



# A Comparison of Heavy Metals in Plant and Animal Based Meats and Fish by Microwave Digestion & ICP-OES and ICP-MS Analysis

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# What are Plant Based Meats and Fish?

- Manufactured food items with the appearance, texture, and taste of animal based meats
- Comprised of plant based and other ingredients
  - Often pea powder is the source of protein
  - Salts for taste including Na, K, Ca
  - Nutritive minerals such as Fe and Zn
  - Other metal based ingredients as necessary for color and texture
- Growing Market
  - US alone accounted for over 1.4 billion dollars in 2021
  - Includes vegan substitutes for beef, chicken, pork, turkey as well as fish and seafood

# Metals Considerations for Food in General

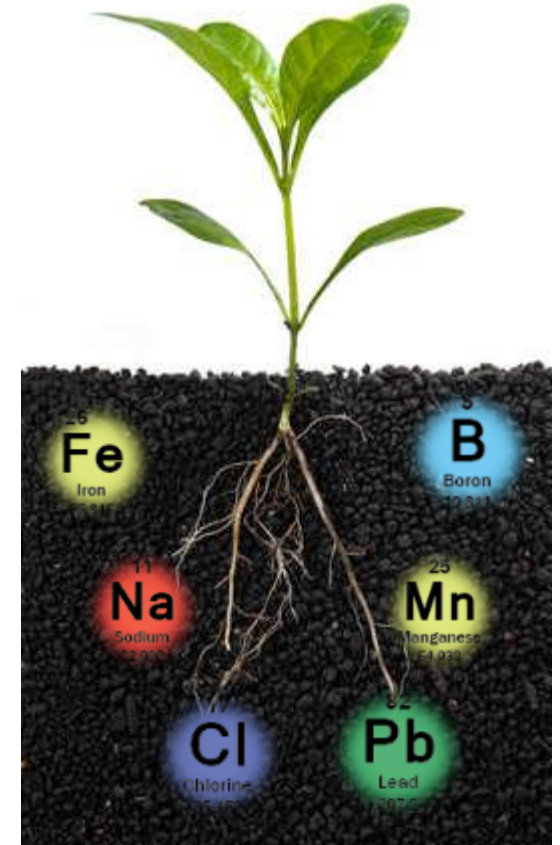
- Four highly toxic elements known as the Big 4 (As, Pb, Cd, Hg) pose the biggest threat to human health.
- Limits have been set for these and other elements by the United States Pharmacopeia or (USP) for pharmaceuticals.
- Currently the Food and Drug Administration (FDA) only regulates metals in bottled water, juice, and candy; but its only a matter of time before there's further legislation.
- As the FDA is the regulatory arm for the USP it is widely anticipated that these limits or similar would be set for all foods, both animal and plant based, in the future.

# Where Do Metals Come from in Plant Based Foods?

- The environment
  - Most plants are grown in soils which will have some level of heavy metals; either naturally occurring or soil that has been contaminated over time
- Primary causes of soil contamination include
  - Industrial waste – current and past manufacturing facilities
  - Automotive exhaust
  - Water from irrigation or runoff
  - Fertilizers and pesticides
- Other metals in plants
  - Added seasonings such as salts (Na, K, Ca)
    - These elements are also abundant in soil
  - Metals added as nutritional elements such as Fe and Zn

# Uptake of Heavy Metals in Plants

- Plants uptake metals from the soil via the root and vascular system, and they are typically stored around the leaves.
- Plants that uptake large amounts of metals are referred to as hyperaccumulators.
- Plants processed into vegan meat products will contribute to the metal concentrations in the final product.



# Comparison of Animal vs Plant Meats (Raw Product)

- In theory the plant based products could contain higher concentrations of some heavy metals due to uptake from the soil.
- Other metals are added in plant based products for taste, nutrition, color and texture.
- We chose a variety of meats and a fish that were minimally processed in order to get the best comparison.
  - Uncooked products
  - No spices added to animal based meats
- Note that we had to test a formed plant based chicken tenderloin as plant based ground chicken is not available.
- The tuna fish is an albacore sample and the plant tuna is a formed, but unflavored portion.

# Sample Listing (All Purchased at Local Stores)

## Animal Meats

- Ground beef
- Sausage roll
- Ground chicken
- Albacore tuna portion

## Plant Based Meat

- Ground beef
- Sausage roll
- Chicken tenderloin
- Tuna portion

# Microwave Digestion Batch

- A MARS 6 with MARSPress Plus Vessels were used for our study.
- All samples were run in triplicate.
- Two Standard Reference Materials (SRM's) were prepared with the samples.
  - NIST SRM 1577C Bovine liver
  - NIST SRM 1947 Lake Michigan fish tissue
- Spiked samples and method blanks were run as part of the digestion batch.



# Microwave Digestion Equipment

- CEM MARS 6 Microwave Digestion System
- MARSXpress Plus Digestion Vessels
  - Simple 3 part design



# Digestion Procedure - FDA EAM 4.7

- An approximate 0.5 g sample is weighed into a 110 mL MARSXpress Plus Vessel.
- Add 8 mL of Nitric Acid ( $\text{HNO}_3$ ).
- Add 1 mL of 30% Hydrogen Peroxide ( $\text{H}_2\text{O}_2$ ).
- Digest sample at 200 °C (microwave digestion method to follow).
- Cool, open and add 0.5 mL of Hydrochloric acid ( $\text{HCl}$ ).
- Dilute samples to 100 mL and analyze.

# MARS 6 Microwave Digestion Method

Stage	Ramp (min)	Temperature (°C)	Hold (min)
1	20:00	200	15:00

**Note: Cooling time was 15 minutes**

# ICP-OES Equipment and Conditions

- Agilent 5110 ICP-OES

- Used to analyze Na, K, and Ca
- 45 second rinse between samples
- Yttrium, measured at 377.433 nm, used as internal standard
- Fitted background correction

Parameter	Value
RF Power	1200 W
Viewing Mode	SVDV
Viewing Height	8 mm
Nebulizer Flow	0.7 L/min
Plasma Flow	12 L/min
Aux Flow	1 L/min

# ICP-MS Equipment and Conditions

- Agilent 7850 ICP-MS

- Used to analyze As, Pb, Cd, Hg, Se, Fe, and Zn
- No gas, H<sub>2</sub>, and He tuning modes used
- 3 minute rinse between samples
- Li, Sc, Ge, In, Rh, and Tb used as internal standards
- No gas dilution techniques used

Parameter	Value for [He] mode
RF Power	1550 W
Sampling Depth	8 mm
Carrier Gas	1.05 L/min
Dilution Gas	N/A
Helium Cell Gas	5.0 mL/min
Energy Discrimination	5.0 V

# ICP and ICP-MS Results

- All results in ppb other than Na, K, Ca, Fe, Zn (ppm)

	As (ppb)	Cd (ppb)	Hg (ppb)	Pb (ppb)	Se (ppb)	Fe (ppm)	Zn (ppm)	Na (ppm)	K (ppm)	Ca (ppm)
<b>Beef</b>	2.634	0.2173	1.037	4.874	104.39	24.75	43.23	518.17	3399	46.29
<b>Plant Based Beef</b>	13.24	9.739	0.9196	5.911	73.62	31.5	41.61	3781	2692	223.9
<b>Ground Chicken</b>	0.5576	0.0776	0.848	2.449	157.8	5.682	14.39	529.5	2848	64.63
<b>Plant Chicken Cutlet</b>	4.329	14.61	0.9736	15.2	18.59	19.61	5.34	10096	789.1	420.04
<b>Pork Sausage</b>	0.5356	0.1246	0.6223	5.943	141.5	3.545	11.71	425.6	3182	39.14
<b>Plant Sausage</b>	9.059	18.12	1.833	17.6	54.9	19.01	37.63	7076	3957	1469
<b>Tuna</b>	1624.02	10.23	245.1	2.838	519.64	3.93	3.183	2060	2285	44.39
<b>Plant Based Tuna</b>	4.642	22.6	0.3313	3.575	72.62	32.67	13.78	3887	1206	434.5
	As (% Rec)	Cd (% Rec)	Hg (% Rec)	Pb (% Rec)	Se (% Rec)	Fe (% Rec)	Zn (% Rec)	Na (% Rec)	K (% Rec)	Ca (% Rec)
<b>1577C Bovine Liver</b>	111.63	92.98	104.37	88.53	108.97	91.37	91.07	96.37	104.99	105.98
<b>1947 Lake Michigan Fish Tissue</b>	105.02	N/A	96	N/A	94.81	98.5	106.04	N/A	N/A	N/A

# USP 232 Big Four Oral Limits ( $\mu\text{g}/\text{day}$ )

Arsenic (As)	Cadmium (Cd)	Mercury (Hg)	Lead (Pb)
15	5	30	5

- In order to convert  $\mu\text{g}/\text{g}$  to  $\mu\text{g}/\text{day}$  you must make assumptions
  - Portion = 1/4 pound or 112 g
  - One portion eaten per day?
  - ppb = 1  $\mu\text{g}/\text{kg}$

The calculation for  $\mu\text{g}/\text{day}$  is then

$112 \text{ g} \times \text{ICP-MS result } (\mu\text{g}/\text{kg}) \times 1 \text{ kg}/1000 \text{ g} = \mu\text{g}/\text{portion}$  or  $\mu\text{g}/\text{day}$  if one portion

# Results Based on % of Daily Limit per Serving

	<b>As</b>	<b>Pb</b>	<b>Cd</b>	<b>Hg</b>
<b>Beef</b>	1.93	11	0.4	0.4
<b>Plant Beef</b>	9.86	13.2	21.8	0.33
<b>Chicken</b>	0.4	5.4	0.2	0.33
<b>Plant Chicken</b>	3.2	34	2.4	0.37
<b>Pork Sausage</b>	0.4	13.4	0.2	0.23
<b>Plant Sausage</b>	6.73	39.4	40.4	0.67
<b>Tuna</b>	1212.67	6.4	23	91.47
<b>Plant Tuna</b>	3.46	8	50.6	1.47
<b>USP <math>\mu\text{g}/\text{Day}</math></b>	<b>15</b>	<b>5</b>	<b>5</b>	<b>30</b>



# Discussion of Big Four Elements

- In general the plant based meat products were higher in metals compared to the animal meat product
  - Likely due to the uptake of metals from soil
- None were close to the limits as set by USP 232
- The plant based tuna was the exception
  - Slightly higher for lead and cadmium
  - But much lower than tuna fish in As and Hg
  - The Hg in tuna fish is just under the daily limit
  - If you eat anything else that day you will likely go over the limits
- Arsenic level for tuna fish is well in excess of the USP recommended daily limit
  - This has been reported in previous studies, but we will do more testing on tuna fish samples to confirm these results

# Discussion of Salt Results (Na, Ca, K)

- Salts are primarily added as seasonings
- Sodium and calcium levels are much higher in plant based meat
  - It is likely to improve the overall taste and care should be given for those on reduced sodium diets
  - It is also very likely that these elements are taken up by the root system
- Potassium results are fairly consistent between both animal and plant based meats
- None pose any health hazard for humans

# Discussion of Nutrients Results (Fe, Zn, Se)

- Some nutritive metals are naturally occurring like Fe which is present both in animal meats and plant proteins such as pea protein
  - Other than beef there is significantly more iron in plant based meats
  - Possible fortifying higher since vegans in general have lower iron intake
- Some elements like Zn are added to animal feeds or used as an additive for plant based meats to provide better nutrition
  - Zn is almost identical for beef, lower in plant based chicken, and higher in plant based pork and tuna.
  - The highest level we had in meat is less than half the 10 mg/day recommended allowance
- Se is sometimes added in small amounts
  - Selenium is an essential element but should be kept to no more than 150 µg/day
  - The highest level found in our study was tuna fish at 58 µg/serving

# Conclusions

- Plant based meats are a rapidly expanding segment in the consumer market place
- In general the big four elements are elevated in plant based meats and fish vs animal meats and fish but not at levels well below USP standards
- The big exception is that tuna fish is very high in arsenic and close to maximum level for mercury
  - Plant based is a much healthier alternative
- The other elements we analyzed were usually higher in the plant based but well below recommended daily allowances

# Future Work

- Cooked vs raw products including restaurant samples
- More tuna fish samples to see if the arsenic levels vary or are consistently high
- Add more seafood plant based products such as crab cakes to our study
- Dairy plant based products

# Thank You

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