Systems Approaches for Resilient Agriculture

for GEAR-UP II, Taichung, Taiwan, Nov 16 2015

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Office of Texas State Chemist
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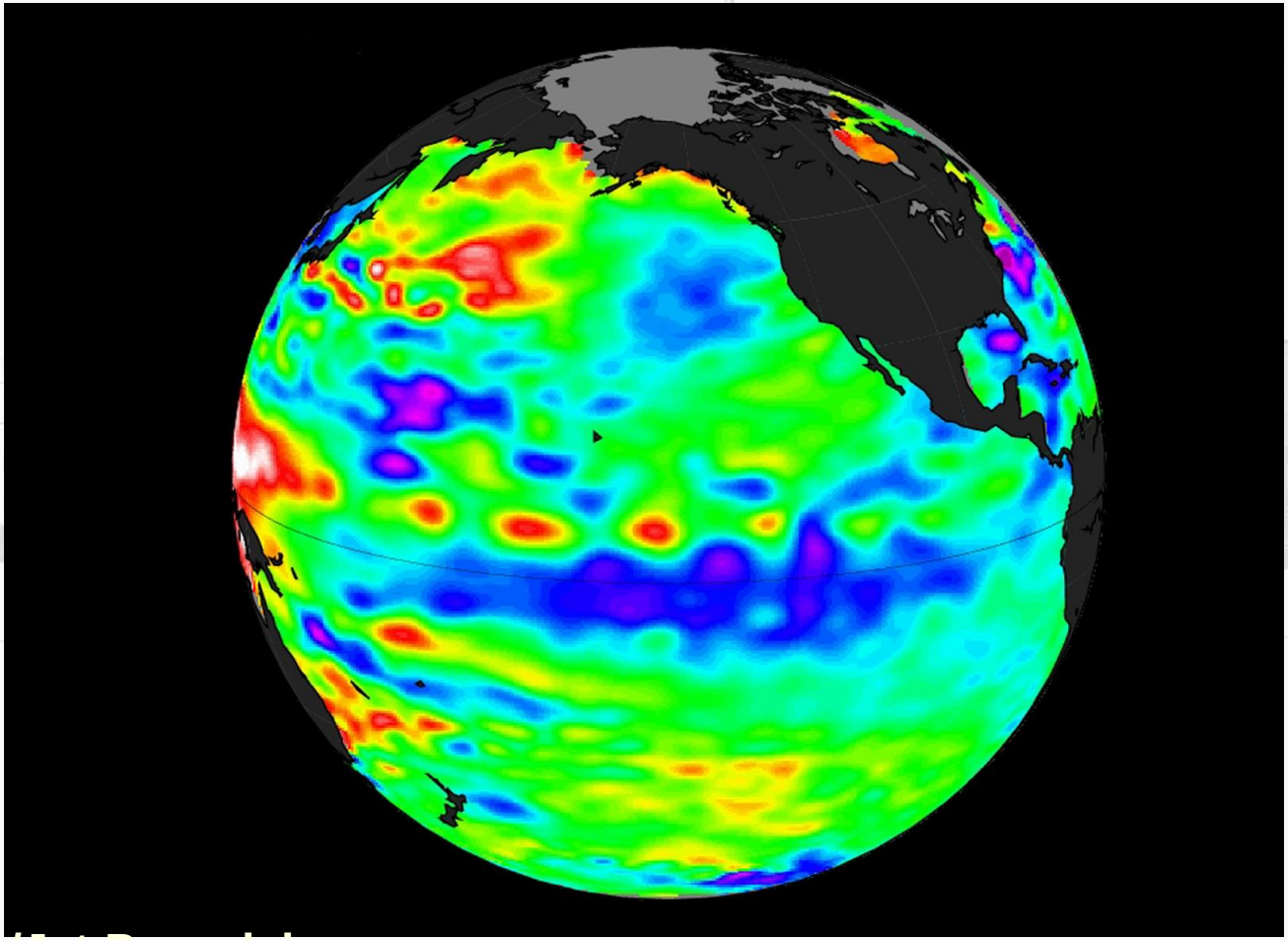
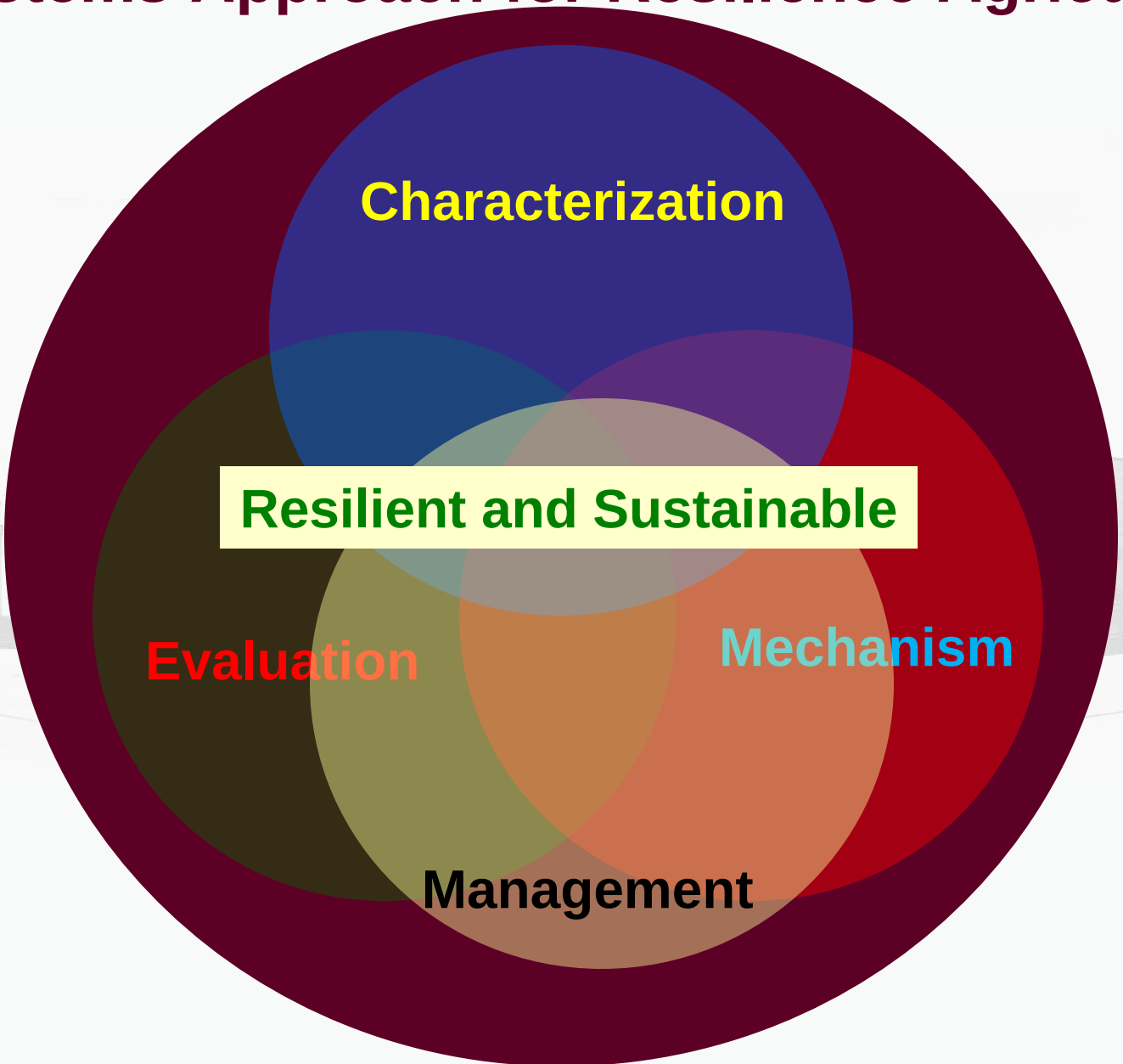
Texas A&M University

Global Climate Change as a Major Challenge for Agriculture



2010 NASA/Jet Propulsion Laboratory false-color image

Systems Approach for Resilience Agriculture



Outline

- **Innovative Technologies to Enable Mechanism Study**: Systems Biology for Resilience Agriculture
- **Characterization and Evaluation Tools:** Enable Safety of Agriculture Products in a Changing Climate
- **Science-Driven Management:** A Systematic Approach for Food and Feed Safety toward Resilient Agriculture – “One Sample Strategy”
- **Perspectives:** Regulatory Science to Improve Food and Feed Safety for More Resilience in Production System

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Proteomics at Systems Biology Age

Bioinformatics

DNA – Genome

Genomics and Metagenomics

Transcription

RNA – Transcriptome

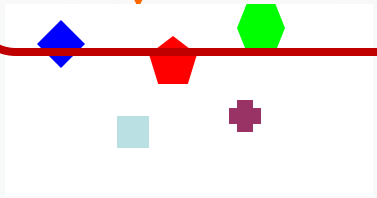
Transcriptomics and Metatranscriptomics

Translation

Protein – Proteome

Proteomics and Metaproteomics

Catalysis



Metabolite – Metabolome

Metabolomics

Systems Biology

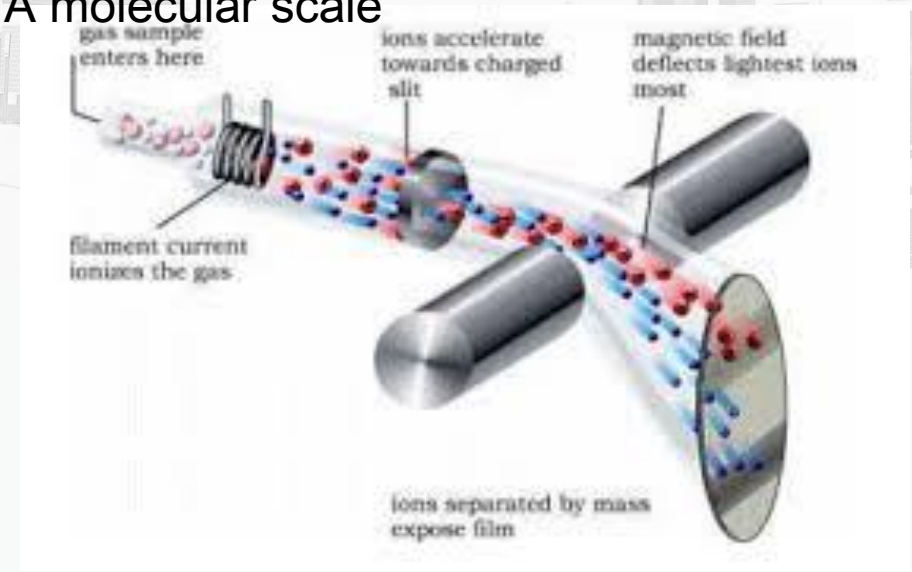
Gene Discovery

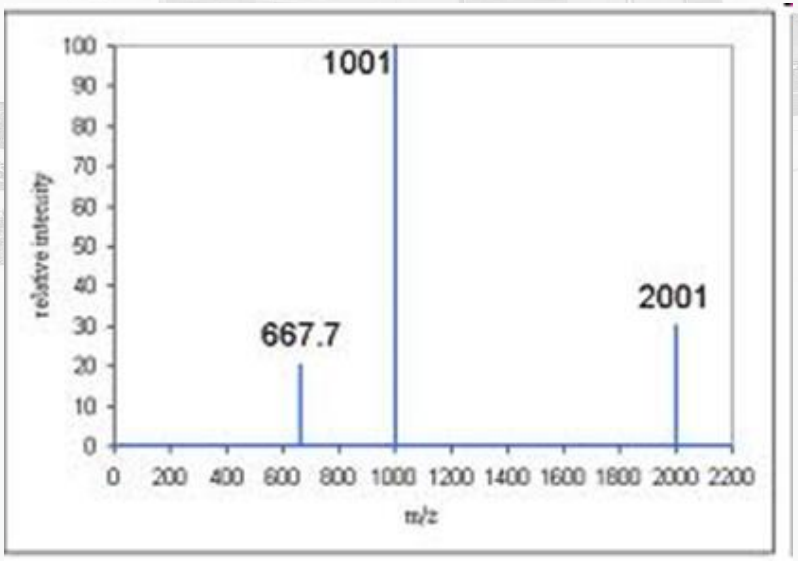
Enabling Technologies

Mass Spectrometry

- Technique to determine the relative weight of atoms and molecules by separation of charged atoms and molecules based (ions) on their mass in the gas phase. (first mass spectrometer 1910, Ne-isotope 20/22)
- Molecules need to be in the vapor phase
- Molecules need to be ionized

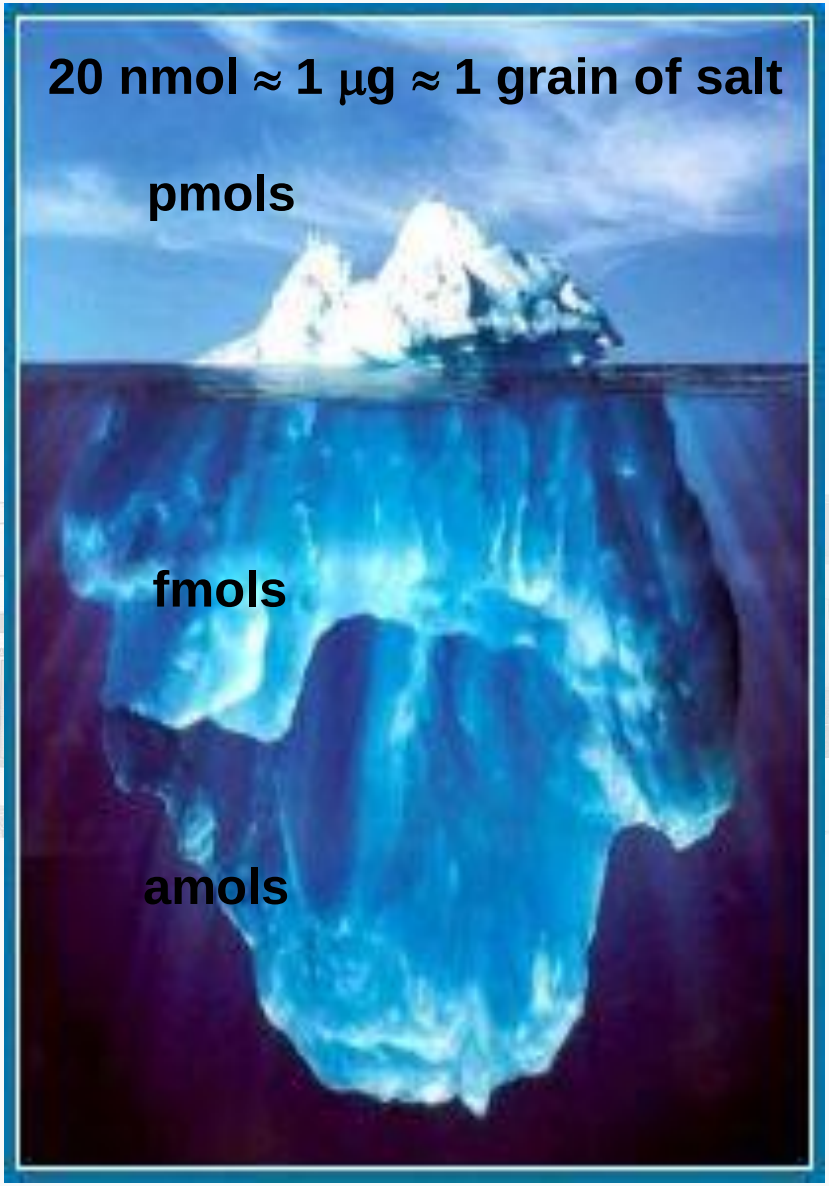
A molecular scale





State of the Art Shot-gun Proteomics to

Improve Protein Identification



1-10 pmol →

100 fmol →

2 fmol ≈ 1 copy/cell
(1 x 10^9 cells) →

Typical Western →

50 amol Sequence
LOD on LCQ →

"Housekeeping"
Soluble proteins

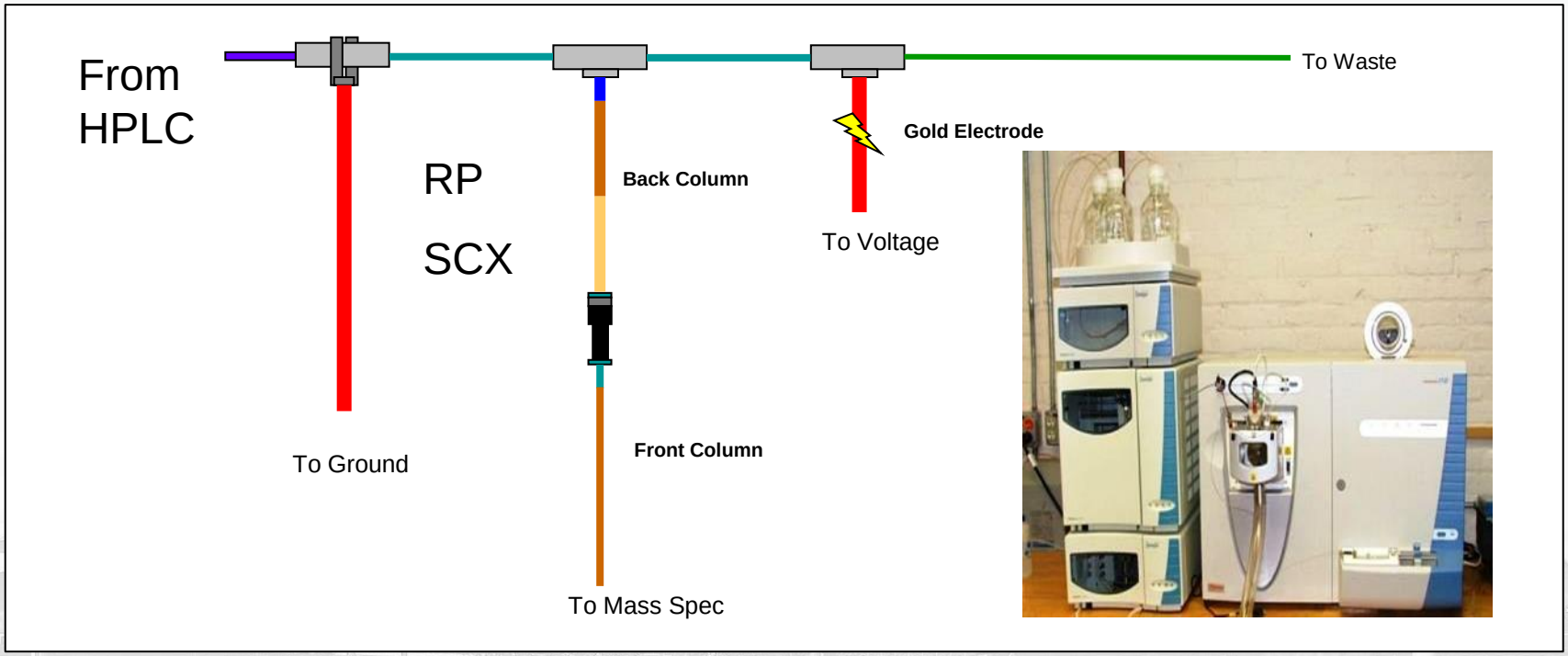
Soluble proteins

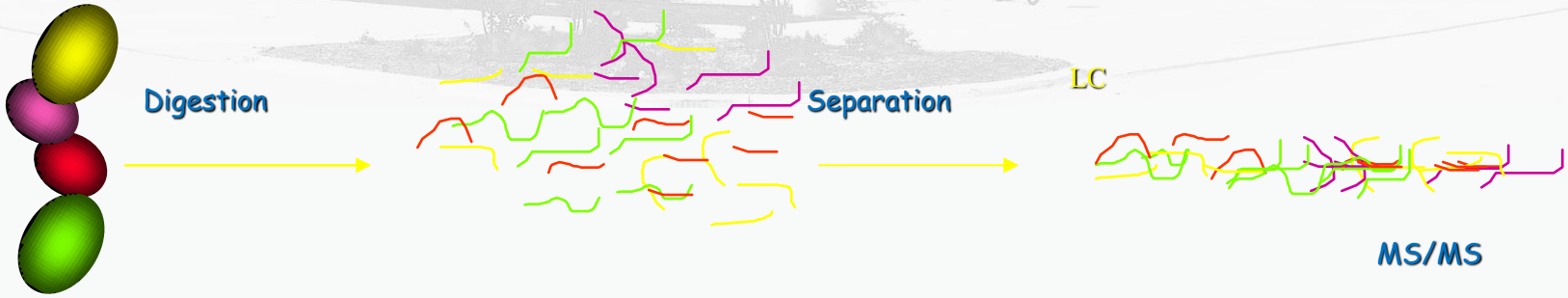
Membrane proteins

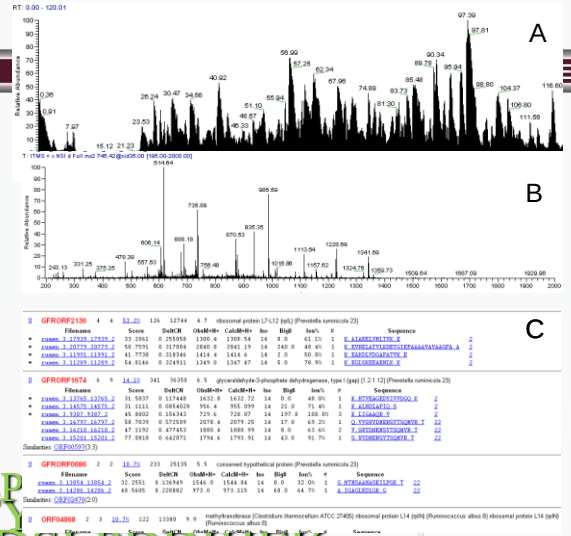
Phosphoproteins

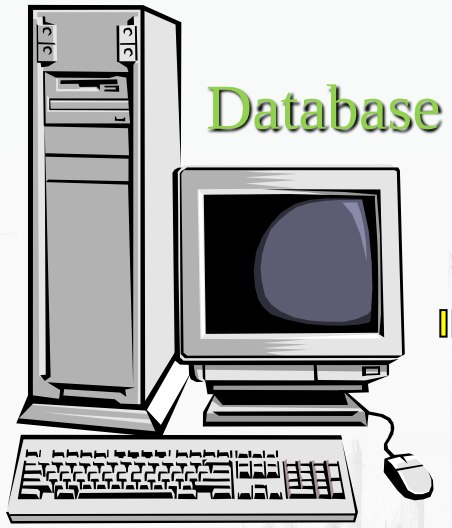
Glycoproteins

Latest LC-MS/MS Platform at Our Lab



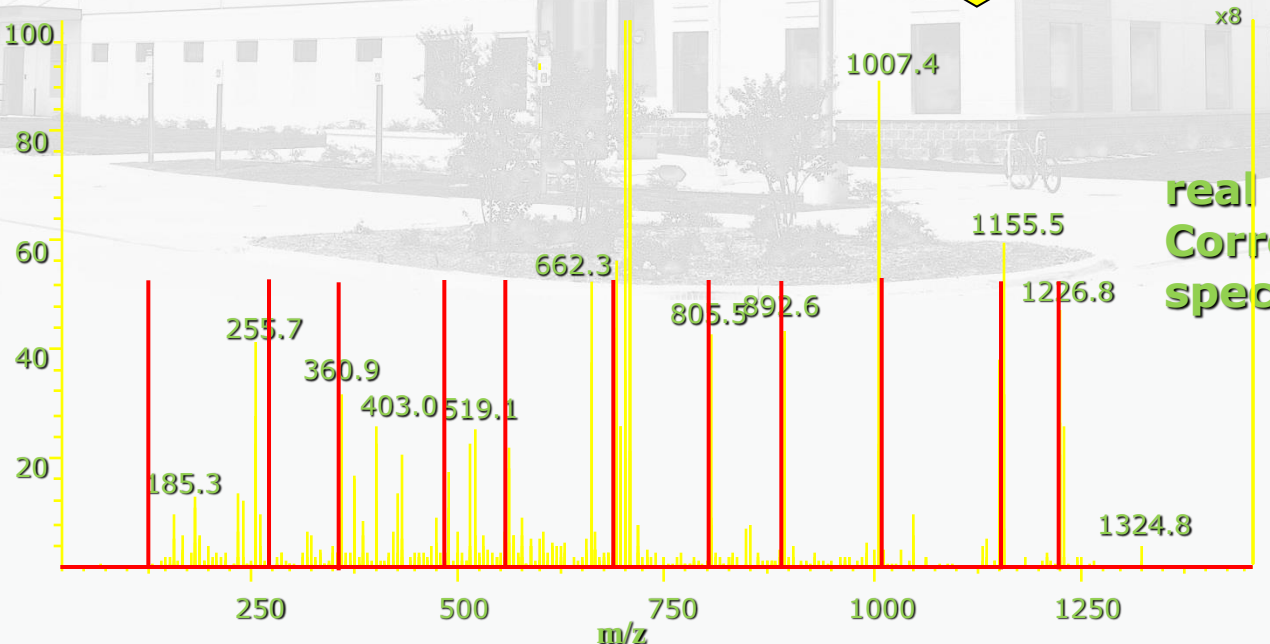






1410.6

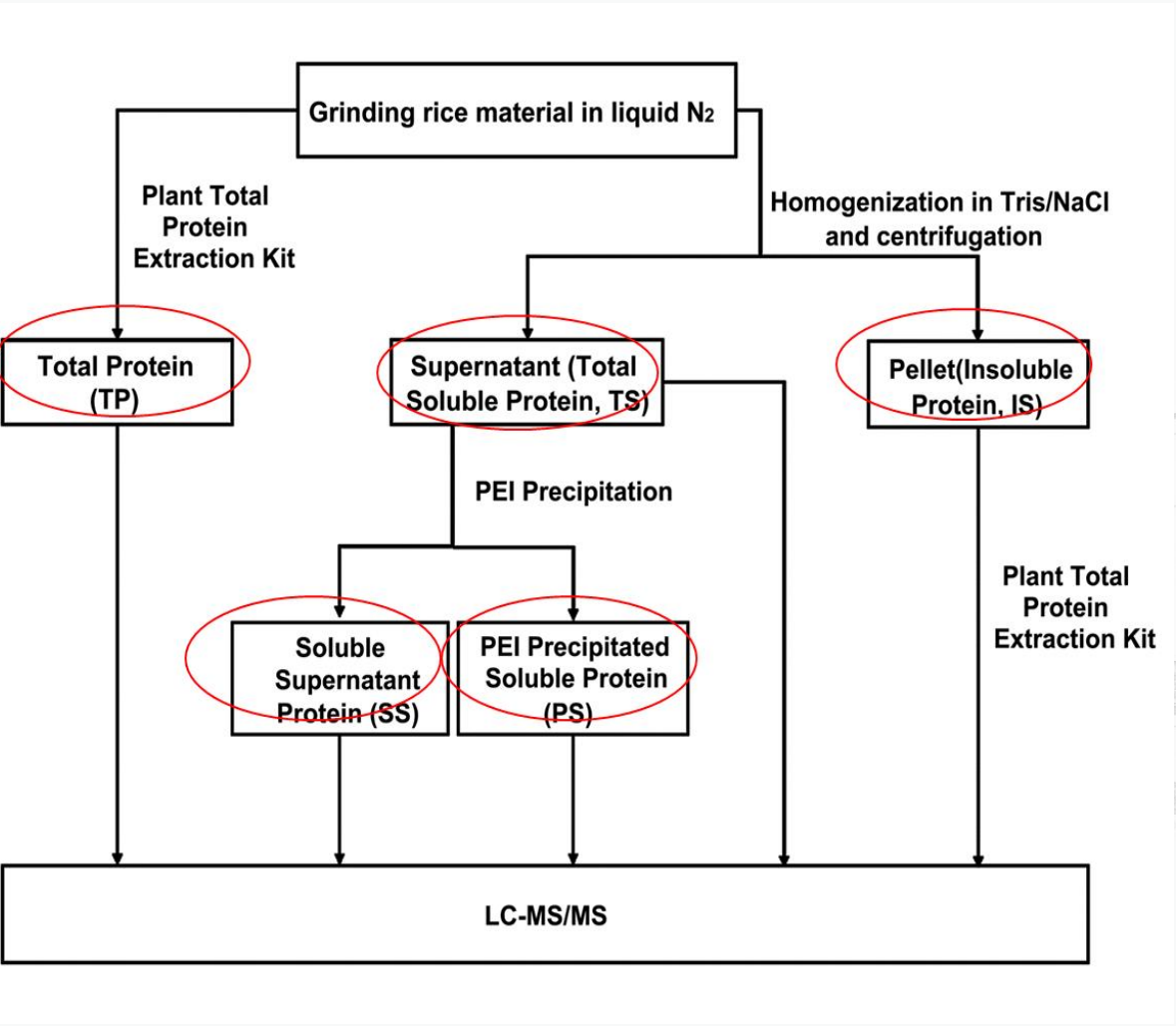
GGILAQSP
IIGHFY
AFDSLPDDIHEK
SPAFDSIMAETLK

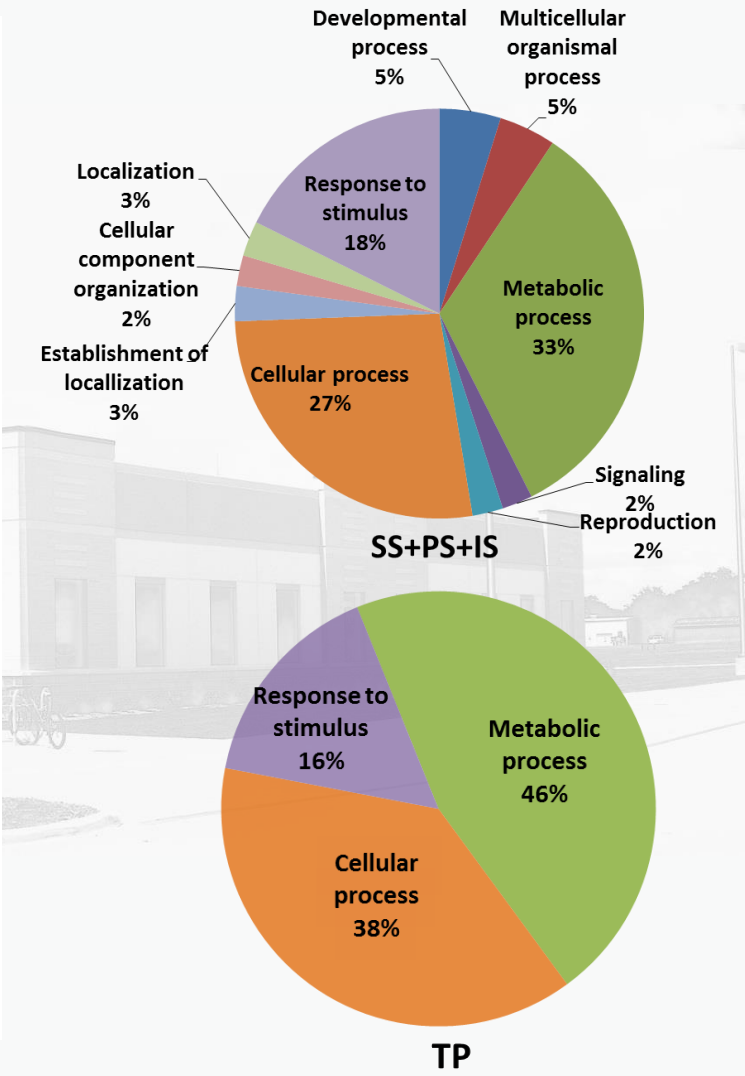


real spectrum Cross-Correlated with model spectrum

Case 1: Systems Biology Analysis of Rice Insect

Defense to Deliver Resilient Crops





Zhang et al, Molecular and Cellular Proteomics, 2013 Nov;12(11):3431-42

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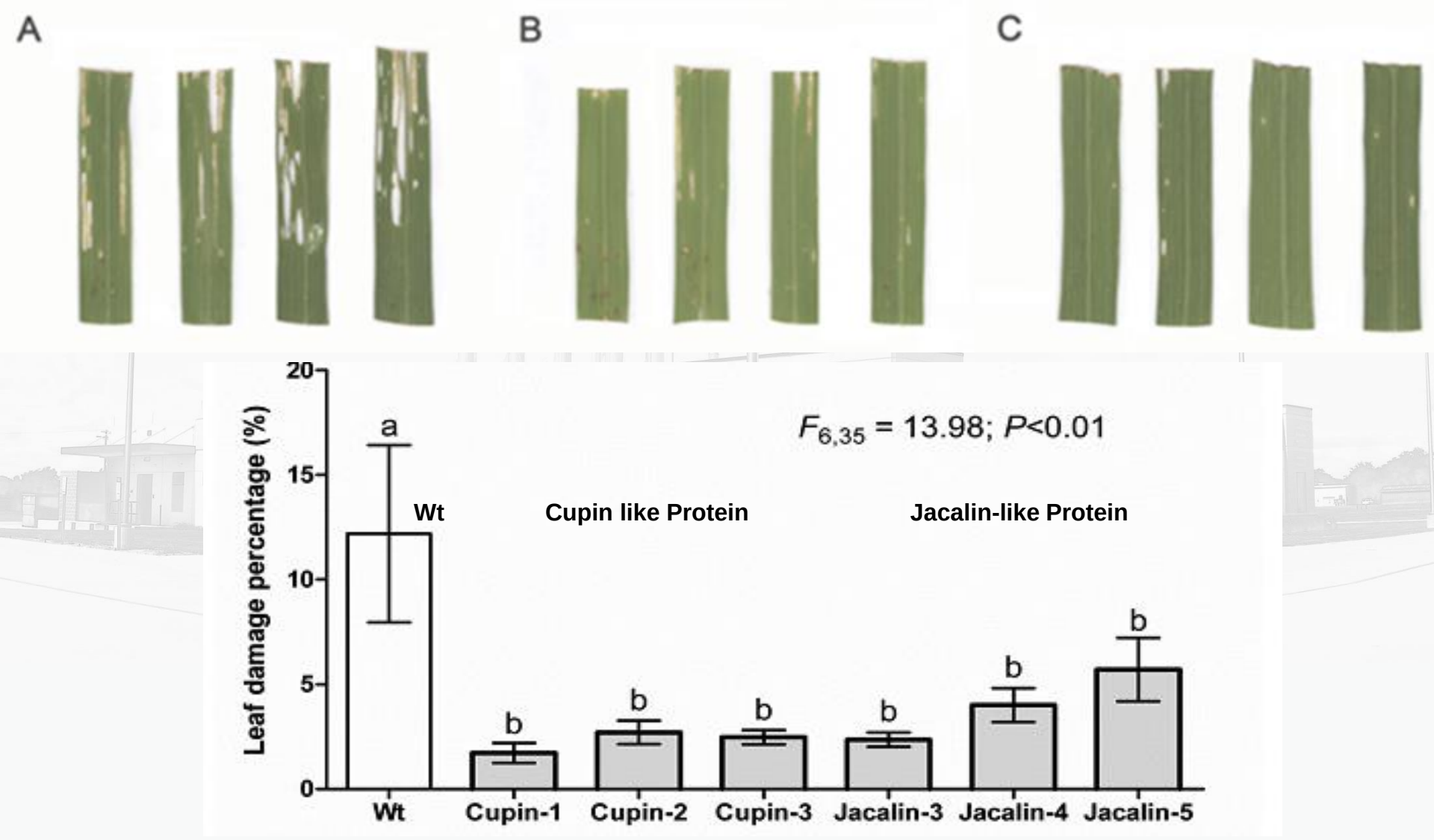

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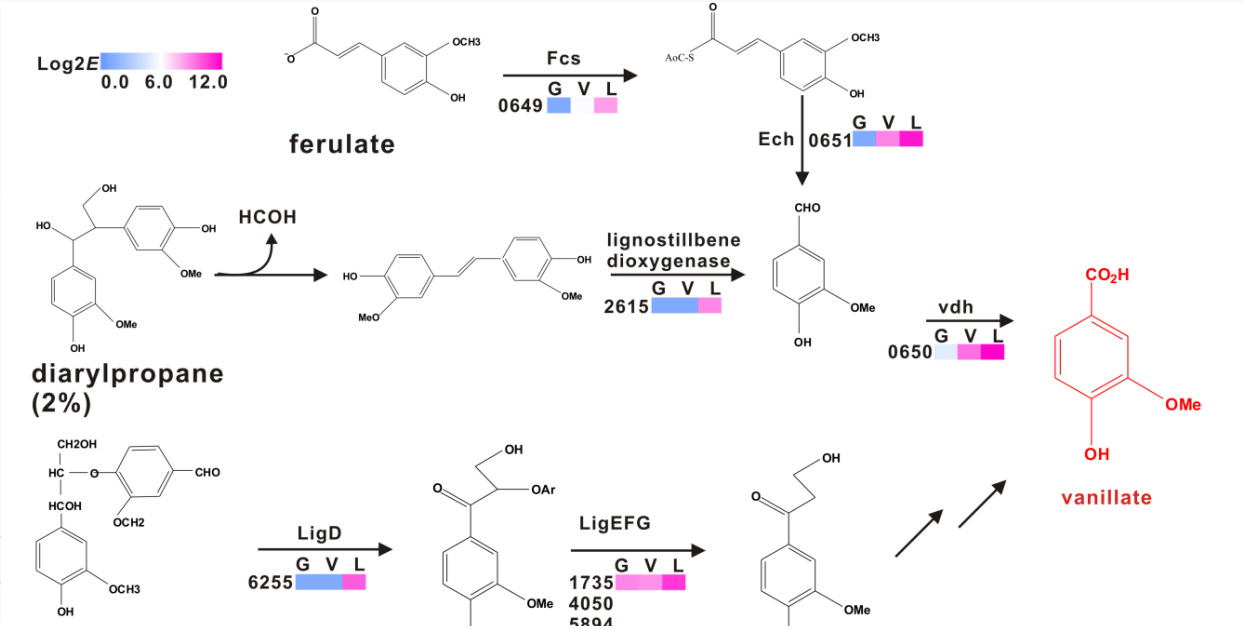
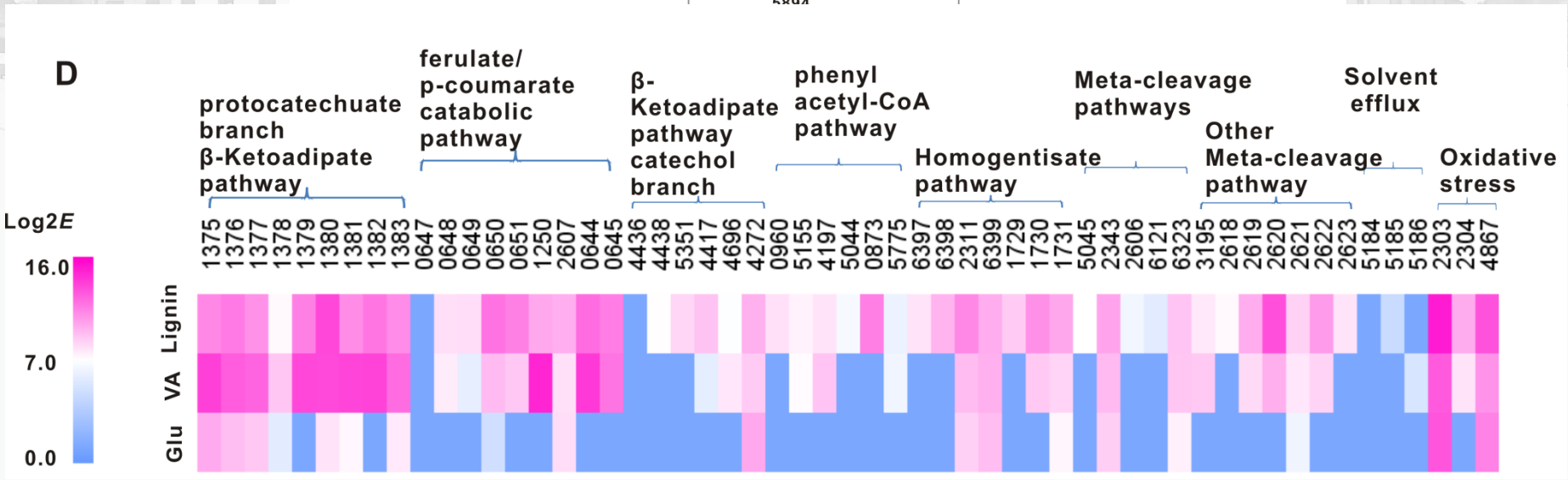
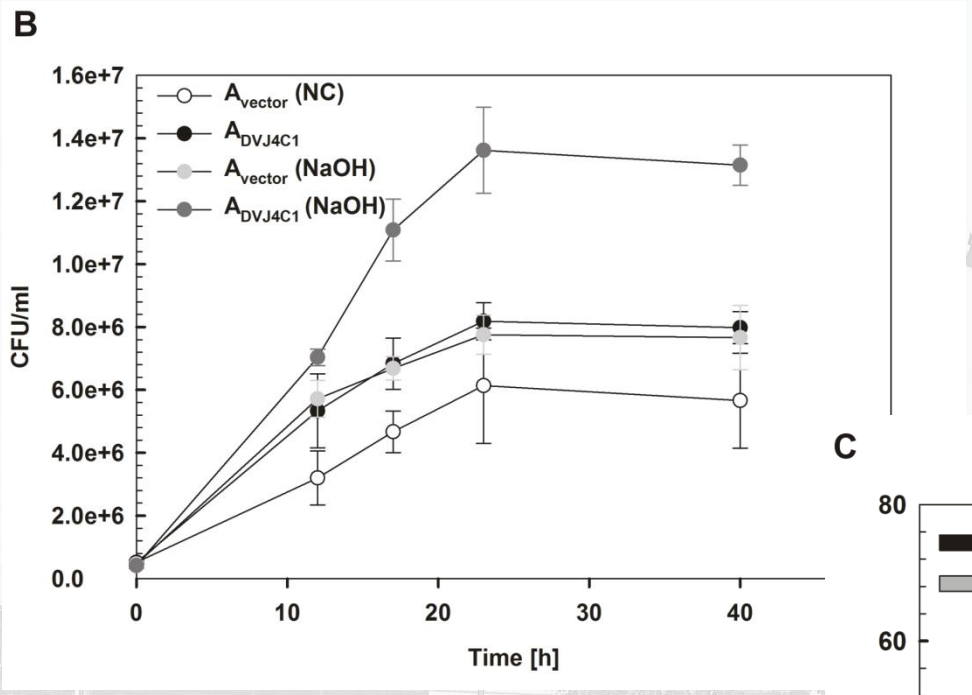
Case 2: Systems Biology to Enable Efficient Lignin

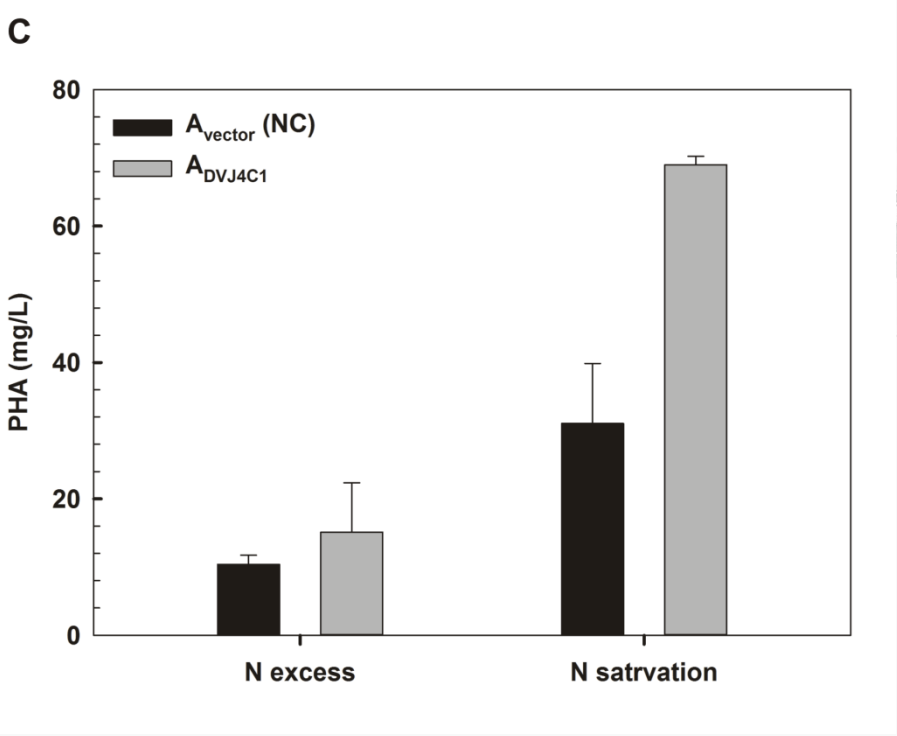
Conversion – Path for Green Energy





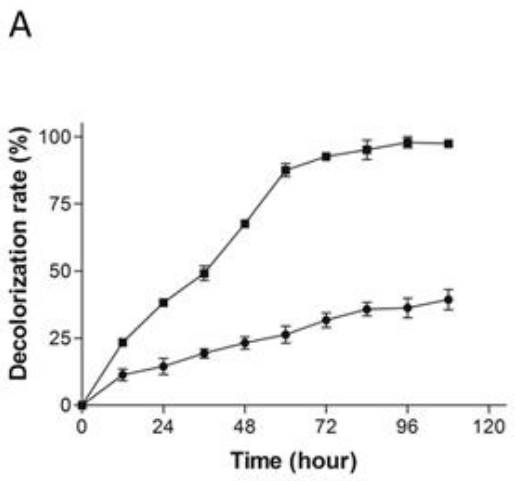
Case 2: Systems Biology to Enable Efficient Lignin Conversion – Path for Green Energy

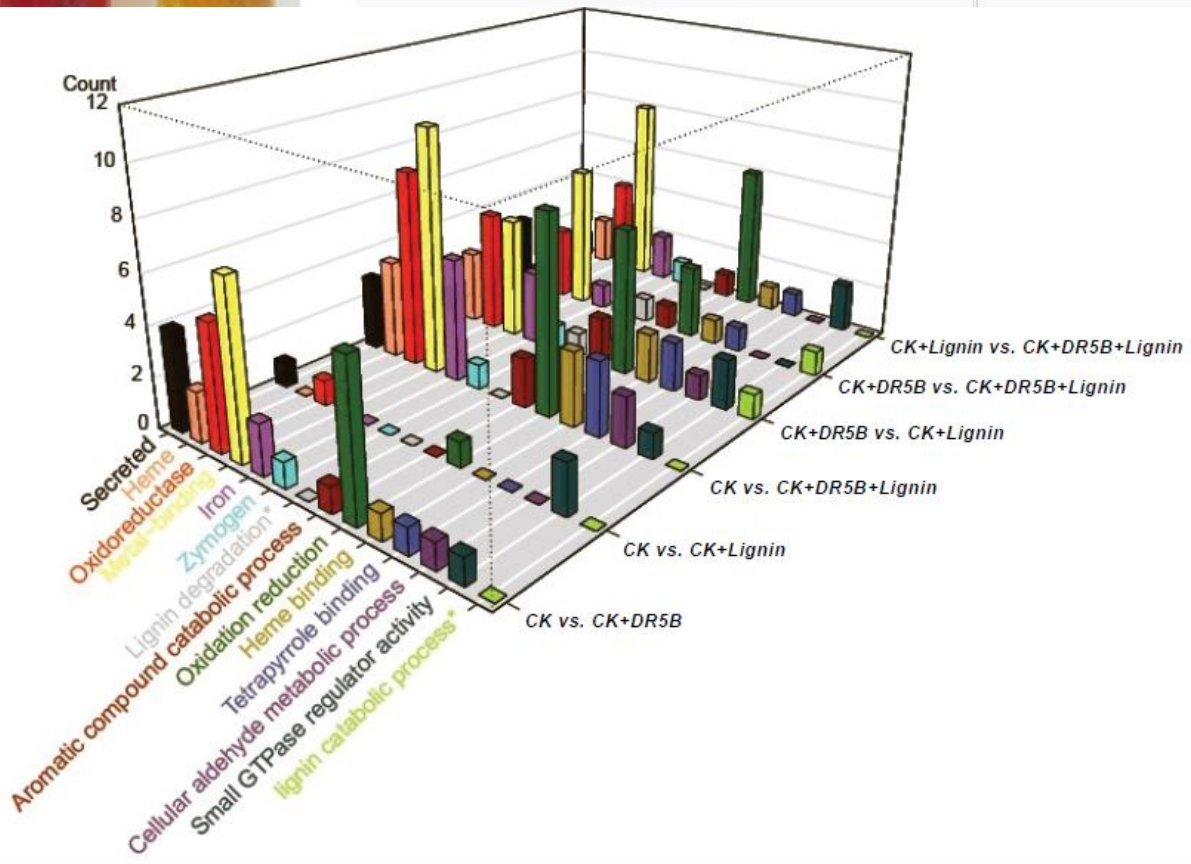




Case 3: Proteomics to Enable More Efficient Fungal

Bioremediation of Dye and Lignin





Su et al. Submitted to J of Proteomics

Case 3: Proteomics to Enable More Efficient Fungal

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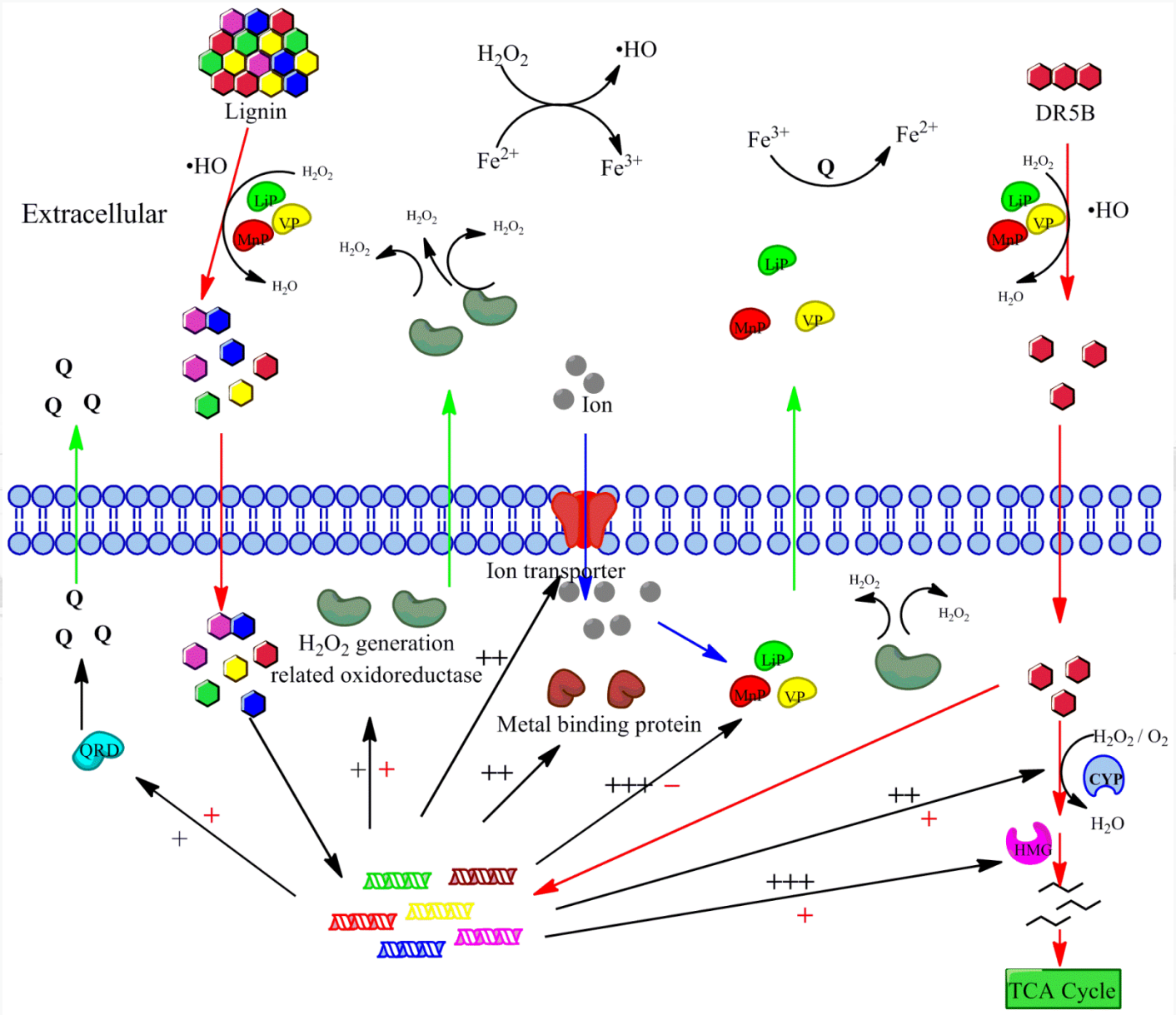

Conclusions I

- Texas A&M Agrilife Implemented the State-of-the-Art Proteomics Platform as an Enabling Systems Biology Tool to Address Scientific Challenges in Resilient Agriculture
- The Platform can Identify a Few Thousand Proteins within One to Two Days and Greatly Improved the Protein Identification as compared to Gel-based System
- Complementary to the Genome approach and discovered functional pathways for variety of biological questions
- Proteomics-based Systems Biology has Enabled Improved Crops for Insect Defense, More Efficient Biomass Utilization, and Enhanced Fungal Bioremediation, All of Which are Supporting the Response to Global Climate Challenges

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Characterization and Evaluation – Global Climate

Change Leads to More Pathogen Outbreaks

FDA Aflatoxin Action Levels

ppb	Product Description
20	Corn, peanut products, cottonseed meal, and other animal feeds and feed ingredients intended for dairy animals, for animal species or uses not specified above, or when the intended use is not known
20	Corn, peanut products, and other animal feeds and feed ingredients, but excluding cottonseed meal, intended for immature animals
100	Corn and peanut products intended for breeding beef cattle, breeding swine, or mature poultry
200	Corn or peanut products intended for finishing swine of 100 pounds or greater
300	Corn and peanut products intended for finishing (i.e., feedlot) beef cattle

Regulation in Taiwan

Sanitation Standard for the Tolerance of Mycotoxins in Foods

DOH Food No.0980462647, 12/04/2009
DOH Food No.1011302722, 09/03/2012
MOHW Food No. 1021350146 Amended, 08/20/2013

Article 2

The tolerance of aflatoxin in foods shall meet the following standards:

Food Category	Tolerance of Total Aflatoxin (Including Aflatoxin B_1, B_2, G_1, G_2)
Peanut, corn	Not more than 15 ppb
Rice, sorghum, legumes, nuts, wheat, barley and oat	Not more than 10 ppb
Edible oils and fats	Not more than 10 ppb
Milk	Not more than 0.5 ppb (as aflatoxin M_1)
Milk powder	Not more than 5.0 ppb (as aflatoxin M_1)
Other foods	Not more than 10 ppb

Food Chain: Feed to Milk

- Exposure of Aflatoxin contaminated corn **greater than 20 ppb** to feed **dairy cattle**
- **Contaminated** milk containing **>0.5 ppb** Aflatoxin M1.
- **Milk Dumping.**

LC-MS Tools for Characterization at Our Lab

FOOD CHEMICAL CONTAMINANTS

Rapid Determination of Fumonisins in Corn-Based Products by Liquid Chromatography/Tandem Mass Spectrometry

WEI LI
Texas A&M University, Texas AgriLife Research, Office of the Texas State Chemist, 445 Agronomy Rd, College Station, TX 77843
TIMOTHY J. HERRMAN[1]
Texas A&M University, Department of Soil and Crop Sciences and Office of the Texas State Chemist, College Station, TX 77843
SUSIE Y. DAI[1]
Texas A&M University, Department of Veterinary Pathobiology and Office of the Texas State Chemist, College Station, TX 77843

A simple, fast, and robust method was developed for the determination of fumonisin B_1 (FB_1), fumonisin B_2 (FB_2), and fumonisin B_3 (FB_3) in corn-based human food and animal feed (cornmeal). The method involves a single extraction step followed by centrifugation and filtration before analysis by ultra-performance liquid chromatography/electrospray ionization (UPLC/ESI)-MS/MS. The LC/MS/MS method developed here represents the fastest and simplest procedure (<30 min) among both conventional HPLC methods and other LC/MS methods using SPE cleanup. The potential for high throughput analysis makes the method particularly beneficial for regulatory agencies and analytical laboratories with a high sample volume. A single-laboratory validation was conducted by testing three different spiking levels (200, 500, and 1000 ng/g for FB_1 and FB_2; 100, 250, and 500 ng/g for FB_3) for accuracy and precision. Recoveries of FB_1 ranged from 93 to 98% with RSD values of 3–8%. Recoveries of FB_2 ranged from 104 to 108%, with RSD values of 2–6%. Recoveries of FB_3 ranged from 94 to 108%

Texas (7) upon fumonisins exposure have also been reported. Fumonisin B_1 (FB_1), the most abundant of the fumonisins, has been classified a group 2B carcinogen, i.e., possibly carcinogenic to humans (8).

Because of their wide prevalence and potential toxicities, fumonisin B_1, fumonisin B_2 (FB_2), and fumonisin B_3 (FB_3), the major fumonisins found in naturally contaminated corn, are included in the guidelines set by the U.S. Food and Drug Administration (FDA) for industry in the United States (9). The recommended maximum levels for fumonisins in human foods and animal feeds that FDA considers achievable with the use of good agricultural and good manufacturing practices are regulated (i.e., 2000 ng/g in degermed dry milled corn products for human food, and 5000 ng/g in corn and corn byproducts intended for equids and rabbits). Keeping fumonisins below these recommended levels can reduce exposure to fumonisins that may be found in corn products intended for human and animal consumption. Within the European Union (EU), the Commission Regulation has recently established regulatory limits of fumonisins in foodstuffs based on the sum of FB_1 and FB_2 (10); more specifically, a maximum level of 1000 ng/g has been set for

Better lab efficiency

W. Li, T. J. Herrman, **S.Y. Dai** #
Journal of AOAC International. 2010, 93, 1472.

W. Li, T. J. Herrman, **S.Y. Dai** #
Rapid Commu. Mass Spectrum. 2011, 25, 1222-30

Improved throughput

Research Article

Received: 23 December 2010 Revised: 8 February 2011 Accepted: 10 February 2011 Published online in Wiley Online Library

Rapid Commun. Mass Spectrom. **2011**, *25*, 1222–1230
(wileyonlinelibrary.com) DOI: 10.1002/rcm.4979

Determination of aflatoxins in animal feeds by liquid chromatography/tandem mass spectrometry with isotope dilution

Wei Li[1], Timothy J. Herrman[1,2*] and Susie Y. Dai[1,3*]

[1] Office of the Texas State Chemist, Texas AgriLife Research, Texas A&M University, 445 Agronomy Rd., College Station, TX 77843, USA
[2] Texas A&M University, Department of Soil and Crop Sciences, Office of the Texas State Chemist, College Station, TX 77843, USA
[3] Texas A&M University, Department of Veterinary Pathobiology, Office of the Texas State Chemist, College Station, TX 77843, USA

The objective of the present study is to develop a simple, fast method for detection of aflatoxins in animal feeds. Simultaneous quantitation of four aflatoxins (AFB_1, AFB_2, AFG_1 and AFG_2) in animal feeds was achieved in a single liquid chromatography/tandem mass spectrometry (LC/MS/MS) run. The solid-phase extraction cleanup step is eliminated with the stable isotope dilution method. Matrix effects were observed and overcome by isotope dilution. The method was tested in a variety of animal feed matrices and proved to be accurate and reliable. Method ruggedness tests resulted in recoveries of 78% to 122% with an intra-day assay precision of 2% to 15% and an inter-day assay precision of 3% to 17%. These results indicate that this method is suitable for quantitation of aflatoxins in animal feeds.

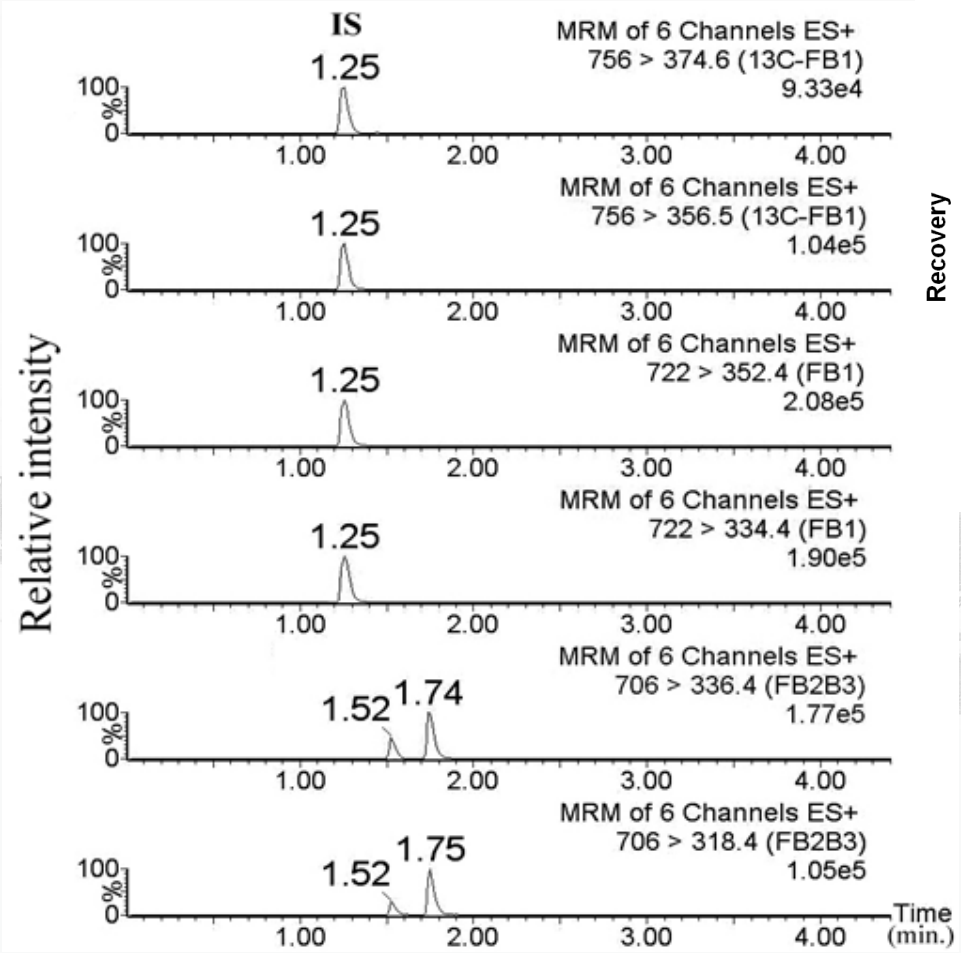
Aflatoxins (AF) are secondary metabolites of fungal species such as *Aspergillus flavus* or *Aspergillus parasiticus* growing in a wide variety of agricultural and food products. As the major aflatoxins produced in nature, aflatoxin B_1, B_2, G_1, G_2 are included in the setting of United States Food and Drug Administration (USFDA) guidelines for industry and the regulation of the European Commission due to their high carcinogenic potency.[1 3] The USFDA allows for a maximum of 20 parts per billion (ppb) of total aflatoxin in corn, peanut products, cottonseed meal, and other animal feed ingredients intended for dairy animals in the USA, whereas the European Commission established maximum acceptable levels ranging from 5 to 20 ppb for AFB_1 for a variety of animal feeds.[4]

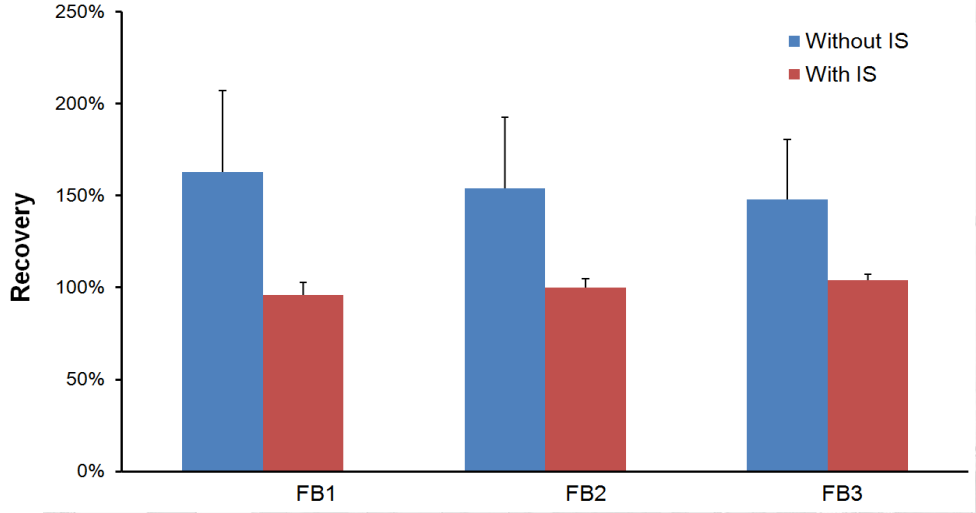
The major commodities that are prone to aflatoxin contamination include peanuts, corn, rice, dry fruit, tree nuts and spices. Since animal feed utilizes these agricultural crops, contamination of aflatoxins poses a risk to animal health. However, animal feed has complicated compositions such as cereal, oil seed, vitamins, fats and other chemicals, which challenges the analyses of aflatoxin in animal feed. In

Generally, the extraction of aflatoxins from animal feed includes a solid-liquid extraction step followed by a cleanup procedure. The cleanup steps can minimize the influence of matrix components and improve limit of detection (LOD). Most liquid chromatography based methods for food and animal feed analysis have been developed based on this practice.[15 24]

More recently, analysis of aflatoxins with liquid chromatography/tandem mass spectrometry (LC/MS/MS) has gained popularity. By using the mass spectrometry as the detector, identification of aflatoxin can be based on the molecular weight and precursor ion fragmentation pattern. The specificity and sensitivity of the modern mass spectrometry instruments thus offers the possibility of eliminating the extensive purification steps, which is the so-called 'dilute-and-shoot' method.[25] The separation power of mass spectrometry instruments also requires less chromatographic separation for both the analytes and the matrix components. A common observation with the 'dilute-and-shoot' method is the severe matrix effect, which is manifested as a signal enhancement or suppression of the analyte in the LC/MS/MS analysis. Because

Rapid LCMS Method for Fumonisin Analysis in Corn-based products





Comparison of recovery rates without internal standard (IS) and those with IS when testing blank cornmeal samples fortified with 1 µg g^{-1} for FB_1, 0.5 µg g^{-1} for FB_2 and 0.25 µg g^{-1} for FB_3.

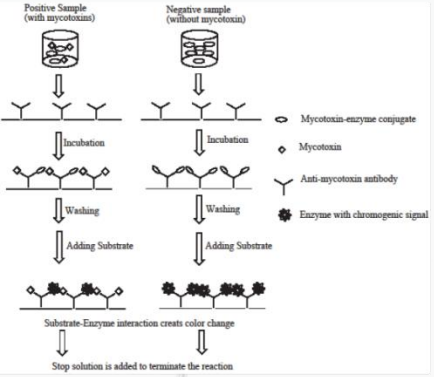
(Wei et al. J AOAC. 93, 2010, 1472)

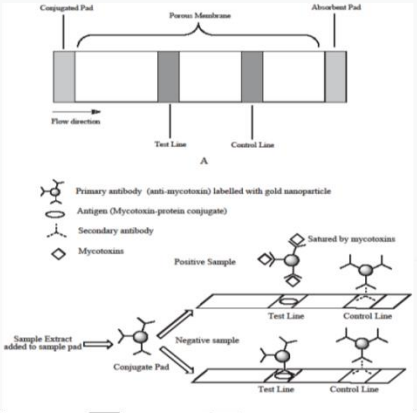
Comparison

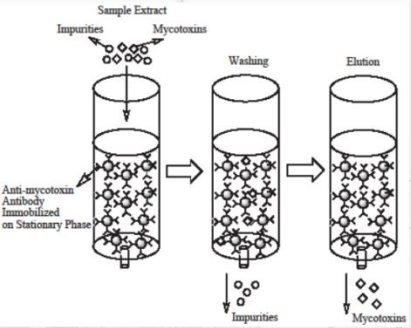
Aspects	HPLC/Fluorescence	HPLC/MS/MS
Sample preparation	10 h	2.5 h
Instrumentation	6 h	2 h

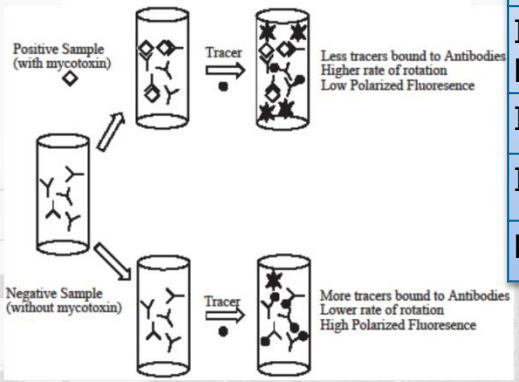
Based on 24 samples estimation.

Rapid Methods: Point of Sampling









Test Format	Frequency	Percent
Competitive ELISA	97	51
Fluorescent Polarization Immunoassay	9	5
Immunoaffinity column, Competitive ELISA	3	2
Immunoaffinity column, Fluorometer	5	3.62
Immunoaffinity column, Fluorometer/HPLC	2	1
Immunoaffinity column, UV	1	1
Immunoaffinity column,HPLC/ELISA	5	3
Lateral Flow Tests	67	35

Li et al, Using commercial immunoassay kits for mycotoxins: 'joys and sorrows'? World Mycotoxin Journal Volume 7 2014

World Mycotoxin Journal, 2014; 7 (4): 417-430
SPECIAL ISSUE: *Rapid methods for mycotoxin detection*
Wageningen Academic Publishers

Using commercial immunoassay kits for mycotoxins: 'joys and sorrows'?

Wei Li[1], S. Powers[2] and S.Y. Dai[3]*

[1]Office of the Texas State Chemist, Texas A&M University, 445 Agronomy Road, College Station, TX 77843, USA [2]VICAM, 34 Maple Street, Milford, MA 02157, USA [3]Department of Veterinary Pathobiology, Texas A&M University, College Station, 77843, USA; susie@otsc.tamu.edu

Received: 29 January 2014 / Accepted: 2 June 2014

- **Decision Making**
- **Surveillance**
- **Compliance**

Conclusions II

- We have systemically developed and utilized series of analytical technologies to characterize and monitor fungal toxins in food and feed sectors
- The methods were implemented to support the government surveillance program in the changing global climate

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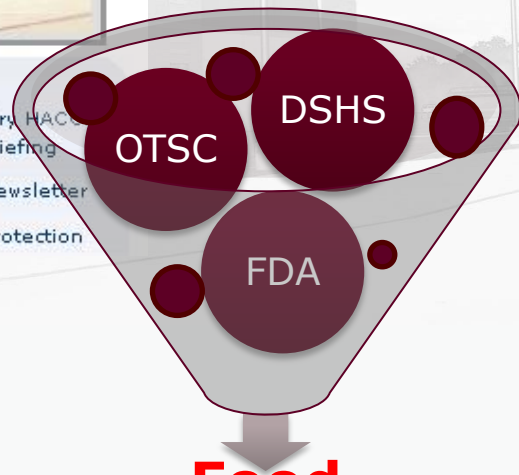
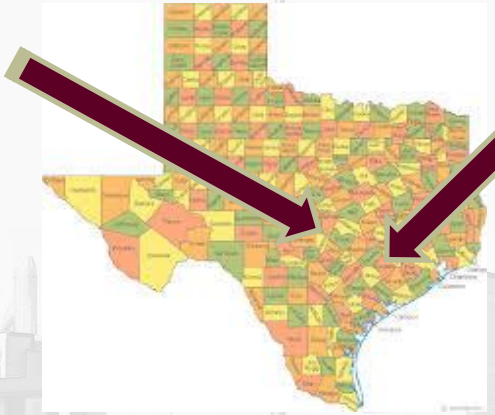
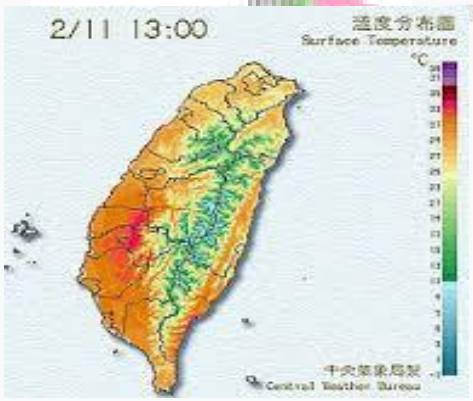


Resilient Agriculture → **Food Regulation**

TEXAS Department of State Health Services





	Area (km²)	Population	
Taiwan	36,193	23,461,708	GDP $1.021 Trillion
Texas	696,241	27,695,284 (2nd of US States)	GSP $1.648 Trillion

From Wikipedia

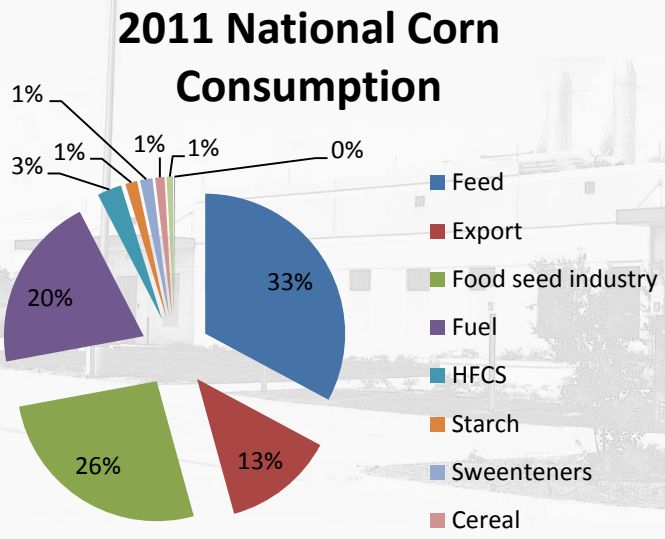
One Sample Strategy
A Risk Management Program

- Regulatory program to improve analytical capability, increase market uniformity, reduce market uncertainty and improve food safety

- Using one analytical result for multiple purposes

Corn Industry

- Feeding livestock remains the primary use for American corn
- Nationally, livestock and poultry directly consume approximately 40 percent of the country's corn crop - in addition to a significant amount of corn co-products such as distillers grains.
- **96% of corn produced in Texas is used for livestock feed**



Year 2012	Texas
Harvest (**acres**)	**1.55 million**
Yield (**bushels/acre**)	**130**
Contribution	**$1.5 billion**

National corn grower association

www.texascorn.org

www.mafes.msstate.edu

Corn Harvest

In harvest, each truck load of corn will stop at the elevator(grain warehouse) for about half an hour.

Corn Feed Regulation: Aflatoxin 20 ppb

- Aflatoxin level table

ppb	Product Description
20	Corn, peanut products, cottonseed meal, and other animal feeds and feed ingredients intended for dairy animals, for animal species or uses not specified above, or when the intended use is not known
20	Corn, peanut products, and other animal feeds and feed ingredients, but excluding cottonseed meal, intended for immature animals
100	Corn and peanut products intended for breeding beef cattle, breeding swine, or mature poultry
200	Corn or peanut products intended for finishing swine of 100 pounds or greater
300	Corn and peanut products intended for finishing (i.e., feedlot) beef cattle

- One truck load of the corn can be sampled three or more times:
  - By elevator operators for purchasing decision
  - By insurance representatives for value determination
  - By regulators for control of sale and distribution

One Sample Program

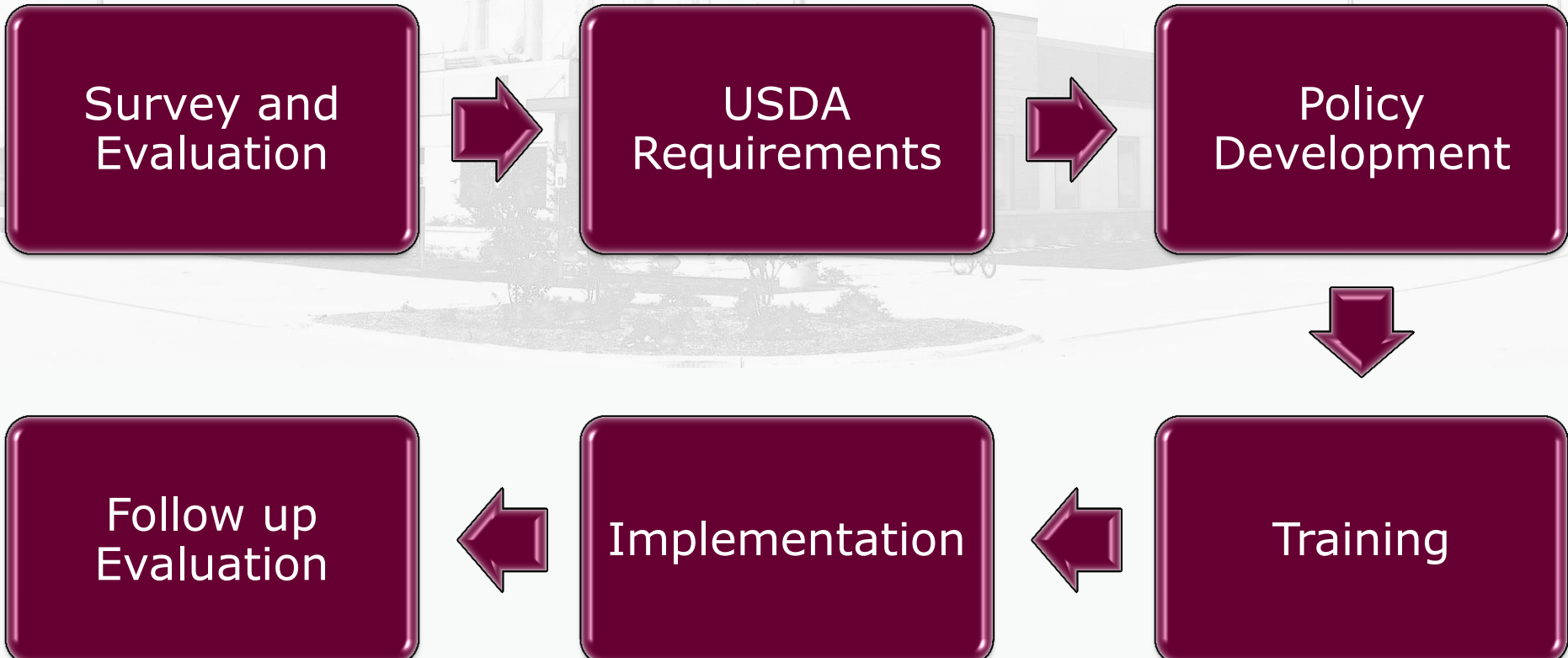
- The current practice creates market uncertainty and various troubles.

- Use one sample result for multiple purposes:
  - Purchasing
  - Insurance
  - Regulation

- Requirement of measurement:
  - Fast
  - Accurate

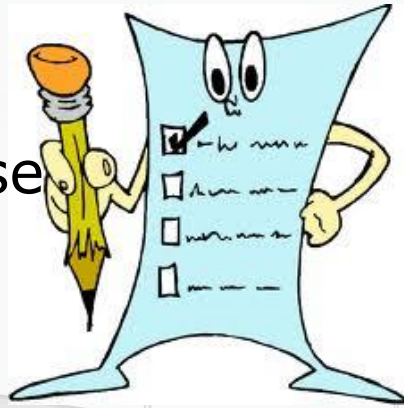
Science Driven Approach: Regulators, Stakeholders and Customers

- Evaluation of the current analytical capacity in the field
- Science-based approach



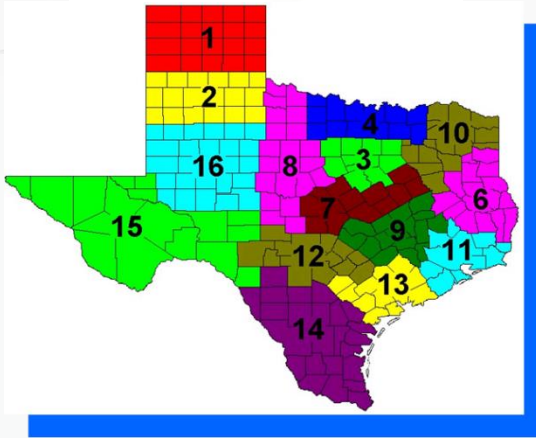
TX Elevator Survey of Testing Kits

- Areas we surveyed:
  - Testing kit model/manufacturer
  - Expiration date of the current testing kit in use
  - Users' experience
  - Sample preparation method/device
  - Up limit of aflatoxin measurement range
  - Samples at three different concentration levels (by 21 independent HPLC measurements)
    - 52 ppb
    - 379 ppb
    - 581 ppb



Survey Results

Area	Vendor 1	Vendor 2	Vendor 3	Vendor 4	
	Kit 1	Kit 2	Kit 3	Kit 4	Kit 5
2			1		
3	1	3			
4		**1**			
7	3	6			
9	3	6	1	3	
10					1
12	1		2		2
13	2	**2**			
14		1			
Total (Texas)	**10**	**19**	**4**	**6**	



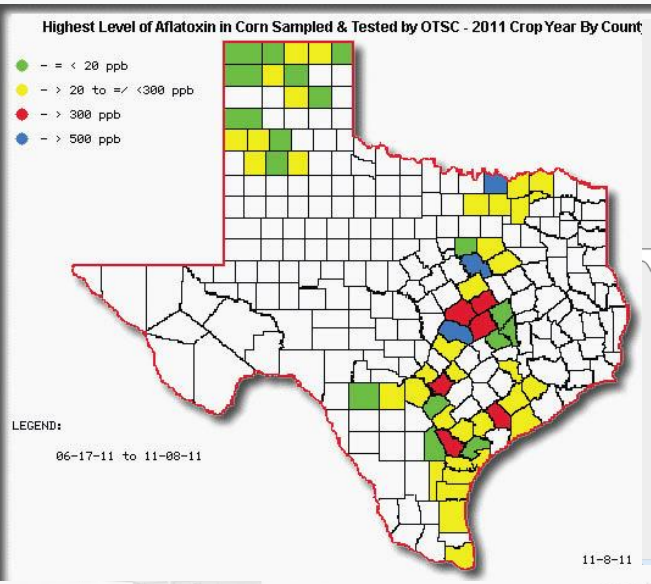
Five testing kits from four major kit manufacturers

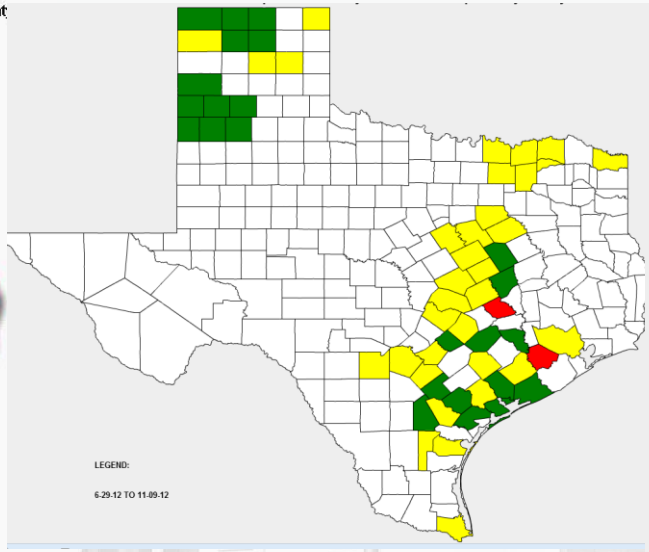
Returning Results

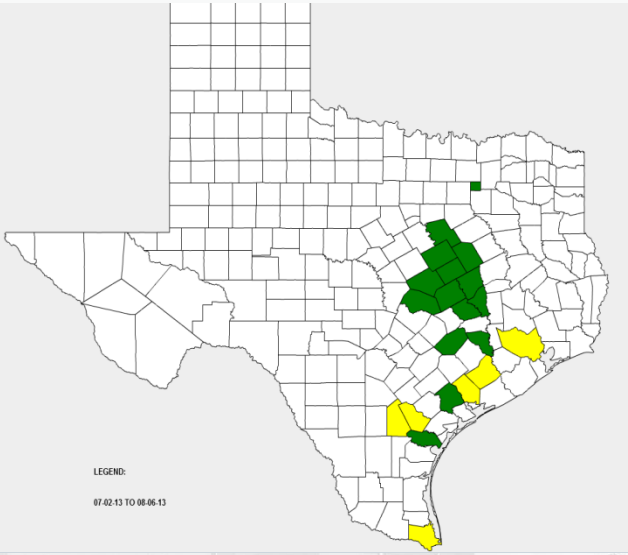
HPLC Results (ppb)	STD (ppb)	Elevator results (ppb)	STD (ppb)
52	3	62	50
379	18	250	113
581	34	440	170

- **Measurement capacity varies a lot between firms**
- **Overall performance is terrible**

TX Aflatoxin Map







2011 2012 updated 8/06/2013

=< 20 ppb

>20 to =/< 300 ppb

- > 300 ppb

- > 500 ppb

USDA GIPSA Testing Kit Certification Program

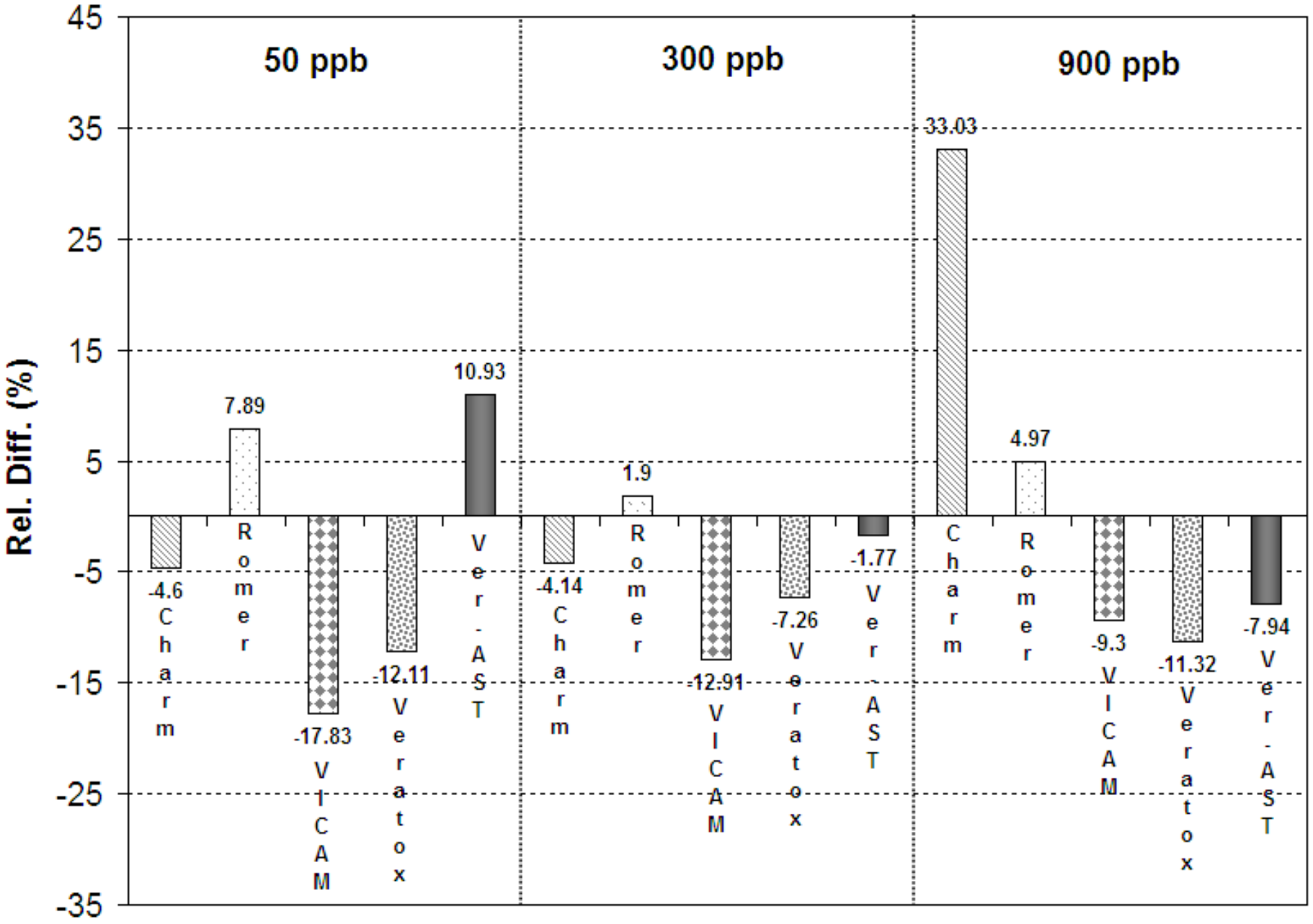
Concentration (ppb)	Maximum RSD (%)	Standard Deviation	Range (ppb)
5	25	1.25	2.5-7.5
10	22	2.2	5.6-14.4
20	20	4	12-28
100	16	16	68-132

Study Design to Evaluate Kits

Target level (ppb)	Testing kit			HPLC
	Analyst 1	Analyst 2	Analyst 3	Analyst 4
50	7	7	7	21
300	7	7	7	21
1000	7	7	7	21

Eligibility to be used in the risk management program

Performance of test kits on samples with different levels of mycotoxins



Actions and Preparation

- Follow up with the testing kit company for corrective actions
- Guidance with regard to testing kit usage in the “One Sample Strategy” program was developed.
- Training material for the elevator who is participating the program
  - Sampling
  - Grinding
  - Analysis
  - Data report
- Distributes OTSC reference material
- Sample to be retained for six weeks
- Field investigators collect retained sample for HPLC analysis

Reduce Market & Food Safety Risk

USDA

United States Department of Agriculture

Farm and Foreign Agricultural Services

Risk Management Agency

1400 Independence Avenue, SW Stop 0801 Washington, DC 20250-0801

BULLETIN NO.: MGR-12-004 APR 5 2012

TO: All Approved Insurance Providers
All Risk Management Agency Field Offices
All Other Interested Parties

FROM: William J. Murphy
Administrator

SUBJECT: Continuation of One Sample Strategy for Aflatoxin Testing in Texas

BACKGROUND:

The Risk Management Agency (RMA) issued Manager's Bulletin MGR-11-011 on July 26, 2011, authorizing the "One Sample Strategy (OSS)" for aflatoxin testing in approved Texas elevator facilities for the 2011 crop year. The Bulletin stated RMA would annually reauthorize the program. RMA held discussions with the Office of the Texas State Chemist (OTSC), Regional Offices, and other interested parties, and received written summary results from OTSC to determine whether to continue the program beyond the 2011 crop year.

ACTION:

APPENDIX C – EXAMPLE ANALYST ID CARD

Office of the Texas State Chemist
AGRICULTURAL ANALYTICAL SERVICES
College Station, Texas

Name of Designee

Authorized under the provisions of the Texas Agricultural Code of 1983 to collect samples and perform chemical analysis and tests in accordance with the provisions of the Feed Laws and Regulations adopted thereunder.

EXP: 05/2012

☐ Employee
☐ Designee

Signature of Designee

State Chemist & Director

APPENDIX C – EXAMPLE OTSC CERTIFICATE OF ANALYSIS

OFFICE OF THE TEXAS STATE CHEMIST
Agricultural Analytical Services
445 Agronomy - College Station, TX 77843-2114

Mailing Address
P.O. Box 3160
College Station, Texas 77841-3160

Tel (979) 845-1121
Fax (979) 845-1389
http://otsc.tamu.edu

Official Sample Certificate of Analysis

Date

Sampled: Date

CERTIFICATE #: 2013-facility#-scale ticket

Guarantor: Your firm's license #
Firm Name
Address
City, State ZIP

Facility: Your facility's license #
Facility Name
Sampling Loctaion
Address
City, State ZIP

Producer: Farm #
Producer's Name

Risk Assessment and Management

- Uniformity in the market and improved accuracy

ppb	Product Description
20	Corn, peanut products, cottonseed meal, and other animal feeds and feed ingredients intended for dairy animals, for animal species or uses not specified above, or when the intended use is not known
20	Corn, peanut products, and other animal feeds and feed ingredients, but excluding cottonseed meal, intended for immature animals
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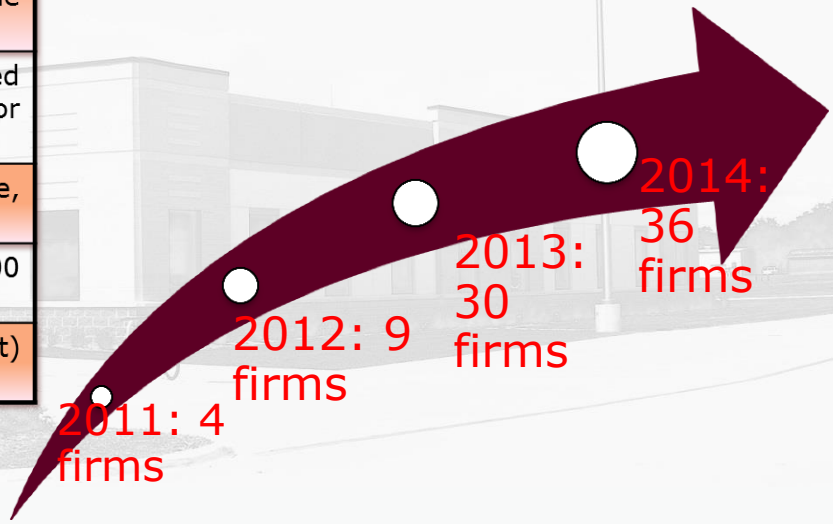


Picture of Cargill at the Port

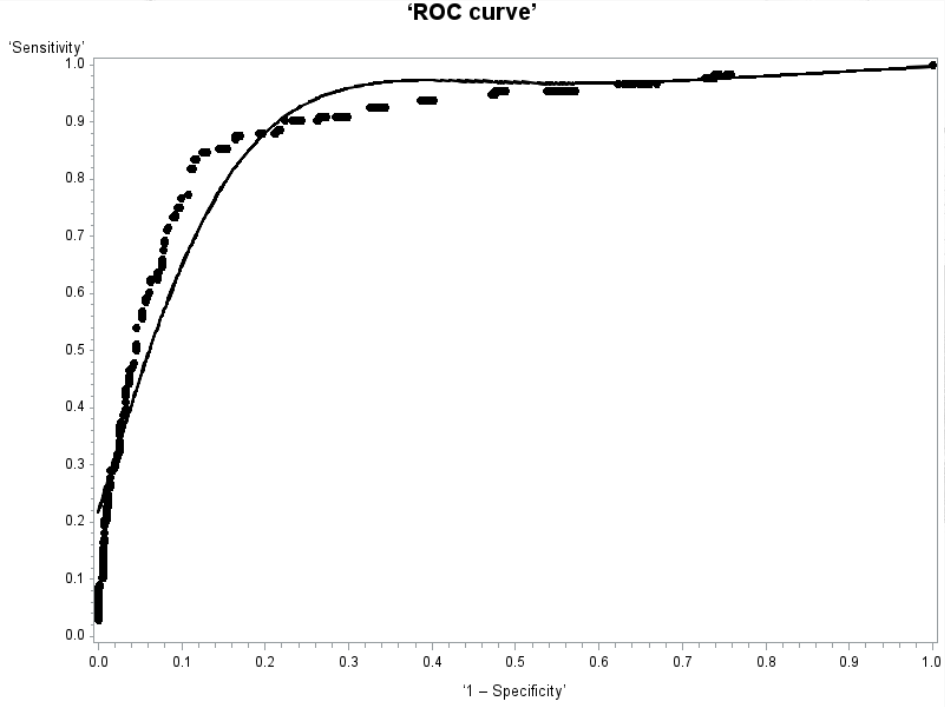
~6 weeks

Year	Samples by testing kits in industry	HPLC verifications by government agency
2011	720	34
2012	2115	84
2013	13,928	588
2014	14,918	875

- What do we learn from a medical diagnostic test?
- Diagnostic tests: Industry measurements(kits)
- Gold standard tests: Government agency measurements (HPLC)

Receiver Operating Characteristic Curve (ROC): 2013

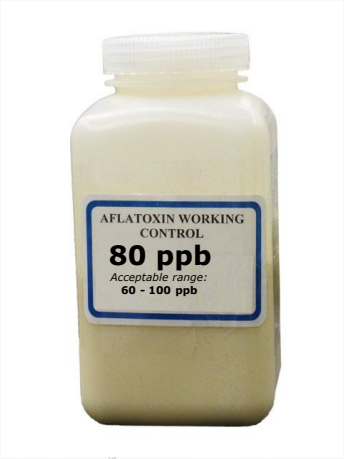
Rejection Concentration = 20 ppb by HPLC



- Sensitivity: Being able to know > **20 ppb**
- 1-Specificity:False positive, incorrectly tell >**20 ppb**
- Area under the curve: Accuracy (0.9-1 suggests excellent) **0.9013**

Industry performance evaluation

A Systematic Approach to Aflatoxin Risk Management



Main
Current Weather
Disease & Epidemic
Droughts
Earthquakes
Fires & Wildfires
Floods
Heat Waves
Household Issues
Hurricanes
Loss of Utilities
Thunderstorms, Lightning and Hail
Tornadoes
Winter Storms

Droughts

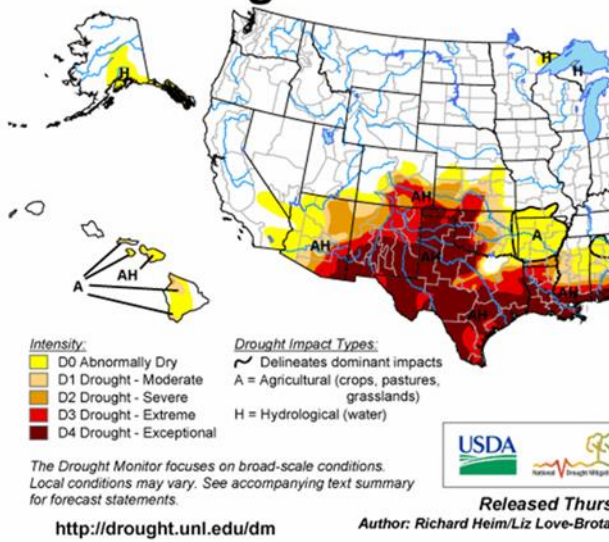
A drought is a period of abnormally dry weather that persists long enough to produ
imbalance. Droughts have wide-ranging adverse economic, environmental, and s
reservoirs, groundwater levels, and soil moisture all drop.

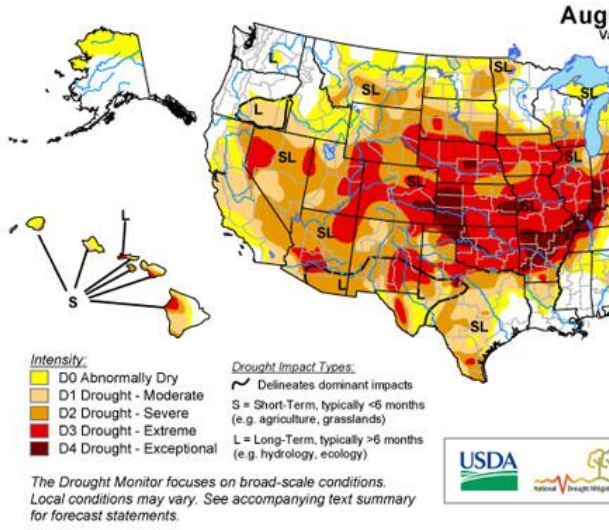
Drought resources collected by Texas AgriLife Extension Service and organize

1. Agricultural Economics
2. Animal Science
3. Ag Engineering
4. Ecosystem Science and Management (Range & Forestry)
5. Horticulture
6. Home Water Conservation
7. Soil & Crop Sciences
8. Veterinary Medicine

Additional Resources by Texas AgriLife Extension Service:

1. Water Education Network
   Texas AgriLife Extension Service
2. Agricultural Drought Task Force
   Texas AgriLife Extension Service





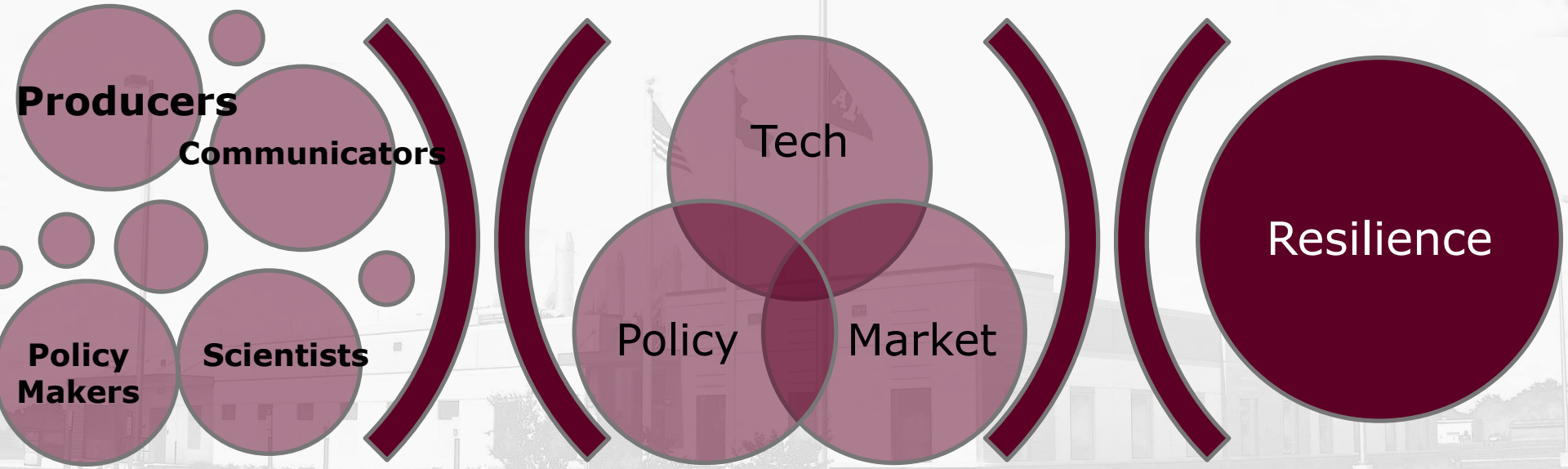
Conclusions

- The “OSS” program harmonizes standards and practices between multiple parties within the agricultural community.
- A systems approach requires the coordination and collaboration between multiple parties.
- Harmonization and plasticity are equally important for a resilient resolution.
- A science based approach ultimately benefits the whole agricultural sector and government regulation, and promotes resilience and sustainability.

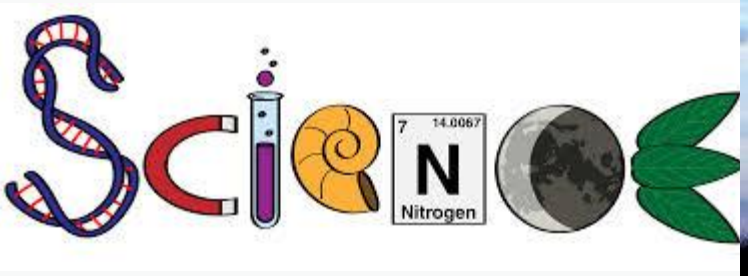
Outline

- **Innovative Technologies to Enable Mechanism Study:** Systems Biology for Resilience Agriculture
- **Characterization and Evaluation Tools:** Enable Safety of Agriculture Products in a Changing Climate
- **Science-Driven Management:** A Systematic Approach for Food and Feed Safety toward Resilient Agriculture – "One Sample Strategy"
- **Perspectives:** Regulatory Science to Improve Food and Feed Safety for More Resilience in Production System

A Systems Approach for Resilience

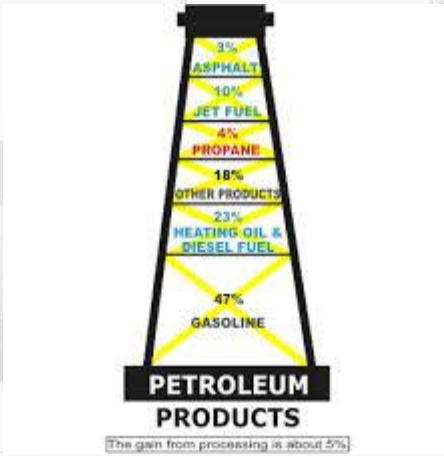


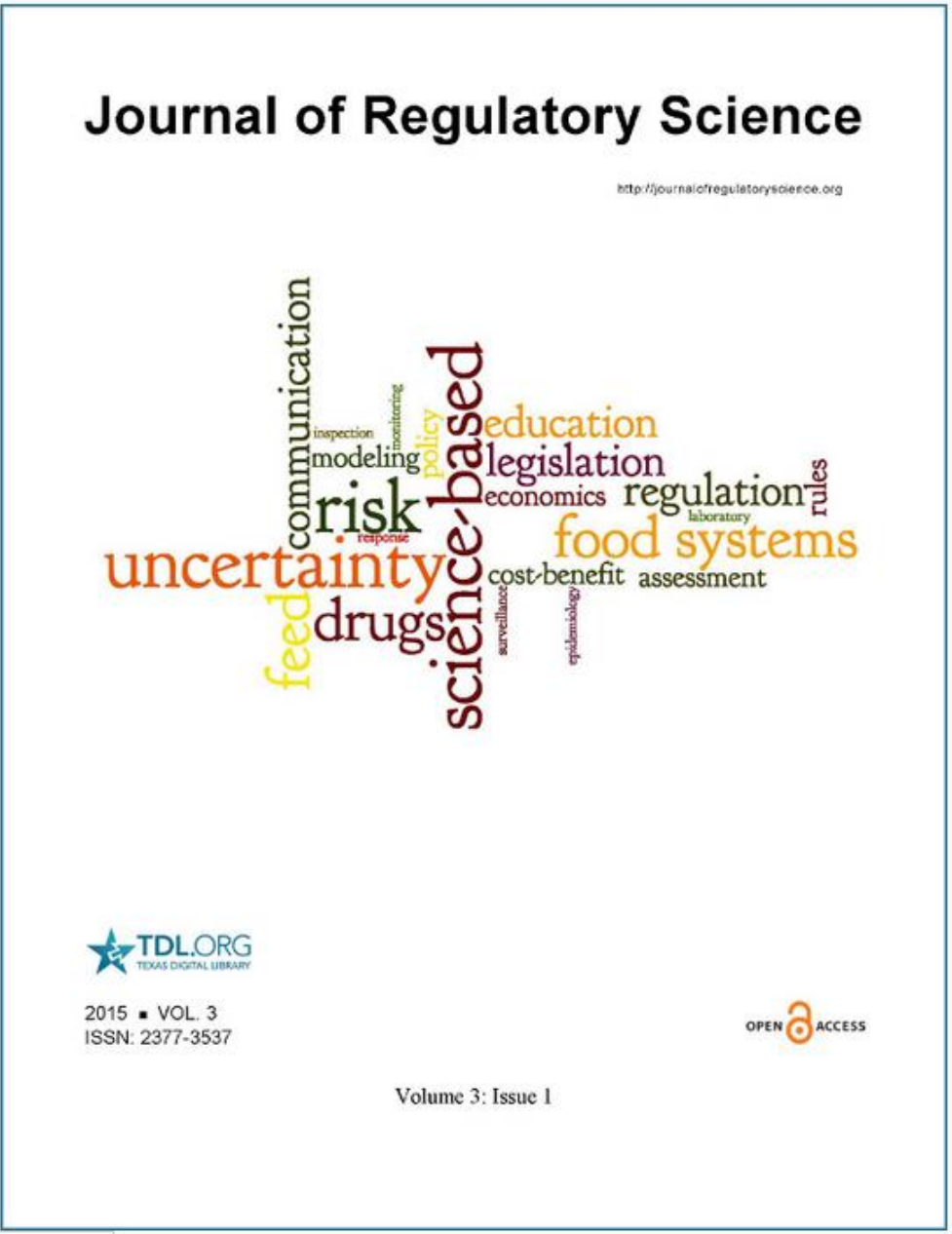
People Science Resolution



What is Regulatory Science

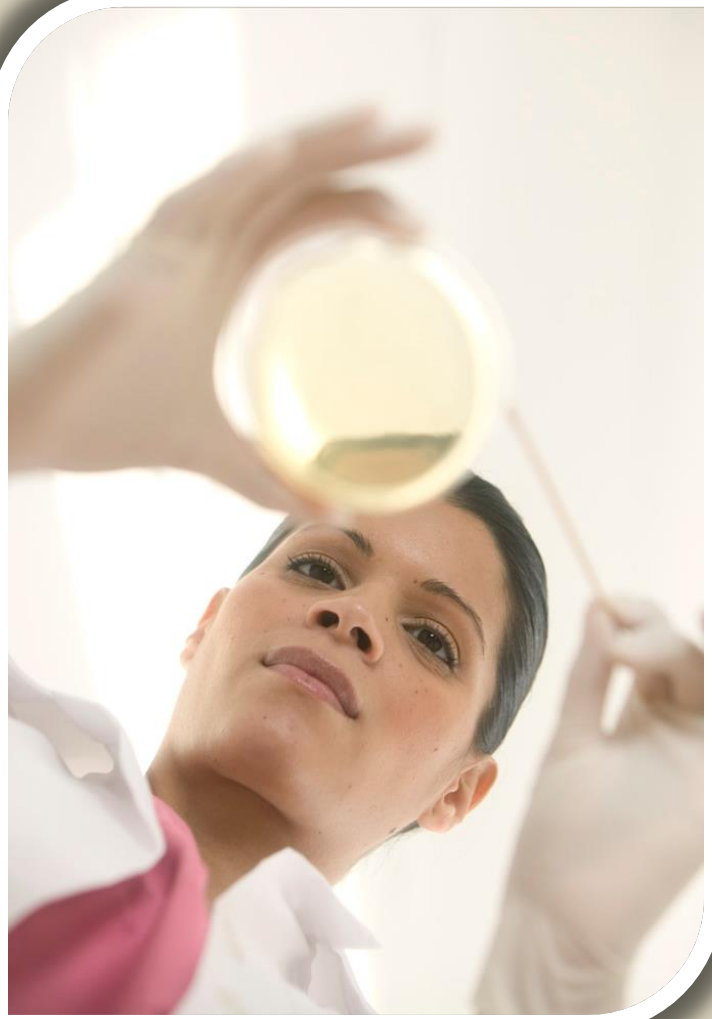
- Science for regulated products
- Agriculture
- Environment
- Health related products
- You name it……





www.journalofregulatoryscience.org

TEXAS A&M UNIVERSITY



Regulatory Science Graduate Curriculum

Advancing the science

of creating tools, standards,

and practices to improve the

protection and compliance

of food systems

One of the Key Curriculum

SCSC 629/VTMI 629

Laboratory Quality Systems

- **Validity & reliability of laboratory data**
- **Laboratory process control**
- **Quality assurance procedures, tools and methods**
- **Laboratory management**

Acknowledgements

AgriLIFE RESEARCH
Texas A&M System

Texas Department of Agriculture
Todd Staples, Commissioner

Division of Agricultural Sciences
And Natural Resources

SunGrant
INITIATIVE
South Central Region

FERN

arpa·e
CHANGING WHAT'S POSSIBLE

U.S. DEPARTMENT OF
ENERGY
Energy Efficiency &
Renewable Energy

W

Department of Energy
United States of America