

**Effects of aflatoxin B₁ on growth performance, health indices,
phagocytic activity and histopathological alteration in
*Fenneropenaeus indicus***

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Abstract

Mycotoxins contamination of feedstuff for aquatic animals is common in regions with humid tropical conditions. In this study Indian white shrimp, *Fenneropenaeus indicus*, (11.79 ± 1.76 g) were fed with diets containing 0, 20, 50, 100, 200, 400, 800 and 1600 ppb levels of aflatoxin B₁ (AFLB₁) for 8 weeks. Final weight, aflatoxin B₁ residue (2-week intervals), Total Hemocyte Count (THC), Total Plasma Protein (TPP), Phagocytic Activity (PA), Survival rate (4-week intervals) were determined. Histopathological alterations in hepatopancreas, midgut and muscle tissues were studied at the end of 4 and 8 weeks. Shrimps fed with the 1600, 800 and 400 ppb concentrations of AFLB₁ exhibited slow growth, and more reddish discoloration disseminated over the body at 4th week. Growth parameters, survival rate and health indices (THC, TPP) of *F. indicus*, are affected by the different doses of AFLB₁ in diets. At the end of 8th week, doses of AFLB₁ in the diets showed negative correlation to final weight, survival rate, THC and TPP ($r = -0.312, -0.603, -0.237$ and -0.649 at $P < 0.001$, respectively). Moreover, significant histopathological alterations in the hepatopancreas, midgut and muscle tissues of exposed shrimps to different levels of AFLB₁ were observed and these alterations are obviously indicated by changes in the health indexes (THC and TPP).

Keywords: Aflatoxin B₁, *Fenneropenaeus indicus*, growth performance, health indices, histopathological alteration

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Introduction

Most of the problems currently facing the shrimp culture activities are related to the widespread occurrence of disease, e.g., bacterial and viral infections or parasitic invasions. These diseases can lead to drastic scathe to the industry; thus the researchers have focused much of their attention to study such threats. Nonetheless, there are other potential threats caused by other agents, such as the environment or the feed which can also affect seriously the success of the shrimp culture industry (Bintvihok et al., 2003). These agents have been some way neglected by the shrimp industry. Intercontinental trade in agricultural commodities has imparted significantly to the discussion about potential hazards involved and has particularly increased the consciousness of mycotoxins (Binder et al., 2007).

Mycotoxins are produced by the growth of molds (fungal spoilage) on a wide range of foodstuffs which can occur at many stages during food production during plant growth, harvesting, storage and processing (Anklam et al., 2002). Due to the omnipresent nature of fungi, it has been estimated that approximately twenty percent of whole food products (chiefly of plant origin) are contaminated with substantial toxin. About 300 different mycotoxins have been reported that are produced by approximately 200 dissimilar fungal species. All the same, there are only twenty mycotoxins that are often found in food and feedstuffs at concentrations likely to pose a health hazard for people and animals consumption so-called "primary exposure"

(Anklam et al., 2002). However, all fungal growths don't lead to mycotoxin producing. Thereupon detection of fungi does not show inevitably the presence of mycotoxins (D'Mello and Macdonald, 1997).

Consumption of a food containing mycotoxins can induce acute or long-term chronic effects resulting in teratogenic, carcinogenic, oestrogenic and immunosuppressive effects. Consumption of mycotoxin contaminated feed lead to: reduced feed intake, feed refusal, diminished body weight gain, increased feed conversion, disease prevalence (due to reduce immunity defense functions) and decrease in reproductive capacities (Malins and Ostrander, 1994; Meerdink, 2002; Fink-Gremmels and Malekinejad, 2007). Feed commodities with high deal of starch and lipids may be susceptible to fungal contaminations if not properly dehydrated. For example, peanuts and peanut by-products, tree nuts, copra, maize, cottonseed meal and sunflower meal are especially susceptible to fungal colonization, most often by *Aspergillus flavus*, but occasionally by *Fusarium* spp. and *Altemaria* spp. *Aspergillus* spp. which can produce several classes of aflatoxins. AFLB₁ is known as an actual toxin and hepatocarcinogen (Jantrarotai et al., 1990; Achim, 1997; D'Mello and Macdonald, 1997). AFLB₁ is a potent toxin to a number of cell types, plants, invertebrates and vertebrates (Coulombe and Roger, 1993).

Fungal contamination of feedstuff for aquatic animals is common in regions with

humid tropical condition, such seaports. Some factors, such as improper quality of feedstuff ingredients and incompatible storage of feed can increase probability of fungal contamination (Bintvihok et al., 2003). Many aquatic vertebrates are known to suffer toxic effects of dietary AFLB₁. For example, dietary administration of AFLB₁ at 1 ppb has shown hepatocarcinogenic effect in rainbow trout. It's believed, warm water species are often less sensitive to AFLB₁ than cold water species (Lovell, 1998). In marine shrimp, AFLB₁ can lead to decrease in growth, low apparent digestibility, physiological disorders and histopathological changes, mainly in the hepatopancreas tissue (Lightner et al., 1982; Sindermann and Lightner, 1988). Hepatopancreas is the major digestive organ in decapod crustaceans. This organ has some vital biological functions, such as synthesis and secretion of digestive enzymes (Frandsen et al., 2009). The effects of dietary AFLB₁ on aquatic invertebrates, particularly Penaeid shrimps, have been some deal defined. Study of juvenile Pacific white shrimp, *Litopenaeus vannamei* (Lightner, 1988), indicated that shrimp feed containing 100 ppb AFLB₁, (from AF-contaminated peanut meal) resulted in a moderate incidence of aflatoxicosis within a 171-day grow out period. Some researchers described mortalities caused by aflatoxicosis among juvenile *L. vannamei* after they were fed diets containing 50-300 ppm AFLB₁, for 28 days (Wiseman, 1980; Wiseman et al., 1983). Bautista et al. (1994) have reported histopathological changes in the hepatopancreas tissue of shrimp chronically exposed to AFLB₁. The degree of histopathological changes

correlated with the concentration of AFLB₁. In the current study, the effects of different concentrations of AFLB₁ in diets on health indexes, haemocytes phagocytic activity and histopathology of shrimps were deliberated.

Materials and methods

Juvenile Indian white shrimps, *F. indicus*, of 11.79±1.76g average weight were stocked into six glass aquaria (30 shrimps each). Shrimps were obtained from Tiab region in Hormozgan province and transferred to a research station in Iran Shrimp Research Center (ISRC) in Bushehr province in the south of Iran. Shrimps were placed in fiberglass containers (4m³) to acclimatize (26.06 ± 2.80°C, 30.09 ± 2.84ppt, DO 7.71 ± 0.74mg/l and pH 8.23± 0.32) for two weeks. During the acclimation period, shrimps were fed three times daily with a pelleted shrimp feed (provided from Havourash Company, Bushehr).

One batch of commercial diets (Havoorash feed Company, Bushehr, Iran), consisting preliminary of soybean meal, wheat, fish meal and shrimp meal was analyzed prior to use and were found to be free from AFLB₁. Analytical reagent grade AFLB₁ (Sigma Chemical Co. No. A6636 or Calbiochem No.121741) was purchased. The crystalline AFTB₁ was first dissolved in ethanol to prepare solutions of AFLB₁ and then according to Boonyaratpalin et al. (2001) eight homologous diets contain desire levels of AFLB₁ were prepared as follows: treatment 1 (control) contained 0 ppb (µg/ml) AFLB₁, treatments 2 to 8 contained 20, 50, 100, 200, 400, 800 and 1600ppb AFLB₁, respectively. For all treatments, diets were processed by a meat grinder with about one

third moisture and then pelleted. This process was followed by 6 h of drying at 65°C until the moisture content came down to 10%. The dried pellets were stored in plastic bags in a Laboratory refrigerator until used. The shrimps were fed these aflatoxin-contaminated feeds twice daily for 8 weeks. Moribund or dead shrimps were removed and recorded. Moribund and recently dead animals were preserved in Davidson fixative for histopathological examination.

Haemocyte lyses or degranulate *in vitro* quickly. Therefore, 10% formalin in 0.45 M NaCl was used for the fixation of the collected haemolymph. Haemolymph (0.1ml) was collected from the abdominal surface and the base of a walking leg by using a syringe containing 0.1ml fixative, transferred to Eppendorf tube and mixed gently. After 10 min at 4°C, 10 µl of fixed haemolymph was placed on Haemocytometer (improved Neubauer bright line) and counts were done under microscope (Nikon Photolab, Japan) with magnification of 40× for 5/25 squares to calculate THC per ml hemolymph ($0.5 \times \text{count} \times 10^5 \times \text{dilution factor}$).

Concentrations of plasma protein in each sample were determined by the Lowry method (Lowry et al., 1951).

For evaluation of phagocytic activity, the glassware and solutions were pyrogen-free to avoid enzymatic interruption and all chemicals were of analytical reagent grade. Phagocytic activity was determined by the method of Jiang et al. (2004). Briefly, 25ml of collected haemolymph was placed on a dichromate-cleaned glass slide and incubated for 30 min at room temperature. Subsequently, 25µL of a

Staphylococcus aureus suspension (1×10^8 cells/ml) was added to each sample and the preparation was incubated for an additional 30 min. Then, each slide was washed with anticoagulant, fixed with 4% glutaraldehyde in the solution of anticoagulant for 1 min, rinsed in distilled water for 1 min, post fixed with 95% ethanol for 1 min, and air-dried. The slides were then stained with toluidine blue for 5 min and decolorized in running tap water. Numbers of ingested *S. aureus* and numbers of haemocytes that had ingested *S. aureus* were counted from any 200 haemocytes observed using a light microscope at a magnification of ×100 (Nikon, Photolab, Japan) (Jiang et al., 2004). Percentage of phagocytosis was calculated as below:

$$\text{Percentage of phagocytosis} = (\text{number of cells ingesting bacteria} / \text{number of cells observed}) \times 100$$

After 4 and 8 weeks of the feeding trial, tissue samples from the hepatopancreas, midgut and muscle of live shrimps were obtained and examined using an optical microscope. Briefly, three cephalothoracic regions and muscles (first segment) from each treatment were fixed in Davidson's fixative overnight at the start point, on the fourth and the eighth week of the experimental rearing. Fixation was accomplished by first injecting 0.3 ml of fixative (depending on the size of the animal being preserved; using a 1 ml syringe) directly into the hepatopancreas. Then the cuticle for the length of the animal was opened along the lateral midline using dissecting scissors, and the animal was immersed into fixative. After 24 to 72 h in Davidson's fixative, preserved shrimp were transferred to 50% ethyl alcohol for storage. Tissues were prepared for light

microscopy using routine paraffin techniques, and were stained with hematoxylin and eosin. Tissues were processed for paraffin embedding in a 110KP automatic tissue processor (KP-110) and sections of 5-6 μm thickness were cut with a Leica Jung RM 2045 semi-automatic rotary microtome. Longitudinal and transverse sections of the tissues were taken. Histological terms used to describe the tissues and organs in this study were according to Lightner (1996).

All data were subjected to analysis of variance (Two-way (univariate) ANOVA) to determine differences in means ($P < 0.05$).

Results

The actual AFLB₁ content in final diets after feed preparation was determined from 5g samples of each. Actual feed levels were 20.44, 42.50, 85.10, 212.50, 425.50, 793.20 and 1380.00 mg/kg in the final prepared diets (Table 1).

Discolorations on the ventral part of the body were evident during the second week of treatments in shrimps fed diets containing more than 200 ppb AFLB₁. The body and appendages changed from off white to yellowish (in the first

week) and eventually had a reddish discoloration (after 2 weeks). The color of fecal matter changed from brown to brownish red. These changes were not seen in shrimps fed with diets containing less than 800 ppb AFLB₁, even in the last weeks of treatment. Hepatopancreas of shrimps treated by diet containing 800 ppb and 1600 ppb AFLB₁ change to red and later to off white and were reduced to half of its size than the control group. Moribund shrimps showed abnormal movements and soft shell, specially the shrimps that were fed with diets contain more than 800 ppb AFLB₁.

Normal distribution was certified by SPSS 18 software. Four weeks after treatment, shrimps fed with the 1600, 800 and 400 ppb concentrations of AFLB₁ exhibited slow growth, and more reddish discoloration disseminated over the body and the tail, which was not observed in the other treatments. They also recorded the lowest final weight, daily weight gain, specific growth rate and survival rate, which was significantly different from other concentrations treatments (Table 2).

Table 1: Aflatoxin B₁ (AFLB₁) content of experimental diets

AFLB ₁ content (ppb)	Diets							
	0	20	50	100	200	400	800	1600
Amount incorporated diet	0	20	50	100	200	400	800	1600
Parameters*	AFLB ₁ concentration (ppb)							
Amount after analysis	0.00	20.44	42.50	85.10	212.50	425.50	793.20	1380.00

	0	20	50	100	200	400	800	1600
final weight (g)	13.50±1.22 ^b	13.75±0.95 ^b	13.97±0.82 ^b	13.63±1.02 ^b	13.53±0.92 ^{ab}	13.06±1.23 ^{ab}	13.07±1.05 ^{ab}	12.42±1.36 ^a
Specific Growth Rate (%)	0.10±0.062 ^{cd}	0.06±0.009 ^{cd}	0.14±0.058 ^d	0.02±0.009 ^{cd}	0.01±0.009 ^c	-	-	-
Survival (%)	98.89±0.57 ^d	95.56±1.15 ^{cd}	100.00 ^d	97.78±1.15 ^{cd}	94.44±0.57 ^{cd}	88.89±0.57 ^c	68.89±1.52 ^b	58.89±3.05 ^a

Table 2: Final weight, weight gain and survival

* Values are (mean ± SD) for each row. Means with the same superscript are not significantly different ($P < 0.05$).

Eight weeks after commencing the feeding trial, shrimps fed with more than 200 ppb of AFLB₁ showed slow growth, and more reddish discoloration disseminated over the body and the tail, which was not observed in the other treatments. They also exhibited the lowest final weight, daily weight gain, specific growth rate and survival rate, which was

significantly different from treatments given the diets with less than 200 ppb of AFLB₁. At the end of week 8, the concentration of AFLB₁ in the diets was negatively correlated with the final weight at the 0.001 level (2-tailed) ($r = -0.339^{**}$). At the same time, dose of AFLB₁ in the diets and duration of feeding were showed negatively correlated with the survival rate at the 0.001 level (2-tailed) ($r = -0.603^{**}$ and -0.571^{**}).

Table 3: Final weight, weight gain and survival rate in *F. indicus* fed with different concentrations of aflatoxin B1 (AFLB₁) for 8 weeks

Parameters*	AFLB ₁ concentration (ppb)							
	0	20	50	100	200	400	800	1600
Final weight (g)	14.15±1.19 ^c	14.22±1.01 ^c	14.12±1.09 ^c	13.80±1.03 ^c	13.42±1.15 ^{bc}	12.86±1.17 ^b	12.49±1.27 ^{ab}	11.78±1.14 ^a
Specific Growth Rate (%)	0.03±0.002 ^d	0.05±0.005 ^d	0.01±0.025 ^d	0.02±0.005 ^{cd}	-0.01±0.001 ^c	-0.02±0.019 ^b	-0.08±0.005 ^b	-0.09±0.033 ^a
Survival (%)	98.89±0.57 ^c	93.33±0.00 ^{dc}	91.11±0.57 ^{dc}	94.44±1.15 ^{dc}	83.33±1.00 ^{cd}	76.67±1.73 ^c	54.44±3.21 ^b	38.89±2.88 ^a

* Values are (mean ± SD) for each row. Means with the same superscript are not significantly different ($P < 0.05$).

Shrimps fed diets containing 0 (control) to 100ppb of AFLB₁, gave significantly higher growth compared with those given increased levels of AFLB₁. Daily weight gain started to slow down at day 28 for shrimps fed diets with more than 400 ppb AFLB₁ but Shrimp fed a diet with 1600 AFLB₁, started to lose weight in the first week and the daily weight gain and specific growth rate were negative, from the first week.

In the control group, the survival rate after 8 weeks was 98.89 ± 0.57 %, while that of the shrimps that received 400, 800 and 1600 ppb of AFLB₁ were affected after 4 weeks. The survival rate in higher concentrations of AFLB₁ (800 and 1600 ppb), fed group as decreased to 68.89 ± 1.52 % and 58.89 ± 3.05 %, respectively. After 8 weeks the survival rate in

two last groups reduced to 54.44 ± 3.21 % and 38.89 ± 2.88 % (Table 3).

There was a noticeable increase in THC in the juvenile *F. indicus* given feed with high levels of AFLB₁ (more than 200 ppb) after 2 weeks. The mean THC in the control group was 76.15 ± 8.62 , 74.48 ± 5.36 and 75.81 ± 10.95 ($\times 10^5$ cells/ml) at the end of 2, 4 and 8 weeks, respectively. Afterward, THC exhibited a decrease after 4 weeks in 400 and 1600 ppb treatments while at the end of 6th week, there was a gradual decrease in the number of

circulating haemocytes in 200 and 800 ppb treatments (Table 4).

Concentrations of AFLB₁ in the feed and duration of feeding were positively correlated with THC at the 0.05 level (2-tailed) in the second week ($r = 0.334^*$ and 0.301^*) while at the end of 8th week, concentrations of AFLB₁ in the dates and duration of feeding showed negatively correlated with THC at the 0.001 level (2-tailed) ($r = -0.237^{**}$ and -0.523^{**}).

Table 4: Total Haemocyte Count in *F. indicus* fed with different concentrations of aflatoxin B₁ (AFLB₁) for 8 weeks.

Total Haemocyte Count ($\times 10^5$ cells/ml)*	AFLB ₁ concentration (ppb)							
	0	20	50	100	200	400	800	1600
2 nd week	76.15±8.62 ^a	70.40±8.96 ^a	70.40±18.07 ^a	58.70±5.50 ^a	82.20±25.22 ^a	98.76±11.96 ^a	97.39±3.87 ^a	93.28±17.55 ^a
4 th week	74.48±5.36 ^{ab}	71.32±5.61 ^{ab}	53.41±3.73 ^{ab}	49.84±3.85 ^a	80.06±16.09 ^b	47.14±11.80 ^{ab}	69.92±3.87 ^b	51.04±22.50 ^{ab}
8 th week	75.81±10.95 ^a	60.74±24.94 ^{ab}	55.19±25.51 ^{ab}	51.86±32.00 ^b	39.77±18.97 ^{ab}	40.08±17.31 ^b	30.61±15.82 ^{ab}	31.56±10.16 ^b

* Values are (mean ± SD) for each row. Means with the same superscript are not significantly different ($P < 0.05$).

The Total plasma protein means in control group at the end of 4 and 8 weeks was 74.48 ± 5.36 and 75.81 ± 10.95 mg/ml, respectively. The TPP showed drastic decrease in the groups that were fed with diet containing 800 and 1600 ppb of AFLB₁. The TPP values at the second week showed a drastic decrease to 36.21 ± 6.25 mg/ml and 17.49 ± 3.44 mg/ml, respectively. The TPP values were reduced to

15.16 ± 5.33 mg/ml at the end of the eighth week in the group fed with the highest concentration of AFLB₁ (Table 5)

The correlation between dose of AFLB₁ in the diets and TPP at the 0.001 level (2-tailed) at 4 and 8 weeks demonstrated that there was a negative correlation ($r = -0.542^{**}$ and $r = -0.649^{**}$).

Table 5: Total Plasma Protein in *F. indicus* fed with different concentrations of aflatoxin B₁ (AFLB₁) for 8 weeks

Total Plasma Protein (mg/ml)*	AFLB ₁ concentration (ppb)							
	0	20	50	100	200	400	800	1600
2 nd week	77.10±13.36 ^{ab}	85.06±21.01 ^b	82.24±19.80 ^b	76.08±15.19 ^b	84.01±13.04 ^b	71.12±25.02 ^{ab}	36.21±6.25 ^{ab}	17.49±3.44 ^a
4 th week	80.99±9.73 ^c	79.43±17.86 ^c	83.43±12.26 ^c	79.86±23.35 ^c	70.89±17.86 ^c	48.15±5.85 ^{bc}	34.99±6.25 ^{ab}	20.55±12.71 ^a

8 th week	78.52±5.80 ^{bc}	81.14±12.19 ^c	82.10±12.17 ^c	79.36±8.57 ^c	71.54±26.05 ^{bc}	56.47±16.70 ^b	30.37±11.5 ^a	15.16±5.33 ^a
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* Values are (mean ± SD) for each row. Means with the same superscript are not significantly different ($P < 0.05$).

Phagocytic activities were found to increase in the 20,50,100,200,400 ppb groups when analyzed at the end of the 2nd week, while the decreased phagocytic activities were observed after 8 weeks in the groups fed with diets

containing 800 ppb and 1600 ppb AFLB₁ (Table 6).

Two-way ANOVA test showed no significant difference in experiment period.

Table 6: Phagocytic activities in *F. indicus* fed with diets contain different levels of aflatoxin B₁ (AFLB₁) for 4 and 8 weeks

Phagocytic activity (%) [*]	AFLB ₁ concentration (ppb)							
	0	20	50	100	200	400	800	1600
2 nd week	35.86±8.44	41.41±17.73	43.76±4.54	42.14±9.28	40.32±6.56	39.09±8.04	35.01±16.29	34.43±12.55
4 th week	37.16±18.41	37.22±17.73	35.98±7.18	36.47±9.28	37.04±11.63	32.48±13.10	30.98±13.58	30.97±12.78
8 th week	36.70±14.97	35.22±12.93	36.28±7.79	36.73±9.25	36.67±8.61	32.08±8.49	30.75±12.40	28.57±8.66

* Values are (mean ± SD) for each row. Means with the same superscript are not significantly different ($P < 0.05$).

The AFLB₁ residue levels detected in the shrimp carcass in the different treatments are shown in the Table 5. AFLB₁ residues were not detected in the control group. After receiving diets containing AFLB₁ for 8 weeks, the highest concentrations of AFLB₁ residue were found in the muscles of shrimps which received diets containing 50 to 400 ppb AFLB₁, 4 weeks after commencing the trial. These levels of AFLB₁ residues decreased after 8 weeks. The residues found in the head were smaller than those found in muscle and was stable throughout the

treatment period (Table 7). The correlation between duration of feeding and residue at the 0.001 level (2-tailed) at 4 weeks, verified that there was a high positive correlation ($r = 0.836^{**}$). The correlation between concentration of AFLB₁ in the feed and duration of feeding with residue of AFLB₁ in the shrimp carcass at the end of week 8 were significant at the 0.001 level ($r = 0.300^{**}$ and 0.512^{**}). Paired samples t-Test showed a significant difference between AFLB₁ residue in head and muscle ($df = 47$, $t = -3.753$ and $P < 0.05$).

Table 7: AFLB₁ residues in the carcass of *F. indicus* after dietary treatments with diets contain different doses of aflatoxin B₁ (AFLB₁) at the end of weeks 4 and 8

AFLB ₁ in diet (ppb)	AFLB ₁ residue (ppb)			
	Head		Muscle	
	4 weeks	8 weeks	4 weeks	8 weeks
0	0.00 ^{a*}	0.00 ^a	0.00 ^a	0.00 ^a
20	1.00 ^a	0.85 ^{ab}	2.25 ^a	1.30 ^b
50	2.55 ^b	0.75 ^b	12.75 ^c	0.85 ^{de}
100	3.80 ^{bc}	1.75 ^c	13.65 ^c	1.55 ^e
200	6.55 ^d	4.90 ^e	12.15 ^c	0.30 ^{de}
400	8.80 ^e	6.40 ^f	11.60 ^c	0.35 ^d
800	3.15 ^{bc}	5.85 ^d	7.95 ^b	0.65 ^c
1600	4.35 ^c	7.10 ^e	7.50 ^b	0.15 ^c

* Means with the same superscript in each column are not significantly different ($P < 0.05$).

The normal hepatopancreas tissue has a tubular pattern. The hepatopancreas as a midgut gland is the essential organ of digestion in crustacean. It is made of blind ending tubules consisting of four cell types. The E cells (embryo cells or Stem cells) at the summit of the tubules mature into R cells (absorption and storage of nutrients), F cells (production of digestive enzymes) and B cells (presumed to be secretory in function) (Bell and Lightner, 1988). The differences in the size and shape of the epithelial cells lead to the star appearance of the tubule lumen (Figure 1A). Hepatopancreas has been observed to be very sensitive to an altering in the normal (Dall, 1990) diet and water borne pollutants and R-cells are the first severely affected cell type in the tubular epithelia of the hepatopancreas thus it is used as a monitor organ to control the effects of various toxicants.

The Star shape appearance of tubule lumen was observed in 20, 50 and 100 ppb treatments but at 200 ppb, a reduction in the lipid content in the hepatopancreas tubule because of R-cell atrophy was observed. No inflammatory reaction was observed in the hepatopancreas of shrimps at less 200 ppb treatments. In the histological sections of the hepatopancreas of shrimp fed a diet with 200 ppb AFLB₁, infiltration of haemocytes around the tubules and in the interstitial sinuses, was observed.

The initial sign of inflammation was haemocytic infiltration in the interstitial spaces in between the tubules. More advanced lesions were in the form of necrosis, either in the

tubule itself or the sinuses around it. These lesions were most common in the proximal region of the hepatopancreas. Changes in B cell structure from cylindrical to cubic shape, loss of brush-border appearance, extinction of secretory tubule aperture and reduction in E cells count were observed in shrimps given more than 400 ppb AFLB₁ for 4 weeks (Figure 1B). In shrimps received 400 ppb and more AFLB₁ in the diet for 8 weeks, degenerative changes, necrosis of the hepatopancreatic tissues were observed. Furthermore, individuals with such symptoms had poorer growth performance.

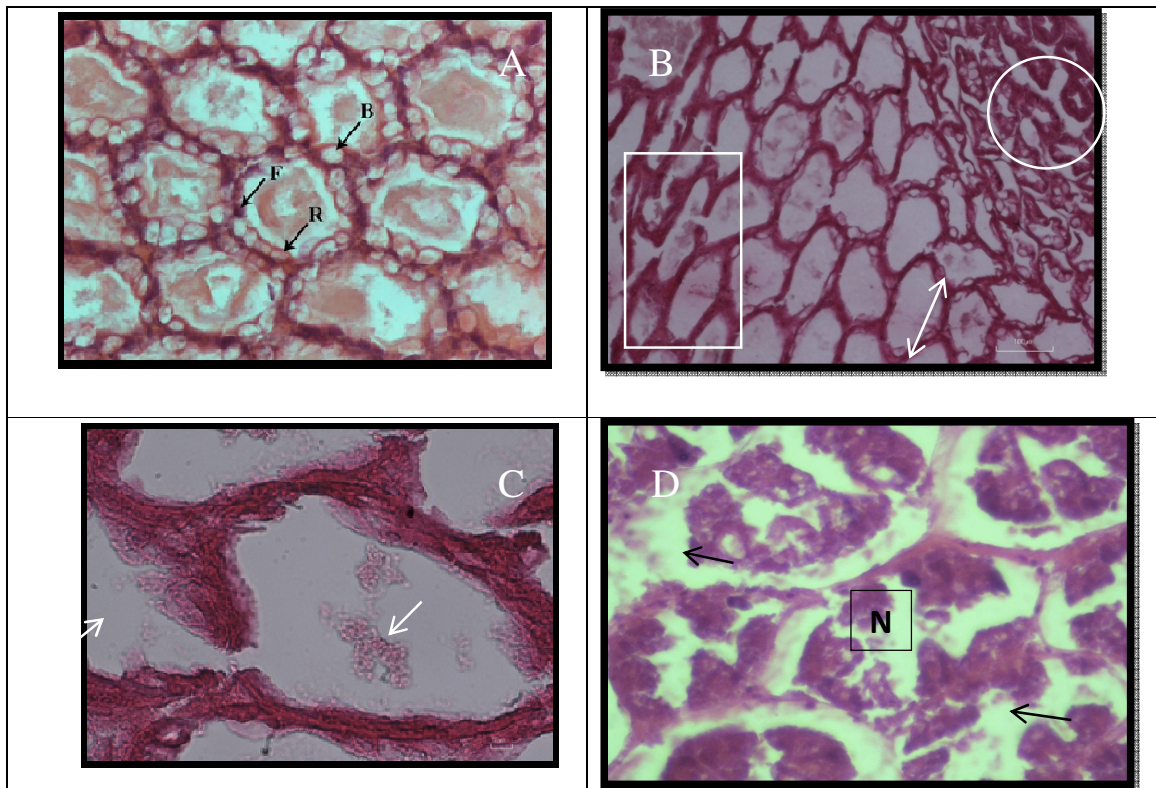
The effects of AFLB₁ on histopathological alteration are directly correlated with the concentrations of AFLB₁ and the time period of the feeding according to the statistical analysis. This experiment obviously shows that when more than 400 ppb concentrations of AFLB₁ were introduced for 8 weeks, it led to the histopathological alteration in the hepatopancreas tissue of all the samples examined. When lower concentrations of AFLB₁ were fed, there were fewer shrimps showing histological abnormality.

At the end of week 4, the shrimps given the feed contain 800 and 1600 ppb AFLB₁ developed noticeable alterations in hepatopancreas tissue. R-cells became atrophied and severe necrosis and shrinkage of the tubules could be observed. Infiltration of haemocytes and fibroblastic cells produced a fibrosis-like exterior look. The cytoplasmic content of degenerated cells and pyknotic nuclei were observed in the lumen (Figure 1D).

Such changes were detected in nearly half of the samples examined. After 8 weeks, the shrimps fed with 800 and 1600 ppb AFLB₁, had showed severe histopathological alterations, similar to those observed at week 4. Spread necrosis and complete destruction of B cell were observed. Presentation of fibroblastic cells in the tubule structure inhibit of its complete demolition (Figure 1C). In 1600 ppb treatment connective tissue was completely isolated from hepatopancreas tissue and in midgut tissue,

separation between mucousal and sub mucousal layers as well as necrosis and structural destruction were clearly seen (Figure 2A). In muscular tissue, in shrimps have been fed with diet contain more than 800 ppb AFLB₁, separation among muscular fibers were obviously observed (Figure 2B).

Figure 1: Transverse section (TS) of the hepatopancreas, lumen and muscle of the *F. indicus* feed with diets containing aflatoxin B₁ (AFLB₁) for 8 weeks. The structure of hepatopancreas in shrimps fed with diet containing 50 ppb AFLB₁ and Black arrows indicate three types of cells, × 200 (A). Changes in B cell structure from cylindrical to cubic shape, extinction of secretory tubule aperture (white arrow), Early degenerative changes (rectangle) and reduction in E cells count (circle) in shrimps given more than 400 ppb AFLB₁ for 4 weeks, × 100 (B). Spread necrosis and complete destruction of B cells and subversion of necrotic tissue into the tubule lumen (white arrow), × 400 (C). Cytoplasmic content of degenerated cells and pyknotic nuclei (N letter) in the lumen, × 400 (D). H&E, Haemotoxylin and Eosin.



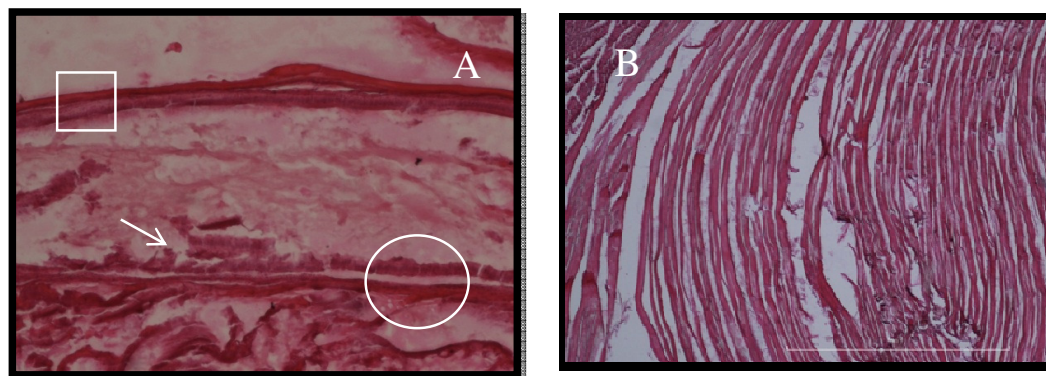


Figure 2: Separation between mucosal and submucosal layers (circle) versus normal structure (rectangle), necrosis and structural destruction of midgut tissue (arrow) in shrimp received more than 1600 ppb aflatoxin B₁ for 8 weeks (A). Abnormality in muscle fibres (B). × 40, H&E, Haemotoxylin and Eosin.

Discussion

Aflatoxins contamination is an inconvenience come across by food and feed producers and raw material suppliers especially in the humid tropical countries. AFLB₁ has known as the most toxic mycotoxin, and nearly all the information available on the bioactivity of aflatoxins in animals has been attentive on AFLB₁ and its metabolites. The effects of AFLB₁ on *F. indicus* were studied considering the importance of the species in shrimp aquaculture and the inadequate information in the shrimp industry.

The THC was found to increase suddenly at the end of 2nd week in shrimps fed with diet containing 400, 800 and 1600 ppb while reduction was observed at 4 and 8 weeks. The high THC in shrimps fed higher levels of AFLB₁ during the first 2 weeks, may be due to response of the immune system to eliminate of AFLB₁ from shrimp haemolymph. Decrease in THC at the end of 4 and 8 week, could be related to the weakening of the defense mechanism. It was must consider, the circulating haemocyte frequency is a health or

stress indicator but this parameter was non-specific and show fluctuation according environmental, and physico-chemical stresses (Soderhall and Cerenius, 1992). Environmental and nutritional stresses can modulate the mitotic activity of haemopoietic tissues and lead to the reduction of the turnover of hemocytes in decapoda (Johnson, 1980).

The TPP showed a drastic decrease in 400, 800 and 1600 ppb treatments at the end of 2nd week but after 4 weeks, there was a gradual decrease in the TPP. Albumin and globulin are two major serum proteins. The total plasma and serum protein are involved mainly in nutrition, water distribution, acid-base balance as well as immunity and metabolic needs (Lehninger et al., 1993). Decrease in TPP was correlated with damage severity of hepatopancreas organ. On the other hand, AFLB₁ disrupts endoplasmic reticulum and reduces the RNA biosynthesis, attachment of poly ribosomes to endoplasmic reticulum, and disruption in ribosomes functions also, thus severely affecting protein biosynthesis. In addition AFLB₁ interacts with

the complex structure of nuclear chromatins, by forming DNA-Aflatoxin complex (Scarpelli and Trump, 1964). The reduction in protein biosynthesis and nuclear damage may be the reasons for the decrease in the total protein content in the present investigation. The TPP reduction trend was shown homology with similar studies (Boonyaratpalin et al., 2000, 2001; Gopinath and Paul Raj, 2009).

The reduction of TPP leads to a reduction in growth and survival rate in affected shrimps. It seems that, shrimp physiology prefers to the use of their tissue protein to redress reduction in protein biosynthesis. Thus, alterations in muscle texture, in 800 and 1600 ppb treatments may be indicative of impaired nutrient absorption, impotence and weight loss.

Phagocytic activity is used to show the percentage of hemocytes containing endocytosed yeast or bacteria (Soderhall and Cerenius, 1992). The decrease of PA can be a consequence of alterations in THC in exposed shrimps. Phagocytosis is contributed mainly by hyalinocytes and also in the lower level by semigranulocytes (Brehélin and Arcier, 1986). Gopinath and Paul Raj (2009) reported the increase of phagocytosis percentage in shrimps exposed to AFLB₁ at the end of 4 weeks in a dose dependent manner, while decreasing phagocytic ratio was observed after 8 weeks.

Aflatoxin B₁ residues in carcasses of exposed shrimps were separately detected at the end of 4 and 8 weeks. According to cooking pattern in Iran and some country, only muscular edible part of the shrimp's body is used. The results from the current study showed that the AFLB₁ residue was highest in the muscle of shrimps in 50, 100, 200 and 400 ppb treatments

after 4 weeks of feeding. However, AFLB₁ residue in muscle gradually decreased at the end of 8 weeks to a level which was lower than that detected in the head of carcasses (0.30-1.55 ppb). This finding was agreed with Boonyaratpalin et al. (2001) and Bintvihok et al. (2003). In spite of some studies, the mechanisms of toxic substance elimination from the shrimp body is not obviously proved (Linares and Ochoa 2009). According to Boonyaratpalin et al. (2001), increasing level of alkaline phosphatase, show direct relation with level of AFLB₁ in diets.

The histopathological studies of the hepatopancreas, midgut and muscles of the control shrimps conformed to the structure described by Bell and Lightner (1988). The general disorder in hepatopancreas tissue was similar to histopathological effects of AFLB₁ exposure described by Lightner et al. (1982). Atrophy of hepatopancreatic tubules, was the first histopathological sign of aflatoxicosis observed in *the F. indicus*. Atrophy of hepatopancreas was followed by the destruction of E, R and B cells, cellular inflammation, infiltration of haemocytes, necrosis and infiltration of fibroblastic cells between the tubules of the hepatopancreas. The effect of AFLB₁ on the hepatopancreas appears to be directly correlated with its concentration and the duration of feeding. Similar changes were reported in Penaeid shrimps fed AFLB₁ (Bautista et al., 1994) and AFLB₁ levels above 100 ppb caused inflammation, necrosis, infiltration of hemocytes and severe degeneration of tubules. The degree and severity of the histopathological alterations observed in the hepatopancreas, midgut and

muscles were undoubtedly related to the decreased final weight and survival rate in the 800 and 1600 ppb AFLB₁ exposed shrimps.

The results of the current study show that the growth parameters, survival rate and health indices (THC, TPP) of Indian white shrimp, *F. indicus*, are affected by the different doses of AFLB₁ in diets. AFLB₁ in the diet showed a highly negative correlation to final weight, survival rate. Moreover, significant histopathological alterations in the hepatopancreas tissue of shrimps exposed to different levels of AFLB₁ were observed. These alterations are evidently indicated by changes in the THC and TPP. From the practical point of view, these indicate that the feeding of shrimps with diets containing less than 200 AFLB₁, will not significantly affect the growth of culture shrimps after 8 weeks.

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تأثیر آفلاتوکسین B₁ روی رشد، سلامتی، فعالیت فاگوسیتوز و تغییرات آسیبی در *Fenneropenaeus indicus*

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چکیده

آلود شدن جیره غذایی مورد استفاده در تغذیه آبزیان به مایکوتوکسین‌ها در مناطق گرم و مرطوب امری بدیهی می باشد. در این مطالعه میگوهای سفید هندی (*Fenneropenaeus indicus*) (۱/۷۶±۱/۷۹ گرم) به مدت ۸ هفته با جیره‌های غذایی حاوی مقادیر صفر، ۲۰، ۵۰، ۱۰۰، ۲۰۰، ۴۰۰، ۸۰۰، ۱۶۰۰ ppb آفلاتوکسین B₁ (AFLB₁) تغذیه شدند. وزن نهایی و میزان باقی مانده بافتی هر دوهفته یک بار و تعداد هموسیت کل (THC)، پروتئین پلاسما کل (TPP)، فعالیت فاگوسیتی (PA) و درصد بازماندگی هر چهار هفته یکبار اندازه‌گیری گردید. در پایان هفته‌های چهارم و هشتم تیمار بندی، تغییرات بافت‌شناسی در بافت هپاتوپانکراس، روده میانی و عضله مورد بررسی قرار گرفت. در پایان هفته چهارم، در میگوهای تغذیه شده با جیره‌های حاوی ۴۰۰ ppb، ۸۰۰ ppb و ۱۶۰۰ ppb AFLB₁ میزان رشد کمتر و قرمزشدگی بیشتری در سطح بدن مشاهده شد. پارامترهای رشد، درصد بازماندگی و شاخص‌های سلامتی (THC و TPP) در میگوهای *F. indicus* تحت تاثیر تغذیه با جیره‌های حاوی مقادیر مختلف AFLB₁ قرار گرفت. در پایان هفته هشتم همبستگی منفی بین دوز AFLB₁ موجود در جیره با وزن نهایی، درصد بازماندگی، THC و TPP مشاهده شد (بترتیب ۲ برابر با ۰/۳۱۲، -۰/۶۰۳، -۰/۳۳۷ و -۰/۶۴۹ با $P < 0.001$). افزون بر این، تغییرات بافت‌شناسی قابل مشاهده‌ای در بافت هپاتوپانکراس، روده میانی و عضله میگوهای تغذیه شده با جیره‌های حاوی مقادیر مختلفی از AFLB₁ مشاهده شد و تغییرات بافت‌شناسی با نوسانات شاخص‌های سلامتی هم‌خوانی نشان داد.

کلمات کلیدی: آفلاتوکسین B₁، *Fenneropenaeus indicus*، رشد، سلامتی و تغییرات آسیبی

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