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Impact of *Pomphorhynchus spindletruncatus* (Acanthocephala: Pomphorhynchidae) on Blood Parameters and Muscle Biochemical Constituents of some Freshwater Fishes from Lesser Zab River, Iraq

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ABSTRACT

Fish have a strong resistance to disease when the circumstances are favourable, they are still susceptible to pathogen infection. Fish are routinely put to death by these illnesses, which impede their growth and reproduction. Diseases can reduce feeding rates, rendering fish more vulnerable to other animals. *Pomphorhynchus spindletruncatus* is one of the most dangerous parasitic species to fish. Prevalence of the acanthocephalan *P. spindletruncatus* and its influence on fish blood parameters and muscle chemical composition were evaluated. The study was carried out on seven species of freshwater fishes collected from Lesser Zab River, Iraq. The results showed that *P. spindletruncatus* was recovered from *Capoeta damascina, Capoeta umbla, Capoeta trutta, Chondrostoma regium, Cyprinus carpio, Leuciscus vorax, and Squalius Lepidus*. Higher prevalence of infection with the parasite was observed in the order of *L. vorax* (90 %) > *S. Lepidus* (72.72 %) > *C. damascina* (70 %). Analysis of blood parameters revealed that the infected fishes showed a significant decrease in total blood protein level, except in *C. damascina, C. trutta* and *S. lepidus*. However, there was a reduction in the levels of cholesterol and glucose in the blood of all infected fishes. The analysis of muscle chemical compositions showed that the parasite induced a decline in protein and ash contents, while moisture content was increased in all the infected fishes. However, fat content varied between the infected and uninfected fish muscles. As a result, we may conclude that *P. spindletruncatus* has the potential to harm edible fish species' health.

Keywords: Acanthocephala, Chemical composition, Haematological parameters, Muscle, *Pomphorhynchus spindletruncatus*

Introduction

In spite of the high resistance of fish against diseases when environmental and living conditions are favourable, yet they are also at risk of infection by pathogens. These diseases are often a threat to fish survival and diminish growth and reproduction. Also, diseases reduce feeding rates which increase fish predation rates by other animals.[1] Parasites are associated with their host in a complex dynamic equilibrium relationship and since fish are at the top of the predator-prey pyramid in freshwater, therefore many fish are susceptible to parasite attack.[2]

Parasites are organisms that attach themselves to the outside of their hosts or live internally in their host bodies. The parasites become harmful when they are in high number, thereby resulting in damage in infected fishes.[3] this can be frequently linked to variations in parasite density and community composition. Most often, the associated damage in infected fish is relative to the level of infestation with the parasite. The parasite feeds on the body tissues and fluids of the fish to the extent of causing mechanical damage.[4] Fishes in nature are infected with a great variety of parasites, which include protozoans, monogeneans, trematodes, cestodes, nematodes, acanthocephalans and crustaceans.[5]

Acanthocephalans are small group of obligate endoparasites with 1,300 species reported to be found in the alimentary tract of various vertebrates worldwide. Moreover, this phylum was represented with three species of the genus *Neoechinorhynchus* and two species of the genus *Pomphorhynchus* in fishes of Kurdistan region, north of Iraq as listed in a checklist.[6]

Approximately one-half of these acanthocephalans are detected as adults in the intestine of fishes.[7] Species of the genus *Pomphorhynchus* are broadly distributed and mostly present in freshwater fishes; a few in marine fishes and one in an amphibian host.[8] Amin and his colleagues were the first to describe *P. spindletruncatus* in Iraq.[9] The two species of freshwater fishes, *Aspius vorax* (=*Leuciscusvorax*) and *Barbusxanthopterus* (= *Luciobarbus xanthopterus*) from the Lesser Zab River in northern Iraq.

Generally, haematological tests are used to evaluate normal physiological status such as age and sexual maturity. Also, they can be used to diagnose diseases caused by various factors such as environmental stress, parasitic infections, toxic effect of pollutants, and nutrition.[10,11] The parasites have a major effect in altering blood values of infected fishes.[12,13] Most often, parasites do not affect too much on the health status of their fish hosts. However, internal parasites, which can invade vital organs inside the digestive system, may affect their normal functioning. This is due to the deterioration of nutritional components, derived from both leakage of host tissues and dietary contents in the intestinal lumen of the host. Internal parasites can also exploit modifications in host growth and reproduction especially in massive infestation by the parasites. Such compounds may include fat, carbohydrates, immunoglobulin, proteins, and associated proteins.[14, 15]

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There are enormous reports available on the aspects of parasitic diseases of fishes in general and the nature of acanthocephalan fish parasitism in specific. However, reports related to the haemato-biochemical parameters and muscle chemical composition alternation due to parasitism is scanty. Therefore, the present study was aimed at investigating the prevalence of *P. spindletruncatus*in freshwater fishes obtained from Lesser Zab River in Iraq and also investigating its impact on both blood haemato-biochemical parameters and muscle chemical composition.

Materials and Methods

Source of fish specimens

A total of 118 fish specimens of fishes belonging to seven species were collected from Lesser Zab River, which passes through the Qatrata subrub-Taq, Taq area (35◦88´N; 44.59´E), 61.9 km north of Kirkuk governorate, Northern Iraq during the period from November 2017 to July 2018.

Specimen preparation

After fish capture, blood was taken immediately, using micro capillary tubes, from caudal vein of anaesthetised fishes. Then, they were delivered alive to the laboratory for parasite investigations. After blood sampling, each fish was inspected for parasites. Fish was dissected longitudinally and each internal viscera was removed according to AmLacher.[14] Acanthocephalan specimens were collected from the intestine of the fish samples, they were washed with saline solution and refrigerated in cold water for 12 hr until proboscides come out, after which they were fixed in 70% ethanol. The specimens were stained in Mayer's acid carmine and de-stained in 4% hydrochloric acid in 70% ethanol. Then, they were dehydrated in ascending concentrations of ethanol (70, 80, 90 % twice and 100%), cleared in 100% xylene and then in 50% Canada balsam. Each step of the dehydration was done for 24 hr. Finally, each specimen was mounted in Canada balsam.[16] Quantitative indices of parasite populations were calculated according to the formula described by Margolis. [17]

$$Percentage\ of\ Prevalence = \frac{total\ number\ of\ infected\ host}{total\ number\ of\ examined\ host} \times 100$$

$$Mean\ abundance = \frac{total\ number\ of\ individuals\ of\ a\ particular\ parasite}{total\ number\ of\ hosts\ examined}$$

Haematological and biochemical assays of fish samples

To investigate haematological parameters, blood samples were taken from the caudal vein of fish using a 5 mL plastic syringe. Immediately after blood collection, the samples were divided into two, of which the first part was delivered into EDTA tubes for haematological analysis.[18] the second part of the blood sample was collected into Z Serum sep clot activator tubes and centrifuged at 3000 rpm for 15 min to separate the serum. Then, the serum samples were stored at -20°C until required for analysis. Blood samples for haematological studies were preserved in EDTA-embedded bottles and the following parameters were determined: Erythrocytes count (RBC), leukocytes count (WBC), blood haemoglobin concentration (Hb), packed cell volume (PCV). RBC and WBC were counted using Neubauers haemocytometer by diluting the blood samples with Natt-Herrick solution and values were determined according to Natt and Herrick.[19] PCV was determined by using capillary tube and the blood samples were centrifuged for 15 min at 3000 rpm according to Archer.[20] The Hb values were determined according to Blaxhall and Daisley.[21] Biochemical parameters included total serum protein, glucose and cholesterol concentrations. Serum total protein level was determined by Biuret method using a total protein kit (BIOLABO.FR) with a spectrophotometer at wave length of 500 nm. In addition, serum cholesterol concentration was also determined using a kit obtained from BIOLABO, while glucose level was measured by using a kit from LINEAR Chemicals, SL, Spain.

Determination of chemical composition of fish muscles

Tissue samples were taken from the edible sections of muscle from each fish species for determination of chemical composition. Standard indicators of the chemical composition of total muscle (protein, lipid moisture, and ash) contents of infected and uninfected fishes were evaluated according to Horwitz and Latimer.[22] Percentage of crude protein content and the correlation between crude protein and nitrogen were determined as follows:

$$\%\ crude\ protein = Nitrogen \times 6.25$$

By employing Soxhlet system, total lipid content was estimated by extraction with diethyl ether according to the method described by Horwitz and Latimer.[22] Percentage ash content was determined by incineration in a muffle furnace at 550°C for 6 hours until ash was obtained; For determination of percentage moisture content, the samples were dried in an oven at 105°C for 24 hours to constant weight and the moisture content was calculated as follow:

$$Percentage\ of\ moisture = Weight\ lost/\ weight\ of\ sample \times 100$$

Statistical analysis

All data were expressed as mean ± standard error (M±SE). The experimental design Completely Randomized Design (CRD) and Duncan Multiple Range test was used to evaluate the statistical significance of differences among the group means. Statistical analysis was carried out using the SAS software (version 8.2). Differences between the means of different parameters were considered significant at $p<0.05$.

Results and Discussion

Prevalence and mean intensity of P. spindletruncatus infection in fish species

A total of 118 different fish specimens were collected from the Lesser Zab River passing through Qattara suburb, North of Iraq. According to Tan and Armbruster, [23] The fishes were classified in to seven species belonging to two families (Cyprinidae and Leuciscidae), the scientific names based on Winfield and Nelson recommendation.[24] they included *C. regium*, *C. damascina*, *C. umbla*, *C. trutta*, *C. carpio*, *L. vorax*, and *S. lepidus* were shown in Table 1. The worm was identified as *P. Spindletruncatus* based on the morphology and size of trunk, proboscis, neck, lemnisci, proboscis receptacle, and armature of proboscis.[9] *P. spindletruncatus* was found as adult parasites in the intestine of the studied fishes, the overall prevalence and mean intensity of *P. spindletruncatus* ranged from 38.8-90% for the prevalence and 5.71-45 for the intensity in the different fish species (Table 1). *P. spindletruncatus* was described as a new species in *A. vorax* (*L. vorax*) and *B. xanthopterus* (*Luciobarbusxanthopterus*) from Greater Zab and Lesser Zab Rivers, respectively [9]. Later, it was recorded in *Glyptothorax kurdistanicus*, *Silurus triostegus* and *S. lepidus*.[16] in this study, *P. Spindletruncatus* was recorded for the first time in *C. carpio*, *C. regium*, *Capoeta damasciinus*, *C. umbla*, and *C. trutta*, therefore, and these fish species represent new hosts for this parasite in Iraq.

Many specimens of *P. spindletruncatus* were obtained from intestine of the studied fishes and the prevalence of infection ranged from 38.9 to 90% in different fish species with the highest rate recorded in *L. vorax*. For the mean intensity, values observed extended from 5.7 to 45 with the highest level observed in the *C. umbla*. The difference in prevalence and intensity of infection between different fish species was due to the influence of many factors related to fish host and parasite, such as the host age and size, activity of fish host movement, health status, age, size, sex, and parasite size.[25] Correspondingly, seasonal and other environmental factors such as higher temperature of the surrounding environment and poor water quality in which the host lives might support development and proliferation of the parasite in the fish host population.[26] In addition, temperature has noticeable effect on fish feeding activity with more consumption intermediate hosts during hot weather. In the current study, the differences in the prevalence and mean intensity of *P. spindletruncatus* infection

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between different fish species may be due to the variation in water temperatures especially when the fishes were caught at different periods of the summer months from April to July (25-35°C). Moreover, the fish immune response can be affected by variation in water temperature; high temperature might be immunocompromised by reducing the body's ability to produce antibodies; therefore, becoming more susceptible to parasites infection.[27]

On the other hand, prevalence and intensity of *P. spindletruncatus* infection in common carp *C. carpio* were relatively low (38.8 and 5.71% respectively) compared to others. These variances could be due to the fact that the diet composition of common carp differs from that of other fish studied.[28]Although carp are well known by their resistance to diseases under good environmental conditions, this does not prevent them from parasitic infection but in a low level compared with other fish species. Contrarily, *L. vorax* showed high percentage infection (90%). The reason may be due to being carnivores, mainly feeding on small fishes, molluscs, insects and other aquatic invertebrates which they are considered as intermediate hosts to different parasites species.[29]

Effect of P. spindletruncatus infection on haematological parameters

As blood acts as a pathophysiological indicator of the whole body, the study of blood parameters of fish has an important role in diagnosing the bioactivity of infected fish and evaluating the physiological status and nutritional level of fish.[30] The results of the haematological parameters (Table 2) vividly indicated that *P. spindletruncatus* infection altered haematological parameters. This was obvious in the values obtained for Hb, RBC, PCV and WBC, which were significantly ($p<0.05$) affected by *P. spindletruncatus* infection in all fish species used for this study. All the examined haematological parameters (Hb, RBC and PVC) showed significant decreased in different infected fish species although with different trends, except in the WBC counts, which increased in all infected fishes, compared to uninfected controls.

An increase in the total number of WBC, in fish infected with *P. spindletruncatus* compared with uninfected fish can be used as a clear indication of presence of the parasite. This variation in WBC counts could be due to the physiological state of the host fish and intensity of parasitic infection. Comparing the results of WBC count with the prevalence of infection, there was a significant increase in WBC count in the highly infected fish species, which was obvious in *L. vorax*, *C. trutta* and *S. lepidus* with the highest prevalence of the parasite infection, compared with other fish species (Tables 1 & 2). WBCs are the cells of the immune system that are involved in protecting the body against both infectious disease and foreign invaders. This is achieved by stimulating the haemopoietic tissues and the immune system to produce antibodies and chemical substances working as defence against infection.[31] The WBC count increased in all infected fish species in the current study, possibly because it is part of the body's mechanical or immune defence response to the acanthocephalan infection. WBC count showed considerable independence from other blood parameters such as RBC, Hb, and PVC values, and this was obvious in the result of the blood test as shown in Table 2. There was a distinct reduction in the RBC, Hb and PCV values ($P < 0.05$) in fishes infected with the parasite which has been reported to accompany an increase in WBC count.

There was a significant reduction in RBC count in a number of *P. Spindletruncatus* infected species, such as *S. Lepidus*, *C. umbla*, *C. damascina* and *C. carpio* compared to the uninfected controls. In heavily infected fishes, acanthocephalans may puncture the gut wall with their proboscis and cause substantial damage with severe local inflammatory reaction.[32,33] In addition, the parasitic mechanical damage leads to bleeding and deficiency in iron, vitamins B12 and folic acid, which have crucial roles in RBC production. Reduction in RBC is accompanied with low value of Hb and PCV which may be as a result of the parasitic infestation that often leads to anaemia.[34] Moreover, when there is a high intensity of parasites, an increased blood loss caused by haemorrhage and consumption by the parasites lead to overall reduction in Hb. Consequently, this can affect the

Table 1: Percentage prevalence and mean intensity of *Pomphorhynchus spindletruncatus* infection in different fish species

Fish species	No. of fish examined	No. of infected fish	Parasitic Prevalence (%)	Mean intensity
Squalius lepidus	11	8	72.72	21.125
Chondrostoma regium	35	20	57.14	6.6.000
Capoeta umbla	16	10	62.50	45.000
Capoeta damascina	10	7	70.00	7.7140
Capoeta trutta	18	11	61.00	13.000
Leuciscus vorax	10	9	90.00	12.800
Cyprinus carpio	18	7	38.80	5.710

Table 2: Effect of *Pomphorhynchus spindletruncatus*infection on some haematological parameters of fish specimen

Host	Hb (g %)		RBC ($x10^6$ mm^3)		WBC ($x10^3$ mm^3)		PCV (%)	
	Uninfected	Infected	Uninfected	Infected	Uninfected	Infected	Uninfected	Infected
Squalius lepidus	11.83±1.60a	10.47±1.17b	6.90±1.90b	4.94±1.79a	28.33±3.66b	54.80±2.82a	29.66±2.72b	31.25±0.85a
Chondrostoma regium	12.60±0.79b	12.84±0.85a	2.21±2.26b	2.32±2.39a	28.25±3.91b	35.0±3.84a	34.28±2.20b	34.92±2.31a
Capoeta umbla	17.40±2.61a	13.58±2.64b	2.39±1.44a	2.20±3.08b	21.55±8.04b	29.1±3.90a	35.80±1.15a	32.42±2.05b
Capoeta damascina	13.47±1.93a	12.66±0.23b	2.90±6.90a	1.79±4.94b	26.01±9.91b	34.00±1.87a	30.66±2.18a	34.75±1.37b
Capoeta trutta	14.33±0.33a	11.51±0.75b	1.37±3.39b	1.50±9.60a	50.93±2.13b	75.68±1.94a	41.00±0.57a	34.55±2.27b
Leuciscus vorax	9.23±0.47b	10.16±1.09a	1.37±5.96b	1.62±4.05a	26.00±3.60b	84.67±8.63a	32.66±3.92a	30.50±3.27b
Cyprinus carpio	11.79±0.51b	13.01±0.90a	2.88±2.12a	1.95±3.04b	38.66±3.57b	47.20±8.17a	35.00±1.62a	34.00±0.57b

Different letters indicate significant difference between variables at $P<0.05$ across horizontal rows; Hb: Blood haemoglobin concentration; RBC: Erythrocytes count; WBC: Leukocytes count; PCV: Packed cell volume.

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productivity and growth rate of the fish and also decrease fish meat quality besides making the hosts more susceptible to other pathogenic infections such as parasites and bacteria. However, other studies showed that parasites act as a stressor which stimulate the primary stages of stress, especially in the initial stages of infection. They increase PCV value, while decrease RBC count. Parasitic infection stimulates production of catecholamine hormone that work to mobilize red blood cells from the spleen, leading to deficiency in the erythrocyte count. Alternatively, it may induce erythrocytes swelling due to fluid flowing into the intracellular compartment.[35] This was obvious in the high PCV value and low RBC count in highly infested *S. Lepidus* and *C. damascina* with the parasite (Tables 1 and 2) and this observation agree with Omeji and his workers.[36]

The results of the present study showed that there was an increase in the Hb concentration in a number of fishes infected with *P. spindletruncatus*, though many studies recorded reduction in Hb and RBC in the infected compared to uninfected fishes.[11,36] High parasite number in the intensive infection may result in asphyxiation, which in turn leads to a rise in haemoglobin concentration to increase efficiency of blood to carry and deliver oxygen to the cells and tissues.[37] In addition, there is a clear correlation between low Hb concentration and high PCV value in highly infected fishes as in *C. damascina* and *S. Lepidus*. This could be related to oxygen depletion from host tissues due to increased oxygen consumption by large number of parasites and increased carbon dioxide production via respiration of both host and parasite which lead to a rise in RBC production to transport large amount of O_2 and CO_2.[38] In addition, variation in PCV value between different infected fish species is due to parasites feeding on host blood, and local bleeding in the site of infection, especially in higher rate of infection. This can cause anaemia and thus affects blood profile, number and size of red blood cells.[39]

Effect of P. spindletruncatus infection on biochemical parameters

Table (3) indicated that significant differences ($P < 0.05$) were recorded in the total protein, cholesterol, and glucose levels between the uninfected and *P. spindletruncatus* infected fishes. This observation revealed that *P. spindletruncatus* causes changes in biochemical blood parameters of infected fish. The levels of protein and cholesterol varied significantly ($p<0.05$) between the infected and the uninfected fishes. Nevertheless, the level of glucose was significantly lower in all the infected fishes compared to uninfected controls. Negative significant correlations between acanthocephalan infection and glucose concentration can be explained by the fact that parasite infestation promotes a stress reaction in the host that leads to series of physiological and behaviouralresponses. The parasite also benefits from the glucose as a source of energy for carrying out its vital life processes and for survival.[40]

The results of the total proteins for infected and uninfected fishes among different fish species showed different patterns. *C. regium*, *C. umbla*, *C. carpio* and *L. vorax* showed significantly lower total serum protein compared to uninfected fishes. The decrease in total serum protein level may be due to the requirements of the weakened fish to protein. This observation may be due to parasite infection in order to carry out vital biological functions and/or repair damaged and disrupted internal organs due to parasite penetration. Acanthocephalans penetrate deeply in host tissues and induce formation of a nodule at the site of attachment that some time extends into the coelom of the host. Moreover, physical leakage of substances and protein from plasma to these nodules due to increased feeding activities and movement of the mobile stages of the parasite ensure stable stream of nutrients for the parasites.[41] Moreover, the reduction in the concentration of total blood protein in many disease statuses is owing to a decrease in capability of synthesis and absorption or protein loss.[42] Other factors that affect total protein level in the blood are stress and injury because they reduce appetite of fish and consequently decrease the value of total blood protein.[43] Similarly, reduced ability of parasite-infected fish to synthesize or absorb necessary proteins is due to the loss of proteins during the haemorrhage. As a result of this, the perforation and damaging internal organs by the parasites penetrate their thorny proboscis into the intestinal wall of the host and absorb nutrients. On the contrary, infected fish of *S. lepidus* had significantly higher total blood protein level (66.06±60.54 mg/100 mL) as compared to the uninfected fishes, followed by *C. damascina*, *C. regium*, *C. umbla*, *C. trutta*, *L. vorax* and *C. carpio (*Table 3). In this study, there was a significant increase in total protein in blood of *S. lepidus* infected fishes which might indicate an inflammatory response to the parasite. This observation is due to the high prevalence rate of parasite infections and increased blood globulin production as an immune response to the infection.[44] Cholesterol concentration showed a significant decrease in the infected fishes and this may be due to the possibility of its consumption directly by the parasite as a food for survival and growth.[45] More so, it may be used by infected fish to manage chronic stress caused by the presence of parasites inside the body tissues.[46] Another reason proposed for the low cholesterol may be due to impaired excretion of bile, thus reducing fat emulsification process leading to a decrease in their absorption capacity.[45] On the contrary, it was observed that heavy *P. Spindletruncatus* infection lead to increase cholesterol concentration in *C. umbla* with the highest parasite intensity of 45 and *L. vorax* having highest prevalence of 90 % as revealed in Table 1. This may be explained by accumulation of cholesterol in the body due to disorder of fat metabolism or lipoproteins because of a weak or defective physiological activity of the liver as a result of parasitic infection and the negative influence on the host system.[47] Moreover, existence of a high number of parasites inside a host tissue causes acute and then chronic stress that lead to hypercholesterolemia in salmonids fishes.[47] Almost all parasites might metabolise cholesterol, however the exact pathogenic mechanism is not clear. Therefore, the parasites break down and consume cholesterol by using some factors or a particular enzyme. [48]

Chemical composition of muscles

Nutrient level in muscle and blood tissues are vital signal of their functional normality and health status. Comprehensive investigations have been carried out on how biochemical profile of the entire fish (blood and muscles) varies in healthy and infected fish. It is very clear from the results of the present study that there was a significant change in the levels of protein, lipid, moisture, and ash contents of infected fish compared with healthy fish muscles. This observation may be due to several reasons which include prevention and deprivation of fish from feeding due to parasitic infestation. The consequence of parasite infection is prevention of fish from feeding, directing of nutrients to the site of infection to feed the parasite or used nutrients by the fish host in order to develop and strengthen the immune system to defend against parasitic infection.[50] Muscle composition of infected and non-infected fish is presented in Table 4. There were significant ($P> 0.05$) differences in the muscle composition between all infected and uninfected fish species. The mean percentage of protein level of muscle declined significantly in all infected fishes with *P. Spindletruncatus* compared with uninfected ones. It is likely that the main reason behind low protein content in the muscle of infected fish is due to the acanthocephalan endoparasite on the components of the host's intestine preventing the host from utilizing nutrients to build different body parts. This observation agrees with a previous study by Hassan.[50] Actually, the movements of the acanthocephalan proboscis induces bleeding, disrupts infected intestine cells, leads to degeneration, inflammatory reactions, and necrosis, which decreases the capability to absorb nutrients.[51] A negative correlation was observed between proteins and moisture contents in the muscles of the studied fishes (Table 4). A significant decrease in the protein level was observed in the muscle of almost all infected fishes accompanied with a significant increase in moisture content. The reverse was observed in the healthy fishes; an observation which is in agreement with the findings of Iles and Wood.[52] The decrease in the amount of proteins and fats may be due to the weakness of the intestinal consumption of digested food by the parasite for maintaining fish health, growth and reproduction activities. These lead to a reduction in the level of essential nutrients compared with water level, similarly to other nutrients, fats also have direct relationship with amount of water present in the body and this varies with changes in environment as well as fish species, season and level of feeding.[49]

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Table 3: Effect of *Pomphorhynchus spindletruncatus*on some serum biochemical parameters of fishes

Host	Serum Protein (mg/100 mL)		Cholesterol (mg/100 mL)		Glucose (mg/100 mL)	
	Uninfected	Infected	Uninfected	Infected	Uninfected	Infected
Squalius lepidus	3.43±0.47b	66.06±60.54a	243.26±74.03a	232.26±74.03b	384.9±56.58a	176.96±43.34b
Chondrostoma regium	4.85±39.52a	3.22±0.34b	314.9±56.851a	286.227±32.44b	317.99±37.22a	157.067±23.49b
Capoeta umbla	3.848±0.518a	3.214±0.416b	150.0±12.896b	214.10±92.59a	131.78±16.88a	124.48±27.52b
Capoeta damascina	2.886±0.271b	3.768±0.522a	492.5±172.06a	131.07±4.68b	289.5±26.27a	103.25±9.664b
Capoeta trutta	2.67±0.208b	3.1±0.422a	296.26± 9.953a	252.225±9.125b	353.667±14.97a	299.5±45.586b
Leuciscus vorax	4.26±0.319a	2.86±0.355b	341.867±72.99b	509.175±6.07a	317.53±16.019a	108.67± 0.537b
Cyprinu scarpio	3.563± 0.496a	2.276±0.075b	302.42±72.10a	238.20±14.38b	314.9±15.81a	204.33±38.63b

Different letters indicate significant difference between variables at P<0.05 across horizontal rows.

Table 4: Effect of *Pomphorhynchus spindletruncatus* infection on some muscle chemical constituents of fishes

Host	Protein (%)		Lipid (%)		Moisture (%)		Ash (%)	
	Uninfected	Infected	Uninfected	Infected	Uninfected	Infected	Uninfected	Infected
Squalius lepidus	16.97±0.40a	15.66±0.28b	3.37±0.48a	3.44±0.95a	72.53±0.20a	72.51±0.52a	5.29±0.54a	4.32±1.01b
Chondrostoma regium	14.95±0.68a	13.14±1.01b	4.85±0.34a	2.91±0.53b	71.24±1.18a	75.13±1.03a	2.17±0.20b	2.47±0.44a
Capoeta umbla	17.99±0.43a	15.37±1.63b	3.45±0.21a	3.41±0.36b	71.18±1.11b	71.67±0.88a	3.09±0.31a	2.94±0.28b
Capoeta damascina	16.44±0.58a	14.61±0.24b	2.11±0.29b	3.24±0.46a	71.42±0.25b	74.08±0.48a	2.60±0.20a	2.46±0.41b
Capoeta trutta	14.85±0.26a	13.82±1.58b	2.83±0.10b	6.80±1.20a	71.49±0.06b	71.62±0.45a	3.22±0.45b	3.72±0.79a
Leuciscus vorax	16.10±0.25a	13.88±0.40b	2.62±0.32b	5.71±0.47a	70.90±0.15b	74.54±0.50a	4.80±0.52a	3.56±0.63b
Cyprinus carpio	13.15±1.03a	12.27±0.22b	5.14±0.75a	4.78±0.28a	71.82±2.19b	71.53±0.19a	1.84±0.41b	4.61±0.21a

Different letters indicate significant difference between variables at P<0.05 across horizontal rows.

In the current study, the effect of *P. spindletruncatus* on muscle fat content in infected fishes varied by either a significant decrease or increase compared with uninfected controls. Ash and moisture contents were significantly increased in almost all the infected fishes, whereas protein and fat content were reduced, thus decreasing fish meat quality. More interestingly, it was also observed that the parasite infection did not affect fat content of *S. lepidus*, though it was one of the fishes in which high prevalence and severity of infection were recorded in the current study. This may be due to seasonal variation as the study was carried out during the summer months which were accompanied with increased feeding activity and metabolic rates; thus, parasitism did not negatively affect fat content of infected fish. This observation is consistent with the results of a previous study.[53] Parasites are capable of changing the essential physiological features of the host system, making the host attempts to adapt with the infection by changing its physiology. Increased muscle proteins and liver total carbohydrates in heavily infected fish muscles were observed by Hassan,[50] which was attributed to parasites interference with the host digestion and absorption of nutrients in digested food causing metabolic disorders.

Conclusion

The results of this study provide information on the characteristic features of haematological and biochemical parameters of blood and chemical compositions of muscle in freshwater fishes due to *Pomphorhynchus spindletruncatus* infection. The study reveals that parasite infection was responsible for altering blood haematology and chemical parameters of different fish species. Increased number of WBC may be related to the defence mechanism and immunological responses against parasites. Meanwhile, alteration of muscle chemical compositions in the infected fishes may be related to disruption in metabolic activity by the parasite.

Conflict of interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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