Climate Change, Mycotoxins and Food Safety

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A. Introduction

*Aspergillus flavus* = aflatoxins
Chemical Structures

- Aflatoxin $B_1$ (AFB$_1$)
- Patulin
- Ochratoxin A (OTA)
- Deoxynivalenol (DON)
### Mycotoxin Diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Crop</th>
<th>Fungus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alimentary toxic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aleukia</td>
<td>Cereals</td>
<td>Fusarium</td>
</tr>
<tr>
<td>Balkan Nephropathy</td>
<td>Grains</td>
<td>Penicillium</td>
</tr>
<tr>
<td>Hepatocarcinoma</td>
<td>Peanuts</td>
<td>A. flavus</td>
</tr>
<tr>
<td>Deaths</td>
<td>Maize</td>
<td>A. flavus</td>
</tr>
</tbody>
</table>
How Do They Occur?

Biology

Environment

Harvest

Storage
Gives

MYCOTOXINS
How will climate change affect mycotoxins in food?

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Water activity

ABSTRACT

This invited review and opinion piece, assesses the impact of climate change on mycotoxins in food: only one paper and an abstract referred directly from a substantial literature search and then only in relation to Europe. Climate change is an accepted probability by most scientists. Favourable temperature and water activity are crucial for mycotoxigenic fungi and mycotoxin production. Fungal diseases of crops provide relevant information for pre-harvest mycotoxin contamination. However, the mycotoxin issue also involves post-harvest scenarios. There are no data on how mycotoxins affect competing organisms in crop ecosystems. In general, if the temperature increases in cool or temperate climates, the relevant countries may become more liable to aflatoxins. Tropical countries may become too inhospitable for conventional fungal growth and mycotoxin production. Could this lead to the extinction of thermotolerant Aspergillus flavus? Currently cold regions may become liable to temperate problems concerning ochratoxin A, patulin and Fusarium toxins (e.g. deoxynivalenol). Regions which can afford to control the environment of storage facilities may be able to avoid post-harvest problems but at high additional cost. There appears to be a lack of awareness of the issue in some non-European countries. The era will provide numerous challenges for mycotoxicologists.

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B. Intergovernmental Panel on Climate Change Report

Global Warming Projections

- CCSR/NIES
- CCCma
- CSIRO
- Hadley Centre
- GFDL
- MPIM
- NCAR PCM
- NCAR CSM

Temperature Anomaly (°C)

1900 1950 2000 2050 2100
1. A Warmer Planet – Virtually Definite

- Increased yields
  - In cool regions

- Decreased yields
  - In hot regions

- Increased insects
  - Crop fires
Mycotoxin Effect

- **Increased Mycotoxins**
  - "Parasites lost", Worse storage

- **Decreased mycotoxins**
  - But better storage – hot, dry

- **Increased mycotoxins**
More crop/more mycotoxin

Current production = 1000 kg with 1mg toxin
Changed production = 2000 kg

1. Quality same = 2mg toxin
2. Quality worse = > 2mg toxin
3. Quality better = a. >1<2 mg toxin
   b. 0 - 1 mg toxin
Hence...

• 3b is the only scenario where less mycotoxin obtained from more crop.

• A very specific statement would be needed explaining how 3b might occur.

• I recommend a general statement: “more mycotoxin is “likely” from more crop”.
2. Heat Waves – Very Likely

DECREASED YIELDS FROM FEWER CROPS: FEWER MYCOTOXINS

BUT: MORE MYCOTOXINS IN POORER CROPS
3. Precipitation

Heavy – very likely

Crop damage, soil erosion, uncultivable land

Drought - likely

Lower yields/crop damage and failure
Mycotoxin Effect

Heavy – very likely

More mycotoxins pre/post harvest

Drought - likely

More mycotoxins pre harvest.

Fewer post harvest mycotoxins
C. Asian Climate Change

- Freshwater availability to decrease 2050
- Coastal areas greatest risk from more flooding.
- Weather alterations affect “runoff” and water availability.
By the 2080s

- Floods every year due to sea level rise.
- Largest affect in densely populated, low-lying megadeltas.
- Small islands are especially vulnerable.
D. Mycotoxin Consequences in Regions

1. Asia

- Fewer total crops fewer total mycotoxins.
- More ingress of fungi, storage major problem all from flooding.
- Compounded malnutrition effects.
2. Africa 2020

• More mycotoxins in current cooler areas.
• Fewer mycotoxins in current hot regions.
• Storage better (hot and dry).
• But basic survival main problem.
3. Europe

• Problems move South to North, e.g. *A. flavus* in Hungary.
• More aflatoxin, OTA, fumonisins in sub mediterranean.
• Less patulin and *Alternaria* toxins in current temperate.
• Tropical mycotoxin problems?
4. Australia/New Zealand 2030

- Too hot/dry for crops per se.
- Can cope as a developed country.
- Fewer crops so fewer mycotoxins, but those produced high in mycotoxins.
- Storage improves.

- **New Zealand**: more crops/more mycotoxins.
5. Latin America 2050

- Soybean mycotoxins to increase.
- Chance of fungal “extinction”, low mycotoxins.
- Less healthy crops – more mycotoxins.
- Fewer mycotoxins from arid land.
- Storage may be efficient in hot dry areas.
6. North America

- Increase yields produce more mycotoxins.
- Floods and drought - more mycotoxins.
- Cool areas change to hot - more mycotoxins.
- Floods/higher temperature - storage probs.
Tropics: Less Developed Countries

Coconut, Maize, Soybeans, Coffee, Cocoa
To Subtropics: Developed

Coconut, Coffee, Maize,
Soybeans, Coffee, Cocoa
E. Mycotoxin Biosynthesis Rates and Climate Change

- PRECURSORS
- FUNGI
- MYCOTOXINS

- FUNGI UNCHANGED
- FUNGI CHANGED

Rate = k

Global change

Current conditions
Future conditions
F. Climate Change Mycotoxin Cycle Hypothesis

- Climate change
- More mutagen mycotoxins
- Fungal mutation
- Precursors
- More, new Mycotoxins
- Rate = k
### G. Water/Drinking Water

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fungi</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Mycotoxigenic fungi</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Mycotoxins</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Agricultural “run off”</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Growth</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Mycotoxin production</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>
a. More Water

Contamination of crops with mycotoxins and fungi from floods

More fungi in drinking water system from increased growth and floods
More dissolved mycotoxins as temperature increases
b. Less Water - Drought

Less spread of fungi & mycotoxins via water
H. Mycotoxins as Bioweapons

<table>
<thead>
<tr>
<th>Mycotoxin</th>
<th>Weapon</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aflatoxin</td>
<td>Yes</td>
<td>Yes (Iraq)</td>
</tr>
<tr>
<td>T2 toxin</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>


Weaponised fungi to take advantage of changed climates.
I. Fungal Physiology
1. Optimum Growth °C

- *A. flavus* 35 - 21 = 14
- *A. ochraceus* 30
- *P. verrucosum* 26
- *P. expansum* 25
- *Alt. alternate* 23
- *F. graminearum* 21
# Fungal Relative Dominance

(% infected, Brazil)

<table>
<thead>
<tr>
<th>Fungal Species</th>
<th>Pepper</th>
<th>Brazil nuts</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aspergillus flavus</em></td>
<td>44</td>
<td>27</td>
</tr>
<tr>
<td><em>A. ochraceus</em></td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

+ 100 years climate change: No relative change, or extinct in Brazil.
Dominance in Grapes (N. Portugal)

<table>
<thead>
<tr>
<th>Present</th>
<th>100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. carbonarius (OTA)</td>
<td>A. flavus</td>
</tr>
<tr>
<td>A. flavus</td>
<td>A. carbonarius</td>
</tr>
<tr>
<td>P. expansum</td>
<td>No P. expansum</td>
</tr>
</tbody>
</table>

N.B. Reports of *A. flavus* from grapes and aflatoxin in grape juice exist
So *Aspergillus flavus*

Not dominated by (5°C/100 years):

*Alternaria, Fusarium, Aspergillus (other), Penicillium.*
Aflatoxins will not be supplanted by:

Alternariol, deoxynivalenol, fumonisins, ochratoxin A, patulin.

However, all could be diminished in already hot regions.
Same predictions for other mycotoxins possible.
2. Optimum Mycotoxin Production °C

- Aflatoxin 33
- Deoxynivalenol 30 or 26
- Ochratoxin A 28 or 25
- Tenuazonic acid 20
So aflatoxins will not be supplanted by:

- Ochratoxin in peanuts, corn, wheat, cheese
- Deoxynivalenol in corn, wheat
- Fumonisin in corn
Tenuazonic acid (20 °C) to Other Mycotoxins

<table>
<thead>
<tr>
<th>Mycotoxin</th>
<th>Opt °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fumonisin</td>
<td>25</td>
</tr>
<tr>
<td>Ochratoxin A</td>
<td>25</td>
</tr>
<tr>
<td>Alternariol</td>
<td>25</td>
</tr>
</tbody>
</table>
### 3. Minimum Moisture (%) Contents

<table>
<thead>
<tr>
<th></th>
<th>A. ochraceus</th>
<th>A. flavus</th>
<th>Penicillium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soy</td>
<td>14.75</td>
<td>17.25</td>
<td>18.5</td>
</tr>
<tr>
<td>Peanuts</td>
<td>9.25</td>
<td>10.25</td>
<td>12.5</td>
</tr>
</tbody>
</table>
Consequences

- Drought: More *A. ochraceus* & ochratoxin
- Floods: More *Penicillium* spp & ochratoxin, *patulin in temperate wet regions.*
- But ochratoxin more problematic overall from *Aspergillus* & *Penicillium*
J. Amelioration Strategy

• Plant in cooler season avoid mycotoxin heat stress.
• Change crop variety e.g. chili has less AF.
• Crop relocation: “Parasite lost”?
• Biodegradation of mycotoxins.
• Move storage facilities to hot dry areas.
K. Underlying Policy Framework

- Focus R&D on mycotoxins (effect on competition?).
- Who does R&D in developing countries?
- Land reform: Best crop in 50 years?
- Relocate storage equipment, political decision needed.
- Training; capacity building.
L. Implementation Contraints

- Developing countries may not cope with more mycotoxins from increased crops in some regions.

- Markets reject crops grown to avoid mycotoxins e.g. Hot chili too hot, GM?
M. Implementation Opportunities

- Analytical kit manufacturers.
- Developed countries cope with tropical crops.
- Plant crops in “Parasites Lost”.
- New hot dry areas good for storage.
Conclusions

- More mycotoxins
- More “high temperature” mycotoxins
- Region “up” shift - sub trop goes tropical
- Parasites lost
- Heat extinction
- New species
- Storage opportunities
TERIMA KASIH
Thank you
<table>
<thead>
<tr>
<th>Organism</th>
<th>Toxin</th>
<th>Frequency %</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Fusarium verticillioides</em></td>
<td>fumonisin</td>
<td>100</td>
</tr>
<tr>
<td><em>F. graminearum</em></td>
<td>DON</td>
<td>75</td>
</tr>
<tr>
<td><em>Alternaria alternata</em></td>
<td>alternariol</td>
<td>21</td>
</tr>
<tr>
<td><em>Aspergillus flavus</em></td>
<td>aflatoxin</td>
<td>2</td>
</tr>
</tbody>
</table>
Commodity with aflatoxin increase and mycotoxin decrease as too hot in some regions

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Mycotoxin decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>fumonisins, ochratoxin A, deoxynivalenol</td>
</tr>
</tbody>
</table>
Commodity with aflatoxin increase and mycotoxin decrease as too hot in some regions.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Mycotoxin decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>deoxynivalenol, ochratoxin A</td>
</tr>
<tr>
<td>Peanuts</td>
<td>ochratoxin A</td>
</tr>
</tbody>
</table>
### Plus 100 years warming

<table>
<thead>
<tr>
<th>Organism</th>
<th>Toxin</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A. flavus</em></td>
<td>aflatoxin</td>
<td>1st</td>
</tr>
<tr>
<td><em>F. verticillioides</em></td>
<td>fumonisin</td>
<td>2nd</td>
</tr>
<tr>
<td><strong>Too hot:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>F. graminearum</em></td>
<td>DON</td>
<td></td>
</tr>
<tr>
<td><em>A. alternata</em></td>
<td>alternariol</td>
<td></td>
</tr>
</tbody>
</table>
Fusarium verticillioides, F. proliferatum

- will not be replaced by toxigenic (same basic reason relating to optimum temperatures):
  - Alternaria
  - Fusarium (other)
  - Penicillium
But could be replaced by...

Toxigenic:

*Aspergillus flavus* MOST LIKELY

*A. ochraceus*

*Fusarium culmorum*
So in corn...

- Aflatoxins, ochratoxin A (from A. ochraceous), deoxynivalenol (from ...) could increase in relation to fumonisins

- But probably not *Alternaria* toxins (e.g. alternariol, tenuazonic acid). Not found in corn anyway.
Similarly Aspergillus ochraceus/A. carbonarius

- Will not be replaced by:
  - Alternaria
  - *Fusarium gaminearum, F. Culmorum*
  - Penicillium
But could be replaced by...

- Toxigenic:

- *Aspergillus flavus*

- *Fusarium verticillioides, F. proliferatum*
So in actual commodities

- Peanuts: More aflatoxins compared to ochratoxin A

- Corn: More fumonisins, and aflatoxins than OTA

- Grapes, wine: more aflatoxins possible.
C. Specific Regions
1. Africa 2020

• Crop Yields reduced by 50%. Debatable.
• Agricultural production severely compromised.
• Higher levels of crops in some currently cooler areas.
• Adverse affect food security and exacerbate malnutrition.
• Increase of 5 to 8% of arid and semi-arid land
2. Europe

- Magnification of regional differences in natural resources and assets.

- Worsen high temperature/drought reduces water availability/crop productivity in South.
3. Australia/New Zealand 2030

- Water security problems intensify
- Production from agriculture to decline from drought.
- Initial benefits projected in New Zealand.
4. Asia

- Freshwater availability to decrease 2050
- Coastal areas at greatest risk from more flooding from sea/rivers.
5. Latin America 2050

Increased temperature, decreased soil water. Tropical forest goes savanna grassland. Semi arid replaced by arid vegetation. Significant tropical species extinction.
• Crop productivity decrease; adverse food security.

• Soybean yields increase in temperate zones – specific
6. North America

- Warming in western mountains to cause decreased snowpack, more winter flooding and reduced summer flows.

- Water resources stretched.
North America pre 2050

- Increase in rain-fed agriculture 5 to 20%
- Important variability among regions.
- Crops challenged at warm end of range
- Lack of water resources.
Toxigenic fungi, biosynthesis rates and climate models
REPORTED SOYBEAN FUNGI

Aspergillus flavus, A. ochraceus, A. versicolor

Penicillium viridicatum, P. citrinum, P. expansum

Alternaria spp
POTENTIAL SOYBEAN MYCOTOXINS

Aflatoxins, ochratoxin A, sterigmatocystin, penicillic acid, patulin, citrinin, griseofulvin, alternariol, altenuene
Soybean mycotoxins?

- Potentially most mycotoxins.
- Soybeans are resistant to aflatoxins in field.
- Susceptible when stored under high moisture/temperature. But storage easier in new dryer regions.
However, this talk will focus on...