al., 1995), and genetics (Volpe & Penn, 1957; Wolfe and Cornwell, 1964; Dowell and Winier, 1969; Black, 1975; Black & Huner, 1980; Latscha, 1989; Thacker et al., 1993; Walker et al., 2000; Aksu et al., 2012; Kale et al., 2020). One of the first investigations on the coloration of crayfish was published by Kent (1901). The author claimed that key factors are environment and the sun in the coloration of crayfish. Dowel & Winier (1969) documented a bilateral color anomaly in the crayfish (*Orconectes immunis*) captured from a stream in Iowa, USA. The authors concluded that the specimen represented a case of mosaicism conveyed on by somatic separation of which one of a number of chromosomal or genie anomalies may be the responsible factor. The most acceptable reason was noted by the authors as a somatic mutation in very early cleavage. Thacker et al. (1993) put forward that genetic variation among crayfish populations, environmental conditions, and interaction between both environment and genetics are common reasons in the coloration of crayfish. Truong et al. (2002) compared a blue strain of *Cherax destructor albidus* with two normal-colored strains of *Cherax destructor destructor* and *Cherax destructor albidus* in terms of brood size and juvenile weight. The authors found that the reproductive performance and juvenile weight of the blue strain were significantly lesser than the two normal-colored strains. In addition, the authors indicated that the differences in phenotypes between the blue strain and normal-colored strains are most likely genetic. Aksu et al. (2012) claimed that the genetic structure of the species, food composition, and chemical characteristics of water resources have an impact on the color of crayfish.

Figure 3. Comparison of normal crayfish and the blue colored crayfish from Atikhisar Reservoir, Çanakkale, Turkey (both individuals are female)

Kale et al. (2020) reported the presence of albinism in crayfish (*P. leptodactylus*) collected from Atikhisar Reservoir in Çanakkale, Turkey, the same location with the present paper, and the authors noted that albinism is a syndrome that occurs in the lack of melanin. In addition, the authors clearly indicated that there were no further reason as causative agents in the sampling location. As previously noted by Kale et al. (2020), there was no fishing pressure or overexploitation probability of fisheries resources in the reservoir. Then again, any pollution was not observed in the lake surface water of the reservoir during the sampling period. Thus, blue color anomaly is probably occurred due to the genetic mechanism of the specimen and environmental factors are less likely factors that affecting the anomaly for the reported specimens in the present paper. Environmental factors were observed in normal conditions and any extreme weather condition was not recorded during the sampling period.

Schuster (2020) noted that color visualization could be a key factor in interspecific and intraspecific competition, sexual choice, communication, territoriality and camouflage. Hence, this may lead to pressure over the populations in the reservoir. Therefore, a further investigation should be carried out to better understand the main reason causing color anomaly in crayfish in the reservoir.

Colors in crayfishes and other crustaceans are known as the consequence of carotenoid pigments (such as astaxanthin and canthaxanthin) (Fox, 1953; Goodwing, 1960; Buchwald & Jencks, 1968; Latscha, 1989; Ando & Tanaka, 1996; Walker et al., 2000; Patoka et al., 2013; Schuster, 2020). The most common carotenoid is astaxanthin in crustaceans (Latscha, 1989). These pigments can also be found in the integument in addition to the exoskeleton (Schuster, 2020). Patoka et al. (2013) indicated that these pigments forms the color of carapaces and the color changes according to the concentration of each pigment. On the other hand, Buchwald and Jencks (1968) reported that the blue color anomaly in carapace of lobsters was caused by crustacyanin. Momot & Gall (1971) claimed that observed color anomalies in crayfishes could be attributed to genetics and/or diet. Black (1975) noted that the blue color anomaly of *Procambarus acutus acutus* was caused by carotenoid pigments (probably crustacyanin) deposited in the exoskeleton. The author also indicated that the blue color anomaly was still observed in the exoskeleton after molting. Latscha (1989) suggested that pigmentation in crustaceans could also be due to the complex of carotenoid-protein known as carotenoproteins. The author attributed the color anomaly in *Penaeus* shrimp to a dietary carotenoid deficiency such as astaxanthin. Latscha (1989) documented that blue colored shrimp species mutated back to their normal color when they were fed diets with astaxanthin. As noted by Schuster (2020), all these papers highlighted that a single autosomal recessive gene was the main reason of the observed color anomalies in animals. Therefore, further investigations are required to determine the underlying reason of the color anomaly in the crayfish.

CONCLUSION

The present paper significantly contributes to the scientific literature by providing the first information on the occurrence of blue color anomaly in crayfish (*P. leptodactylus*) in the Atikhisar Reservoir, Çanakkale, Turkey.

ACKNOWLEDGEMENTS

This paper is a part of a research project financially supported by Çanakkale Onsekiz Mart University the Scientific Research Coordination Unit granted to Dr. Selçuk Berber (Project number: FBA-2020-3250). Lab experiments were carried out in the laboratory of Biochemistry; and laboratory of Feed and Food Analysis, Faculty of Marine Sciences and Technology, Çanakkale Onsekiz Mart University. An earlier version of the paper was presented at International Conference on Engineering Technologies (ICENTE'20) in Konya, Turkey.

Compliance with Ethical Standards

Authors' Contributions

SB and SK designed the study. SK, SB, DA, TD conducted sampling in the field. SK wrote the first draft of the manuscript. SA, PV, BK helped in the laboratory. All authors have read and revised the manuscript. All authors approved the final version of the paper.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

REFERENCES

Aksu, Ö., Harlıoğlu, A., Kutluyer, F., & Kocabaş, M. (2012). Blue color anomaly in *Astacus leptodactylus* caught from Ardahan region of Çıldır Lake. *Proceedings of the 3rd International Symposium on Sustainable Development*. Sarajevo, Bosnia and Herzegovina, pp. 293.

Ando, S., & Tanaka, Y. (1996). Carotenoid forms in the exoskeleton of crayfish and kuruma prawn. *Memoirs of the Faculty of Fisheries Kagoshima University*, *45*, 5-12.

Black, J. B. (1975). Inheritance of the blue colour mutation in the crawfish *Procambrus acutus acutus* (Girard). *Proceedings of the Louisiana Academy of Science*, *38*, 25-27.

Black, J. B., & Huner, J. V. (1980). Genetics of the red swamp crawfish, *Procambrus clarkii* (Girard): state of the art. *Proceedings of the Annual Meeting of World Mariculture Society*, *11*, 535-543.

Buchwald, M., & Jencks, W. P. (1968) Optical properties of astaxanthin solutions and aggregates. *Biochemistry*, *7*(2), 834-843. https://doi.org/10.1021/bi00842a042

Dowel, W. E., & Winier, L. P. (1969). A bilateral color anomaly in the crayfish, *Orconectes immunis* (Hagen). *Proceedings of the Iowa Academy of Science*, *76*(1), 487-492.

Fox, D. L. (1953). *Animal biochromes and structural colours*. Cambridge University Press, London and New York, 379 pp.

Goodwin, T. W. (1960). Biochemistry of pigments. In T. H. Waterman (Ed.), *The physiology of Crustacea* (pp. 101-140). Academic Press.

Hayes, W. A. II., & Reimer, R. D. (1975). Blue color anomaly in an Oklahoma crayfish (Decapoda: Cambaridae). *Proceedings of the Oklahoma Academy of Science*, *55*, 51.

Kaldre, K., Haugjärv, K., Liiva, M., & Gross, R. (2015). The effect of two different feeds on growth, carapace, colour, maturation and mortality in marbled crayfish (*Procambarus fallax* f. *virginalis*). *Aquaculture International*, *23*: 185-194. https://doi.org/10.1007/s10499-014-9807-1

Kale, S. (2019). *Monitoring climate change effects on surface area and shoreline changes in Atikhisar Reservoir by using remote sensing and geographic information system in terms of fisheries management* [Ph.D. Thesis, Çanakkale Onsekiz Mart University].

Kale, S., & Acarlı, D. (2019a). Spatial and temporal change monitoring in water surface area of Atikhisar Reservoir (Çanakkale, Turkey) by using remote sensing and geographic information system techniques. *Alınteri Journal of Agriculture Sciences*, *34*(1), 47-56. https://doi.org/10.28955/alinterizbd.574361

Kale, S., & Acarli, D. (2019b). Shoreline change monitoring in Atikhisar Reservoir by using remote sensing and geographic information system (GIS). *Fresenius Environmental Bulletin*, *28*(5), 4329-4339.

Kale, S., Berber, S., Acarlı, D., Demirkıran, T., Vural, P., Acarlı, S., Kızılkaya, B., & Tan, E. (2020). First report of albinism in Turkish crayfish *Pontastacus leptodactylus* (Eschscholtz, 1823) (Crustacea, Decapoda, Astacidae). *Acta Natura et Scientia*, *1*(1), 36-42. https://doi.org/10.29329/actanatsci.2020.313.5

Kent, W. J. (1901). The colors of the crayfish. *American Naturalist*, *35*, 933-936. https://doi.org/10.1086/278030

Latscha, T. (1989). The role of astaxanthin in shrimp pigmentation. *Advances in Tropical Aquaculture*, *9*, 319-325.

Momot, W. T., & Gall, J. E. (1971). Some ecological notes on the blue color phase of the crayfish *Orconectes virilis*, in two lakes. *The Ohio Journal of Science*, *71*, 363-370.

Patoka, J., Římalová-Kadlecová, K., Bílý, M., & Koščo, J. (2013). Frequency of new marble-colored morph in wild population of *Austropotamobius torrentium* (Decapoda: Astacidae). *Biologia*, *68*, 707-711. https://doi.org/10.2478/s11756-013-0208-0

Schuster, G. A. (2020). Review of crayfish color patterns in the Family Cambaridae (Astacoidea), with discussion of their possible importance. *Zootaxa*, *4755*(1), 63-98. https://doi.org/10.11646/zootaxa.4755.1.3

Thacker, R. W., Hazlett, B. A., Esman, L. A., Stafford, C. P. & Keller, T. A. (1993). Color morphs of the crayfish *Orconectes virilis*. *American Midland Naturalist*, *129*, 182-199. https://doi.org/10.2307/2426447

Timmermans, T., Sistler, F. E., & Lawson, T. B. (1995). Predicting crawfish molting with machine vision. *Journal of the World Aquaculture Society*, *26*(3), 234-239. https://doi.org/10.1111/j.1749-7345.1995.tb00251.x

Truong, K. Meewan, M., & Austin, C. M. (2002). Comparison of brood size and juvenile weight between a blue strain and normal-coloured strains of the Australian freshwater crayfish *Cherax destructor* Clark (Decapoda: Parastacidae). *Journal of Crustacean Biology*, *22*(3), 538-542.

Volpe, E. P., & Penn, G. H. (1957). Dimorphism of chromatophore patterns in the dwarf crawfish. *Journal of Heredity*, *48*(3), 91-96. https://doi.org/10.1093/oxfordjournals.jhered.a106704

Walker, M. L., Austin, C. M., & Meewan, M. (2000). Evidence for the inheritance of a blue variant of the Australian freshwater crayfish, *Cherax destructor* Clark (Decapoda: Parastacidae), as an autosomal recessive. *Journal of Crustacean Biology*, *20*, 25-30.

Wolfe, D. A., & Cornwell, D. G. (1964). Carotenoids of cavernicolous crayfish. *Science*, *144*, 1467-1469. https://doi.org/10.1126/science.144.3625.1467