# Arsenic Abundance In Arugula And Kale

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## Introduction:

### All About Arsenic (AAA)

The AAA project was started in 2015 as a collaboration between the Community Environmental Health Laboratory at Mount Desert Island Biological Laboratory and Dartmouth College's Toxic Metals Superfund Research Program. This current project involving College of the Atlantic students and faculty is a subproject of the larger AAA citizen science data literacy and public health project.

### Sources of Arsenic

- Regional bedrock geology: metasedimentary and igneous rocks (Peters, 2008; Figures 1 and 2).
- Residuals of historical arsenical pesticide application from the early-mid twentieth century (Robinson and Ayotte, 2006; Figures 3 and 4).

**Groundwater As Occurrence and Bedrock Geology of New England**

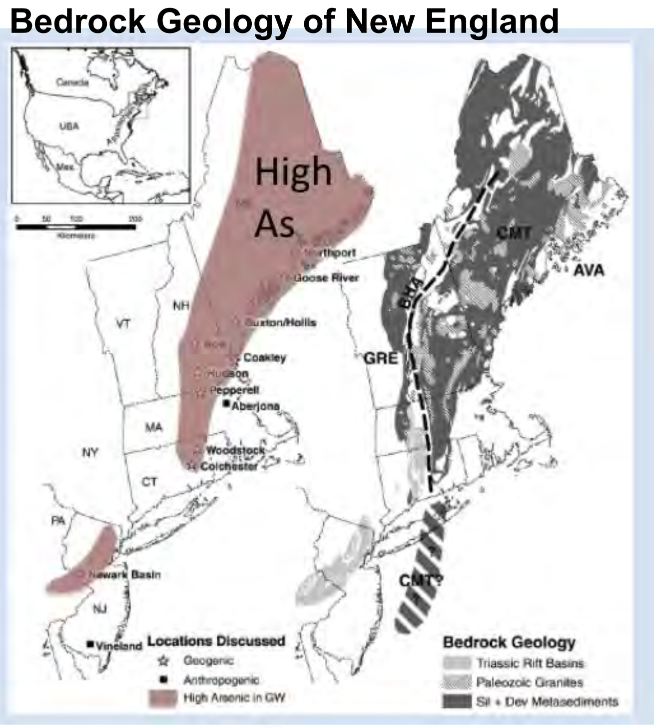


**Figure 1** (right): Arsenic is commonly found in the bedrock of New England thanks to the underlying metasedimentary an igneous bedrock (modified after Peters, 2008).

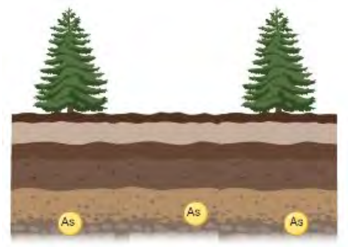

**Figure 2** (right): Arsenic found within bedrock geology and weathering products in soils.

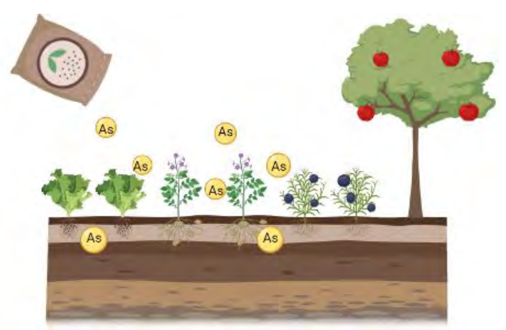

**Figure 3** (left): Application of arsenical pesticides in early-mid twentieth century.

### Arsenic in Humans

Long-term low-dose arsenic exposure is linked to DNA damage and cancers (Normandin et al. 2014; Baris et al. 2016).

- No maximum level set by the United States Food and Drug Administration (US FDA) for arsenic in food products.
- US FDA has an action level guidance of 0.1 mg kg$^{-1}$ on rice cereal products for infants (Food and Drug Administration, 2020).
- The World Health Organization (WHO) set an inorganic arsenic lower limit on the benchmark dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$) at 3.0 μg kg$^{-1}$ (of bodyweight) day$^{-1}$ based upon epidemiological studies (World Health Organization, 2011).

### Arsenic in Plants

In prior research, arsenic levels in Brassica family plants exceeded suggested guidance when grown in orchards where arsenic pesticides were once likely applied in urban environemnts. (Lim and McBride, 2015).

### Project Goals

- Determine if arsenic and kale grown in areas of higher arsenic concentration yield higher arsenic concentrations.
- Use results to make recommendations to farmers about crop selections if arsenic concentrations are high to reduce arsenic exposure.

## Methods:

From local markets, we purchased arugula and kale grown in regions of Downeast Maine with elevated groundwater arsenic levels and/or where there is a high probability of past arsenical pesticide use (Maine CDC; Robinson and Ayotte, 2006; Figure 4).

Each sample (bunch of leaves) were:

- Dried at 70°C
- Homogenized and ground to a powder
- Sent to Dartmouth College's Trace Element Analysis Laboratory for trace metal analysis.

**Past pesticide probability and groundwater arsenic concentrations in the Penobscot Bay, Blue Hill Peninsula, and MDI area**

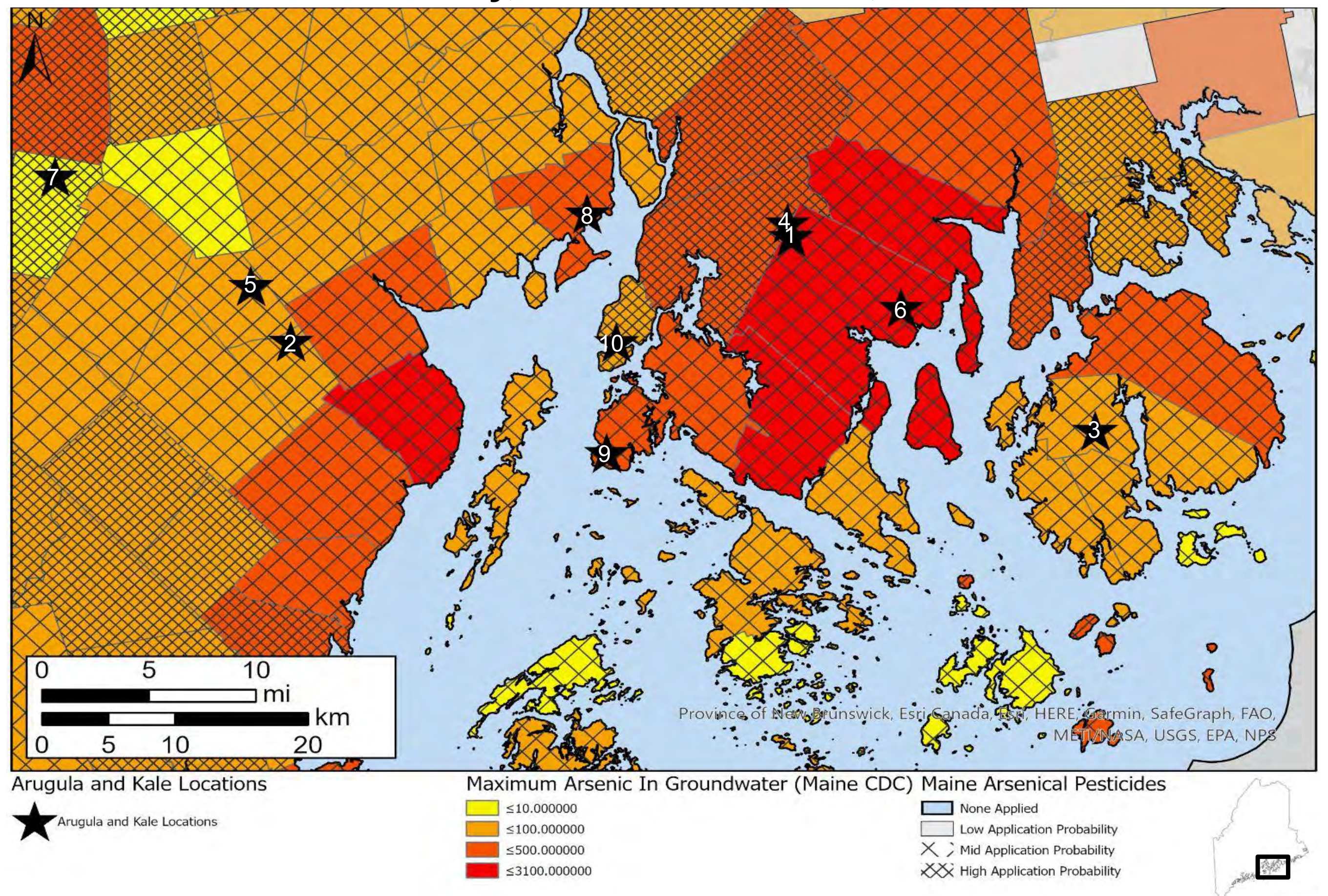


**Figure 4** (above): Map showing the locations where each sample of arugula or kale was grown (stars). Colored units show the maximum recorded arsenic levels in groundwater by town (Maine CDC) and the hatched patterns show the probability of arsenical pesticide application (Robinson and Ayotte, 2006).

## Results:

Arsenic concentrations of each sample are shown on Table 1.

Concentrations of As in kale and arugula range:

- 0.05 to 1.26 mg kg$^{-1}$ in arugula.
- 0.02 to 0.17 mg kg$^{-1}$ in kale.

Nearly all samples yield <1% of $BMDL_{0.5}$ value (WHO)

**Table 1: Arsenic concentrations in individual samples of kale and arugula**

| Sample Name | Sample Type | As (mg/kg) Dry Weight | Arsenic (μg) in 1 US cup of Fresh (Wet) Sample | % Towards 3μg/kg/day Increased Cancer Risk for 50kg Individual |
|---|---|---|---|---|
| Farm 1 | Arugula | 0.12 | 0.21 | 0.14% |
| Farm 1 | Arugula | 0.11 | 0.19 | 0.13% |
| Farm 2A | Arugula | 0.06 | 0.11 | 0.07% |
| Farm 2A | Arugula | 0.05 | 0.09 | 0.06% |
| Farm 2B | Kale | 0.03 | 0.32 | 0.21% |
| Farm 2B | Kale | 0.03 | 0.30 | 0.20% |
| Farm 3 | Kale | 0.02 | 0.17 | 0.11% |
| Farm 3 | Kale | 0.02 | 0.25 | 0.17% |
| Farm 4 | Kale | 0.02 | 0.21 | 0.14% |
| Farm 4 | Kale | 0.02 | 0.22 | 0.14% |
| Farm 5 | Kale | 0.06 | 0.70 | 0.47% |
| Farm 5 | Kale | 0.04 | 0.41 | 0.27% |
| Farm 6 | Kale | 0.14 | 1.60 | 1.07% |
| Farm 6 | Kale | 0.08 | 0.92 | 0.61% |
| Farm 7 | Arugula | 1.26 | 2.27 | 1.51% |
| Farm 7 | Arugula | 1.16 | 2.08 | 1.39% |
| Farm 8 | Kale | 0.02 | 0.18 | 0.12% |
| Farm 8 | Kale | 0.02 | 0.26 | 0.18% |
| Farm 9 | Kale | 0.04 | 0.47 | 0.31% |
| Farm 9 | Kale | 0.03 | 0.35 | 0.24% |
| Farm 10 | Kale | 0.12 | 1.36 | 0.91% |
| Farm 10 | Kale | 0.17 | 1.95 | 1.30% |
| 1 US Cup Fresh Kale = 67g, 1 US Cup Fresh Arugula = 20g. | | | | |

**Arsenic abundance within samples alongside past pesticide probability.**

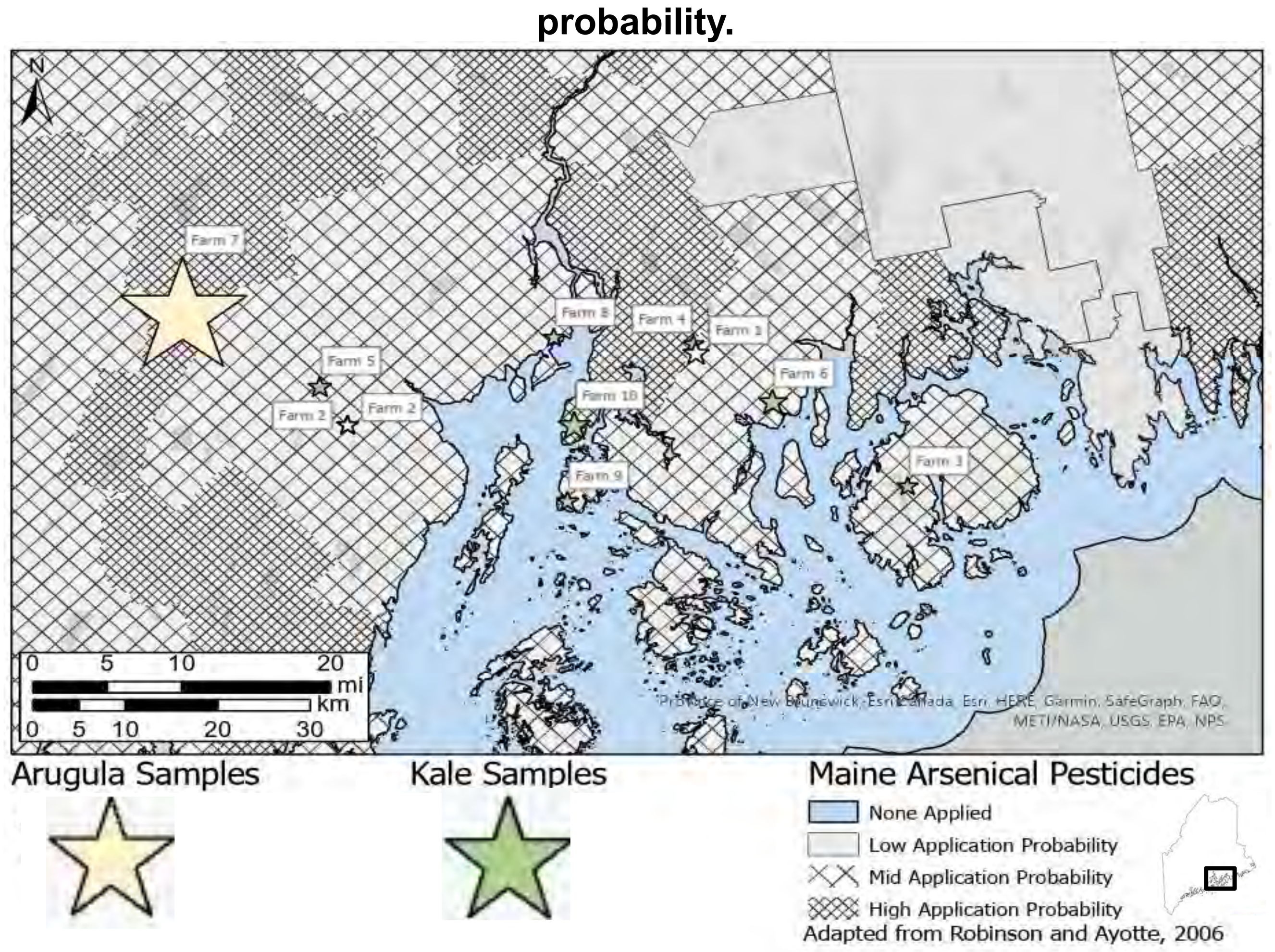


**Figure 8** (left): Sites of sample locations, color coded based upon plant type: arugula (yellow) and kale (green). The size of the stars are scaled with their arsenic concentration in mg kg$^{-1}$ of dry sample. Notice that the arugula and kale samples with the most elevated arsenic levels (Farm 7 and Farm 10, respectively) come from a region with a high probability of the historical application of arsenical pesticide (Robinson and Ayotte, 2006).

**Arsenic Levels in Kale and Arugula**

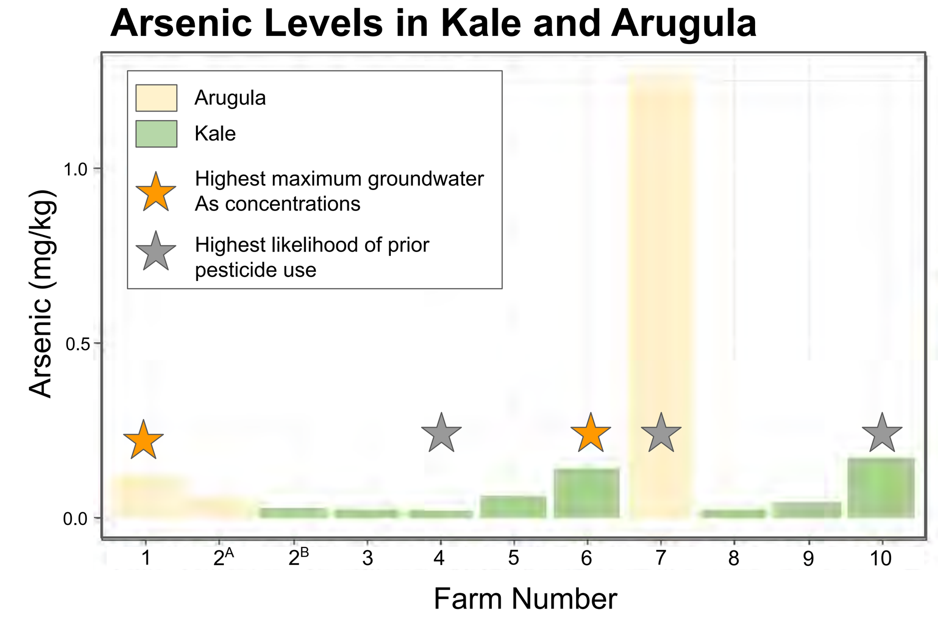


**Figure 6** (right): Arsenic abundance (mg kg$^{-1}$) of dried sample.

**Arsenic (μg) in 2 US Cups Samples**

2 US Cup Fresh Kale = 134g, 2 US Cups Fresh Arugula = 40g

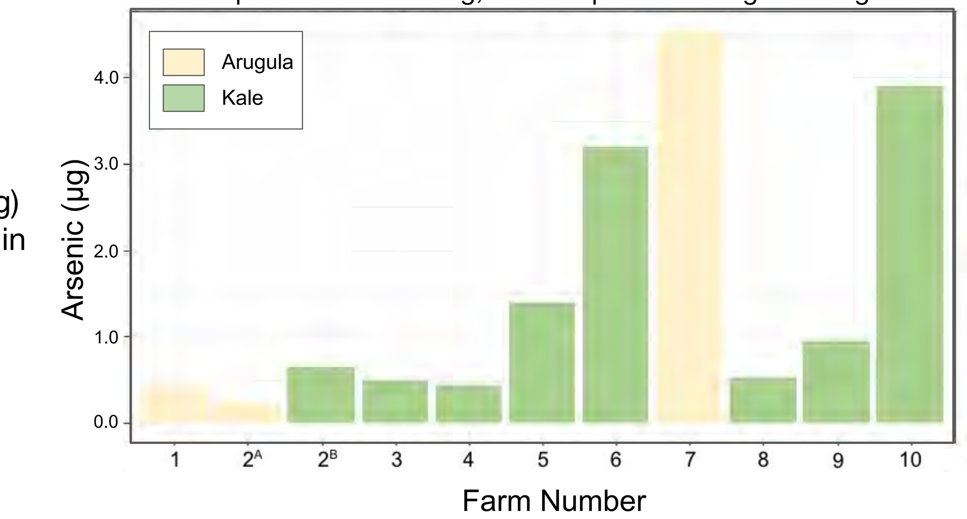


**Figure 7** (right): Arsenic (μg) found within 2 US cups of fresh sample.

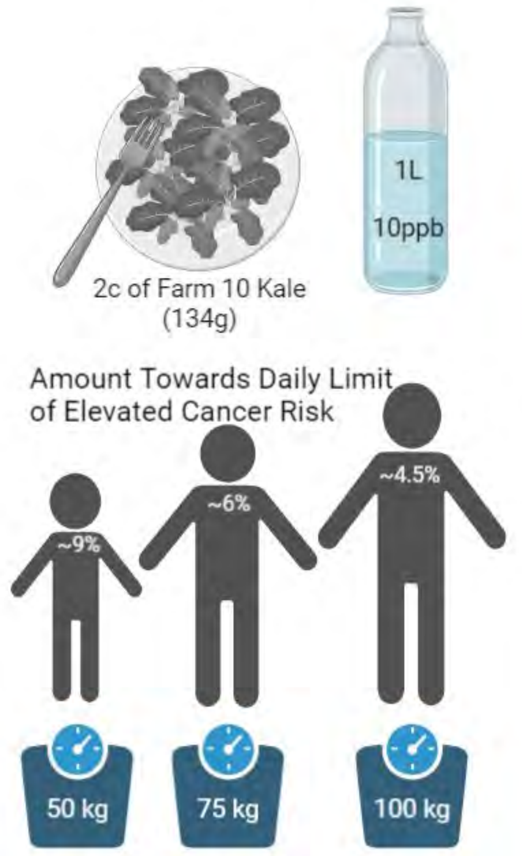


**Figure 9** (right): The percentage towards the WHO $BMDL_{0.5}$ for individuals of three different weights if they consumed 2 cups of kale from Farm 10 and had 1 liter of water at 10 ppb of arsenic. 10 ppb is the Maximum Contaminant Level (MCL) for drinking water in Maine (Maine CDC, 2012).

## Discussion and Conclusion:

- Our data suggest that there is some arsenic uptake by arugula and kale, potentially slightly more by arugula, consistent with past research (Lim and McBride, 2015).
- Samples were grown in regions identified to have mid or high probability of prior application of arsenical pesticides. Future work could include testing the soil and water used at these farms to determine the pathways of arsenic migration into the plants.
- Using the WHO $BMDL_{0.5}$ of 3.0 μg kg$^{-1}$ day$^{-1}$ as a maximum daily intake guideline, a moderate consumption of arugula and kale from all farms in this study does not pose a substantial risk to an individual assuming there are no other major contributing factors to arsenic exposure in their diets.

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*Graphics were created with BioRender.com. Graphs were created with R. Maps were created with Esri ArcGIS Pro.*

## Support:

This work was supported by a Science Education Partnership Award (SEPA) R25GM129796-0 from the National Institute of General Medical Sciences (NIGMS) of the National Institutes of Health (NIH), NIGMS SEPA Supplement 3R25GM129796-02S1, and award P42ES007373 from the National Institute Of Environmental Health Sciences (NIEHS) of the NIH. The content is solely the responsibility of the authors and does not necessarily represent the official views of the federal funding agencies. Gordon Longsworth, COA GIS Lab manager, provided technical mapping support.