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Effects of different LED light spectra on rainbow trout (*Oncorhynchus mykiss*): in vivo evaluation of the antioxidant status

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Abstract Rainbow trout (*Oncorhynchus mykiss*) farming is one of the major aquacultures in Turkey. Some conditions in fish farming can induce oxidative stress leading to the deterioration in properties such as appearance/color, texture, and flavor in fish meat. This situation may cause the consumer not to prefer edible fish. Although there are some studies on the impacts of light intensity on fish welfare, the changes in the antioxidant enzyme activities have not been elucidated. In the current study, it was intended to examine in rainbow trout how cultivating under different wavelengths affects the antioxidant enzymes and acetylcholine esterase (AChE) activity, because its activity is associated with oxidative stress, and also the determination of which light is suitable for fish welfare was aimed. Rainbow trout larvae were grown under four lights with different wavelengths: natural sunlight and incandescent long-wave (red light), medium-wave (green light), and short-wave (blue light) LED light. The experiment lasted for 64 days. Biochemical assays were carried on in the brain, gill, and liver of rainbow trout. Antioxidant enzymes and AChE activity, which play an important role in the central nervous system, were assayed. In gill tissues, superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glucose 6 phosphate dehydrogenase (G6PD), glutathione reductase (GR), glutathione S-transferase (GST), and AChE activities increased under all three light wavelengths. In the liver, while activities of antioxidant enzymes and AChE decreased in red light, all of them increased in blue and green light. In the brain, GPx, GST, G6PD, and SOD activities were reduced but AChE activity did not alter under all three light sources. In conclusion, light sources with different spectral structures caused important changes in the activities of antioxidant enzymes in rainbow trout. On this basis, it may be thought that this may be a response to the changing redox status of a cell. Based on our results, blue light sources may be suggested for fish welfare in rainbow trout culture, and providing fish welfare by changing light sources can be easy and cheap in fish farming.

Keywords Acetylcholine esterase · Antioxidant enzymes · Light wavelengths · Rainbow trout

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Introduction

Light is an important factor in the growth and survival of juvenile fish, as in all animals and plants. Light-emitting diodes (LEDs) can provide specific wavelengths and

can be used effectively in fish farming (Dawson et al. 2001; Young 1988). The red or long spectrum penetrates only shallow waters and negatively affects the physiological functions of fish while blue or short spectrum is dominant in deep waters. On the other hand, several studies reported that oxidative stress decreases in short wavelengths such as green light (Choi et al. 2016; Migaud et al. 2007; Shin et al. 2011). Depending on fish species habitat characteristics and their specific visual abilities, light spectrum is known to affect multiple physiological aspects such as growth (Downing 2002; Ruchin 2004), neurohormonal system (Bayarri et al. 2002; Diler et al. 2003), reproduction (Diler et al. 2003; Noar et al. 2001), and behavior (Karakatsouli et al. 2007). In the early stages (larvae) of trout farming, artificial lighting is generally used in all hatcheries, because the larvae stage is carried out in closed environments.

Rainbow trout (*Oncorhynchus mykiss*), with 814 tons of live weight production, is one of the oldest species and the 14th most important cultured fish species in the world (FAO 2018). In Turkey, trout farming began in the 1970s, and with the use of cages in lakes and dams, it has continued to grow and develop (DOĞAKA 2014). Fishing is one of the four major components of the agriculture industry in Turkey. In addition to providing useful nutrition to people, fishing creates a high potential for employment opportunities and exports in the industrial sector (Harlıoğlu and Yonar 2007).

Rainbow trout is a fast-growing fish and can easily tolerate changing environmental conditions. It can be found in many different habitats such as gravel bottom, fast-flowing, well-oxygenated rivers, cold main waters, streams, and lakes (Coombs 1999). They can withstand a wide variety of temperature changes, but the temperature range for spawning and growth is narrower (Parisi et al. 2014). However, when fish are exposed to unfavorable environmental conditions, some endocrine and physiological responses occur and, if they are sustained in time (chronic response), can lead to alterations in the survival, growth, and reproduction ability of the fish. On the other hand, these environmental stressors can lead to an oxidative stress condition affecting fish performance under aquatic conditions (Barton and Iwama 1991; Pickering 1992).

Previous research showed that changes in environmental parameters such as temperature or light wavelength can affect fish breeding conditions, causing oxidative stress response and affecting fish welfare and growth performances (Bonga 1997). Regarding this, in vitro and in vivo studies have reported that rainbow trout and sea bass are more sensitive to changes in light wavelengths especially peaking at 450–500 nm (Pickering and Pottinger 1989).

Oxidative stress originates from the production of reactive oxygen species (ROS) and the imbalance of the antioxidant defense system in living organisms (Nishida 2011). Although enzyme isoforms are not completely identified in several fish species, antioxidant defense mechanisms include an enzymatic system and low molecular weight antioxidants in fish similar to the mammals (Di Giulio and Meyer 2008). Superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glucose 6 phosphate dehydrogenase (G6PD), glutathione reductase (GR), and glutathione S-transferase (GST) are the fundamental antioxidant enzymes, which are the markers of antioxidant status (Kelly et al. 1998).

SOD catalyzes the dismutation of $O_2^{\cdot -}$ to H_2O_2, which would later be transformed into H_2O and O_2 by CAT. GPx, on the other hand, contributes to the disintegration of H_2O_2 and other organic peroxides (Winston and Digiulio 1991). GR catalyzes the generation of reduced glutathione (GSH) from oxidized form (GSSG), in the presence of pyridine nucleotides (NADPH). GSH would later be used by GPx and GST which is responsible for cellular detoxification of xenobiotics by catalyzing the conjugation of electrophilic xenobiotics with GSH (Güller et al. 2018; Hayeshi et al. 2007). The source of utilized NADPH is created in the pentose phosphate pathway as a result of the reaction catalyzed by the G6PD enzyme (Keha and Küfrevioğlu 2012). Figure 1 schematizes the interrelationship of the enzymatic antioxidant system. Many organs are affected by oxidative stress, but the brain is the most affected organ. Since brain tissue consumes more oxygen and its antioxidant system is weak, it is more vulnerable in struggling against ROS than other organs of the body and this sensitivity of brain tissue can cause neurodegenerative diseases. Also, the increased percentage of lipids in this organ joined to lower antioxidant defenses makes it more prone to lipid peroxidation (Konishi 2009; Milatovic et al. 2006; Sanz et al. 2013).

If oxidative stress cannot be prevented by the antioxidant defense system, it can cause oxidation of different biomolecules integrating cells such as leading for example to lipid peroxidation (Halliwell and Gutteridge

1989). Furthermore, sensory properties (flavor, appearance, texture, and color), which are the main factors used by consumers to evaluate fillet quality, and functional properties (water holding capacity and emulsifying ability) of meat are affected by lipid oxidation (Gray et al. 1996; Torrico et al. 2018).

On the other hand, acetylcholinesterase (AChE) hydrolyzes the neurotransmitter acetylcholine (Ach) to choline and acetate in cholinergic synapses and neuromuscular synapses, thus playing an important role in cholinergic neurotransmission (Tripathi and Srivastava 2008) and regulating animal behavior. Effects on AChE activity in fish can be dangerous, as it will affect nutritional ability, swimming activity, predator avoidance, and spatial orientation of species (Das and Mukherjee 2003). Besides, AChE is associated with oxidative stress responsible for the formation of free radicals, which cause disorders in fish mobility and disturbed swimming (Blenau et al. 2012; Salbego et al. 2010).

Data related to the effects of different light spectra on fish welfare showed that while some light wavelengths negatively affect physiological functions in farm fish, some of them reduce oxidative stress. For this propose, the present study aimed to investigate the activities of antioxidant enzymes and AChE in rainbow trout cultivated under light sources with different spectral structures, to discuss whether these growing conditions cause oxidative stress, and to response which light is suitable for fish welfare?

Materials and methods

Materials

Animals and experimental design

Rainbow trout (*Oncorhynchus mykiss*) larvae (4.39 ± 0.5 mean weight ± SEM) were obtained from a production facility in Van province Gürpınar Township. After a 3-week adaptation period, rainbow trout larvae were placed in eight 5-ton PVC experiment tanks including 44 larvae per tank. The eight tanks were exposed to different wavelengths of light (two tanks of the same wavelength) and were separated by light-proof curtains.

The water quality parameters mean dissolved oxygen, average water temperature, and mean water pH were measured as 6.3 ± 1.6 mg/L, 15.5 ± 0.5 °C, and 8.1 ± 0.7, respectively. The highest average water temperature was 17.15 °C during August and the lowest was 13.68 °C in November. Among the environmental parameters, the average flow rate of the tank influent was constant at 17 ± 0.2 L/s, while the intensity of the light received by the tanks was also constant at 50 ± 3 lx.

For each group, three different types of LED light boxes (MGN Lighting, Bali, Indonesia) were fixed above the aquaria. The properties of light wavelengths were set up as presented in Table 1. The tank influent flow rate was set at 1 L/11 s. All tanks contained equal water volume and were equipped with two air stones each. Animals were fed on a commercial feed produced by Inve and were used in the study. A 1.6-mm feed was used during the adaptation stage. The experiment stage was started with 2.0-mm feed. Then, based on measurement findings, feed size was first increased to 3.0 mm and later on to 4.0 mm. Feeding was manual and ad libitum. The water temperature and dissolved oxygen in the tanks were measured with a digital oxygen meter (YSI Pro 20). A mobile pH meter (Thermo) was used for pH measurement. The experiment lasted 3 months.

The tests concerning the effects of light on trout larvae were conducted at Van Yüzüncü Yıl University (YYU) Research and Application Farm Hatchery, and enzyme activity measurements to determine oxidative stress were conducted in Atatürk University, Faculty of Sciences, and Department of Chemistry Biochemical Research Laboratory. All chemicals were procured from Sigma Chem. Co.

Tissue collection and sampling treatment

At the end of the experimental period, three fish were sampled from each tank. Six fish per experimental condition were used for analysis. The fish were anesthetized by using MS-222.

The liver, gill, and brain tissues were lacerated separately with liquid nitrogen and the samples were homogenized in 50 mM Tris/HCl (pH 7.5) containing 1 mM DTT, 1 mM EDTA, and 1 mM PMSF and to remove the cellular residue, they were centrifuged at 13,000 rpm, at + 4 °C for 30 min. The supernatant of samples was used immediately for activity measurements (Güller et al. 2014).

Antioxidant enzymes assays

Activity measurements of antioxidant enzymes were given as below.

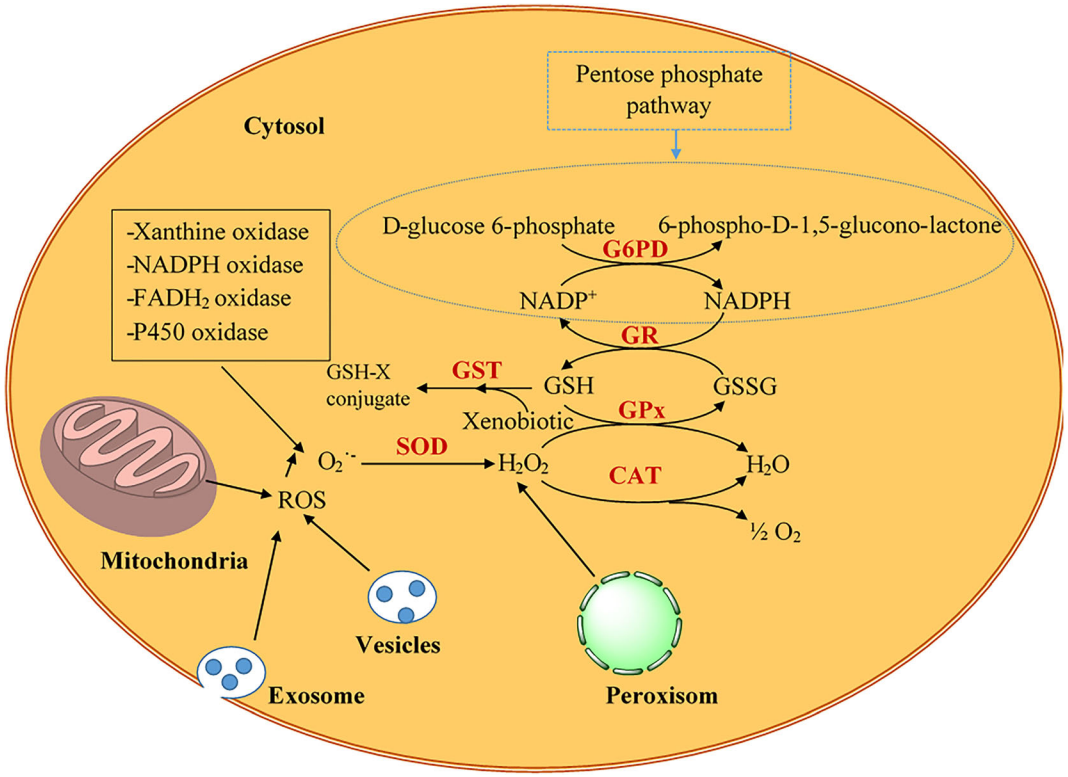

Fig. 1 Cellular ROS (reactive oxygen species) generation and the cooperation of main antioxidant enzymes

The total SOD activity was assayed via xanthine oxidase (XO) activity according to Sun et al. (1988). The assay is based on the transformation of xanthine to uric acid in the catalyst of XO, associated with the formation of superoxide radical (Chung et al. 1997). Then superoxide radical reacts with 4-nitroblue tetrazolium (NBT) in the reaction mixture and formazan occurs, when SOD added in reaction medium formation of formazan is inhibited. The absorbance of formazan was measured at 560 nm for each sample. One enzyme unit of SOD is defined as the amount of enzyme causing 50% inhibition of the reduction of NBT.

The CAT activity was determined according to the method put by Aebi (1984). The method is based on the determination of the decomposition of H_2O_2 to H_2O and O_2. The absorbance reduction of the depleted H_2O_2 was measured at 240 nm.

The total GPx activity was measured via GR activity according to Wendel (1980). The mechanism involves oxidation of GSH by hydrogen peroxide. GSH is produced from GSSG in the presence of NADPH and this reaction is catalyzed by GR. One enzyme unit determines the amount of enzyme that catalyzes the oxidation of 1 μmol NADPH per minute. The decreasing NADPH at 340 nm is monitored.

Table 1 Light characteristics and color temperature of the groups used in the experiment

Group	Wavelength (nm)	Color Temperature (Kelvin, k°)	Lux
Control group 1 (sunlight, N)	–	4230	50
Long wavelength (red light, R)*	570–620	< 2300	50
Medium wavelength (green light, G)*	495–570	< 2300	50
Short wavelength (blue light, B)*	450–495	> 10,000	50

*Mgn, LED brand used

GR activity was assayed according to Carlberg and Mannervik (1975) modified by Taser and Ciftci (2012). The method is based on following the oxidation of NADPH associated with the reduction of GSSG to GSH. The decreased absorbance was monitored at 340 nm.

The enzyme activity of G6PD was performed by following Beutler's (1984) method. G6PD converts D-glucose 6-phosphate (G6P) into 6-phospho-D-glucono-1,5-lactone and in this reaction, $NADP^+$ is reduced to NADPH. The increased absorbance was monitored at 340 nm.

GST activity was determined according to Habig et al. (1974) at 340 nm. The method is based on a decreasing absorbance of dinitrobenzene S-glutathione (DNB-SG), formed by conjugation of glutathione and 1-chloro-2,4-dinitrobenzene in the GST-catalyzed reaction.

Acetylcholinesterase activity assay

Acetylcholinesterase (AChE) activity was assayed at 436 nm with a spectrophotometer according to Worek et al. (1999), a modified method of the Ellman procedure.

Quantitative protein assay

For determination of the specific activity of enzymes, quantitative protein analysis in homogenates was assayed at 595 nanometer by using 1 mg/ml of bovine serum albumin standard, based on the methodology determined by Bradford (1976).

All the enzymatic assays were carried on at room temperature and measured for three biological replications. Except for SOD that was previously explained, a unit of the activity was defined as the amount of enzyme causing 50% inhibition of reduction of NBT per minute. For all enzymes, absorbance was assayed in a spectrophotometer (The Beckman Coulter DU 730 UV/Vis Spectrophotometer).

Statistical analysis

The statistical analyses of the in vivo inhibition studies were performed using GraphPad Prism 6 (GraphPad, La Jolla, CA) Software 7.0 and *t* test to compare each experimental group with the control. Statistical results are given with mean standard error (SEM) deviations ($n = 9$ per group). Significant changes in activities are marked by an asterisk, whereby $p < 0.05 = *$ is significant, $p < 0.01 = **$ is very significant, $p < 0.001 = ***$ and **** are highly significant.

Results

Regarding the antioxidant enzymes, Fig. 2 shows that in the liver of rainbow trout exposed with blue and green light, activities of all enzymes increased very significantly ($p < 0.001$) except the CAT under green light. But under red light, activities of CAT, GPX, GR, G6PD, and GST significantly decreased ($p < 0.01$) apart from SOD activity. Exposure to green light caused a statistically highly significant increase in the activities of G6PD and GST.

As indicated in Fig. 3, activities of all related antioxidant enzymes significantly increased in the gill tissues of the fish in all groups when compared with those in the control group ($p < 0.05$). In fish exposed to red and blue light, SOD, G6PD, and GST activities rose highly significantly ($p < 0.0001$) in this tissue.

In the brain of rainbow trout growth under red light, while G6PD (significantly), GPx, and GST activities decreased (highly significant), SOD (highly significant) and GR (significantly) activities increased. In the group that grows under blue light, activities of enzymes decreased except CAT and GR. Under green light, while G6PD, GR, GPx, and GST activities significantly reduced, the activities of CAT and SOD did not show any changes (Fig. 4). At all light wavelengths, GST activities were highly decreased ($p < 0.0001$).

Besides, alteration in AChE activities was controlled in the liver, gill, and brain tissues of rainbow trout under red, blue, and green lights. As illustrated in Fig. 5, in the brain tissue, there were no significant changes in all groups, but its activity was increased in all light wavelength groups in the gill tissue. While AChE activity was decreased in the liver of trout under red light, it increased in the blue and green light groups.

It was monitored that GR activities were higher in gill compared with those in the brain and liver. While CAT activities were higher in the liver, SOD activities were high in the brain. Activities of G6PD, GPx, and GST showed similar values in all tissues.

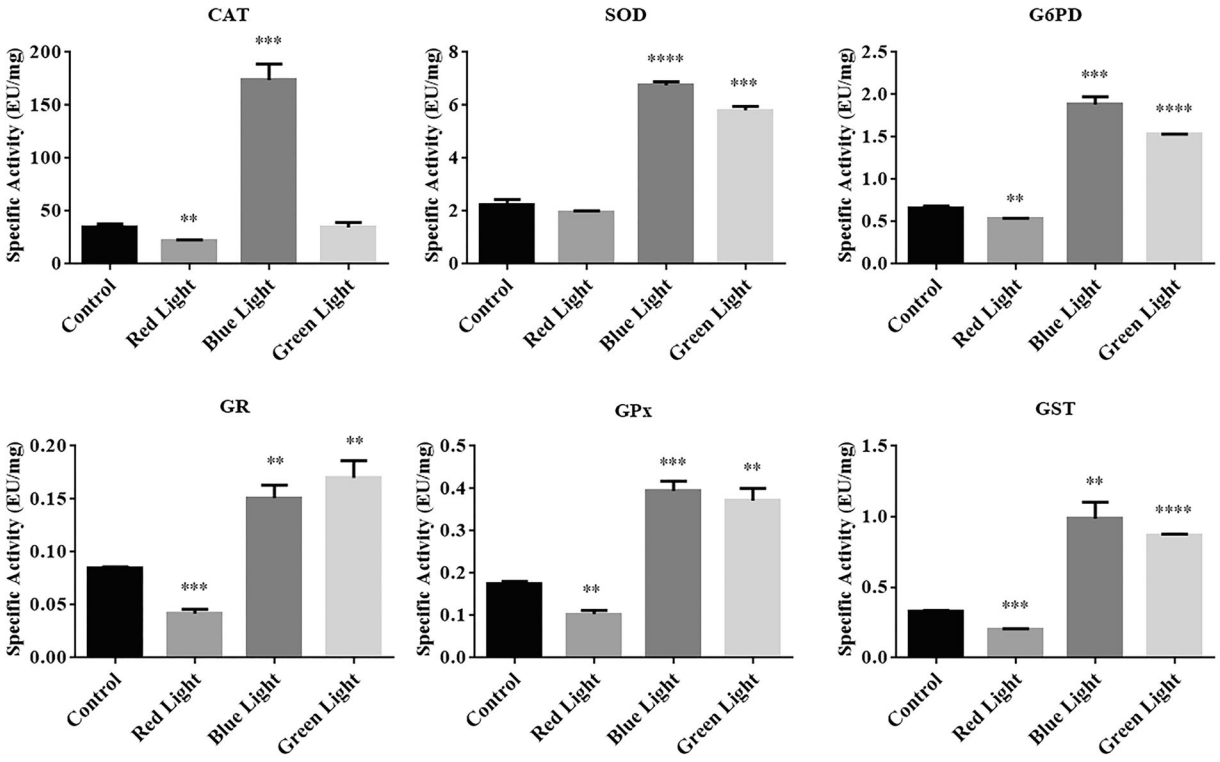

Fig. 2 Antioxidant enzyme activities in the liver of rainbow trout grown under red, blue, and green light. The mean ± standard error (SEM) values were analyzed for all the results. The values expressed by an asterisk represent significance values obtained from statistical analysis ($p < 0.05$ = * is significant, $p < 0.01$ = ** is very significant, $p < 0.001$ = *** and **** are highly significant)

Discussion

Trout farming for domestic consumption has become the most widespread aquaculture industry in the last few years. The freshness of fish meat and its biochemical composition, such as protein and fat, play an important role in consumer demand and also studies confirm that the consumer associates the color of fish meat with taste, quality, and freshness (Anderson 2000; Gormley 1992; Yağız et al. 2008).

In previous studies, it has been shown that stressors in fish can induce ROS production and disrupt antioxidant balance (Braun et al. 2010; Halliwell and Gutteridge 1989). Increased production of ROS, caused by adverse environmental factors, may lead to lipid peroxidation, protein oxidation, and even DNA damage (Halliwell and Aruoma 1991; Kucukbay et al. 2009). The most important form of lipid oxidation in meat is free radical oxidation, called autoxidation, and causes odor production, the formation of toxic compounds, and loss of functional properties and nutritional value and changes the color of the meat (Soladoye et al. 2015). The fluent coordination of antioxidant enzymes, CAT, SOD, G6PD, GR, GPx, and GST, joined to antioxidant molecules, is extremely important to prevent possible damage of ROS to the cell.

Up to now, the effects of light on the physiology of many vertebrates from reptiles to fish have been studied (Choi et al. 2016; Reguera et al. 2014). In fishes, previous studies have shown that some parameters such as different crowding, handling, flow velocity, water temperature, dissolved oxygen, photoperiod, and LED light spectra affected activities of antioxidant enzymes on various species (Braun et al. 2010; Choi et al. 2019; Kim et al. 2019; Li et al. 2019; North et al. 2006; Qiang et al. 2019; Sahin et al. 2014; Trenzado et al. 2006, 2008; Wei et al. 2019).

Recent studies have investigated the effects of light on the living body and have shown that certain light wavelengths can affect various physiological responses in fish. It has been shown that the red wavelength from LEDs can cause oxidative stress and negatively affect the physiological functions of fish; short wavelengths such as green light can effectively reduce oxidative

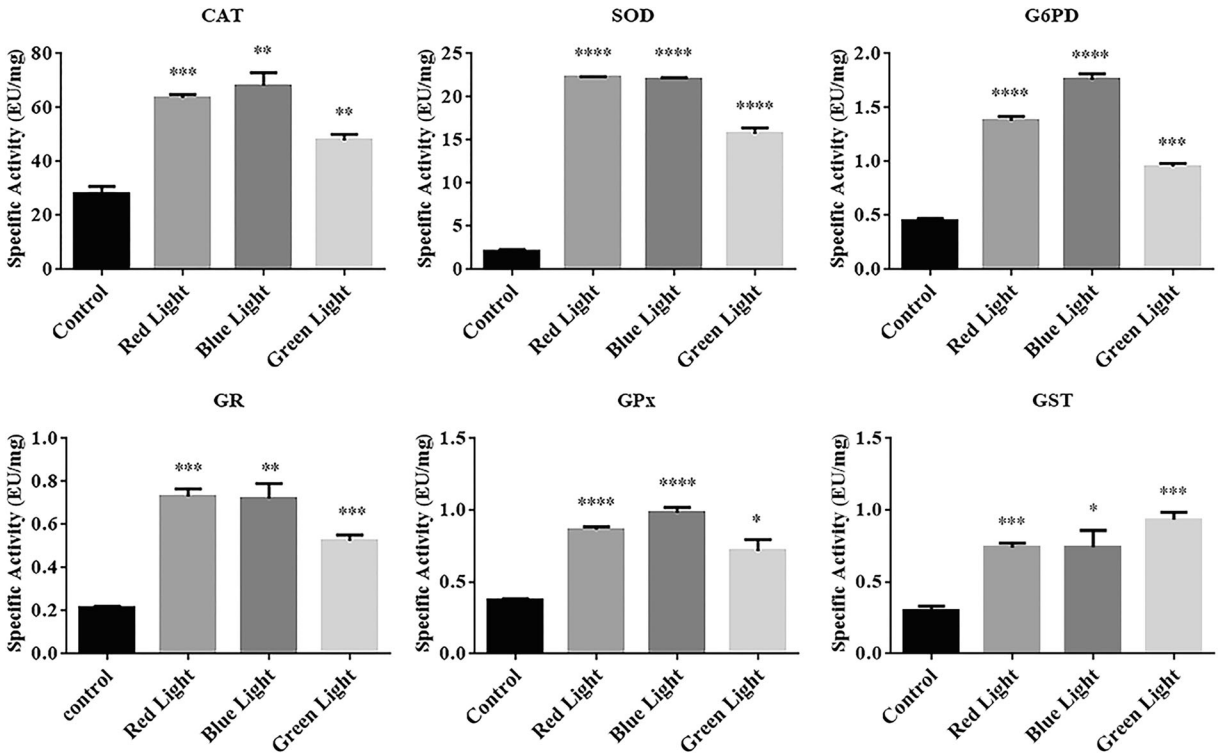

Fig. 3 Antioxidant enzyme activities in the gill of rainbow trout grown under red, blue, and green light. The mean ± standard error (SEM) values were analyzed for all the results. The values expressed by an asterisk represent significance values obtained from statistical analysis ($p < 0.05$ = * is significant, $p < 0.01$ = ** is very significant, $p < 0.001$ = *** and **** are highly significant)

stress and increase immunity (Choi et al. 2012; Choi et al. 2016; Shin et al. 2011; Villamizar et al. 2009). In the liver of juvenile gibel carps (*Carassius auratus*), under increased time to light exposure from 0 to 24 h, it was observed that SOD, GPx, and GST activities decreased while CAT and GR activities increased (Wei et al. 2019). Previous research also reported that low wavelength light alleviates stress in olive flounder (*Paralichthys olivaceus*) during starvation (Choi et al. 2019). Other authors manifested that for the development of the normal fish farm, the minimum light intensity is required, whenever not reached a level of intensity that causes stress (Boeuf and Le Bail 1999).

This paper focused on whether the growth under different light wavelengths causes oxidative stress in the rainbow trout and how these conditions affect the activities of antioxidant enzymes and AChE in the liver, gill, and brain tissues. In our earlier study, the effects of different wavelength farming on the growth of rainbow trout were investigated and statistically, it was observed that the mean body weights and lengths of the fish in the groups at the end of 96 days had not been affected by the light wavelengths (Timucin et al. 2016).

The liver plays an important role in the metabolism of sugars, lipids, steroids, and xenobiotics, many of which are highly toxic, mutagenic, and/or carcinogenic. Detoxification of oxygen by-products includes superoxide and H_2O_2 that are produced by autoxidation of small molecules in hepatocytes or by the redox cycle of xenobiotics (Kehrer and Smith 1994). Antioxidant enzymes protect cells from oxidative stress. It is well known that the liver is the primary tissue of GSH synthesis (Shi et al. 1996); therefore, it has a better antioxidant defense compared with the other tissues. In the current study, the activities of CAT and SOD were increased sharply in the liver of trout grown under blue light and while SOD activity was not affected, CAT activity was decreased. Similar results were found by Yuan et al. (2017) with zebrafish *Danio rerio* growth under blue and red light-emitting diodes. They found in zebrafish liver that the enzymatic activities of Cu/Zn-SOD and CAT were significantly increased by light-emitting diodes (blue LEDs, LDB), while SOD activity was unchanged and

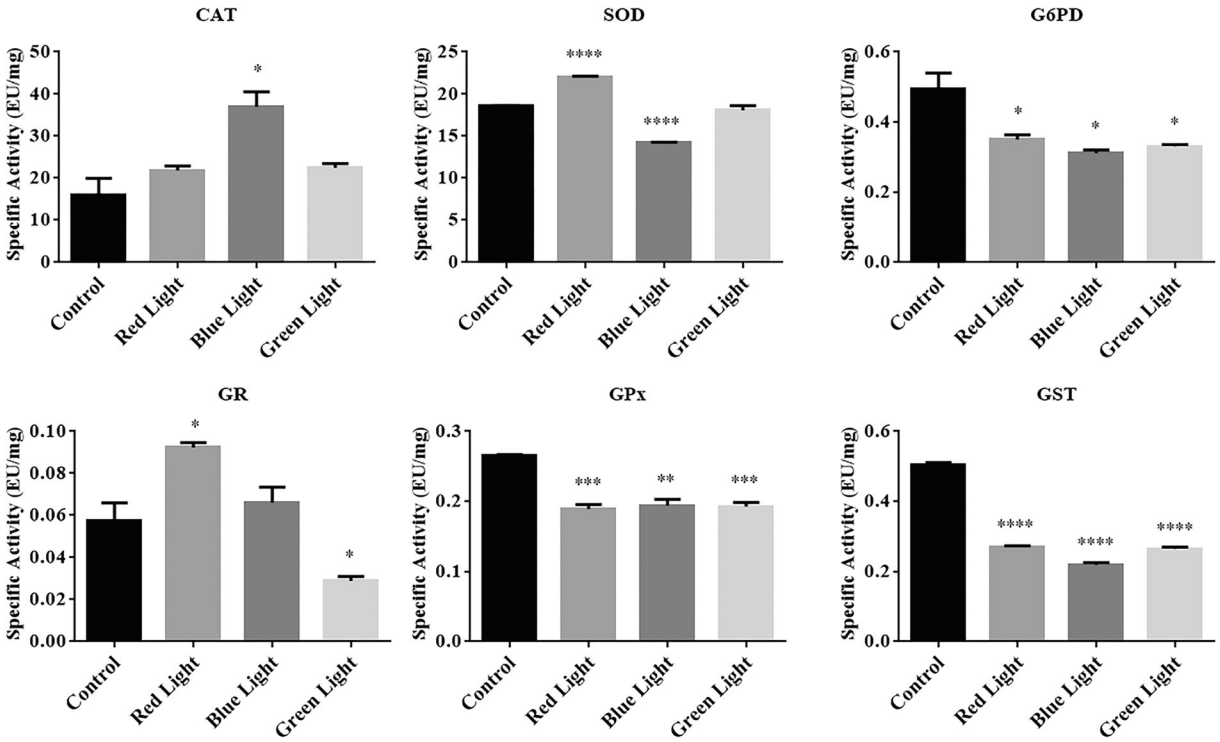

Fig. 4 Antioxidant enzyme activities in the brain of rainbow trout grown under red, blue, and green light. The mean ± standard error (SEM) values were analyzed for all the results. The values expressed by an asterisk represent significance values obtained from statistical analysis ($p < 0.05$ = * is significant, $p < 0.01$ = ** is very significant, $p < 0.001$ = *** and **** are highly significant)

activity of CAT was decreased (but not significantly) by light-emitting diodes (blue LEDs, LDR).

The activities of antioxidant enzymes in the gill tissues increased significantly at all light wavelengths. Gills are the multifunctional organs that perform vital functions such as respiration, osmoregulation, and acid-base balance. Because of their role in respiration, gills are especially prone to the production of oxygen radicals since there is a significant exchange of oxygen. In gill tissues, stress raises blood pressure and permeability of the epithelium by increasing the secretion of adrenaline and this causes ionic losses in freshwater fish. Besides, hydroxyl radicals cause disruptions in ion transport mechanisms by attacking unsaturated lipids in the gill cell's membrane (Braun et al. 2010; Cech et al. 1996; Postlethwaite and Mcdonald 1995; Sundin 1999). On this basis, these high

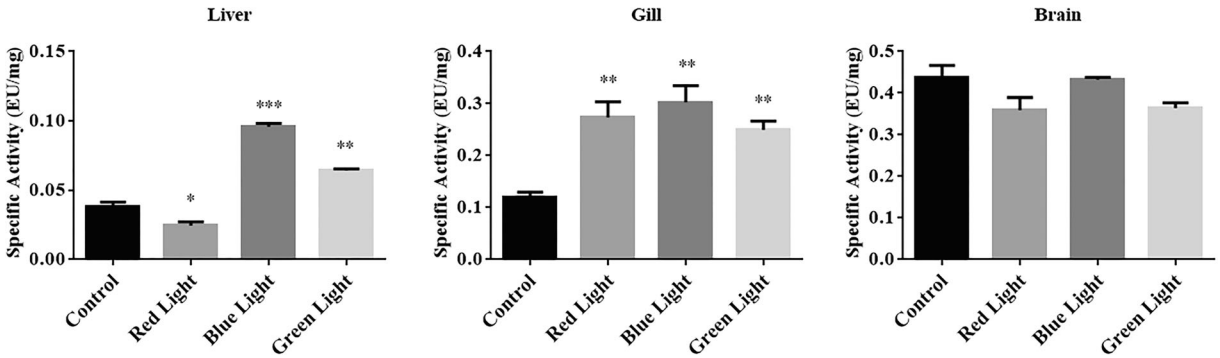

Fig. 5 AChE activities in the liver, gill, and brain of rainbow trout grown under red, blue, and green light. The mean ± standard error (SEM) values were analyzed for all the results. The values expressed by an asterisk represent significance values obtained from statistical analysis ($p < 0.05$ = * is significant, $p < 0.01$ = ** is very significant, $p < 0.001$ = *** and **** are highly significant)

activities in gill can be a physiological response of the fish against the oxidative stress produced as a result of growth under light sources with different spectral structures (Parvez and Raisuddin 2005).

Since the brain contains a high level of unsaturated fatty acids and consumes high amounts of oxygen per unit weight, it is an important organ where the effect of oxidative damage can be examined (Afifi et al. 2010; Afifi et al. 2016; Karageorgos et al. 2006). In the literature, there was not found a study examining the changes in the activities of antioxidant enzymes in the brain tissues of fish grown under varying light spectra. In a study performed by Jung et al. (2016) after investigating the stress parameter in brain tissues, it was reported that green wavelength LED light in goldfish (*Carassius auratus*) reduced the effects of stress caused by high water temperature. In the brain tissues, contrary to the findings of Matkovics et al. (1977), who reported that CAT activity shows a certain parallelism with SOD activity, CAT activity changed only under blue light (short wavelength) and SOD activity increased under long wavelength (red light) and decreased under short wavelength (blue light) (see Fig. 4). SOD and CAT act together in the deactivation of $O_2^{\cdot-}$ and H_2O_2. As for the activities of glutathione system–related antioxidant enzymes, G6PD, GPx, and GST were repressed in the brain of fish growth light sources with different spectral structures but GR activity did not change under blue light while its activity increased under red light and decreased under green light. GPx, GR, and GST enzymes are involved in regulating the GSH/GSSG ratio, a marker of intracellular redox status. GR catalyzes the recovery of GSH from GSSG in an NADPH-dependent way and NADPH is produced in a reaction catalyzed by G6PD in the pentose phosphate pathway, while GST acts conjugation of xenobiotics with GSH. GPx catalyzes the conversion of H_2O_2 to H_2O by using GSH. The resulting GSSG is again converted into GSH using GR, thereby maintaining the GSH/GSSG ratio (Budak et al. 2014; Duthie et al. 1989; Franco et al. 2019). Besides, when compared with liver and brain tissues, significantly increased antioxidant activities in gill show that this organ is particularly prone to ROS production associated with its oxygen exchange function.

Kumar et al. (2017) studied the effects of different spectral bands of visible light and natural sunlight on *Lymnaea acuminata*. They found that maximum change in AChE activity in the nervous tissue of *L. acuminata* was observed when exposed to red monochromatic light (314% of control) than blue light (296% of control) and yellow (294% of control). As mentioned before, the inhibition of AChE activity in fish can be dangerous. On the other hand, there are no data related to the effects of light wavelength on AChE in fish; our work is the first in this respect. In the current study, the effects of light sources with different spectral structures on AChE activities in the liver, gill, and brain tissues were examined. AChE activities did not change in the brain tissue. In agreement with previous results in old and aged rats' plasma and brain (Haider et al. 2014), changes in AChE activity were generally in parallel with the changes in the activities of antioxidant enzymes in the liver and gill tissues of the fish growth under different light wavelengths.

Conclusion

On the basis of this study results, growing under light sources with different light wavelengths caused statistically significant changes in the activities of antioxidant enzymes and AChE activities in the liver, brain, and gill, except for AChE in the brain tissue. Moving on, it may be thought a cell response to changing redox status. Nevertheless, when the growth parameters of a previous study (Timucin et al. 2016) and the changes in the activity of the antioxidant enzymes and AChE assayed in this study are evaluated together, blue and green light, primarily blue light, can be used to improve rainbow trout culture. We think that our work can benefit fish farming by changing only physical culturing conditions, that is, to provide fish welfare without the need to add any additives to feeds or water.

Authors' contribution Conceived and designed the experiments: UG and ŞÖ. Performed the experiments: UG, ŞÖ, MA, and BK. Analyzed the data: UG, ÖİK, and MY. Contributed reagents/materials/analysis tools: ÖİK and MY. Wrote the paper: UG and ŞÖ. All authors read and approved the final manuscript.

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Compliance with ethical standards

Ethics statement The study was carried out following ethical approval by the University of Van YYU, Van, Turkey. All animal care and procedures were in accordance with the ethical principles of animal use and care.

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

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