Mapping Elemental Nutrient and Surface Treatment Distribution in Produce

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Kimberley A. Russell, Bruker Nano Analytics (Handheld-Mobile-Portable),
415 N. Quay Street, Kennewick, WA 99336, USA.

Introduction

Nutritionists address the benefits of obtaining elemental nutrients directly from food, especially fresh, uncontaminated produce. This project will demonstrate non-destructive techniques developed to visually map distribution and relative abundance of elemental nutrients and treatments of produce.

Three types of X-ray fluorescence (XRF) spectrometers were used. All provided user control of atmosphere, power, filters and collimators for optimization of elemental analysis in various matrices. They also provided qualitative and quantitative XRF elemental analysis software.

Data presented will include maps of elemental nutrient rich locations in fruit as well as distribution of elemental surface treatments for preservation of produce from farm to market. The various methods utilized for data collection will be described. Future research planned includes monitoring elemental nutrient distribution changes over time and with different storage conditions.

Elemental Analysis Mapping Technology

Micro XRF

Micro XRF (µXRF) is an elemental analysis technique with a spatial resolution significantly smaller than conventional XRF enabling micron size sample analysis. This is particularly useful for forensics, contaminants, films & coatings and elemental mapping of small features.

This project employed a closed-beam benchtop 2D µ-XRF spectrometer with a 30W powered rhodium x-ray tube, silicon drift detector, programmable X-Y-Z stage, fish eye camera, two optical video microscopes, polycapillary x-ray optics for spot sizes of 25µm and software designed for collecting large elemental data sets and mapping distribution via “stitching”.

Portable EDXRF with programmable X-Y-Z Stage

Energy Dispersive XRF (EDXRF) is an elemental analysis technique which characterizes elements by their photon energies and intensities. Portable EDXRF allows one to take the analyzer to the sample instead of bringing the sample to the analyzer.

This project employed a non-contact, open-beam portable 2D XRF spectrometer with a 4W powered rhodium x-ray tube, silicon drift detector, programmable X-Y-Z stage, microscope camera and external video camera, alignment lasers, x-ray optics for spot sizes of 1mm and software designed for data acquisition and visualization of maps via “stitching”.

Handheld EDXRF

Handheld EDXRF enables the analysis of samples “in-situ”, in the situation they occur. It is the most convenient XRF form factor for rapid elemental characterizations of samples in their varied native and prepared forms.

This project employed an open-beam handheld XRF spectrometer with a 4W powered rhodium x-ray tube, silicon drift detector, internal VGA CMOS camera, x-ray optics for spot sizes of 3 and 8 mm and software capable of transferring acquired elemental analysis data to external mapping software to visualize maps in 2D or 3D.

M4 TORNADO 2D
Small Sample Spot
Micro-XRF Spectrometer

ELIO Portable 2D
ED-XRF Spectrometer
Compact Detection Head

TRACER Handheld 2D
ED-XRF Spectrometer
On-Board PC Control

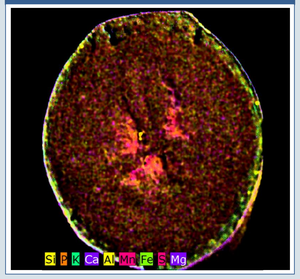
Elemental Nutrient Distribution Mapping Data

Mapping relative abundance of nutrients

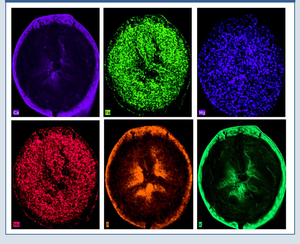
Nutritional information encourages us to obtain as many of our nutrients as possible from unprocessed fruits and vegetables. We eat produce as-is, juice it or turn it into smoothies. But, how do we know just where the nutrients are? XRF shows us.

Consumption of bananas is encouraged for their potassium (K), magnesium (Mg), phosphorus (P), calcium (Ca), manganese (Mn) and iron (Fe) content. It can be clearly seen from the XRF mapping images of a banana slice that K, P and Ca are concentrated in the peel and phloem bundles which travel through the center to distribute nutrients; while, the Mg, Mn and Fe are evenly distributed throughout the pulp.

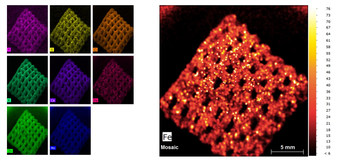
Elemental nutrient distribution map of a banana



Elemental nutrient rich locations of a banana



Elemental fortification and enrichment distribution on cereal and snack food



Mapping images for elements on cereal help determine fortification distribution: P, sulfur (S) and Fe distributions are clearly evident

Enhanced image of Fe fortification on cereal clearly shows its distribution

Salt distribution on a 20mm^2 cracker is distinct: chlorine (Cl) in green, sodium (Na) in red, aluminum (Al) in purple and silicon (Si) in pink

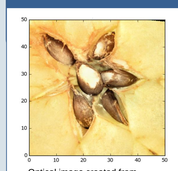
Visual imaging of elemental nutrients

On-site portable EDXRF mapping enables the acquisition of high resolution maps with a 1 mm spot size level of detail. This visualization of elemental analysis data can be performed for both light and heavy elements. Integrated software can store a “picture” of each pixel, allowing easy look-up of previously collected information. A full spectrum can be displayed by clicking on the point of interest on the XRF map or on the stored visible image.

A lightweight and compact motorized X-Y stage can be used to create maps of up to 10 cm x 10 cm used in conjunction with a tripod. This combination with the integrated software enables full control of the mapping area as well as the ability to revisit a data point or to repeat a measurement.

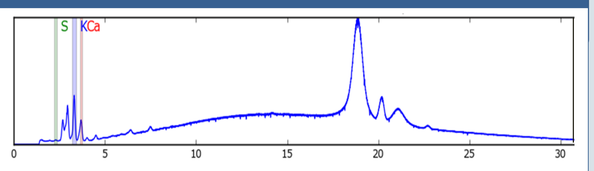
Although optimum XRF analysis requires a flat, homogenous, tightly packed and clean sample, those conditions are rarely found in-situ. A significant challenge for mapping produce or other food product elements is reasonable sample presentation to the XRF to provide informative and actionable results.

Apple core slice mapping software provides clear imaging and accompanying spectra



Optical image created from pictures recorded during mapping

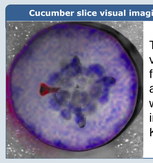
Stitched XRF and image map: K in green, Ca in blue and S in red



Spectra of potassium (Kα@ 3.31 keV), calcium (Kα@ 3.69 keV) and sulfur (Kα @ 2.31 keV) in the apple core slice

The adage, “an apple a day keeps the doctor away” is partly based on its high nutrient content of K and Ca, as well as many others including S. Spectra can be stored at each pixel in the map; and, then the spectrum can be selected, viewed and interrogated at any point.

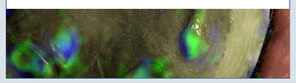
Cucumber slice visual imaging of Ca and K



The cucumber is a vegetable recommended for calcium content. Ca and K maps are overlaid with a stitched optical image. Ca is in red and K is in blue.

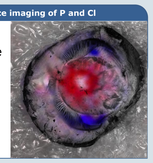
Zucchini slice visual imaging of K and P

Zucchini is a vegetable recommended for its high potassium content. Mapping a slice of zucchini clearly shows K in blue and P in green.



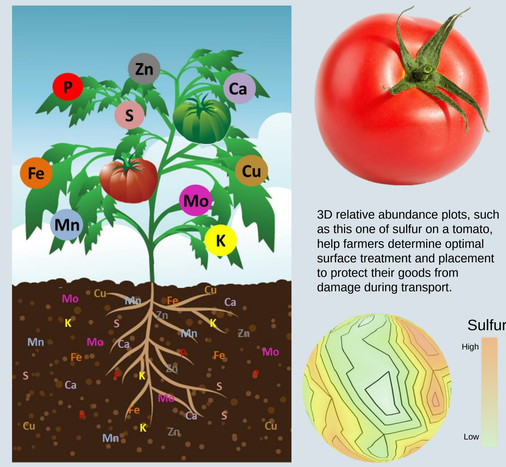
Portobello mushroom slice imaging of P and Cl

Portobello mushrooms, fungi not vegetables, are recommended for their phosphorus content. Chlorine (Cl) from water spraying can dilute their natural flavor. P is in blue and Cl is in red.



Mapping surface treatments of produce

Handheld XRF is a widely accepted technique for on-site monitoring of heavy and toxic metals in soil caused by anthropogenic pollution and their migration due to weather events. It is also used to assess elemental nutrients and fertilizers for precision agriculture. More recently, handheld XRF has been used to help optimize surface treatments such as Ca, Cl and S on produce for preservation of product from farm to market to minimize financial loss. Visual elemental maps of their relative abundance can be generated in 2D or 3D.



3D relative abundance plots, such as this one of sulfur on a tomato, help farmers determine optimal surface treatment and placement to protect their goods from damage during transport.

Summary

Elemental mapping of produce with XRF helps quickly identify nutrient rich locations; it also helps understand fortification distribution of processed foods. XRF even helps optimize surface treatments for preservation of produce from farm to market to help minimize financial loss caused by transport.

Further studies planned include examination of the distribution of elemental nutrients over time and with different storage conditions.

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- Tomato plant elemental uptake in nutrient rich soil illustration courtesy of Christabel Brand, Portable XRF Services Pty Ltd.

X-Ray Fluorescence