2018, vol. 29, no. 3, pp. 131–134.

Mullarney, K., Svensson, L., Zetterstrom, D., and Grant, P.J., *Collins Bird Guide. the Most Complete Guide to the Birds of Britain and Europe*, London: Harper Collins Publishers Ltd., 1999, 1st ed. ISBN: 9780007267262.

Roselaar, C.S., *Songbirds of Turkey. An Atlas of Biodiversity of Turkish Passerine Birds*, Sussex: NL and Pica Press, 1995, p. 240. ISBN: 9781873403440.

Skrip, M.M. and McWilliams, S.R., Oxidative balance in birds: an atoms-to-organisms-to-ecology primer for ornithologists, *J. Field Ornithol.,* 2016, vol. 87, no. 1, pp. 1–20. https://doi.org/10.1 1 1 l/jofo.12135

Sun, Y., Li, M., Song, G., Lei, F., Li, D., and Wu, Y., The role of climate factors in geographic variation in body mass and wing length in a passerine bird, *Avian Res.*, 2017, vol. 8, no. 1, pp. 1–9.
https://doi.org/10.1186/s40657-016-0059-9

Svensson, L., *Identification Guide to European Passerines*, Stockholm: British Trust for Ornithology, 1992, 4th ed., p. 318. ISBN: 978-9163011184

Şahin, Ö.K., Aksoy, M.Ç., Uz, E., and Dağdeviren, B.H., Investigation of the effects of resveratrol on total oxidant/antioxidant capacity on experimental cigarette smoking model, *SDÜ Sağlık Bilim. Derg.*, 2015, vol. 6, no. 1, pp. 10–14.

Tracey, J., Bomford, M., Hart, Q., Saunders, G., and Sinclair, R., *Managing Bird Damage to Fruit and Other Horticultural Crops*, Canberra: Bureau of Rural Sciences, 2007, p. 268. ISBN: 0975044370, 0644292407.

Vágási, C.I., Vincze, O., Pătraş, L., Osváth, G., Pénzes, J., Haussmann, M.F., Barta, Z., and Pap, P.L., Longevity and life history coevolve with oxidative stress in birds, *Funct. Ecol.*, 2019, vol, 33, pp. 152–161.
https://doi.org/10.1111/1365-2435.13228

Wang, C., Zhao, F., Li, Z., Jin, X., Chen, X., Geng, Z., Hu, H., and Zhang, C., Effects of resveratrol on growth performance, intestinal development, and antioxidant status of broilers under heat stress, *Animals*, 2021, vol. 11, no. 1427, pp. 2–10.
https://doi.org/10.3390/ani11051427

Wiersma, P., Selman, C., Speakman, J.R., and Verhulst, S., Birds sacrifice oxidative protection for reproduction, *Biol. Lett.*, 2004, vol. 271, pp. 360–363.

Yaprakci, M.V., Ciğerci, İ.H., Ali, M.M., and Kabu, M.M., DNA damage, total antioxidant and oxidant status in gunshot wounded wild falcons, *Pak. J. Zool.*, 2016, vol. 48, no. 5, pp. 1417–1421.

Yılmaz, C., Sarıkum Gölü ekosistemi (Sinop), in *TURQUA—Symposium of Türkiye quaternary V, İstanbul, Turkey, July 2–5, 2005*, Tüysüz, O. and Erturaç, M.K., Eds., İstanbul Technical University, Publish of Enstitue of Avrasya Earth Science, 2005, pp. 219–226.