Evaluation of the efficacy of hydrated sodium aluminosilicate in the prevention of aflatoxin-induced hepatic cancer in rainbow trout

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The use of aluminum silicates for decontaminating animal feed containing aflatoxins has yielded encouraging results in chicken and turkey poults. In contrast, very few studies have tested these substances in aquaculture. In this work, we investigated the efficacy of a trout diet containing 0.5% hydrated sodium aluminosilicate (HSAS) in protecting against contamination with aflatoxin B1. Trout were reared on these diets for one year and the experimental groups were examined monthly for hepatic presumptive preneoplastic and neoplastic lesions. Regardless of the presence of HSAS, all of the fish that received aflatoxin in their diet have shown hepatic lesions indicative of a carcinogenic process, presenting also the development of cancer in some fish. The concentration of HSAS used in this study was ineffective in preventing the onset of hepatic lesions induced by aflatoxin B1 in rainbow trout.

INDEX TERMS: Aflatoxin adsorbents, hepatocarcinogenesis, liver, mycotoxin, teleost.

Introduction

The aflatoxins are produced by only a few strains of Aspergillus flavus and Aspergillus parasiticus that generally just synthesize two or three aflatoxins under a given set of conditions, one of which is always aflatoxin B1 (AFB1), the most potent toxin and carcinogen of the group (Shank 1981). Aflatoxins represent a serious problem in tropical...
countries, as their hot and humid climate favors the growth of *Aspergillus*. The feed contamination is responsible for large economic losses in the livestock industry (Rodriguez-Amaya & Sabino 2002).

The binding of AFB1-oxide to cellular DNA is a trigger for AFB1-mediated mutagenesis and carcinogenesis. AFB1 is carcinogenic in a variety of vertebrates, including rats, ducks, monkeys, trout and humans (Bailey et al. 1996, Benford et al. 2010). Several studies have shown that aflatoxicosis is the most common cause of hepatic neoplasia in cultured rainbow trout (Hendricks et al. 1984, Bailey et al. 1996, Arana et al. 2002).

The introduction of aflatoxin adsorbents has been proposed as a means of sequestering this mycotoxin from contaminated food. The hydrated aluminosilicates have proven to be efficient as aflatoxin adsorbents (Phillips et al. 1988), and their efficacy as aflatoxin adsorbents and in preventing the deleterious effects of these toxins on animal health have been tested *in vivo* by adding the silicate to the diets for chickens and turkey (Kubena et al. 1990a,b), pigs (Schell et al. 1993), cows and lambs (Harvey et al. 1991a,b), rats (Mayura et al. 1998, Abd el-Wahhab et al. 2002) and dogs (Bingham et al. 2004).

This way, the use of substances like hydrated sodium aluminosilicate (HSAS) provides new perspectives for controlling intoxication by aflatoxin-contaminated animal and human feed. In aquaculture, specifically fish farming, only a few studies have examined the usefulness of aluminosilicates (Winfree & Allred 1992, Ellis et al. 2000). Due to concerns regarding liver lesions caused by contaminated commercial feed in trout farms in Brazil, we have studied the efficacy of HSAS in preventing aflatoxin-induced liver lesions in these fish.

**MATERIALS AND METHODS**

**Animals.** Four hundred and thirty-two rainbow trout (*Oncorhynchus mykiss*, Walbaum), originated from domesticated stock reared at the Experimental Salmon Farm Station, in Campos do Jordão (22° 45’ S and 45° 30’ W), São Paulo State, Brazil were used in this study. Six month-old rainbow trout, with a mean weight of 50 g at the beginning of the experiment, were kept in six 1500 L circular fiberglass tanks, under natural photoperiod conditions. Each tank was independently supplied with flow-through surface water (1–2 exchanges/hour). The water temperature varied during 12-month duration of the experiment between 9 and 17°C, and the dissolved oxygen in discharge water was above 5mg L\(^{-1}\).

**Diet.** Hydroxylated sodium aluminosilicate (\(14SiO_2·1Al_2O_3·1Na_2O·4H_2O\) kindly supplied by Rhodia SA) was added as a powder to a commercial rainbow trout diet (Nutravit Com. Ind. Ltda., Brazil) as the last component before the pelletization. The pelletization of experimental diet was made using a small pelletizing machine from the Ration Factory of the Faculdade de Zootecnia e Engenharia de Alimentos da USP. AFB1 (Sigma-Aldrich Fine Chemicals, St Louis, MO, USA) was dissolved in dimethyl sulfoxide (Merck) and added carefully to the ration with a special small industrial mixer at the Experimental Salmon Farm Station, in 4 Kg aliquots. After careful mixing, the commercial rainbow trout, with or without HSAS and/or AFB1, was kept at -20°C. The various preparations were analyzed by a conventional chromatographic method to verify the levels of AFB1 on the experimental diet, and to confirm the absence of this mycotoxin in the control diet (Soares & Rodriguez-Amaya 1989).

These analyses were done for each new preparation throughout the experiment, usually once every two months. On that occasion, the residue of the feed prepared previously was also analyzed to check the levels of contamination during the storage period.

**Experimental procedure.** Six experimental groups were used: Group C - control diet without AFB1 or HSAS, Group H - diet plus 0.5% HSAS, Group A40 - diet with 40μg of AFB1/kg; Group AH40 - diet with 40μg of AFB1/kg plus 0.5% HSAS, Group A80 - diet plus 80μg of AFB1/kg; Group A80H - diet with 80μg of AFB1/kg plus 0.5% HSAS. All groups received their respective experimental diet, supplied by hand twice a day for 12 months. The daily amount of feed distributed corresponded to 2% of the fish biomass per tank per day, based on monthly fish weight data.

Four hundred and thirty-two animals were evaluated at monthly intervals for 12 months, six fish from each group, with the first evaluation commencing 30 days after the beginning of the treatment. The fish were sacrificed by immersion in a solution of benzocaine (100 mg/L). Liver samples were fixed in 10% buffered formalin for 24 h, embedded in paraffin and 6 mm tick sections were stained with haematoxylin-eosin for histopathological examination. The animals were maintained and killed in accordance with the guidelines of The Institutional Committee for Ethics in Animal Experimentation (Unicamp).

The degenerative and presumptive preneoplastic hepatic lesions were characterized based on the criteria defined to rainbow trout by Hendricks et al. (1984) and adapted following the Arana et al. (2002) criteria, which were used to determine the incidence of lesions in the different groups. The criteria described by Arana et al. (2002) were used to define three basic situations that indicated the incidence of these lesions in hepatic sections based on histopathological inspection: 1 = one lesion in the hepatic area analyzed, 2 = two lesions per area, and 3 = three or more lesions per area. A dichotomous classification of absent (0 or no) or present (OK or yes) was applied to the neoplastic lesions.

**Statistical analyses.** The statistical analyses to compare the effect of the treatment on the occurrence of hepatic lesions were done using the Wald test, with significance corresponding to \(P \leq 0.05\). Statistical analyses were performed using a standard statistical software program (MINITAB version: 15.1, Minitab Inc., State College, USA).

**RESULTS**

No mortality was verified during the experimental period. The fish in group C and most of those in group H showed the typical anatomical and histological liver structure for rainbow trout throughout the experimental period (Fig.1A). Two fish in group H developed a presumptive preneoplastic lesion, a basophilic nodule (BN), one of them in the tenth month of experiment and the other in the eleventh month. This spherical lesion consisted of small basophilic cells that formed cords which were easily differentiated from the surrounding normal hepatocytes.

In group A40, presumptive preneoplastic lesions were observed as early as the fourth month of treatment. These lesions consisted of basophilic foci (BF) formed by basophilic cells, with round nuclei and evident nucleoli; these cells were smaller than adjacent hepatocytes (Fig.1B). Figures of mitosis and apoptosis could occasionally be seen between the cells of the basophilic foci. The hepatocytes around the lesion appeared either normal (Fig.1B) or showed characteristics of anaplastic cells. The occurrence of BF lesions increased with the duration of treatment. After nine months, degenerative lesions, such as acidophilic foci (AF), were found. They consisted of large acidophilic cells with mitotic figures and were usually surrounded by anaplastic cells. Frequently, the AF were...
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Fig. 1. Trout liver, stained by HE. (A) Liver of the trout from control group, showing the typical tubular organization, the nuclei of a preductular cell is noted in the center of one tubule (arrow). Bar: 20μm. (B) Basophilic foci (BF) in liver from trout treated with diet with 40μg of AFB1/kg plus 0.5%, note the limits of the basophilic foci and the parenchyma apparently normal where there are less intensely stained hepatocytes. Bar: 20μm.

Fig. 2. (A) Acidophilic foci intensely infiltrated by leucocytes in liver of trout from group A40. Stain: HE. Barr: 50μm. (B) Vacuolated foci surrounded by liver parenchyma apparently normal in trout from A80. Stain: HE. Bar: 50μm.

Fig. 3. (A) Basophilic nodules in liver of trout from group AH80. Stain: HE. Barr: 50μm. (B) Area of HCC in liver of trout from group AH40 showing mixed pattern characterized by proliferating ductal areas (arrows) surrounded by desmoplastic tissue and micronodules of basophilic cells. Stain: HE. Bar: 20μm.
infiltrated and largely destroyed by leucocytes (Fig.2A). In the three last months of the experiment, another degenerative lesion as vacuolated foci (VF) consisting of cells with an intensely vacuolated cytoplasm (micro and macrovacuolization) were also observed (Fig.2B) together with BF and AF. After eight months basophilic nodules (BN) were observed (Fig.3A), alone or in association with BF, VF or AF. Neoplastic lesions classified as hepatocellular carcinoma (HCC) surrounded by anaplastic cells were observed in one fish in this group. HCC showed a mixed pattern characterized by proliferating ductal areas surrounded by desmoplastic tissue and micronodules of basophilic cells (Fig.3B). At the end of the experiment, other fish in this group showed a cholangiocarcinoma, which is characterized by a lesion composed entirely of ductular elements supported by stroma.

The time and frequency of the development of BF, AF, VF and BN were similar in groups A40, AH40 and A80. However, HCC was not observed in group AH40 and developed earlier and was more frequently found in A80 than in the groups that received diet with 40μg of AFB1/kg. Livers from fish in group AH80 showed BF after the third month of treatment, and HCC was seen at the seventh month in one fish. At the end of the experiment, 6 fish showed HCC and one also had cholangiocarcinoma.

Statistical analysis showed that the differences in the incidence of degenerative, presumptive neoplastic and neoplastic lesions were significant when the results of the aflatoxin-treated groups were compared with those for groups C and H, and when the results of the groups treated with 40μg of AFB1/kg were compared with those for groups treated with 80μg of AFB1/kg. The differences between the aflatoxin-treated groups were not significant whether with HSAS or not (Table 1).

**DISCUSSION AND CONCLUSIONS**

The normal liver architecture and histological features seen in most of the trout in C and H groups indicated that a concentration of 0.5% HSAS in the feed was not toxic to rainbow trout, as also observed in birds and other animals (Phillips et al. 1988, Harvey et al. 1991a,b, Abdel-Wahhab et al. 2002).

The most commonly used nomenclature for altered foci in fish mimics the system used for rodents, that is, eosinophilic, basophilic and vacuolated foci (Wolf & Wolf 2005), but between these lesions the basophilic foci appear to be precursors of hepatocellular neoplasms (Hendricks et al. 1984). In fact, Hendricks et al. (1984) registered that AF in trout hepatocarcinogenic process is commonly observed infiltrated by cells of the immune system, predominantly lymphocytes, and largely destroyed by these cells. The authors suggested that these foci are recognized as antigenically foreign by the immune system and could be a degenerative lesion, not really involved in carcinogenic process. Our results, where AF were infiltrated by leucocytes and largely destroyed, agree with the observations of Hendricks et al. (1984). Thus, we did not consider AF as presumptive preneoplastic lesion.

In this study vacuolated foci occurred in the three last months of the experiment, with suggest that this type of foci are not involved with the carcinogenic process induced by aflatoxin in trout. This observation is in agreement with Hendricks et al. (1984) which discussed the possibility that this type of foci are not involved in any type of stepwise progression toward neoplasia in trout, but represent another toxic effect of the carcinogenic compounds usually tested on trout.

Considering our results and the notes listed above, only basophilic foci and basophilic nodules could be considered presumptive preneoplastic lesions in hepatocarcinogenic pro-cress of trout.

The occurrence of a presumptive preneoplastic lesion in trout in group H was not statistically significant compared to the control group. This lesion was not attributable to feed contaminated with aflatoxin since analysis of the feed in this group revealed no traces of this toxin. A possible explanation for the appearance of this pathologic process could be spontaneous formation of lesions caused by a congenital genetic disorder, such as occurs in mice (Frith et al. 1994).

The histopathological and statistical results indicate that the dose of HSAS employed here was not effective in preventing or reducing the occurrence of preneoplastic and neoplastic lesions induced by AFB1 in the trout. Previous reports have yielded conflicting results regarding the efficacy and potential adverse consequences of adding hydrated aluminosilicates to animal feed. There are a few reports in the literature that analyzed the efficacy of aflatoxin adsorbents using histopathological analyses, actually the majority of reports emphasized analysis of growth performance. Some researchers, using histopathological parameters, reported that the addition of 0.5% HSAS to poultry feed had little effect on liver lesions induced by aflatoxin (Kirby et al. 1990, Kubena et al. 1990a).

The addition of HSAS to feed contaminated with aflatoxin improves the immunological resistance of birds and helps prevent alterations in plasma protein levels frequently caused by this toxin (Kirby et al. 1990, Kubena et al. 1990a). Treat-

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**Table 1. Probability of the occurrence of: degenerative, presumptive preneoplastic and neoplastic lesions, considering the total occurrence of each one in 12 months, in different combinations of treatments**

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Treatment combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/C</td>
<td>H/AH40/AH80d</td>
</tr>
<tr>
<td>VF&lt;sub&gt;b&lt;/sub&gt;</td>
<td>0.9999 0.0638 0.1786 0.5620 0.8859 0.0772 0.0350*</td>
</tr>
<tr>
<td>AF&lt;sub&gt;b&lt;/sub&gt;</td>
<td>0.9999 0.1894 0.0007* 0.1196 0.0093* 0.0355* 0.5237</td>
</tr>
<tr>
<td>BF&lt;sub&gt;f&lt;/sub&gt;/BN&lt;sub&gt;f&lt;/sub&gt;</td>
<td>0.9999 0.0001* 0.0001* 0.3004 0.7796 0.4732 0.5438</td>
</tr>
<tr>
<td>HCC&lt;sub&gt;d&lt;/sub&gt;</td>
<td>0.9999 0.0003* 0.0001* 0.4645 0.5670 0.0001* 0.0001*</td>
</tr>
</tbody>
</table>

<sup>a</sup>Group C = control, <sup>b</sup>group H = 0.5% HSAS, <sup>c</sup>group A40 = 40μg of AFB1/kg, <sup>d</sup>group AH40 = 0.5% HSAS and 40μg of AFB1/kg, <sup>e</sup>group AH40 = 0.5% HSAS and 40μg of AFB1/kg, <sup>f</sup>group AH80 = 80μg of AFB1/kg, <sup>g</sup>VF = vacuolated foci, <sup>h</sup>AF = acidophilic foci, <sup>i</sup>BF = basophilic foci, <sup>j</sup>BH = basophilic nodules, <sup>k</sup>HCC = hepatocellular carcinoma. Probability of the test values to be less than 0.05.
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Abdel-Wahhab M.A.A., Nada S.A. & Khalil F.A. 2002. Physiological and metabolic effects of aflatoxin were apparently not inhibited by HSAS, probably because of high fish sensitivity to this toxin (Williams et al. 2009).

In a manner similar to that seen in trout, Mayura et al. (1998) observed in rats treated with AFB1 plus clinoptilolite (a zeolite) the occurrence of more serious liver lesions as nodules of regenerating hepatocytes in addition to massive bile duct proliferation and hepatocellular degeneration also observed in rats treated only with AFB1. These authors suggested that zeolite might interact with dietary components that modulate aflatoxicosis. Furthermore, Huwig et al. (2001) pointed out that the inclusion of aluminosilicates in diet has the disadvantage of potentially interfering with the assimilation of vitamins and minerals.

In the present study, HSAS may have interfered with absorption of some feed components, thereby affecting fish treated with higher doses of AFB1. In fact, Shi et al. (1994) demonstrated in an in vivo study on rats that selenium inhibits AFB1-DNA binding and adduct formation. Many other vitamins and anti-oxidants naturally found in diet produced this inhibitor effect (Atroshi et al. 2002). However, the suggestion that the lack of effect against AFB1 in trout can be due to binding of protective components by aluminum silicate lies on confirmation by specific analyses.

Finally, our results reinforce the belief that aflatoxin adsorbents should be rigorously tested individually and in vivo characterized. Particular attention should be given to favorable thermodynamic characteristics of sorption, safety and efficacy in multiple animal species, safety and efficacy in long-term studies and negligible interactions with vitamins, iron and zinc (Philips et al. 2008), as well as economic and technical applicability (Galvano et al. 2001).

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