interest and debate continues today in the U.S. and Europe over whether organic foods are healthier for the consumer. Several studies show that fruits and vegetables may contain higher concentrations of vital nutrients. Using the PIXE technique, which is a quick and inexpensive way to analyze samples, this study is inconclusive on whether eating organic is necessarily healthier for an individual. However, it was shown that some foods do contain slightly higher amounts of nutrients such as Flour and Lettuce. In addition, store brand Corn Flakes contains nearly 19 times the amount of Iron than does the organic brand, but the organic brand contains 7 times the amount of Zinc. Both metals are vital to nutritional health. The most notable observation made while comparing milk is that store brand milk contains higher levels of Strontium, a potentially a poisonous agent to the human body if the concentration is high enough.

1. Organic Foods and PIXE

Increasing interest and debate continue to engage the American public and much of Western Europe over organic vs. non-organic foods. Often the actual meaning of ‘organic’ is not understood so it is worthwhile to detail some essential characteristics that are common to foods. What is important in this research is organic farming because all foods tested come from organically grown food or organic cows. A good source online explains a few main features [1]:

- Organic farming severely restricts the use of artificial chemical fertilizers and pesticides.
- Instead, organic farmers rely on developing a healthy, fertile soil and growing a mixture of crops.
- Animals are reared without the routine use of drugs, antibiotics, and wormers common in intensive livestock farming.
- Organic milk comes from so-called organic cows. The grass and other foods organic cows eat must be grown from organic soil.

A major focus in the debate is whether organic foods are safer and healthier for consumption by the consumer, who has become concerned about potentially toxic chemicals, such as fertilizers, pesticides, and nutrition-based techniques used in non-organic foods. UK and US government statistics indicate that levels of trace minerals in fruit and vegetables fell by up to 76% between 1940 and 1991. In addition, there is growing evidence that organic fruit and vegetables generally contain more nutrients than non-organic food. This includes but is not limited to calcium, magnesium, iron, chromium, and phosphorous [1].

The Particle Induced X-ray Emission (PIXE) technique possesses the capability to determine elemental structure of food-based samples. Of the many possible food choices, four were selected for experimentation: one type of breakfast cereal, flour, lettuce, and 1% milk. The cereal contains the food group corn (Corn Flakes). Flour is primarily made of wheat. Lettuce and milk were selected because they are perishable food products, which contain various minerals and other elements. In addition, some independent reviews claim that organic lettuce is higher in all 21 essential minerals when compared non-organic lettuce [1]. Furthermore, PIXE possesses the ability to test that claim to a certain degree. However, it will not be able to detect all 21 minerals since not all are
simply elemental structures (such as vitamin C). In addition, all the foods tested with the exception of milk are soil grown.

Besides introducing chemical fertilizers and pesticides, soil can become ‘contaminated’ by other natural ways. The Soil Association claims:

Plants remove up to 60 minerals from the soil but non-organic farmers usually replace only those necessary for plant growth – nitrogen, phosphorus and potassium (NPK). Over time, this can lead to depletion of all the other minerals. Organic farmers use manures and composts containing a wide variety of minerals and not just NPK, so deficiencies are less likely to develop [1].

Another aspect of this research will be looking for any such deficiencies in the composition of non-organic foods.

While traditional means are also possible to determine the composition of certain foods via analytical chemistry, PIXE offers a rapid and sometimes lower cost method of analysis. On the average, less than 1 milligram of a food product is needed for sample analysis. In addition, PIXE eliminates the need of much wet chemistry in sample preparation. These factors played an important role for choosing particular foods for analysis. Essentially, only small amounts of all the food products were to suffice.

PIXE utilizes some essential features of nuclear physics for accurate compositional analysis. A 1.7 MV Pelletron Tandem Accelerator shoots a beam of protons towards a particular sample. A subsequent proton will slam into an atom, kicking
out inner shell electrons. This allows electrons from outer shells to drop in and fill the lower shell gaps and consequently electromagnetic radiation is given off in the form of X-rays. An X-ray detector then counts the number of occurrences and energy of emitted rays. The energy of each X-ray is proportional to the square root of the atomic number of the atom that emits the ray. In addition, the X-rays are also proportional to the concentration of the elements composing the sample [2]. Finally, a meter registers how much of the beam has struck the target. The units are in micro Coulombs, and this reading plays a central role in data analysis.

2. Sample Preparation

Of the four food groups chosen for experimentation, each required separate care while preparing the samples. Flour is sufficiently sand-like and the purchased product suffices for direct analysis. Considering laboratory preparation, the Corn Flakes are the simplest; a small quantity of the cereal is placed into a mortar and crushed with a pestle until the quantity appears sand-like. Next, it is placed into a dismemberer to break it down into smaller pieces. The final product is then stored in a small plastic container and labeled appropriately. Milk and lettuce require a more elaborate preparation. Both organic and non-organic milk, while stored in a plastic container, is frozen overnight. They are then placed into an automatic freeze dryer for approximately 60 hours. After the allotted time, the two samples will appear crystal-like and a similar procedure follows as with the Corn Flakes, namely crushing the milk crystals with a pestle but ignoring the dismemberer procedure (the milk is sufficiently sand-like after crushing). Again, the
samples are stored in a small plastic container and labeled. Finally, two samples of lettuce, organic and non-organic, are placed within an evaporation chamber for approximately 60 hours. Once removed from the chamber, each sample is placed into a mortar and crushed immediately. A significant time delay between drying and crushing can allow water moisture to creep back into each lettuce sample. If this happens, it is quite difficult to sufficiently grind the samples. Again, each sample is then placed into a plastic container and labeled.

The final step is common to all prepared samples. Aluminized Mylar and plastic rings form the backing for each sample. The PIXE chamber allows for small circular samples of any kind. Rings are placed onto a surface and sprayed with adhesive glue. Next, they are placed onto the Mylar and allowed ample time to dry (usually only a few minutes). A Polystyrene solution is loaded into a syringe and a small amount, a drop or two, is placed onto a Mylar ring. This solution acts like glue. Using a spatula approximately one milligram of each sample is dropped onto the Polystyrene.

3. Data Collection and Calibration

Each sample is placed into the PIXE chamber and bombarded with a 2.5 MeV beam of protons. Before striking the target, the beam passes through a gold foil to distribute the beam evenly over the sample. The beam intensity ranges from about 20 nA to 70 nA. X-rays are absorbed by 30 mm$^2$ by 3mm thick Kevex Si(Li) detector. During the course of this research, two filters were used inside the detector chamber. One filters out low Z elements and the other, called the 'funny' filter, allows for a certain quantity of
low Z elements to pass. Data are sent to a nearby computer where a program composes spectra: X-ray energy vs. the number of counts registered at a particular channel. A program called RobWin analyzes the spectrum for elements and the data eventually are converted to Microsoft Excel format where final graphs are composed.

![A Sample Spectrum](image1)

FIGURE 1 - A sample spectrum. The x-axis corresponds to the channel number is related to the energy of an emitted X-ray.

The energy per channel is found by calibrating the detector using an Iron sample and a short digression follows. A $^{55}$Fe sample, an X-ray source, is placed in the PIXE chamber. Figure 2 shows that $^{55}$Fe emits two X-rays labeled $K_\alpha$ and $K_\beta$.

![X-Ray Spectrum of Iron](image2)

FIGURE 2 - An X-ray Spectrum of Iron.
The energy of $K_{\alpha} = 6.400$ keV and $K_{\beta} = 7.059$ keV, and these are known energies. To find the energy per channel, one computes $\delta = K_{\beta} - K_{\alpha} = 0.659$ keV. Next, $\delta$ is divided by the number of channels between the peaks (which turned out to be 25); $C = 0.659$ keV/25 channels = 26.36 eV/channel. Once the calibration $C$ is found, a calculation of the detector resolution ($R$) is possible. The number of channels that range the FWHM (Full Width at Half Maximum) of the Iron $K_{\alpha}$ are counted and then multiplied by $C$. For this research, $R = 197.7$ eV.

4. Analysis

The spectrum graphs only show which elements are present within each sample. In order to extract valuable data concerning quantities of each element present, it is necessary to massage the data such that a different graphical view yields meaningful information about composition. The appropriate graph to make sense of the data turns out to be a logarithmic graph of the Element vs. Count Number per 10 micro Coulombs because it allows the viewer to observe, for example, a higher amount of Iron in an Organic sample compared to a non-organic one. This is done by first noting the number of counts for each peak on the spectrum graphs. Next, the number of peaks is then divided by the Coulomb count (recalling that the Coulomb count is a measure of how much beam strikes a sample). In this research project, each ratio of counts is multiplied by 10 so that the numbers are more easily readable. This was determined necessary because for many of the ratio numbers, decimal values occurred. Essentially, bringing up
the majority of ratio numbers represented on any one graph to whole number values allows the viewer to make sense of the data quicker.

The first analysis (see Appendix A) compares Organic vs. Non-Organic Lettuce. Figure 3, which compares the ratio of Organic to non-Organic Lettuce for each element, shows that Calcium (Ca), Manganese (Mn), Nickel (Ni), Copper (Cu), Bromine (Br), and Strontium (Sr) are slightly higher in concentration for the Publix Lettuce. The Organic sample shows a slightly higher concentration of Titanium (Ti) and Iron (Fe). Zinc (Zn) appears to be nearly equal in concentration for the Organic and non-Organic lettuces.

<table>
<thead>
<tr>
<th>Ratio of Organic to non-Organic Lettuce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
</tr>
<tr>
<td>Ti</td>
</tr>
<tr>
<td>Cr</td>
</tr>
<tr>
<td>Mn</td>
</tr>
<tr>
<td>Fe</td>
</tr>
<tr>
<td>Ni</td>
</tr>
<tr>
<td>Cu</td>
</tr>
<tr>
<td>Zn</td>
</tr>
<tr>
<td>Ga</td>
</tr>
<tr>
<td>Br</td>
</tr>
<tr>
<td>Sr</td>
</tr>
</tbody>
</table>

FIGURE 3 – Shows the ratio of Organic to non-Organic Lettuce for each element.

The second analysis (see Appendix B) compares Organic vs. non-Organic Lettuce for low Z. Figure 4, which compares the ratio of Organic to non-Organic Lettuce for each element, shows that the non-Organic lettuce is higher in concentration for all elements with the exception of Titanium where the concentration is nearly equal. Looking closely at all elements, each element for both samples rises either up or down in count with the exception of Phosphorous.
Organic to non-Organic Lettuce (low Z)

<table>
<thead>
<tr>
<th>Element</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.21</td>
</tr>
<tr>
<td>Mg</td>
<td>0.19</td>
</tr>
<tr>
<td>Al</td>
<td>0.74</td>
</tr>
<tr>
<td>Si</td>
<td>0.74</td>
</tr>
<tr>
<td>P</td>
<td>0.36</td>
</tr>
<tr>
<td>Si</td>
<td>0.44</td>
</tr>
<tr>
<td>Cl</td>
<td>0.57</td>
</tr>
<tr>
<td>K</td>
<td>0.69</td>
</tr>
<tr>
<td>Ca</td>
<td>0.39</td>
</tr>
<tr>
<td>Ti</td>
<td>0.94</td>
</tr>
<tr>
<td>Cr</td>
<td>0.59</td>
</tr>
</tbody>
</table>

FIGURE 4 - The ratio of Organic to non-Organic Lettuce for low Z elements.

The third analysis (see Appendix C) compares Organic vs. Non-Organic Corn Flakes. Figure 5, which compares the ratio of Organic to non-Organic Corn Flakes for each element, shows that the organic sample is slightly higher in concentration of Potassium (K), Calcium, and Rubidium (Rb). The non-organic sample is slightly higher in concentration of Chromium (Cr), Manganese, and Bromine. In addition, the non-organic sample contains considerably more Iron and Copper, and the organic sample has considerably more Zinc.

Ratio of Organic to non-Organic Corn Flakes

<table>
<thead>
<tr>
<th>Element</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>2.1</td>
</tr>
<tr>
<td>Ca</td>
<td>1.62</td>
</tr>
<tr>
<td>Cr</td>
<td>0.75</td>
</tr>
<tr>
<td>Mn</td>
<td>0.69</td>
</tr>
<tr>
<td>Fe</td>
<td>0.054</td>
</tr>
<tr>
<td>Ni</td>
<td>0.77</td>
</tr>
<tr>
<td>Cu</td>
<td>0.25</td>
</tr>
<tr>
<td>Zn</td>
<td>7.45</td>
</tr>
<tr>
<td>Br</td>
<td>0.77</td>
</tr>
<tr>
<td>Rb</td>
<td>2.03</td>
</tr>
</tbody>
</table>

FIGURE 5 – The ratio of Organic to non-Organic Corn Flakes for each element.
The fourth analysis (see Appendix D) compares Organic vs. non-Organic milk. Figure 6, which compares the ratio of Organic to non-Organic milk for each element, shows that the organic sample contains slightly more Bromine and Rubidium while the non-organic sample contains a more Strontium (Sr). Potassium, Calcium, Iron, and Zinc are nearly equal in concentration for the organic and non-organic samples.

![Ratio of Organic to non-Organic Milk](image)

<table>
<thead>
<tr>
<th>Element</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>1</td>
</tr>
<tr>
<td>Ca</td>
<td>1.15</td>
</tr>
<tr>
<td>Fe</td>
<td>0.95</td>
</tr>
<tr>
<td>Zn</td>
<td>0.97</td>
</tr>
<tr>
<td>Br</td>
<td>1.27</td>
</tr>
<tr>
<td>Rb</td>
<td>1.62</td>
</tr>
<tr>
<td>Sr</td>
<td>0.41</td>
</tr>
</tbody>
</table>

**FIGURE 6** – The ratio of Organic to non-Organic Milk for each element.

The fifth analysis (see Appendix E) compares Organic vs. Non-Organic Flour. Figure 7, which compares the ratio of Organic to non-Organic flour for each element, shows that the organic flour contains slightly higher concentrations of Potassium, Calcium, Copper, Bromine, and Strontium and a significantly higher quantity of Iron. The non-organic sample contains slightly more Manganese. Zinc is nearly equal in concentration for both samples.
<table>
<thead>
<tr>
<th>Element</th>
<th>Ratio of Organic to non-Organic Flour</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>1.3</td>
</tr>
<tr>
<td>Ca</td>
<td>1.2</td>
</tr>
<tr>
<td>Mn</td>
<td>0.77</td>
</tr>
<tr>
<td>Fe</td>
<td>2.03</td>
</tr>
<tr>
<td>Ni</td>
<td>0.81</td>
</tr>
<tr>
<td>Cu</td>
<td>1.3</td>
</tr>
<tr>
<td>Zn</td>
<td>1.03</td>
</tr>
<tr>
<td>Br</td>
<td>1.14</td>
</tr>
<tr>
<td>Sr</td>
<td>1.64</td>
</tr>
</tbody>
</table>

FIGURE 7 – Compares the ratio of Organic to non-Organic Flour for each element.

The sixth analysis (see Appendix F) compares Mylar vs. Mylar with Polystyrene. Figure 8, which compares the ratio of the two samples, shows that the Polystyrene sample contains more of each element. However, the Polystyrene sample contains only slightly more Ti, Fe, and Ga. The Polystyrene sample contains significantly more Zn than the regular Mylar.

<table>
<thead>
<tr>
<th>Element</th>
<th>Ratio of Mylar to Mylar with Polystyrene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti</td>
<td>0.78</td>
</tr>
<tr>
<td>Fe</td>
<td>0.88</td>
</tr>
<tr>
<td>Zn</td>
<td>0.11</td>
</tr>
<tr>
<td>Ga</td>
<td>0.83</td>
</tr>
</tbody>
</table>

FIGURE 8 – Shows the ratio of Mylar to Mylar with Polystyrene for each element.
5. Discussion

With the exception of lettuce, the general purpose for comparing foods was to merely observe the differences between organic and non-organic brands. While these experiments have not explicitly yielded information about health and nutrient concerns, it does yield some interesting facts. First, the study presented earlier, levels of trace minerals in fruit and vegetables fell by up to 76% between 1940 and 1991, was a study of non-organic soil. The low Z tests showed that the organic brand contained less of all elements. The claim that organic food does not use synthetic pesticides may indicate that the presence of higher levels of all the elements at low Z are due to the different growing techniques used by non-organic farmers (namely the pesticides and fertilizers). This may conflict another claim, that organic fruits and vegetables contain higher amounts of nutrients and minerals. The organic brand does contain higher concentrations of Iron and Zinc, but on the low Z end the organic lettuce appears not to verify that claim since the non-organic brand dominates in concentration. Finally, the non-organic brand has nearly 3 times the amount of Manganese. Manganese is an important anti-oxidant and is important in the blood breakdown of amino acids [3].

The store brand Corn Flakes contains nearly 19 times the amount of Iron than does the organic brand. Around 1940, the United States began to insert higher levels of certain minerals because many people were deficient in minerals that are needed to achieve and maintain a state of wellness. The Iron that is apparent in the store brand Corn Flakes is a reflection of this action. What is interesting is that the nutritional facts contained on the cereal box of both organic and non-organic brands claims that the non-
organic brand contains 50% of daily Iron needed, whereas the organic brand contains 15% of daily Iron needed. The nutritional facts on the organic source also claims that eating one serving contributes 0% of daily calcium people need. In addition, the results show that organic Corn Flakes have double the Calcium than does the store brand. The store brand (Publix) also says that eating one serving of Corn Flakes provides 0% of Calcium needed, so it can be said that the levels of Calcium in both the organic and non-organic brands are virtually irrelevant concerning health and nutrient issues. Another interesting feature is that the organic sample contains 7 times the amount of Zinc than does the store brand. Zinc is an important nutrient; it plays a central role in wound healing [3]. While it’s hard to say why this is because corn undergoes many processes before taking the final form of Corn Flakes, it is an interesting observation. Finally, the store brand contains slightly more Manganese which has the qualities listed above.

Comparison of the Organic Milk shows that there is virtually no difference for Potassium, Calcium, Iron, and Zinc. The presence of lower levels of Strontium in Organic Milk is a plus. Too much Strontium can be poisonous for humans. While it cannot be determined where the extra Strontium is coming from in the store brand, it is worth noting that drinking organic milk will result in lower levels of consumed Strontium.

The organic flour appears to contain higher levels of certain minerals, in particular, Potassium, Calcium, and Iron. However, it is slightly lower in Manganese. In addition, there is slightly more Strontium contained within the organic flour and as mentioned before can be poisonous.
Essentially, this research has not been able to determine if humans ought to eat organic food exclusively. However, it appears to be higher quality for some foods, and about the same quality with others. The good news is people don’t necessarily eat organic foods because they are higher in minerals. In many cases, foods such as grains and milk contain genetically modified organisms or are genetically altered seeds. Much of the public uproar concerns this fact.

6. Acknowledgements

I would like to thank Dr. Eugene Dunnam, Dr. Henri Van Rinsfelt, and Dr. Ivan Kravchenko for their assistance during this research project. Together they made the project fun and enjoyable, not to mention they got most of the machinery (the accelerator) up and running for Kara Chapman and me. This research could not have been done without them.
Appendix A

FIGURE 9 – Spectrum of Publix lettuce.
FIGURE 10 – Spectrum of organic lettuce.

FIGURE 11 – Log chart of organic vs. non-organic lettuce.
Appendix B

Average Publix Lettuce @ 30 µC

FIGURE 12 – Spectrum of Publix lettuce at low Z.
FIGURE 13 – Spectrum of organic lettuce at low Z.

FIGURE 14 – Log chart of organic vs. non-organic lettuce for low Z.
FIGURE 15 – Spectrum of Publix corn flakes.
FIGURE 16 – Spectrum of organic corn flakes.

FIGURE 17 – Log chart of organic vs. non-organic corn flakes.
FIGURE 18 – Spectrum of Publix milk.
FIGURE 19 – Spectrum of organic milk.

FIGURE 20 – Log chart of organic vs. non-organic milk.
FIGURE 21 – Spectrum of Publix flour.
FIGURE 22 – Spectrum of organic flour.

FIGURE 23 – Log chart of organic vs. non-organic flour.
Appendix F

FIGURE 24 – Spectrum of Mylar.
FIGURE 25 – Spectrum of Mylar with polystyrene.

FIGURE 26 – Log chart of Mylar vs. Mylar with polystyrene.
Bibliography


Slices by Proton Induced X-Ray Emission.” *Environmental Health Perspectives*.
101(4), 302 (September 1993).