Outlook for Fish to 2020 – A Review

The supplies of fish in the world's vast oceans once seemed inexhaustible. Not any more. In the past three decades, production and consumption of fish have risen so dramatically that the world's wild fisheries may fall victim to their own success. Meanwhile, the growing aquaculture industry has attempted to fill the gap between supply and demand. But as the global appetite for fish continues to increase, current trends in the fish sector pose serious risks to the environment, to the well-being of poor people, and to the viability of the fish sector itself.

What is the outlook for fish in a globalizing food economy, and how Will trends in the fish sector affect the poor and the environment during the next two decades? A new book from IFPRI and the World Fish Center, Fish to 2020: Supply and Demand in Changing Global Markets, and an accompanying food policy report, Outlook for Fish to 2020: Meeting Global Demand, examine changes in the fish sector; the forces driving these changes; and the implications of the changes for fish consumption, production, prices, trade, the environment, and the world's poor.

SURGING
FISH CONSUMPTION, PRODUCTION, AND TRADE

Global consumption of fish has doubled since 1973, and the developing world has been responsible for nearly all of this growth. Countries with rapid population growth, rapid income growth, and urbanization tend to have the greatest increases in consumption of animal products, including fish products, and the developing world has experienced all three trends. China, where income growth and urbanization have been major factors, dominates consumption of fish products. It accounted for about 36 percent of global consumption in 1997, compared with only 11 percent in 1973 (Figure 1). India and Southeast Asia together accounted for another 17 percent in 1997, with total consumption doubling since 1973. Although total fish consumption declined somewhat in the developed countries, this decline was dwarfed by the increases in the developing world.

Besides being used as food, fish is also increasingly demanded for use as feed. Nearly one-third of the world's wild-caught fish are "reduced" to fishmeal and fish oil, which are then used in feeds for livestock like poultry and pigs and in feeds for farmed carnivorous fish. Because aquaculture is likely to grow quickly over the next 20 years, some experts are concerned that rising demand for fishmeal and fish oil could place heavier fishing pressure on already threatened stocks of fish used for feed.

To meet the burgeoning demand for fish, production has soared. The growth in production, like that in consumption, comes almost entirely from developing countries (Figure 2), which now produce nearly three times as much fish as developed countries.

Exploitation of wild fish stocks rose rapidly during the 1970s and 1980s, thanks to expanded fishing fleets, new fishing technologies, and increased investments in the fishing sector. Global capture of fish for food jumped from 44 million tons in 1973 to 65 million tons in 1997. By the late 1980s, however, the stocks fished by many wild-fishing operations were fully exploited and even overexploited. Since then, despite increases in investment and fishing capacity, fish production from wild fisheries has slowed or stagnated.

Developing countries have taken the lead in producing fish from wild fisheries since the 1980s, partly because of the establishment of 200-mile exclusive economic zones (EEZs) around coastal nations. Whereas developed-country production from wild fisheries exceeded developing-country production by 6.6 million tons in 1973, by 1997 the developing countries were producing twice as much as the developed countries.

Because most wild fisheries are near their maximum sustainable exploitation levels, production from these fisheries will likely grow only slowly to 2020. Although fishers could probably produce more by targeting underexploited species that have been in lower demand, it is not clear that consumers will accept these species. More important, such a change could cause large shifts in species composition and indirectly harm predator species, with severe consequences for the environment.

With wild fish production stagnating, growth in overall fish production has come almost entirely from the global boom in aquaculture, especially in developing countries. Aquaculture now represents more than 30 percent of total food fish production, and Asia accounts for 87 percent of global aquaculture production by weight. In the coming decades aquaculture will likely be the greatest source of increased fish production as fish farmers expand the water surface area under cultivation and increase yields per unit of area cultivated. But the sector must overcome several major challenges if it is to sustain the rapid growth of the past 20 years. It will face competition from other users for land and water. Disease and the scarcity of fishmeal and fish oil derived from wild-caught fish may also constrain aquaculture production. Growth in aquaculture production will also depend heavily on the level of public and private investment in the sector. Because of the slow growth in wild fisheries, the level of aquaculture production will play a large role in determining the relative prices of fish commodities.

Fish products are a heavily traded commodity— roughly 40 percent of global fish output by value in 1998 was traded across international borders—and the enormous rise in fish production in developing countries has caused an about-face in the direction of trade in fish products since the early 1970s. In 1973 the developed world was a net exporter of 818,000 tons of food fish, but by 1997 these countries were net importers of 4,045,000 tons of food fish. By the late 1990s more than 50 percent of fish exports came from developing countries.

As a consequence of rising demand and slower growing production, the real prices of most fresh and frozen fish have risen since World War II, in contrast to prices of most animal-origin foods, which have declined steeply over the past several decades. Exceptions to the general rise in fish prices are canned finfish, which have declined in popularity in developed countries since the early 1970s, and some individual commodities like shrimp and salmon, which have seen large gains in production owing to aquaculture.

PROJECTIONS AND SCENARIOS TO 2020

To help clarify the consequences of different policy and environmental scenarios for the fish sector, IFPRI researchers drew on a tool called the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT).This model projects fish (and other food items) supply, demand, and trade not only for a baseline (or most likely) scenario in 2020, but also for alternative scenarios, such as slower or faster aquaculture expansion, lower Chinese production, more efficient use of fish feed, and ecological collapse of wild fisheries.

Fish are highly likely to continue becoming more expensive to consumers compared with other food products over the next two decades, according to the model. Prices for food fish, fishmeal, and fish oil are likely to rise under nearly all scenarios. Faster aquaculture expansion is the only scenario leading to a drop in the projected real prices of low-value food fish, though it would also cause a significant rise in the price of fishmeal. The one scenario that leads to slightly lower real fishmeal prices is the one that improves efficiency in fishmeal and fish oil conversion through rapid technological progress.

People in the developing world will increase their total consumption of food fish, whereas total consumption will remain static in the developed world. Even under the ecological collapse scenario, global per capita consumption declines only a small amount—from 17.1 kilograms per year under the baseline scenario to 14.2 kilograms. This is largely because producers respond to resulting major price increases for fish products by pursuing greater aquaculture production.

The rapid growth in fish production is also likely to continue, with developing countries producing an ever increasing share. More and more fish production will come from aquaculture, whose share in worldwide fish production is projected to increase from 31 to 41 percent in 2020 in the baseline scenario.

Assumptions about investment in aquaculture are crucial for production results in other scenarios. For instance, faster aquaculture expansion would produce 25 million metric tons more fish than slower aquaculture expansion. Technology also matters greatly. Making fishmeal more efficient in its effects on the growth of farmed fish reduces fishmeal production by 1 million tons compared with the baseline, a result that would reduce fishing pressure on fish used as feed.

Net exports from the developing world are projected to continue through 2020, though at a lower level than presently. This is mainly because of rising domestic demand within developing countries for fish because of population growth, income growth, and urbanization.

FISHERIES AND THE NATURAL ENVIRONMENT

A healthy natural environment is essential to maintaining fish harvest levels in the face of increasing demand. Unfortunately, fishing activities around the world often cause large-scale damage to the aquatic environment.

Most environmental damage stems from wild fisheries, where over fishing poses by far the greatest environmental threat. Over investment in fishing and the resulting overcapacity have led to excessive exploitation of fish stocks, especially by developed-country fleets. During the 1970s and 1980s fleet size increased twice as fast as fish harvests. Most stocks of wild fish today are classified as fully exploited, and an increasing number are overexploited, in decline, or in recovery. Moreover, wild-fishing operations capture, kill, and discard a massive quantity of bycatch—fish that are the wrong size, the wrong species, or otherwise undesirable. Global discarded bycatch of fish and other marine organisms is currently estimated at more than 20 million tons a year, nearly one-quarter of the world fish catch.

Some fishing practices—like bottom trawling, blast fishing, and poison fishing—destroy marine habitats. Fishing itself can also harm ecosystems by removing massive quantities of a species and leading to wholesale changes in the food web dynamics of those systems.

Many people hope aquaculture can sustainably ease pressure on threatened wild stocks, but it has environmental problems of its own. As aquaculture production has become more widespread and intensive, the movement of live aquatic animals and products has increased, making the accidental spread of disease more likely. Effluent from aquaculture ponds and pens, like fertilizer, undigested feed, and biological waste, is often released directly into surrounding waterways. And rapidly increasing demand for fishmeal and fish oil may place pressure on the wild stocks from which these products are derived.

Over the past few decades coastal aquaculture development, especially shrimp farming, has caused the destruction of hundreds of thousands of hectares of mangrove forests, which are crucial for filtering nutrients, cleansing water, and protecting ecosystems from floods and storms. In addition, farmed fish that escape into the wild can threaten native species by acting as predators, competing for food and habitat, or interbreeding and changing the genetic pools of wild organisms. Concern over escaped species is likely to intensify in coming years as genetically modified fish are developed for aquaculture.

FISH IN THE LIVES OF POOR PEOPLE

Poor people are facing new barriers in both their production and consumption of fish. Even by the standards of developing countries, landless fish workers and artisanal fishers are often among the poorest of people, and they generally operate at a small scale and use traditional fishing practices. Yet new technologies and environmental requirements may favor large-scale, capital-intensive operations at the expense of traditional and small-scale commercial fishers.

The rising importance of fish trade also raises barriers to poor producers. Developed countries have erected non-tariff barriers in response to consumers' concerns about the food safety of fish. Meeting the new requirements for documenting the safe handling, processing, and origin of fish products requires considerable experience, skill, and investment. Developing countries that can address new hygiene and food safety requirements, fair labor practices, and environmental needs will have the opportunity to capture more of the lucrative export market. But if the poor are to benefit from this potentially profitable activity, policymakers will need to find ways of including smaller-scale producers in these arrangements.

In addition, the rising cost of low-value food fish to the poor is a real policy concern. Even a small amount of fish is an important dietary supplement for poor people who cannot easily afford animal protein and who rely mainly on starch diets. But over the past 30 years fish has become more expensive relative to other food items because fish demand, primarily from relatively wealthy consumers in developing countries themselves, is outstripping supply.

NEW TECHNOLOGIES NEEDED

As demand for fisheries products grows during the next several years, technology must play a crucial role in helping suppliers keep pace in a sustainable way.

REDUCING PRESSURE ON WILD FISHERIES

Nearly one-third of the world's wild-caught fish are not consumed directly by humans but rather are "reduced" to fishmeal and fish oil and consumed in feed by farm raised animals, such as chickens, pigs, and other fish. This situation has raised concerns that demand for fishmeal and fish oil from the burgeoning aquaculture sector will raise prices for these commodities and place increasingly heavy pressure on wild fisheries to produce fish for feed.

Technology can reduce the risks of higher prices and overfishing by providing alternatives to fishmeal and fish oil in aquafeeds, such as protein-rich oilseed and grain byproduct meals. For a variety of reasons, vegetable meals are not ideal substitutes for fishmeal in aquafeeds, so research is needed to help overcome this problem.

IMPROVING MANAGEMENT OF WILD FISHERIES

Technological advances that improve information and management methods are now needed more than advances to increase fishing capacity. Satellite remote sensing and other information technologies can help provide better information about wild fish stocks as well as help monitor fishing activity and improve consumer information about the condition and origin of fish products. But successful management of the world's wild-fishing operations will depend on the coordination of technology and policy. One example is a vessel monitoring system, which employs satellite tracking to allow onshore tracking of vessel movements, thereby enhancing the enforcement of regulations.

Technology is also crucial to avoiding the environmental damage and waste caused by certain fishing practices. Although some types of fishing gear may be banned altogether, others may be modified. Bycatch reduction devices, or BRDs, are increasingly used in fishing operations to lower the amount of unintended catch. But without policy incentives to encourage their use, along with training and extension, BRDs will remain unused or ineffectively used.

RAISING PRODUCTIVITY IN AQUACULTURE

Breeding technology in aquaculture is in its relative infancy. Breeders have significantly raised productivity for a few commercial species such as salmon, trout, and tilapia, but the successful cultivation and breeding of other species such as cod and bluefin tuna would be a tremendous boost to high-value aquaculture.

Genetic modification and biotechnology also hold tremendous potential to improve the quality and quantity of fish reared in aquaculture, although not without significant controversy and risk. Biotechnology has the potential to enhance reproduction and the early developmental success of cultured organisms. The possible environmental effects of genetically modified aquatic organisms are not well understood, however, and concerns exist over possible human health risks. The documented escapes of farmed salmon and their threat to native wild populations demonstrate that caution should be employed when considering the introduction of a new species into an ecosystem.

INTENSIFYING AQUACULTURE SUSTAINABLY

Although intensification of aquaculture can potentially generate high levels of environmental problems, capital intensive production systems often give producers more control over problems like effluent pollution and the spread of disease. Technology may in fact present economies of scale in the control of environmental problems.

Intensification can raise the risk of disease. Management techniques such as rotation of cultured species and lower-density stocking of organisms can partially address this risk, but antibiotics and water control technologies like aerators and water recirculation systems can also mitigate the stress caused by high concentrations of organisms.

Technologies based on local knowledge systems and different political and cultural contexts can also help develop aquaculture in underexploited water bodies, such as rice paddies, irrigation canals, reservoirs, and seasonal or perennial ponds in developing countries. Some technologies long employed in traditional aquaculture systems can also be useful in addressing concerns raised by water management, effluent control, disease control, and land use in intensified aquaculture.

THE ROLE OF POLICY IN THE FISH SECTOR

In both developing and developed countries, policymakers can establish policies and promote institutions that will lead to more sustainable management of fish resources while also ensuring the survival of small-scale producers. One basic step is simply seeing to it that the sector gets the policy attention it deserves.

To improve policy outcomes in the developing countries, policymakers in the developed countries should rationalize their food safety systems for seafood imports, harmonize and modernize tariff classifications, and offer technical assistance in eco-labeling and food safety to small-scale, developing-country fish exporters.

Finally, the focus of demand-side policies in developing countries should be to facilitate South-South trade, to provide public goods to assure domestic food safety, and to help ensure that fish products reach those in developing countries who need them the most from a nutritional standpoint.

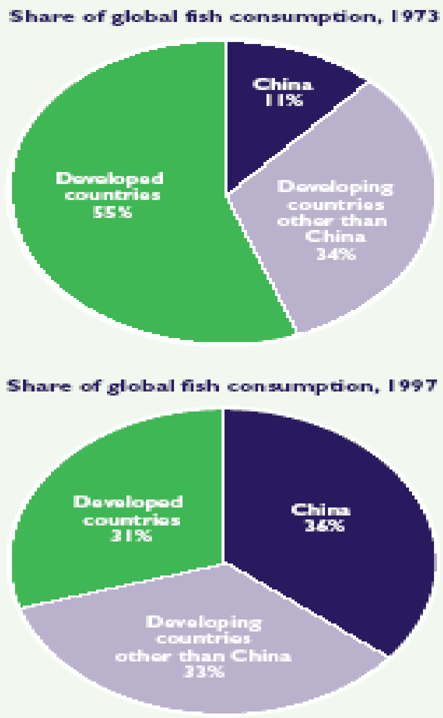
By taking account of the major shifts taking place in the fish sector and combining forward-looking policies with useful new technologies, policymakers can help ensure that the fish sector remains environmentally sustainable as well as beneficial for the world’s poor people.

CHINA: A POWERHOUSE FISH PRODUCER OF UNCERTAIN PROPORTIONS

One of the most striking trends in the capture of fish for food has been China’s emergence as the largest producer and the simultaneous decline of Japan’s production. Whereas Japan’s production fell from 18 percent of world production in 1973 to 7 percent in 1997, China increased its share from 9 percent to 21 percent.

But China’s astonishing growth during the 1990s in fish production, and the contrast between reported production data and household consumption survey data, has raised suspicions about the accuracy of reported totals. One study concluded that Chinese fishery production—including aquaculture—was overestimated by 43 percent in 1995. If China has indeed over reported its fish production (possibly because of institutional incentives), global fish production trends are much less rosy than they otherwise appear.

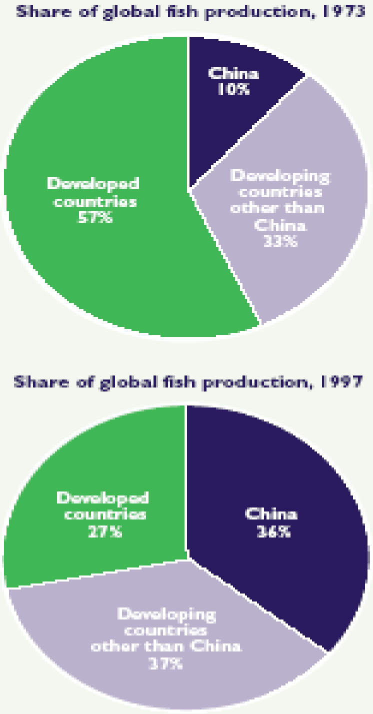
Figure 1 Changing share of developing countries in fish consumption, 1973 and 1997



SOURCE: Calculated by authors from FAO statistical databases, www.apps.fao.org/subscriber (accessed January 2002).

NOTE: Data are three-year averages centered on 1973 and 1997, respectively.

Figure 2 Changing share of developing countries in the production of fish for food, 1973 and 1997



SOURCE: Calculated by authors from FAO, Fishstat Plus: Universal Software for Fishery Statistical Time Series (Rome: FAO Fisheries Department, Fishery Information, Data and Statistics Unit, 2002).

NOTE: Data are three-year averages centered on 1973 and 1997, respectively.

Mycotoxins - a rising threat to aquaculture

Introduction

The primary objective in fish nutrition is to provide a nutritionally balanced mixture of ingredients to support the maintenance, growth, reproductive performance, flesh quality and health of the animals at an acceptable cost.

The diet should also have a minimal effect on water quality and culture systems. In order to achieve these goals the diet must provide all required nutrients in the correct balance and must be formulated to keep any anti-nutritional components below concentrations that would impede the performance and health of the fish (NRC, 1993). Anti-nutritional factors can be present as natural components of feed ingredients or occur as contaminants of feedstuffs, such as ycotoxins, algal toxins, products of lipid auto-oxidation, pesticides or heavy metals. The risk of each contaminant varies among feed ingredients. Changes in diet formulation to include new ingredients or higher concentrations of existing ingredients can significantly alter the risk of contamination. Risk assessment for each contaminant should be reviewed constantly and diet composition and preventive measures adapted accordingly.

Over the last 10 years plant-based ingredients have been increasingly used in fish diets. This change is the product of increased economic/ market pressures on the fish meal and oil manufacturing industries and animal feed compounders, and the drive to produce lower cost, sustainable alternatives by the aquafeed manufacturing sector (Tacon, 2004). The aquaculture sector will have no choice but to further reduce its dependency on fish meal and oil in order to sustain its growth and remain competitive. Although this change can be achieved with relative ease in omnivorous/herbivorous finfish and crustacean species, it is a great challenge in carnivorous fish. In omnivorous fish such as channel catfish (Ictalurus punctatus) nutritional formulation has already developed over the last decade to include little or no animal protein.

Because plant ingredients pose a high risk of mycotoxin contamination, moving to plant protein sources in the aquafeed industry demands careful risk assessment regarding mycotoxins, as well as the development of appropriate protection strategies for fish fed contaminated feeds.

Mycotoxins are naturally occurring, toxic chemical compounds produced by filamentous fungi (molds).

Molds can infect agricultural crops, particularly cereals and oilseeds, during crop growth, harvest, storage or processing. If the conditions for fungal growth and metabolism are right, mycotoxin contamination is often the result. Thus, production of toxic metabolites can occur during the growth of the crop, during post-harvest storage or during the storage of the compounded feed. The use of more plant-based ingredients in aquafeeds enhances both the risk of introducing mycotoxins into the feed at the point of feed manufacturing, and mycotoxin production during storage of compounded feed. Through contamination with fungal spores, plant ingredients can infect the final diet with spores. If temperature and moisture in the storage environment allow for fungal growth, additional mycotoxins can be produced in between manufacturing and use of the feed.

Since conditions for fungal growth vary greatly between the field and storage, different fungal populations may result, producing cocktails of mycotoxins. This possibility must be considered when conducting a risk assessment and implementing preventive measures. Although several hundred mycotoxins are known, the mycotoxins of most concern, based on their toxicity and common occurrence, are aflatoxin, ochratoxin A, the trichothecenes (DON, T-2 toxin), zearalenone, fumonisin, and moniliformin (Table 1).

Table 1. Occurrence of key mycotoxins.

Mycotoxin	Producing fungi	Commodities affected
Aflatoxin	*Aspergillus flavus* *Aspergillus parasiticus*	Corn, cotton seed, peanuts, soy
Ochratoxin A	*Aspergillus ochraceus* *Aspergillus nigri* *Penicillium verrucosum*	Wheat, barley, oats, corn, others
Trichothecenes	*Fusarium graminearum* *Fusarium culmorum*	Corn, wheat, barley
Zearalenone	*Fusarium graminearum*	Corn, wheat, barley
Fumonisin	*Fusarium verticillioides* *Fusarium proliferatum*	Corn
Moniliformin	*Fusarium moniliforme*	Corn

Adapted from Bhatnagar et al., 2004

Mycotoxicoses

Mycotoxins are structurally very diverse, a characteristic that leads to a wide range of symptoms in mycotoxin affected animals. The mode of action of mycotoxins is grouped by three primary mechanisms: (1) alteration in the content, absorption and metabolism of nutrients; (2) changes in endocrine and neuroendocrine function; and, most importantly, (3) suppression of the immune system (CAST, 1989). The effects on the immune system are of particular importance as they predispose animals to infectious diseases and reduce productivity.

The fact that most of the symptoms of mycotoxicoses are rather nonspecific and can have multiple causes often makes it difficult to properly diagnose mycotoxin problems. General symptoms (reductions in performance and immune status) are seen when dealing with moderate toxin levels, while symptoms caused by higher toxin levels are more specific. Further complications in mycotoxicosis diagnoses can be caused by secondary symptoms resulting from opportunistic disease related to the suppression of the immune system after mycotoxin exposure. To effectively recognize mycotoxicosis, experience with mycotoxin-affected animals is important. This experience, combined with adequate feed and tissue analyses, provides the most accurate diagnosis of mycotoxicosis.

Aflatoxin

Aflatoxin is produced primarily by Aspergillus flavus, and is a major concern due to its carcinogenicity and ubiquity, especially in warm and humid climates. It can be produced both in the field and during storage. Due to the growth requirements of the fungi, aflatoxin poses a particular risk in warmer climates. Bautista et al. (1994) surveyed commercial shrimp feeds in the Philippines and reported aflatoxin B1 concentrations varying from 0 to 120 ppb. Surveys in Egypt showed even higher levels (>1000 ppb) for different commercial fish feeds (Abdelhamid et al., 1998).

Since aflatoxin is transferred at low rates into edible tissues, it is not only of concern for animal health, but also for the health of humans consuming food of animal origin. Therefore, in some countries the regulatory authorities have set upper limits for aflatoxin in feeds and animal products. In these markets, ingredients or diets with aflatoxins that exceed these limits must be removed and destroyed.

Aflatoxin was the first of the mycotoxins to be investigated in aquaculture. As in other animal species, aflatoxin exerts carcinogenic effects in fish. Wolf and Jackson (1963) traced hepatomes in rainbow trout exposed to increased concentrations of dietary aflatoxin B1; and exposure to low levels of aflatoxin was observed to cause hepatocellular carcinomas. Different research groups have reported that long-term exposure of <1ppb of dietary aflatoxin B1 can be sufficient to cause hepatomes (Lee et al., 1968, Sinnhuber et al., 1965).

The carcinogenic or toxic effects of aflatoxin in fish seem to be species specific. Coulombe et al. (1984) reported greater aflatoxin sensitivity in rainbow trout than in coho salmon, and noted that the ability of aflatoxin B1 to bind DNA was much greater in trout compared with salmon liver. Such differences could be linked to cytochrome P-450 metabolism of aflatoxin, which is not uniform between these species. Lower hepatotoxic effects were also reported for tilapia compared with rainbow trout (Ngethe et al., 1993).

In a 10-week feeding period, tilapia fingerlings were reported to tolerate 50 ppb aflatoxin B1 with little or no effect on performance. However, fingerlings showed a reduction in performance when feeding time was increased. A reduction in performance was observed within 10 weeks when the mycotoxin dose was raised to 100 ppb (El-Banna et al., 1992). In a second trial, with Nile tilapia, a 25-day exposure to 1880 ppb dietary aflatoxin B1 significantly reduced feed consumption and growth rate (Chavez-Sanchez et al., 1994). Normal consumption levels resumed after switching back to uncontaminated feed, although growth rate remained at a lower level, indicating long-term organ damage that affected fish were not able to overcome.

In an investigation into 'yellow disease' of tilapia in commercial farms in the Philippines, Cagauan et al. (2004) found that feed made with different levels of aflatoxin-contaminated corn did not significantly affect weight or weight gain of fish. However, fingerling survival was reduced by aflatoxin ($P<0.001$). The authors concluded that the 'yellow disease' was indeed the result of aflatoxin contamination of feed. Clinical signs observed in fish fed the aflatoxin-contaminated feeds were eye opacity, cataracts and blindness; skin lesions; fin and tail rot; yellowing of the body surface; abnormal swimming and reduced appetite and feeding. Histology also revealed damage or gradual deterioration of the liver.

The complexity of the task has made it impossible to determine a safe level for mycotoxins in feeds. Adverse effects depend not only on the dietary concentration, but also on the length of exposure, the fish species, the age of the fish, their nutritional status and health status.

Since aflatoxin can impair immune function (Ottinger and Kaattari, 2000), exposure increases fish susceptibility to disease. A healthy fish is less likely to succumb to secondary infections and has a greater tolerance for the toxin. Reduced immune function has been reported in Indian major carp (Labeo rohita) after exposure to aflatoxin B1 in the feed at doses as low as 1.25 mg/kg body weight (Sahoo and Mukherjee, 2001). Sahoo and Mukherjee (2002) later reported that addition of high levels of α-tocopherol in feed (1000 mg/kg) significantly improved immune response in fish exposed to aflatoxin-contaminated feed.

Aflatoxin has been shown to significantly reduce shrimp performance. Bautista et al. (1994) reported a significant reduction in performance of pre-adult shrimp (Penaeus monodon) at aflatoxin B1 concentrations of 75 ppb in a 60-day study (Figure 1). At the same level of challenge, higher susceptibility to shell diseases was also noted.

Histopathological changes in the hepatopancreas of shrimp were observed at the lowest inclusion level of 25 ppb, and became more pronounced with increasing dietary toxin concentrations. No tissue residues were detected after 60 days even at the highest inclusion level of 200 ppb, suggesting a low potential for transmission of the toxin from edible shrimp tissue to the consumer. This trial showed that typical aflatoxin concentrations found in commercial shrimp feed exceed the levels that can be tolerated without adverse effects on shrimp health and performance. A decrease in performance in response to aflatoxin B1 was reported in both Pacific white shrimp (Penaeus vannamei) and black tiger shrimp. These results differ from other measured tolerance levels of 400 to 500 ppb (Ostrowski-Meissner et al., 1995; and Boonyaratpalin et al., 2001).

In addition, Bautista and coworkers reported a decrease in diet digestibility and impaired immune function at higher aflatoxin inclusion levels.

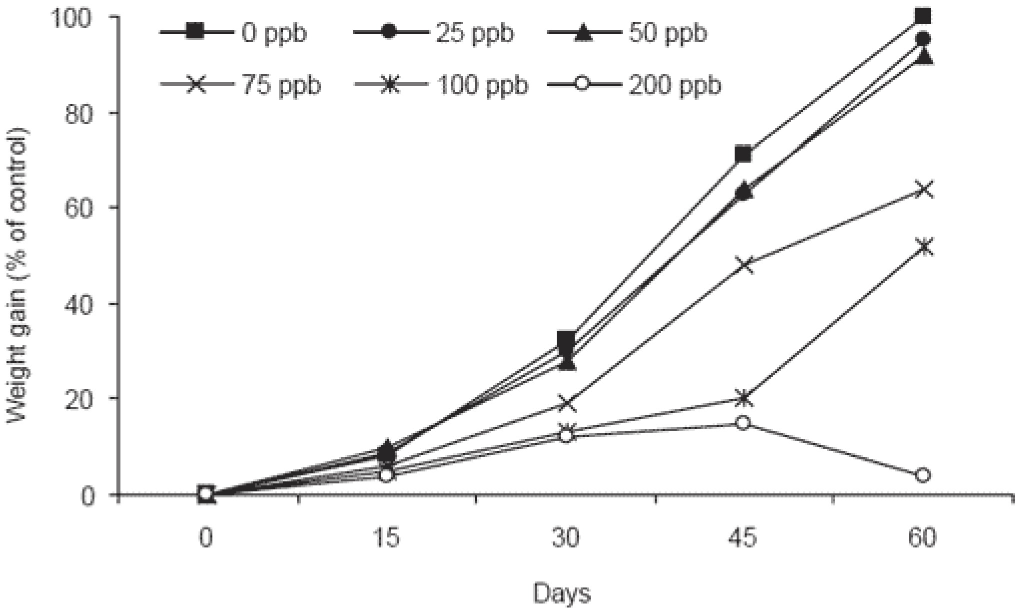


Figure 1. Percentage weight gain of shrimp fed diets contaminated with 0, 25, 50, 75, 100 and 200 ppb aflatoxin B1.

It was concluded that aflatoxin B1 concentrations commonly found in feed (Bautista et al., 1994; Abdelhamid et al., 1998), are in the range that significantly impair aquatic animal health and performance. Therefore, measures to reduce exposure must be taken when striving for maximum health, performance and economic results.

Ochratoxin A

Ochratoxin A has not been studied to the same extent as aflatoxin in aquaculture. Ochratoxin can be present in cereal grains and oilseeds, and is often formed during ingredient or diet storage. Ochratoxin A is primarily produced at higher temperatures by Penicillium verrucosum. Thus, like aflatoxin, ochratoxin is more often found in warmer climates. The key target organ of ochratoxin is the kidney, where it causes necrotic lesions in the proximal tubules.

In catfish, ochratoxin A has been shown to reduce weight gain when fed at 1000 ppb for 8 weeks (Manning et al., 2003b), although 500 ppb did not affect weight gain. Higher inclusion levels (4-8 ppm) significantly reduced feed conversion efficiency and hematocrit values. Interestingly, in contrast to observations in mammalian and avian species, the toxin did not lead to any necrotic changes in the renal tubules. Necrosis was only reported in hepato-pancreatic tissue at toxin concentrations of 1000 ppb and above.

Shalaby (2004) noted a reduction in erythrocyte count, haemoglobin concentration and haematocrit value in response to ochratoxin (at 400 and 600 µg/kg of feed) in tilapia, possibly due to destruction of mature red blood cells and inhibition of new erythrocyte production. This effect is similar to that observed in African catfish (Clarias gariepinus) exposed to ochratoxin (Mousa and Khattab, 2003). Shalaby found that inclusion of ascorbic acid at 500 mg/kg diet could offset the effects of ochratoxin. Other ochratoxin-induced effects were a significant increase in plasma glucose concentration and a dose-dependent reduction in total plasma protein, muscle and liver protein, total lipid in the plasma and a marked reduction in aminotransferase in liver and muscle.

Further research will be required to fully assess the risk ochratoxin A poses to aquaculture.

Trichothecenes and zearalenone

Trichothecenes and zearalenone are produced in temperate climates by the molds Fusarium graminearum and Fusarium culmorum. These toxins are produced in the field and enter fish diets as grain contaminants; and they continue to be produced during storage. Zearalenone has estrogen-like activity that has detrimental effects on the fertility of mammals, although it is probably of less importance in aquaculture. Arukwe et al. (1999) did report that zearalenone could affect reproductive success and the development of fish eggs, and α-zearalenone, one of its metabolites, has been shown to reduce the number and quality of sperm in carp (Sándor and Ványi, 1990).

Trichothecenes have been intensively researched, and are known to affect aquatic species. Chemically, they are structurally similar to compounds such as deoxynivalenone (DON), T2-toxin and diacetoxyscirpenol (DAS). In mammalian and avian species, trichothecenes have been shown to reduce feed intake and performance and impair immune function. In rainbow trout, Woodward et al. (1983) reported that diets containing levels of 1.0 to 12.9 ppm DON caused progressively greater reductions in 4-week live weight gain in juveniles. The depression in weight gain ranged from -12 to -92% compared with the control, and resulted from adverse effects on both feed intake and feed conversion. Complete feed refusal was observed when dietary DON concentrations reached >20 ppm.

Catfish seem more able to tolerate dietary DON (Manning, 2004). In a trial using catfish with initial body weights of 5 g no performance-reducing effect of DON at concentrations <10 ppm were observed. Only concentrations >15 ppm negatively affected performance. Such differences in species susceptibility to DON have not yet been fully investigated, and despite their tolerance to DON, catfish seem quite susceptible to T-2-toxin. Levels as low as 625 ppb have been shown to reduce catfish weight gain (Manning et al., 2003a), and higher concentrations (5000 ppb) significantly reduced feed conversion, survival rate and hematocrit concentrations. Histological inspections revealed an increased incidence of gastritis, a finding that is in agreement with intestinal lesions and gastritis reported in other species.

In shrimp, Trigo-Stockli et al. (2000) reported that DON concentrations as low as 0.2 ppm led to significant reductions in growth rate in the last phase of a 16-week performance trial. Overall body weight was affected at a level of 0.5 ppm (Table 2).

Toxic levels reported in both trout and shrimp seem comparable to concentrations reported in swine, where concentrations of 1 ppm or more are considered problematic, although in young piglets, lower concentrations have been shown to reduce feed intake (Spring and Strickler, 2004).

Table 2. Effect of different dietary concentrations of DON on performance of shrimp in a 16-week trial.

	0 ppm	0.2 ppm	0.5 ppm	1.0 ppm
Final weight, g	11.22^{a}	10.63^{ab}	10.43^{b}	9.67^{c}
FCR	3.25^{a}	3.15	3.66^{a}	3.79^{a}
Survival, %	86.4^{a}	90.9^{a}	81.8^{a}	83.3^{a}
DON level in shrimp	ND	ND	ND	ND

Fumonisin

Fumonisin is of concern to the aquaculture industry because it commonly contaminates corn and its byproducts. A survey of catfish feed ingredients in Alabama and Mississippi in the US revealed that 80% of the corn samples contained detectable levels of fumonisin. Concentrations ranged from 1.3 to 10 ppm (Lumlertdacha and Lovell, 1995). Marasas (1996) conducted a literature review of studies reporting natural occurrence of fumonisin, and noted that over 25 countries around the world had published reports detailing the natural occurrence of fumonisin in both feed and foodstuffs.

The age of animals has been reported to significantly affect the susceptibility to mycotoxicosis in different species, with young animals being more suseptible than older ones. This rule seems also to hold true for fumonisin susceptibility in catfish. Dietary fumonisin at 20 ppm has been shown to reduce growth rate in catfish with an average weight of 1.5 g (Yildirim et al., 2000). Two-year-old catfish only had reduced weight gain when exposed to 80 ppm fumonisin. Toxic effects of fumonisin have been reported in Nile tilapia at concentrations similar to catfish (Nguyen et al., 2003).

Even before performance is affected, mycotoxicosis can suppress immune function. Indeed, concentrations of 20 ppm have been shown to reduce antibody production in two-year-old catfish. These changes did not increase mortality during a challenge with Edwarsiella ictaluri, but when the catfish were exposed to 80 ppm fumonisin, resistance to the pathogenic challenge was significantly impaired (Lumlertdacha and Lovell, 1995.). Besides its effects on the immune system, fumonisin has also been shown to act as a hepatotoxic agent, and inhibits sphinganine biosynthesis (Wang et al., 1991). The sphinganine: sphingosine ratio can be used as a biomarker for fumonisin toxicoses. However, because no quick analytical test for this biomarker is available today; and it is rarely used in field situations.

Moniliformin

Moniliformin challenge trials have mainly been conducted in channel catfish. Individuals with an average initial weight of 1.5 g were fed moniliformin contaminated diets over a 10-week trial period, and results showed that they could tolerate moderate mycotoxin concentrations, but levels of 20 ppm or more significantly reduced weight gain compared with noncontaminated control diets. The diets used in this trial were semi-purified to avoid the presence of other toxins.

When feeding moniliformin in combination with fumonisin, a synergistic negative interaction between the two toxins on weight gain was observed, which is in agreement with research data from mammalian and avian species (Smith et al., 1997). Since toxins are often present as a cocktail in a single ingredient or a final diet, toxic effects due to synergistic action occur on a daily basis in the field. One has, therefore, to be careful when interpreting mycotoxin concentrations and potential risks. A concentration that does not adversely affect animal performance in a semi-purified diet can lead to problems in a natural diet in the presence of a mycotoxin cocktail.

Risk assessment and prevention strategies

Research comparing mycotoxins in different aquatic species has demonstrated that they pose a risk to fish and shrimp performance and health. The exposure to mycotoxins increases with heavier reliance on plantbased raw materials, since these ingredients pose a higher risk of mycotoxin contamination than animal-based products. With increased use of plant ingredients, mycotoxin risk assessment plans, as well as the appropriate prevention strategies, should be put in place in any aquatic production system.

Properly assessing the risk is a major challenge since it is close to impossible to define safe levels of mycotoxins. There are many factors that influence the mycotoxin concentration at which fish and shrimp will be affected in terms of health and performance. Research has shown that species differences exist in the way fish cope with mycotoxins. Both the number of known mycotoxins and the number of fish species in production have increased to large numbers today, and are poised to continue this trend over the coming years. As a consequence, it seems impossible to determine the species-specific susceptibility towards a key range of mycotoxins within a reasonable time frame.

Beside the problems related to species susceptibility, many other factors make risk assessment a great challenge. Duration of toxin exposure, age of the fish, plus their nutritional and heath status are all factors that influence how the fish or shrimp respond to a mycotoxin. Last but not least, determining the dietary mycotoxin concentrations is a great challenge by itself. Mycotoxin distribution in the feed is often uneven, so taking a representative sample is the first important step towards achieving meaningful analytical results. Analyses are limited to a number of key mycotoxins, with many being regarded as less important. Minor (or unknown) mycotoxins may not be taken into consideration.

Since mycotoxicosis risk is very difficult to judge, prevention strategies should be initiated when assessing even a low-risk situation. Prevention strategies must primarily aim at minimizing mycotoxin formation in the field and during storage. A significant reduction in mycotoxin formation can be achieved by good agronomic practices. For example, the selection of crop varieties that are more resistant to fungal foliar diseases may reduce fungal infection and thus mycotoxin formation in the standing crop. Additionally, mold spore levels have shown to be higher with no-till soil management practices and monoculture cropping systems. Proper crop rotation, including plowing up harvest residues, are two of the most effective measures to reduce mycotoxin formation in the field. As toxins are generally very stable, they can persist during storage, independent of storage conditions, and can hence reach the final feed.

During storage mold growth and mycotoxin formation can be controlled successfully by controlling moisture content of the feed. If the moisture content is below 12%, molds become metabolically inactive, and no mycotoxins are produced. The incorporation of technical mold inhibitors such as Mold-Zap (Alltech, Inc.) further enhances stability of feed and ingredients during storage. If problematic levels of mycotoxins occur despite preventative measures being taken in both field and silo, dilution or, preferably, complete removal of the contaminated ingredient is the logical solution. It must be remembered that dilution of contaminated ingredients is illegal in some markets, and it is often not practical to completely remove certain ingredients due to associated costs.

One of the most effective methods of reducing the effects of mycotoxins is the inclusion of a mycotoxinadsorption agent. This corrective action can only be taken if the mycotoxin concentrations are below legal limits (e.g., aflatoxin legal limits for raw materials in certain markets). An effective sequestering agent is one that tightly binds mycotoxins in contaminated feed without disassociating from them in the gastrointestinal tract of the animal. The toxin-sequestrant complex can then pass safely through the animal and be eliminated via the feces, minimizing animal exposure to mycotoxins.

The following guidelines should be utilized when evaluating a mycotoxin binder:

1) High level of specificity and affinity for a wide range of different mycotoxins
2) No absorption of minerals, vitamins and drugs
3) Low level of inclusion
4) Quality control (no contaminants)
5) Stability over different pH values
6) Scientifically tested in controlled in-vitro and invivo studies

One adsorbent product meeting these criteria is Mycosorb® (Alltech, Inc.), which is derived from the glucan fraction of the yeast cell wall. Yiannikouris et al. (2003) have investigated the binding of different mycotoxins by Mycosorb® in vitro, and they have developed complex models to describe the interactions between ZEA and Mycosorb®. The models give detailed information on the physical and chemical mechanisms involved in the linkage between adsorbent and toxins (detailed elsewhere in this volume).

In vitro adsorption of mycotoxins has been confirmed in vivo. For example, Pavicic and coworkers (2001) showed that Mycosorb® was able to alleviate the negative effects of DAS on weight gain in broilers (Table 3).

These effects have been confirmed in other trials with other key mycotoxins where Mycosorb® at 500 to 2000 ppm was shown to partially or completely alleviate the negative effects of the toxins on animal metabolism and performance (Raju and Devegowda, 2000; Swamy and Dewegowda, 1998; Swamy et al., 2002a,b; Raymond et al., 2003).

Table 3. Effect of a trichothecenes (DAS) and Mycosorb® on weight gain in broilers grown to six weeks of age.

DAS (mg/kg)	Mycosorb® (g/kg)	Body weight (g)	Change from control (%)
0	0	1680.6[a]	0
0	1	1793.6[a]	6
1	0	1374.3[b]	-17
1	1	1678.3[a]	1

Pavicic et al., 2001

Conclusions

Plant ingredients pose a high risk for mycotoxin contamination. Since the aquafeed industry is moving towards using more plant ingredients, both risk assessment of mycotoxins as well as the development of appropriate protection strategies will become an integral part of aquaculture nutrition. Prevention strategies must target the production chain from cropping systems to animal feeding. Adsorbents that bind mycotoxins and decrease their bioavailability show a great deal of promise in strategies that attenuate mycotoxin-induced toxicosis. The high affinity and high adsorption capacity of yeast-derived glucomannan preparations make their use as adjuncts for controlling naturally occurring mycotoxins in feeds attractive.

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Enzymes for sustainable aquaculture

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The expansion of global aquaculture production is increasing the demand for aquaculture feeds. Fishmeal is the main and most critical ingredient in aquafeed production. The increasing cost of fishmeal has encouraged feed manufacturers search for cheaper alternative protein sources such as plant proteins. Though the palatability of many plant materials has demerits, anti-nutritional factors are the most serious concern in replacing the fishmeal completely in feed formulations. Anti-nutritional factors have an adverse impact on the digestion of feed and its efficiency. There are many kinds of anti-nutritional factors. Three that are associated with the most widely used plant materials are trypsin inhibitor proteins, glucosinolates and phytate. Heat inactivation and water soaking are the two common detoxification methods used to overcome most of the anti-nutritional factors.

Enzymes provide additional powerful tools that can inactivate anti-nutritional factors and enhance the nutritional value of plant-based protein in feeds. They provide a natural way to transform complex feed components into absorbable nutrients. Endogenous enzymes found in the fishes digestive system help to break down large organic molecules like starch, cellulose and protein into simpler substances. The addition of enzymes in feed can improve nutrient utilization reducing feed cost and the excretion of nutrients into the environment.

Phytic acid is one of the most powerful anti-nutritional factors in plant ingredients. The anti-nutritional activity of phytic acid can be eliminated by the addition of relevant enzymes, for example phytase. The phytic acid or phytate found in cereals, legume grains and oil seeds is bound with phosphorus and also with calcium and magnesium, trace elements like iron and zinc, protein and amino acids. Most fishes do not possess their own enzymes to break down the phytate and release the nutrients so they pass through the fish undigested. This is why higher proportions of valuable nutrients from vegetable sources are not utilized by the animals and are wasted as excreta. The feed enzyme phytase not only releases phosphorus from the phytate but also releases minerals and amino acids that are also bound, paving the way for maximum utilization of nutrients.

Advantages of phytase

1. Since the phosphorus bound in phytate becomes available as nutrient due to the addition of phytase, the inclusion of inorganic phosphorus such as fishmeal can be drastically reduced.

2. The environmental performance of aquaculture operations is under scrutiny due to the discharge of nutrients into the surrounding ecosystems. Excessive phosphorus in particular is an important factor in the eutrophication of waterways. Phosporus bound in phytate may be unavailable to the fish but it will still ultimately be released into the environment as microbial action breaks down the fishes waste. The addition of phytase reduces the release of nutrients into the environment by making the bound phosphorus available to the fish for growth – so it is incorporated into the fishes body instead.

3. Phytase added to the diets improves protein and amino acid digestion in fishes.

4. Phytase can improve the metabolisable energy of feeds by breaking down the phytate-lipid complex.

5. Cheaper plant based protein sources can be substituted for fishmeal lowering feed costs.

Non – starch polysaccharides (NSP)

Another important anti-nutritional factor that can be addressed with feed enzymes is non-starch polysaccharides (NSP), present in the plant materials and found to reduce the performance of animals. Their anti-nutritive effects are mainly due to the increased viscosity of the digest in the intestine and the enclosure of nutrients making them unavailable to digestion. Since the animals lack the intestinal enzymes for the degradation of non-starch polysaccharides, the supplementation of degrading enzymes in the diet will break down these anti-nutritive factors and result in better feed utilization. Such an approach has been successfully used in poultry diets.

Experimental results using feed enzymes

A number of studies have reported successful use of enzymes to combat anti-nutritional factors in plant proteins for fish feeds. Phytase added diets have been shown to have a higher feed intake, growth and better food conversion efficiency than control diets in Channel catfish, as well as reduced phosphorus load in their faecal matter1. Trout fed with phytase-incorporated soybean based diets have been reported to show a 22% improvement over control fish as phosphorus availability increased from 46% to over 70%2. Microbial phytase added diets containing a higher proportion of plant protein have been shown to improve phosphorus and protein digestibility in Atlantic salmon3.

A feeding trial conducted with tilapia *Oreochromis niloticus* fingerlings in Brazil showed the significance of phytase in plant protein based diets. The feed was supplemented with commercial phytase enzyme “Natuphas” at 0, 500, 1500 and 3000 units per kilogram of feed. Fishes fed with 500 units of Natuphas showed higher weight gain and a better food conversion ratio of 1.80. Supplementation of protease-based additive equaled the performance of low protein milk fish diet (24% protein) up to the level of higher protein diets (28% protein)5.

The addition of commercial enzyme Pescazyme TM 5602 in soybean based diets free of fish meal showed equal performance of diets containing 10 or 12% fish meal in carp and tilapia4,5,6.

The future

Aquaculture is fast growing Industry. Successful and sustainable aquaculture depends on economically viable and environmental friendly feeds. Feed is the major operational cost involving 50 to 60% of the total cost in intensive farming. The major feed ingredient, fishmeal, is expensive and there is increasing competition with other livestock industries for the available supply. Hence, research work has been focussed to find alternatives to fishmeal. One alternative is to substitute fishmeal with plant proteins supplemented with feed enzymes. Phytase enzyme is able to release the phosphorus bound in phytate and this permits feed manufacturers to reduce the fishmeal and lower the cost of feed production. Improved phosphorus utilization can also help reduce the discharge of nutrients into the environment. Enzymes can therefore play an important role in formulating eco-friendly aquafeeds. Currently, the use of enzymes is able to reduce fishmeal inclusion by around 5% in most aquafeeds with potential for more as techniques are refined. This may help to reduce the demand for fishmeal from the aquaculture sector in coming years.

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WSSV

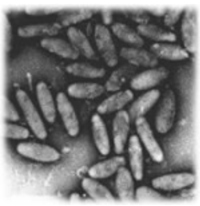
- The outbreak of WSSV was first confirmed in Taiwan in 1992. Since then, the infection area has spread to the shrimp culture farms throughout the world.
- WSSV has wide range of host among carapaces.
- WSSV is in Whispovirus of Nimaviridae family(ICTV, 2002)

Even with the present technology, it is impossible to make inspection to eliminate virus invasion into the pond. WSSV is less than 300 nanometer long (0.0003 millimeters). It is far smaller than bacteria, it can easily pass through normal filters. Therefore, in case that the sea is polluted by WSSV, it is just impossible to prevent the invasion. Besides, the virus continues to live in the water and to be infective for several weeks. Even if grown shrimp is thoroughly inspected to avoid carriers and the culture farm is completely isolated to prevent entry of surrounding creatures, there still and always is a great risk of WSSV with extremely small amount of the virus, as an infection source.

Cultured shrimp, unlike natural shrimp, is reared in mass environment and thus, it always involves a considerable risk of pathogenic bacteria, mold and virus. Especially, the white spot syndrome, which is quite popular in recent years, is one of the most fearful shrimp virus diseases for its serious damage to shrimp culture.

The disease spreads very quickly having strong infectivity and extremely high death rate. Because of this, the shrimp culture farm where infected shrimp is found, often suffer great damage as all the shrimp die out within 10 days after such observation.

However, there had been no effective measures for this disease other than to prevent invasion of WSSV into the pond through the following methods. To avoid infected young shrimp, the prospective virus carrier through gene diagnosis and to eliminate invasion of crustaces including crabs living in the peripheral of the culture farm.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