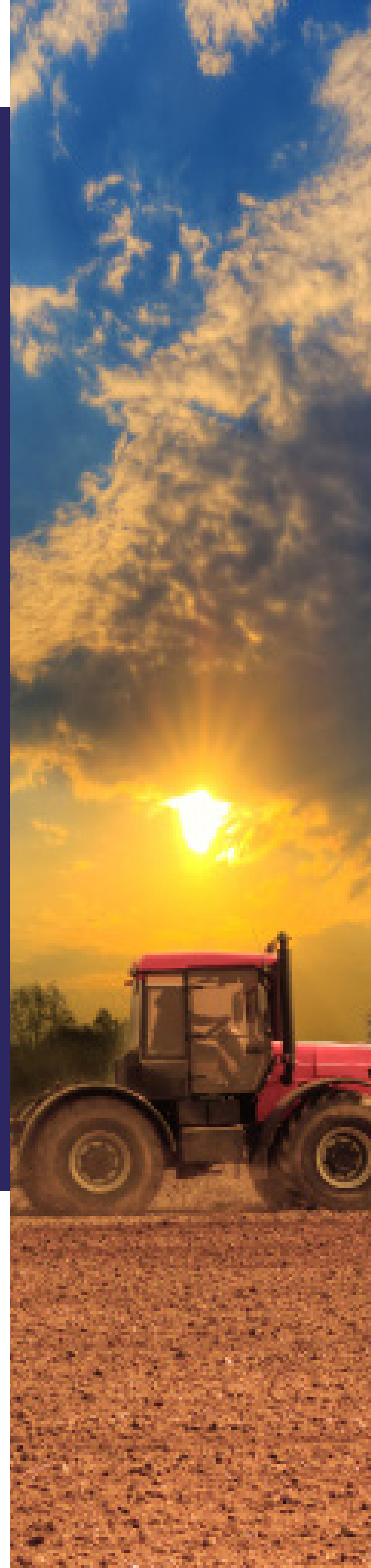
Spectroscopy Applications in Precision Agriculture



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Avantes Powers Precision Agriculture

Welcome

Sustainable agriculture has become a matter of great importance to the economies of the world as humanity faces unprecedented threats from climate change, scarcity of arable lands while simultaneously facing higher populations. The reality we face is that we must use the technologies we have at our disposal to improve the efficiencies of our agricultural practices to feed the world.

Avantes and our parent company Nynomic are genuinely committed to supporting sustainable precision agriculture projects. Our instruments are being used today to control fertilizer utilization, perform quantitative analysis on grains and silage and even characterize manure for nutrient levels (N,P,K). The power of optical spectroscopy to rapidly and non-invasively measure food products, crops and soil mediums is one that we seek to enable amongst the world's agricultural community.

The following compilation is a collection of technical references and experimental data about spectroscopy applications for agriculture and food production. We hope you find this information useful and interesting and look forward to supporting you in whatever spectroscopy application you may seek to explore.

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01

NIR Spectroscopy in Agriculture and Food Production

Demands for increased agricultural production and sustainable farming methods are always growing. Consumers demand high-quality, convenience, and diversity of selection. Quality of food products is dependent on internal and external factors that are potentially quantifiable and can be objective which leads the world's researchers to seek novel ways to apply data to agricultural production.

Benefits of NIR Spectroscopy

Near-infrared spectroscopy has been studied and applied in numerous applications across five key product areas: fruits and vegetables, meats and fish, beverages and dairy, cereals and grain stocks, grapes, and olives; but also, areas regarding production factors like soils and manures, and environmental applications. The mechanisms of near-infrared spectroscopy are well understood and the benefits are clear. NIR spectroscopy can deliver rapid, accurate, cost-effective results in the lab or in the field with little or no sample prep, and multiple parameters can measure with the same scan.

Handheld NIR Reflection Spectroscopy

Avantes has shared applications in the past, but new applications are discovered, or rather developed, every day, all around the world using Avantes spectrometers. The Avantes family of InGaAs diode array-based spectrometers for the

NIR gets a new member in 2020. The new AvaSpec-Mini-NIR will be a game-changer in handheld NIR applications. With nearly the power and resolution of the full-sized desktop InGaAs spectrometers, this instrument packs the performance into an ultra-small deck-of-card-sized form factor. This new device is a natural fit for the precision agriculture market.

Fruits and Vegetables

Avantes instruments are utilized in numerous grading and sorting at-harvest applications for fruits and vegetables that use NIR spectroscopy including but not limited to apples, cherries, avocadoes, peaches, and mangoes. Near-infrared spectroscopy allows the rapid, non-destructive measurement of several internal parameters of ripeness and quality such as water content, soluble sugars content (SSC), acidity, pH, and aromatic compounds like anthocyanin. Handheld applications for near-infrared reflection spectroscopy would facilitate such measurements while produce is still on the vine.

Meats, Fish and Eggs

Near-infrared spectroscopy in meat grading enables the discrimination of proteins to fat content, and measurements of moisture content, color, pH, and indicators of tenderness. It can also detect the presence of common contaminants like volatile nitrogen. The non-destructive, non-chemical nature of spectroscopic sampling can bolster yields, for example the monitoring of egg quality through the shell.

Beverages and Dairy

Similar applications for analyzing dairy products are using Avantes spectrometers to measure proteins, fats, water, carbohydrates and minerals in milk and other dairy products, as well as identify adulterated products.

Wine and Grape Production

Near-infrared spectroscopy has been explored as a tool to predict ripeness and characterize grape parameters known to affect wine flavor and quality such as soluble sugar content, acidity, and aromatic compounds such as anthocyanins and polyphenols. Grape characteristics at the time of harvest are the single largest contributing factor to the eventual quality of the wine produced. Spectral reflection in the near-infrared has a very high validation rate as a rapid, non-destructive measurement tool for assessing grape quality at harvest.

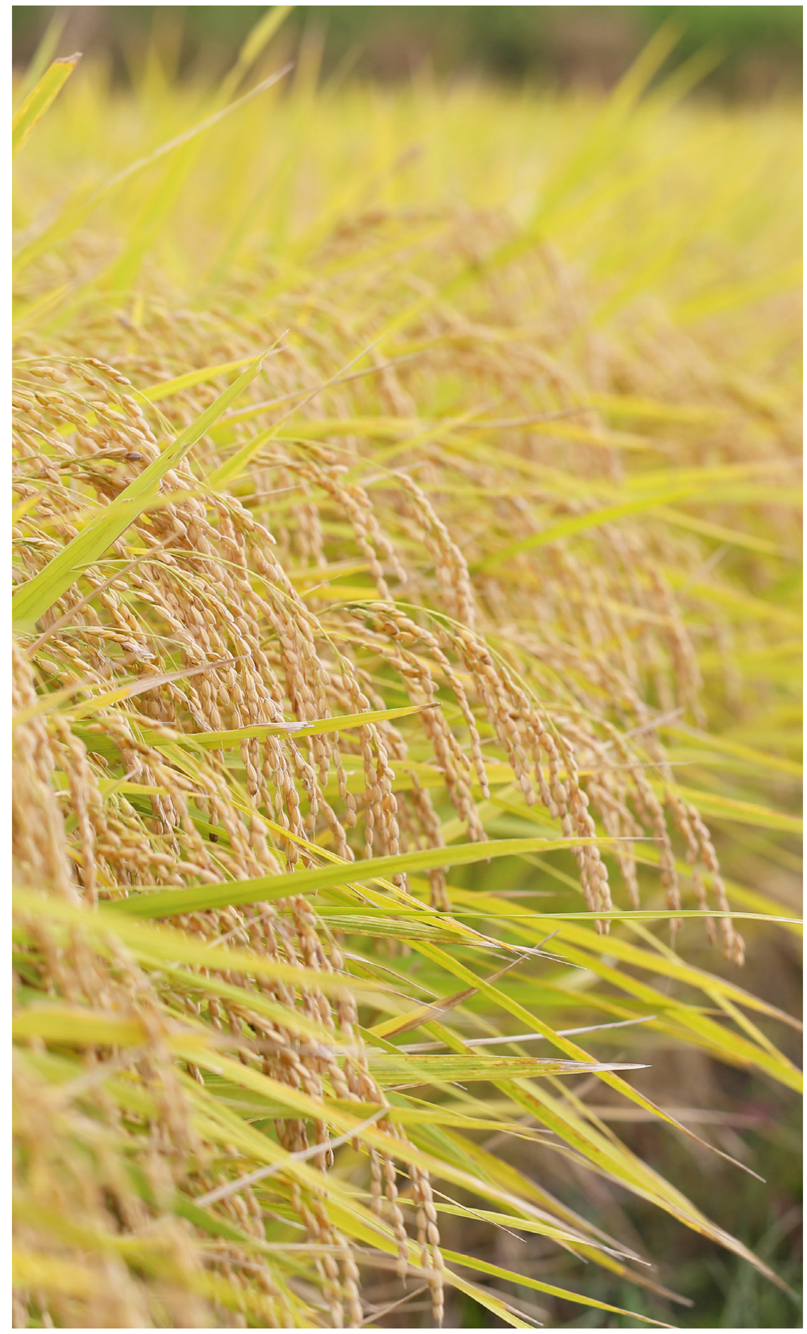
Cereals and Feed

Researchers in wheat, barley, rice, and soybean production are exploring near-infrared spectroscopy to monitor crop health and growing conditions, identify various plant diseases and contaminants, and to assess crop quality at harvest for grading and pricing.

A recent project with the US Department of Agriculture employed NIR spectroscopy to predict protein content of wheat harvests. Wheat pricing is dependent on protein content of the grains, making maximizing protein content a high priority for wheat producers. Similar research also aims to tune the application of nitrogen fertilizers to optimize farming practices.

Soils, Manures and Other Growing Constituents

There are few things more important to the future of sustainable farming than soil management. Soil characterization determines what manner of



treatments or mitigation might be required, or even what crops might be suitable for a particular area. NIR spectroscopy allows rapid data collection on moisture content, and compaction and soil density.

The utilization of manure as a fertilizer and for general land application is a matter of great importance to environmental regulatory agencies as well as farmers looking for quantifiable parameters during application. NIR spectroscopy is has been used effectively in research and industrial applications to quantify manure for N, NH4-N, K2O, P2O5 constituents.

The challenge for Ag/Food application innovators

The significant challenge to developing an agricultural application for diffuse reflection spectroscopy in the NIR range. Getting the most out of spectral data requires special processing and the development of a calibration model. Avantes and our partners can support innovators in agriculture through collaboration from development through commercialization.

Avantes supports early application development

The initial development of a viable application begins with developing the calibration indices, or database of spectral data compiled with samples in various conditions from which

statistical modeling will allow the user to predict characteristics of future samples. Each measurement can add to the body of data and improve future predictive results. Avantes' AvaSpec instruments integrate seamlessly with the chemometric modeling program, Panorama, by LabCognition which can facilitate model development for applications such as those mentioned above.

Avantes also offers feasibility testing and a widely popular demos program to ensure system design and instrument suitability before purchase or allow a developer to get a head start on integration testing in advance of receipt of purchase. Dozens of prospective customers make use of the demo program each month to test drive Avantes instruments.

Establishing a relationship as a component supplier for an application developer or system designer requires a collaborative partnership to ensure engineering specifications and performance are an ideal application match and integration is successful. Scaling production also requires economies of scale on parts and components, and a repeatable standard of performance. Avantes delivers top-rated customer support, turn-key interoperability, and world-class instrument performance repeatability. Don't take our word for it, Avantes is an ISO 9001:2015 accredited organization and stands by our products with a 3 year Warranty.

02

Spectroscopy Plays a Key Role in the Future of Smart Agriculture

Introduction

Agriculture of the future will be shaped by the forces of climate change and population growth as well as technological advances and many other factors. In the end, however, this means that the farms of the future will need to produce more with less, and often in ever-worsening conditions. The advances that will make the farming of the future possible, are in development today.

Plant Physiology Research

Plant physiology, how plants grow, develop, and reproduce, affects production yield and quality in numerous ways. Light is possibly the most important environmental factor that affects plant physiology. Plants produce diverse responses to the quantity, quality, direction, and duration of light cues in their environment. They produce hormones and other secondary metabolites that affect production yield, food quality, and taste.

Understanding plant responses to light cues is essential for successful indoor cultivation. Researchers from Denmark, Bulgaria, and Belgium have been studying the effects of differing light conditions on plant physiology. Plants possess photoreceptors that sense ultraviolet-B, ultraviolet-A, red and blue light.

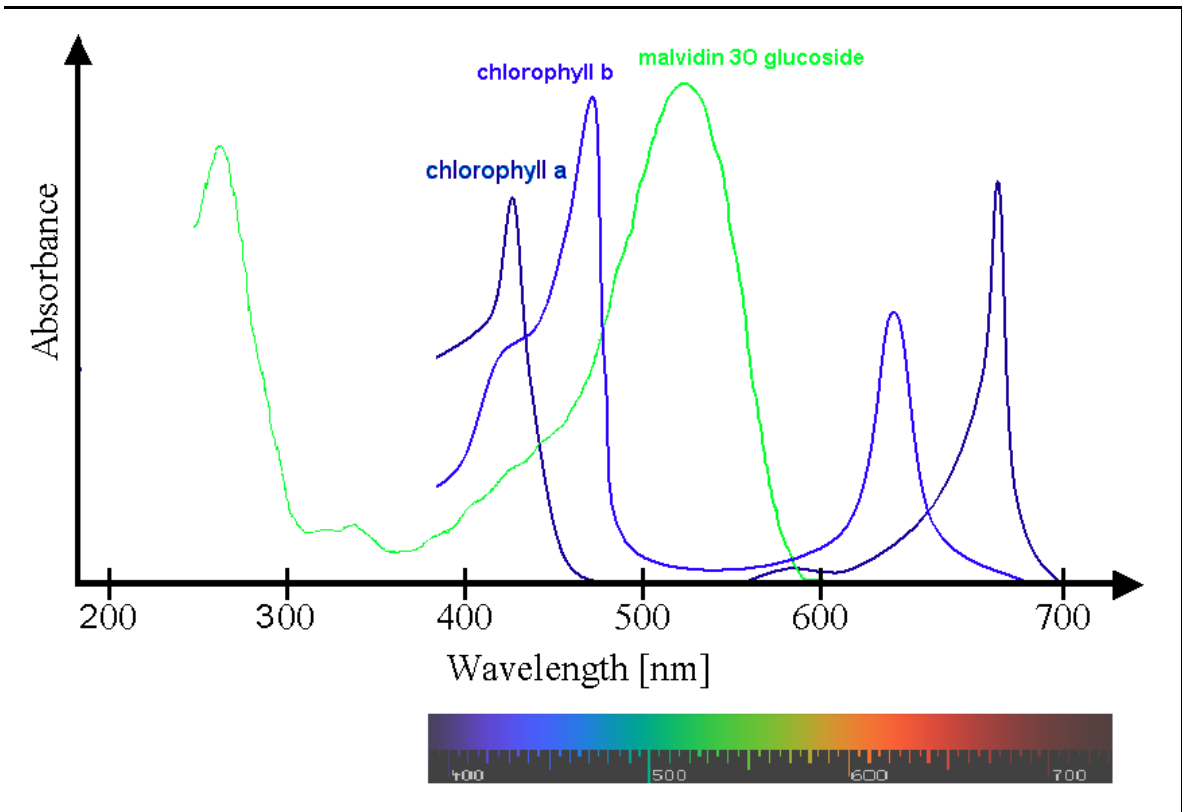
These photoreceptors are capable of sensing the intensity, quality, direction, and duration of light.

Red vs. Blue Light

The photosynthetic photon flux density (PPFD) represents the number of photons used for photosynthesis within the 400-700 wavelength range of photosynthetically active radiation (PAR). Red and blue light are effectively absorbed close to the surface and are the most important wavelengths for photosynthesis. Chlorophyll, the primary plant pigment responsible for photosynthesis, absorbs both blue (420-450 nm) and red (600-700 nm) light. Chlorophyll type-a has absorption peaks at 430 nm in the blue range and 665 nm in the red, while chlorophyll-b demonstrates absorption peaks at 453 nm (blue) and 642 nm (red). Light absorption in chlorophyll dips to its lowest at 550 nm. (Ouzounis 2019)

Because it has a higher frequency and therefore shorter wavelength, blue light contains more energy than red light. Photosynthesis, however, is dependent on the total number of photons absorbed, not the energy content of the individual photons. In the case of blue light, the additional energy is lost as heat. This effect is evident in the lower efficiency in the blue range. (Ouzounis 2019)

Different species of plants respond differently to red and blue light, and even different varieties of the same species might thrive best in differing light conditions. Seedling plants sold in containers are frequently grown in crowded conditions with insufficient light and typically have elongated hypocotyl, the stem found below the seed leaves and directly above the roots, due to poor light quality. This results in plants that are unnaturally tall with thin foliage and low fresh weight yield. This elongated characteristic is particularly pronounced in herbs and spice plants. Dill plants,



Spectral response of chlorophyl

in particular, display very high elongation, fewer leaves and smaller leaf area due to light quality during the germination phase.

Researchers at the Poznan University of Life Sciences, in Poznan Poland, studied varying doses of blue light between 10-15% with a constant proportion of red light and the effect on dill plants. They found that in general, dill plants treated with red light were taller overall and displayed elongated internodes whereas the plants treated with blue light had shorter internodes and produced relatively high herb yields. The plant response to blue light, however, is very sensitive and depends not only on the proportion of blue or red light but also the growth stage of the plant. (Frąszczak 2016)

The elongation of the hypocotyl stem structure was most suppressed under high doses of blue light during the very first weeks of germination, with the shortest hypocotyl length displayed by plants grown under 50% blue light. At later stages of growth, however, lower doses of blue light might be sufficient to suppress elongation, while providing benefits to net photosynthetic rate where the highest values were found in plants that were treated with blue light under 30%. (Frąszczak 2016)

Other plant species demonstrate optimal growth under different conditions. For Cherry tomatoes, for example, a 1:1 ratio of red to blue light was found to be effective, whereas a red to blue ratio of 0.9:0.1 may be a better ratio for some lettuce, spinach, and radish. While blue light suppressed stem elongation in dill plants and lettuce, eggplants grown under blue light display longer stems than plants grown under any other color. Light may modify the expression of non-food commercial plants as well. Increasing the proportion of blue light to roses and chrysanthemums resulted in lower flower heights. (Frąszczak 2016)

Ultraviolet Radiation

Due to depletion of the ozone layer, ultraviolet-B radiation (280-315 nm) has an increasingly negative impact on Earth's living organisms, and other than extremely high altitudes, ultraviolet-C radiation is absorbed in the upper atmosphere and rarely reaches the Earth's surface, except that that may no longer be true. Scientists recorded direct solar UV-C radiation reaching the ground in Madrid in 1997. (Katerova 2009)

Researchers at the Bulgarian Academy of Sciences studied the effect of UV-B and UV-C exposure on three important plant hormones that regulate response to environmental stress, Abscisic acid (ABA), indole-3-acetic acid (IAA), and 1-aminocyclopropane-a-carboxylic acid (ACC).

These phytohormones are involved in regulating developmental processes such as plant growth and lateral root initiation in response to environmental cues. (Katerova 2009)

Spectral Properties of Artificial Light

Greenhouse plants typically supply plants with 16-20 hours of artificial light per day at intensity ranges of 100-200 $\mu mol \bullet m^{-2} \bullet s^{-1}$. For years in indoor plant cultivation, the High-pressure Sodium (HPS) bulb has been the industry standard due to their high efficiency (1.9 $\mu mol \bullet m^{-2} \bullet W^{-1}$) at turning electricity into photosynthetically active radiation. But light from HPS lamps is still suboptimal, producing light mostly in the yellow and orange ranges with some red light between 550- 650 nm. Only about 5% of the light produced by HPS bulbs is in the blue range, and there is no way to modify their spectral output.

Light emitting diodes (LEDs) provide light within a narrow spectrum ranging from ultraviolet to near-infrared allowing manipulation of the light spectrum to trigger physiological changes with potential benefits to plant growth. The light distribution properties for LEDs are comparable or better than their HPS counterparts, making them a fully scalable substitute. LEDs increasingly have comparable quantum efficiency to HPS lamps, and in the cases of some new Dutch and Danish manufactured fixtures (2.2-2.4 $\mu mol \bullet m^{-2} \bullet W^{-1}$), may even exceed the capability of HPS lamps. LEDs are also solid state, durable light sources that offer superior bulb life, reaching up to 100,000 hours compared to the average HPS lifespan of 10,000-20,000 hours. (Ouzounis 2019)

Avantes has been a pioneer in the implementation of spectroscopy within greenhouse environments. Spectrometers from Avantes have been used to optimize LED light mixtures as well as automatically adjust shading system within greenhouses to regulate the daily light integral (DLI) which is the total amount of light received by a plant in a 24-hour period.

Plant Health Monitoring and Quality Assessment

One of the more common areas of interest in Smart Agriculture is achieving a non-invasive means of measuring plant health and quality. Spectroscopic diffuse reflection is ideally suited to this application as it requires limited hardware and can be performed at very high speeds (e.g. 600 spectra per second). A notable example of this technique involves a sensor head mounted on the top of a tractor which is pulling a fertilizer implement. This system which was developed and is commercialized by Yara AG simultaneously measures the solar illumination and correlates this with reflection data from the crops. The reflected light from the crops provides rich information about the chlorophyll content allowing for the derivation of a health score which in turn regulates the fertilizer application level in real time and then maps this to GPS coordinates for future monitoring. This system provides an excellent example of the potential of SMART agriculture to better utilize resources to improve agricultural yields.

Crop quality is another important area of agricultural production where spectroscopic techniques have been successfully implemented. Researchers at the Polytechnic University of Valencia, Spain, are using Avantes instruments in developing a mango quality index for prediction modeling and the development of a robotic gripper capable of simultaneous tactile and NIR spectroscopy measurements to determine mango quality and ripeness. (Cortes 2017)

This non-destructive method of assessing fruit quality is based on the biochemical and physical properties of mango samples. Mangoes are typically not ready for consumption at the time of maturity. They require a period for ripening during which many important chemical and physical changes take place within the fruit. Diffuse reflectance spectroscopy was used with a fiber-optic probe in direct contact with the mango skin to measure changes in soluble solids, ascorbic acid, water content, and skin color. An Avantes multichannel spectroscopy system was used in the development of this quality index. The

AvaSpec-ULS2048CL-EVO Starline spectrometer covered the visible range from 600-100 nm and an AvaSpec-NIR256-1.7-EVO NIRLine spectrometer covered 900-1750 nm.

Spectroscopy for Light Characterization

Spectrometers and spectroradiometers are

essential tools for the characterization of natural and artificial light in agriculture. While sometimes confused with a sensor, these devices provide robust information about the quality and quantity of light which is received, absorbed, or transmitted by plants. A sensor, conversely, is typically limited to measuring a narrow band of light wavelengths received in aggregate. Given the importance of the composition of light wavelengths received by plants, spectrometers are valuable tools for characterizing this composition.

Avantes AvaSpec instruments are robust and optimized for the challenges of field spectroscopy. Within the UV/VIS range, the most common instruments used in this application are the AvaSpec-ULS2048CL-EVO and the AvaSpec-Mini2048CL. Both are optimal candidates for field use due to their robust yet compact designs, high-speed data acquisition, and thermal stability. For near-infrared applications, the AvaSpec-NIR256/512-1.7-EVO and the cooled AvaSpec-NIR256/512-1.7-HSC-EVO are the go-to instruments. These instruments are especially well suited for grain and silage analysis in the field.

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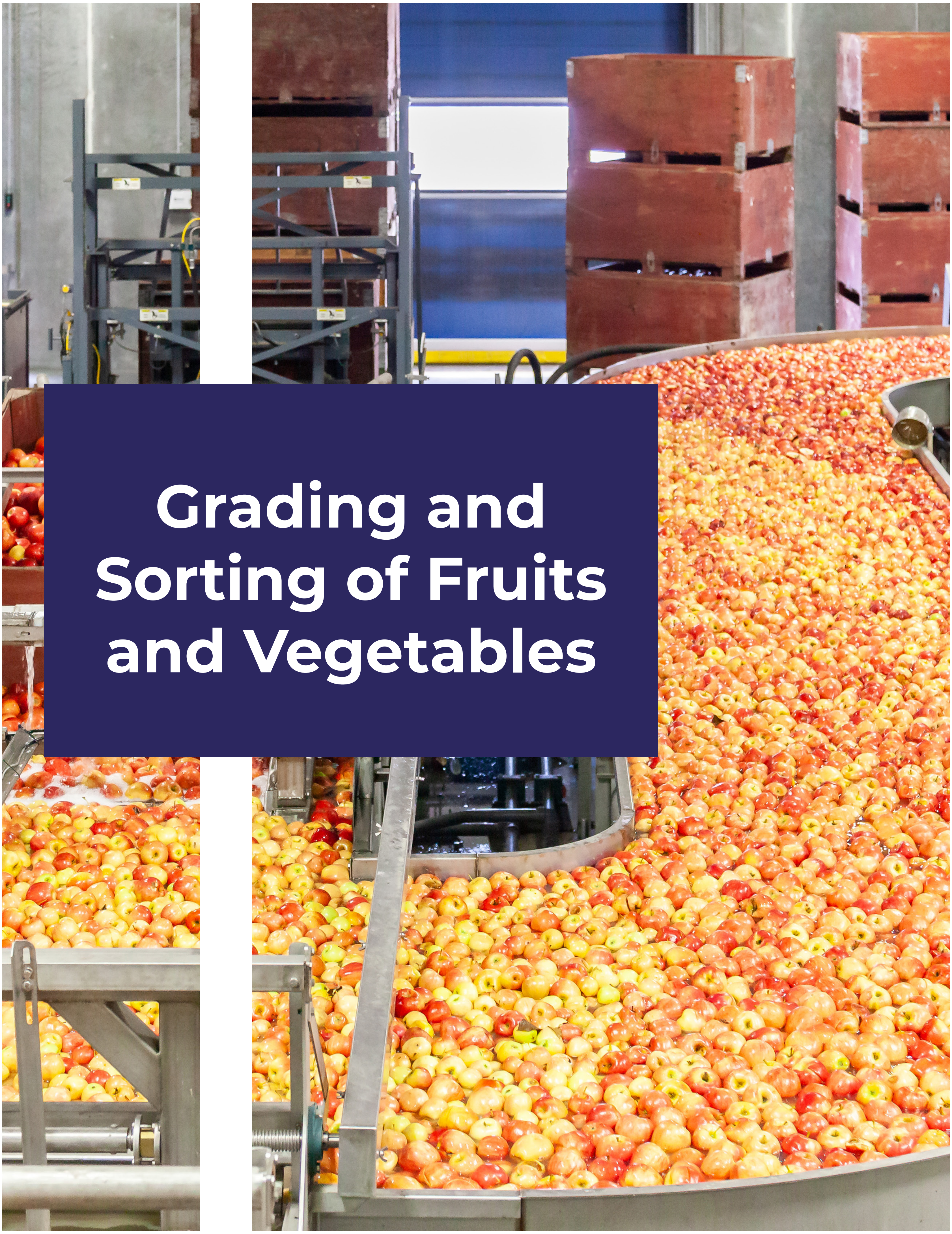
Grading and Sorting of Fruits and Vegetables

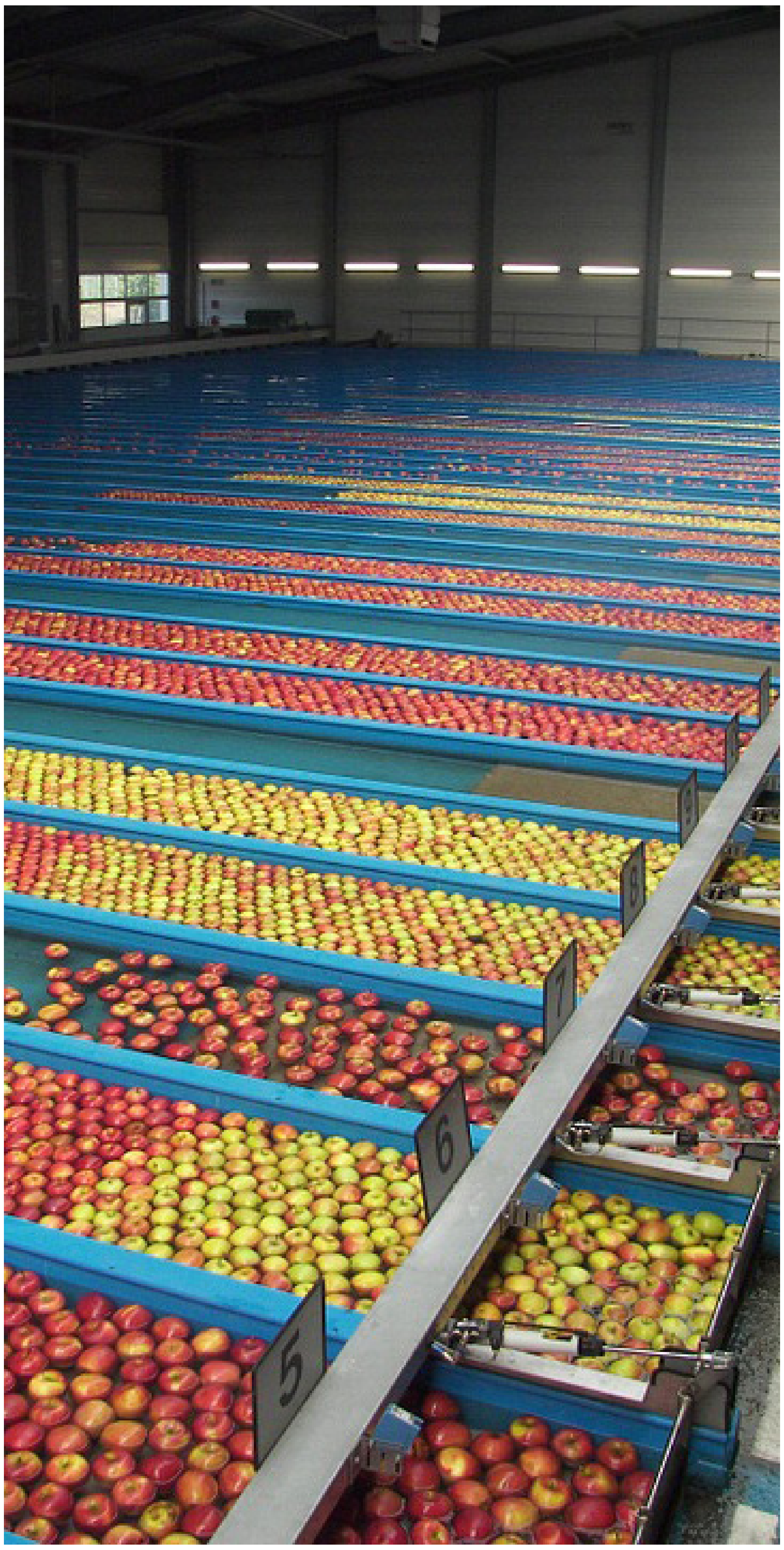


03

Spectroscopy in Fruit Grading & Sorting

NIR Monitoring in Agricultural Production

Monitoring fruit quality during production, throughout the harvest, and while bringing a harvest to market, is likely to become increasingly important to the sustainability of modern food production. During production, key data might include soluble solid content, water content, or firmness. Post-harvest, and from a marketing standpoint, monitoring bruising, scald or frost damage, and rot, allows producers to guarantee uniform quality reaches the consumer, even while maintaining the highest possible yield



Work with 'Fuji' Apples Improves Production

Researchers employing Near-Infrared Spectroscopy (600–1,100 nm) on Fuji apples studied the near-infrared spectra to, first, develop an algorithm correlating fruit characteristics for solid content, water content, and firmness. From this data, the team was able to isolate sensitive wavelengths useful for predicting internal fruit quality. This team went further to discuss the variety of methods for selecting appropriate wavelengths for the purpose of reducing the data set compared to monitoring the entire NIR spectra. This method of selecting key wavelengths to minimize the data set becomes integral to the development of portable and inline sensing systems such as those currently being developed by Avantes' OEM partners.

These researchers relied on the AvaSpec-ULS2048-USB2 spectrometer along with a Tungsten Halogen illumination source (the AvaLight-HAL-S-Mini), fiber optic reflection probes (400-µm diameter, FCR-7IR400-2-ME, Avantes) and power supply (PS-12V/1.0A, Avantes). Since the publication of this article, Avantes released the AvaSpec-ULS2048X64-EVO in our Sensline product family. This spectrometer is ideally suited to diffuse reflection measurements in the 3rd overtone of the NIR due to the superior response and signal to noise of this instrument.(Qing 2007)

'Jonagold' Post-Harvest Monitoring

A study published in Post-harvest Biology and Technology analyzed reflectance spectra in the visible/ NIR spectra using a spectrometer and camera system. By comparing the reflectance of damaged and sound tissue, researchers were able to isolate 4 filters that predictably enabled the quantification of apple quality for this bicolor apple variety. Combined with process control systems, this combination of filters encourages innovation in the automation of fruit sorting.

In this study, reflectance spectra were acquired with an early version of the AvaSpec-ULS2048-USB2 spectrometer. (Kleynen 2003)

Sweet Cherries

Researchers in Hungary, which produces roughly 10-12 thousand tons of cherries annually, investigated the absorption characteristics of anthocyanin, a water soluble plant pigment that appears red, blue or purple depending on minute changes in the pH of the plant. The AvaSpec-ULS2048CL-EVO proved to be an optimal instrument for working in the red spectra (570-730 nm) and in the NIR (900-970 nm), and with samples at various stages of the life cycle and varying health status. This project ultimately developed four spectra indices to objectively qualify cherry fruit. In addition to anthocyanin, color and water content indexes were important factors (Atilla 2011).

Peaches

Perceived ripeness is the most important quality indicator for customers, therefore it is the primary consideration after harvest. But, how ripeness is qualified has mostly been subjective because objective tests were destructive in nature. We do know that soluble sugar content (SSC) and water content (which affects firmness) are highly correlated with fruit quality. NIR spectroscopy has been proven an effective means to measure SSC and water content due to their spectra absorption properties.

Italian researchers using an early model equivalent to the AvaSpec-NIR256-1.7-EVO worked on the development of an index standard for correlating the results of NIR spectroscopy to perceptions of ripeness allow this technology to be utilized in commercial applications to put this technology to use in the field (Capone, et al 2002).

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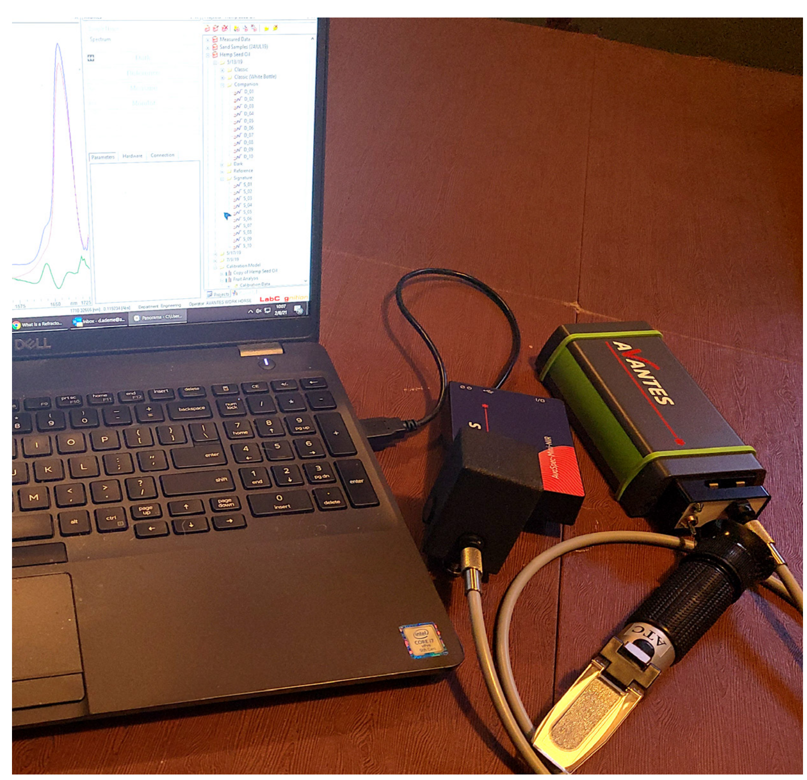
04

Chemoemtric Modeling of Sugar Content in Fruits

The application of visible (400 nm to 750 nm) and near infrared red (750 nm to 2500 nm) region spectroscopy to assess fruit and vegetables is an efficient way to measure the properties of fruit, as opposed to multi or hyperspectral imaging. Vis spectroscopy targets color assessment and pigment analysis, while NIR spectroscopy has been applied to assessment of food quality and ripeness in fresh produce in commercial practice, and a wide range of attributes in scientific studies.

Pairing this information with a chemometric model can aid in the easy identification of fruit quality, which can aid in rapid food sorting for commercial applications.



System Description

A halogen light source is ideal for color measurements because of its good output between the wavelengths of 380nm-780nm, which is the wavelength range of visible light which the human eye can detect. A halogen light source used in this testing, an Avantes AvaLight-HAL-S-Mini. In the region of visible light to near infrared, that's where the AvaLight-HAL-S-Mini works best. The AvaLight-HAL-S-Mini is a compact, stabilized halogen light source with adjustable focusing of the fiber connection, maximizing output power at the desired wavelength. This versatile light source also has adjustable output power to provide extra power or longer bulb life. A filter-slot mounted on the front of the AvaLight-HAL-S-Mini accepts 1" round or 2"x2" square filters, to block specific ranges of wavelengths or instantly lower the intensity. The adjustable focus on the AvaLight-HAL-S-Mini helps you get the most out of your light source: it makes sure all possible power is transmitted through your optical fiber. Bulb replacement is easy and can be done in a matter of minutes.

The AvaSpec-Mini-NIR is a compact near-infrared spectrometer, based on a combination of our popular AvaSpec-NIR256-1.7 and Mini-series. This NIR spectrometer might not be as sensitive as our bigger NIR spectrometers, but this loss in sensitivity is greatly compensated by its size and robustness. Like our other CompactLine spectrometers, this device is only the size of a deck of cards and USB powered, which makes it easy to integrate into other devices, including but not limited to OEM handheld applications. This versatile miniature NIR spectrometer is well suited for various applications, including food analysis and the recycling industry. For this testing, the configuration used has a useable range of 950 nm to 1700 nm. It is also fitted with a Slit-50 and an OSF-850.

Figure 1: The setup of the experiment.

Methodology

For this experiment, the software Panorama, developed by Labcognition, is utilized. Panorama is a powerful spectroscopic tool capable of fully controlling Avantes instruments to give the user the ability to not only collect and save data but compile this data into a mathematical calibration that is generated through the software. This experiment used various fruit samples with our refractometer to generate a mathematical model capable of predicting the amount of sugar in these samples.

A refractometer is a simple instrument used for measuring concentrations of aqueous solutions. It requires only a few drops of liquid, and is used throughout the food, agricultural, chemical, and manufacturing industries. We will use our refractometer to measure the sugar level in a fresh strawberry, orange and avocado. We will then measure the absorbance spectra of each fruit, and then utilize panorama to correlate the absorbance spectra with the sugar level as indicated by the refractometer.

Test Data and Results

Displayed below is the chemometric data and model.

Integration time: 500 ms

Averaging: 10

Click Here to download the complete data set

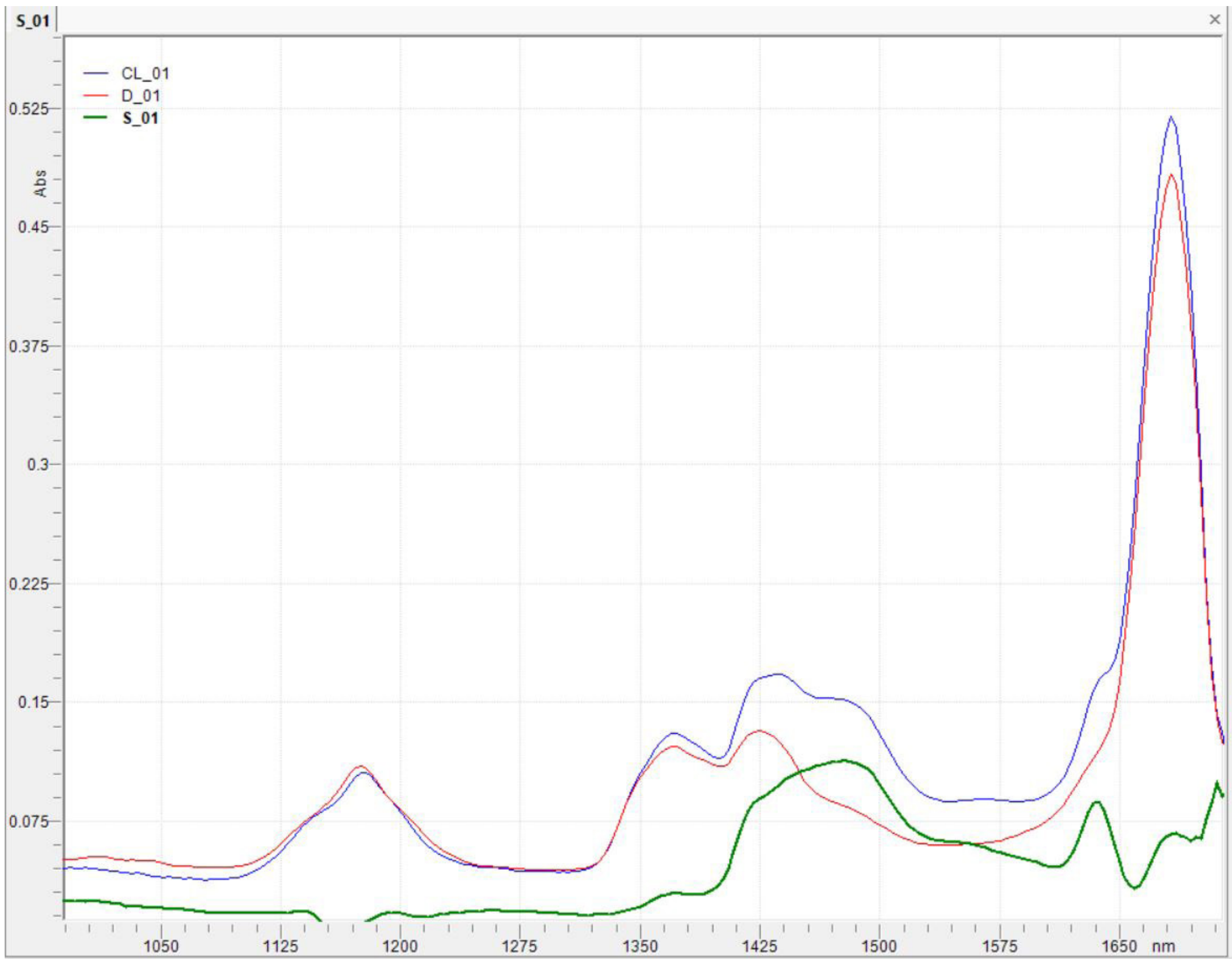


Figure 2: The absorbance spectra of our three samples, with the blue spectrum representing the orange, the red spectrum representing the strawberry and the green spectrum representing the avocado.

Figure 3: The spectra processing screen of Panorama, where the mathematical operations can be manipulated.

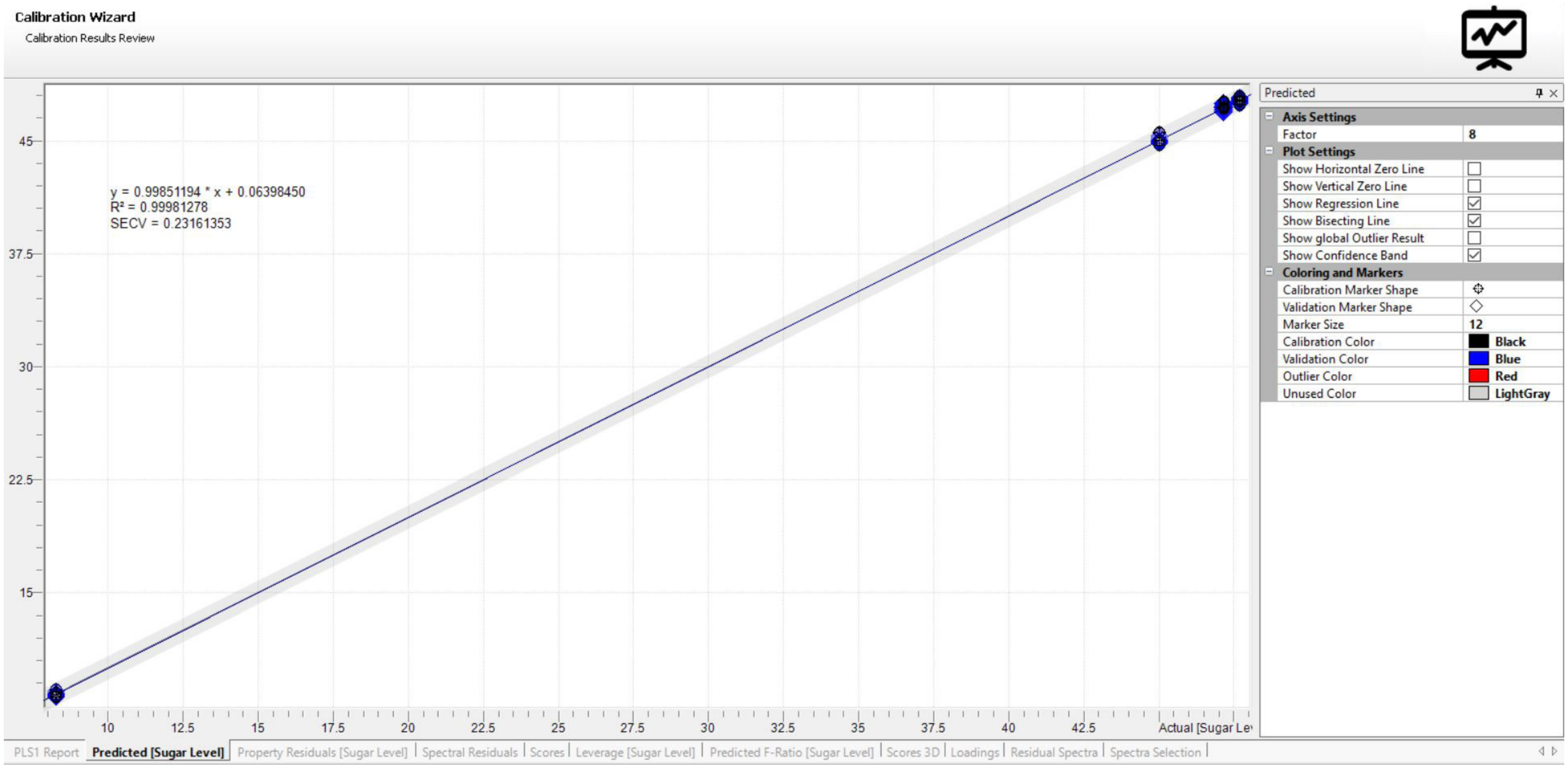


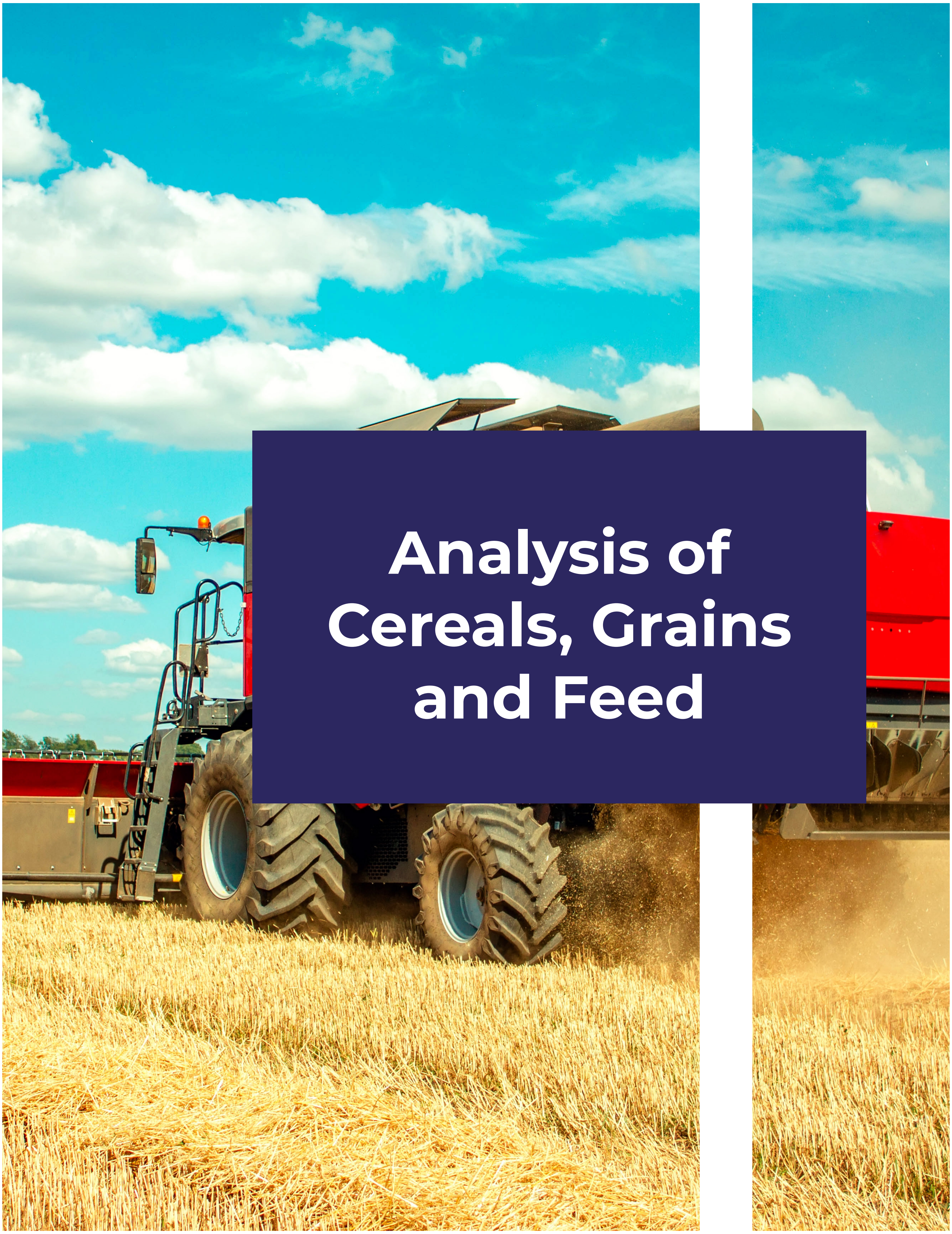
Figure 4: The prediction accuracy of our chemometric model from the Panorama Calibration Wizard.

Analysis

Comparing the collected data with the know absorbance spectra for strawberries, oranges and avocados, our absorbance spectra for these fruits matches very closely. This goes to show how using fiber optic spectroscopy for chemometric models on sugar levels and ripeness of fruits can rapidly improve the analysis and sorting process of fruits.

Conclusion

In conclusion, the AvaSpec-Mini-NIR spectrometer combined with the powerful capabilities of Panorama, can produce a highly accurate chemometric model capable of predicting the quality, condition and ripeness of fruit. In order to further improve this model, additional samples can be added to the calibration. This model development could be applied to a variety of fruits and nutraceuticals products in liquid or powder form with the caveat that sample homogeneity is critical to success with these types of samples.



Analysis of Cereals, Grains and Feed

05

Spectroscopy in Grain Production and Analysis

The agricultural industry is responsible for meeting the food productions demands of an ever growing population. Maximizing production while still protecting the environment is a grave concern in many parts of the world today. Modern food production is increasingly turning to the science of spectroscopy to monitor crop health and improve production yields.

Avantes spectrometers are trusted by researchers in the biological sciences and by agricultural equipment manufacturers to provide accurate spectral data at a fair cost. After more than two decades developing spectrology solutions for numerous applications, we have the expertise to assist with designing an optical spectroscopy system for any application.

The third and second overtone of the near-infrared range can be used to determine organic nitrogen and protein through the characterization of the C-H, N-H, and O-H stretching vibrations in these spectral regions. These measurements are often used in the agricultural industry to analyze grians.

The previously mentioned bands are weakly absorbing, which has the advantage of facilitating unprocessed grain seed because low absorbance means that the material is mostly transparent, allowing for deeper penetration. The downside to these bands that is that they produce low signal intensity and this obviates the need for good signal-to-noise performance.

The AvaSpec-Mini-NIR is an ideal instrument for this measurement. For even higher performance into the second overtone, the ideal instrument is the AvaSpec-NIR256-1.7-EVO , with the Mini-NIR offering a suitable small form factor substitute.

Nitrogen Concentration in Rice

Monitoring plant health characteristics and improving crop conditions are instrumental in maximizing production yield. Researchers from the Institute of Digital Agriculture at the Zhejiang Academy of Agricultural Sciences in Zhejiang, Hangzhou China developed a series of indices for the measurement of chlorophyll in the leaves of rice plants1. Chlorophyll has a very strong and well documented correlation to nitrogen content, a primary indicator of plant health.

Employing an older version of the AvaSpec-ULS2048CL-EVO, these researchers explored the use of the Yellow Edge Reflectance Index (YERI) and Red Edge Reflectance Index (RERI) for calibrating nitrogen and chlorophyll values to reference spectra at each stage of plant development and varying states of plant health2. The theoretical work behind this study is applicable to other crops, once reference spectra can be correlated. (Zhang 2011, Zhang 2011)

Wheat in the Pacific Northwest

Wheat prices are set based on protein content and falling wheat prices have hurt farmers in this region in particular. The soft white winter wheat that is well suited to the climate in the PNW, has a lower protein yield than other varieties. Other varieties that are adapted for the region and have a higher protein yield also require more nitrogen fertilizer. Spectroscopy instruments were used to define a standard for measuring protein levels and the equivalent nitrogen values. This is the critical first step to developing variable-rate fertilizer technology for commercial application in the Pacific Northwest for wheat farmers. (Zhou 2017)

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06

On-Combine Deployment of Miniature Spectrometers for Grain Protein Concentration Sensing

Grain protein concentration (GPC) is a critical measure in grain production, with commodity pricing based on protein content. Protein content is also directly proportional to nitrogen uptake. The measurement of protein content and nitrogen uptake allows the producer to manage application of nitrogen fertilizers to reduce over-use and operate more economically while maximizing production yield and return.

Near infrared absorbance spectroscopy is a standard and nondestructive analysis technique that has been used to measure the GPC in wheat and other grains. Since 2000, several systems have been developed to deploy this technology in the field, on-combine, but these systems are too expensive for many small producers and have not been widely adopted for that reason. Researchers at the United States Department of Agriculture (USDA) Oregon Field Offices endeavored to develop a low cost near infrared analyzer for in field, real-time grain analysis.

System Description

The instrument adapted for the USDA study was the Avantes AvaSpec ULS2048x64-EVO-USB2 spectrometer (next generation instrument is the AvaSpec-ULS2048X64-EVO) with a 2048 pixel charged coupled device (CCD) linear array detector and configured with a 600 lines mm-1 grating to measure the range 650-1150 nanometers. The spectrometer is fiber coupled to a fiber optic cable that connects to an integrating sphere (AvaSphere 50-LS-HAL) with built-in halogen lamp. Light is collected through an aluminosilicate glass covered aperture for a sealed, light transmitting collection window. Thermal stabilization of the system was achieved with the help of a thermoelectric cold plate and a Styrofoam insulated enclosure. An inexpensive notebook computer, off-the-shelf global positioning system, and programmable controller completed the equipment list for a total cost of less than $9,000 US, putting this system in reach of a wider segment of small producers.

Designing the system began with lab testing, but it was also important to mimic field conditions. A test stand was used to simulate grain flow

conditions on an auger conveyor system like that on a combine harvester. The probe head was secured to an opening in the auger housing at 30 degrees above the center of the grain stream at a flow rate of 1.63 kg/s^{-1}. This allowed further testing of the calibration model under simulated harvest conditions.

Field evaluation of the adapted system was conducted with the integrating sphere head mounted to the housing of the exit auger of a Case International Harvester 1470 combine. Steel mesh screens were used to protect the fan ports on the sphere from debris and fiber optics from the sphere led to instrumentation mounted in the cab. Dark and light referencing was performed each time the combined was stopped for unloading the bulk collection tank, multiple times per day. Data was collected on the notebook computer during operation with processing at the end of each harvest day. The ruggedized Avantes system withstood the rigors of 4 growing season and saw about 200 hours of run time.

Development of the Chemometric Model

The USDA pursued a research product aimed at adapting relatively inexpensive NIR reflectance spectrometers to map GPC across a field. Development of the chemometric calibration model began with a 3-year field study to obtain grain samples of soft white wheat grown under a variety of nitrogen and water level conditions. Custom code interfaces to import Avantes AvaSoft data into DeLight (DSquared Development) spectroscopic software where a process called binning grouped spectra into 126 bands of 16 pixels, a smoothing technique that simplifies a set of variables for modeling. Binning increases the signal to noise ratio while sacrificing resolution, in this case the resolution was reduced to 11.2 nm, which kept resolution within acceptable limits. The application of the second derivative removed baselines shifts caused by the random orientation of grains. And finally, DeLight used partial least squares to find wavelength regions of interest where the grain sample was the independent variable and GPC as the dependent variable and derive a calibration model for grain protein concentration.

Results

The resulting maps of GPC and grain yield demonstrated the inverse relationship between yield and protein content indicative of moisture-limited environments. Low yield area correspond to thin unproductive soils where increased nitrogen fertilizer has little benefit. The protein map derived from the USDA test system was comparable to one created using a much more expensive Polytec spectrometer system.

Predictive models from local samples are limited in data, but the use of machine learning or artificial neural networks can increase system accuracy, but even so, not many farmers have the luxury of time to learn to apply advanced chemometric analysis. Adoption of this technology could be dependent on the availability of commercial services for chemometric modeling.

The final result of this study was proof of the potential for moderately priced alternative to costly (> $20,000) combine -mounted spectral mapping systems.

References

Long, Dan S., and John D. McCallum. "Adapting a relatively low-cost reflectance spectrometer for on-combine sensing of grain protein concentration." Computers and Electronics in Agriculture 174 (2020): 105467.

07

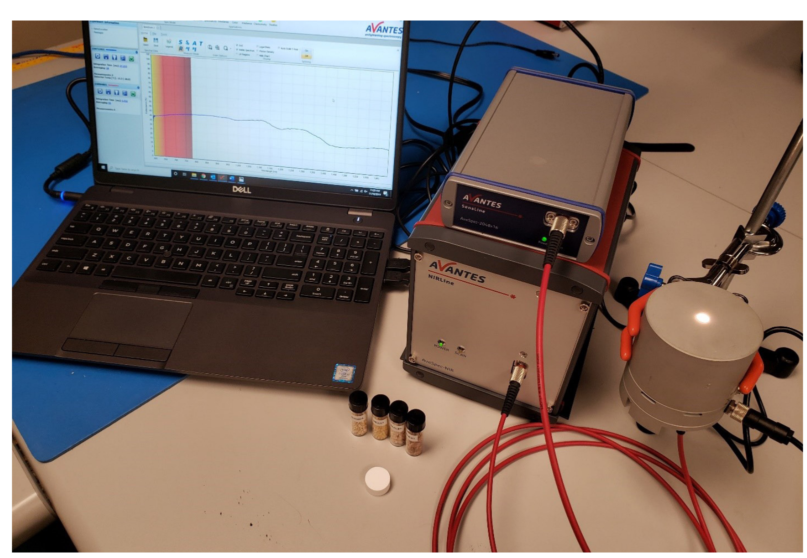
NIR Grain Analysis Experiment

Background/ Applications

Absorption and reflection measurements can be used to determine the freshness of various crops, from fruits and vegetables to even grains. Not only can reflection and absorption spectra be used to identify the properties of different types of grains through chemometric models, but it can also be used to characterize the unique spectra of each sample. NIR spectroscopy is leading the way for the future of agriculture and food production for both qualitative and quantitative measurements.

Description of System

A halogen light source is ideal for absorption measurements because of its power and high spectral energy output in the NIR range, which is the wavelength range many researchers use in agriculture to study and characterize crops. The halogen light source used in this testing is integrated within our Avantes integrating sphere, an Avantes AvaSphere-50-LS-HAL. This integrating sphere and light source combination provides an excellent reading of reflection and absorption data across a larger surface when compared to a reflection probe. The integrating sphere is connected via SMA termination to a bifurcated fiber, with one leg connected to an AvaSpec-ULS2048x64-EVO and an AvaSpec-NIR256-1.7-HSC-EVO. Both spectrometers are combined via



System Setup

AvaSoft to create a single spectrum providing high resolution across a wide wavelength range. If a greater wavelength range was desired to be measured, it would be possible to combine/merge even more detectors to create a single spectrum.

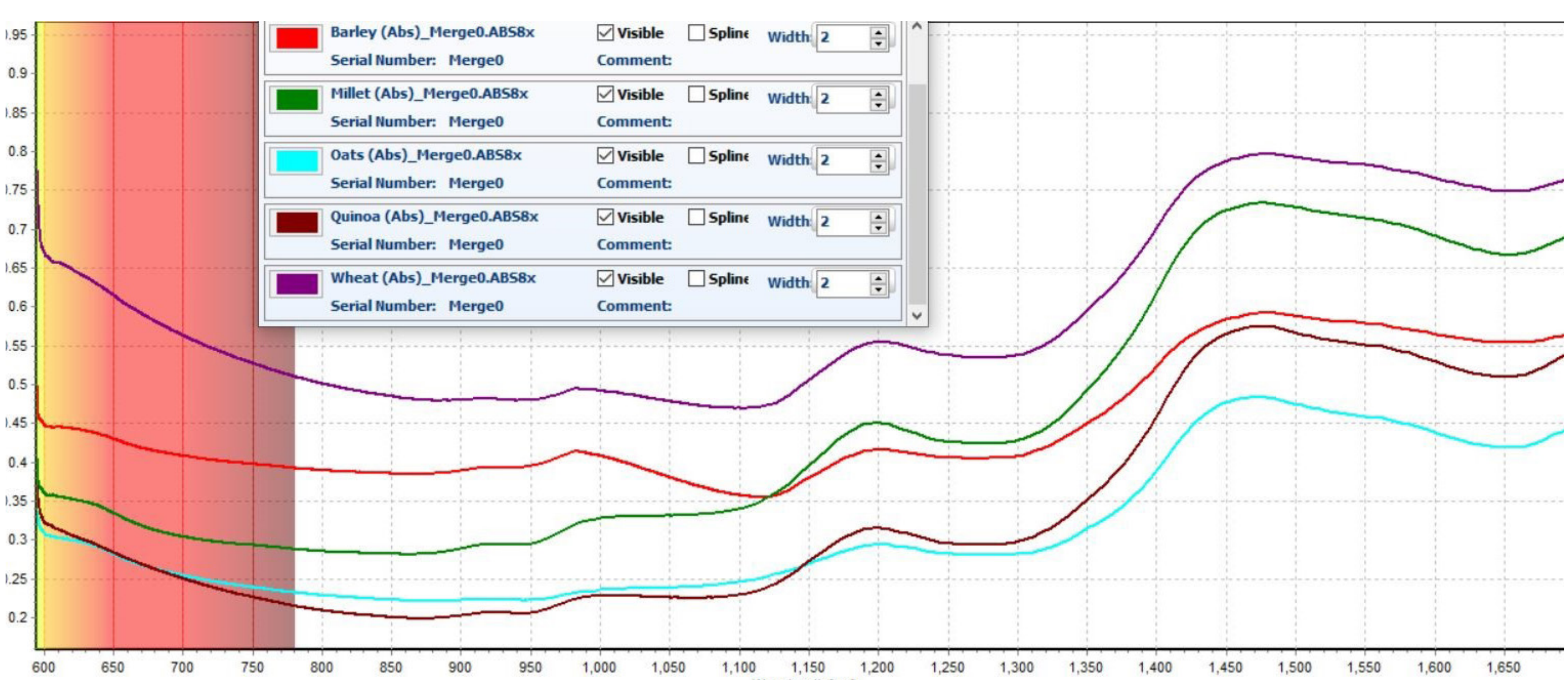
The AvaSpec-ULS2048x64-EVO is the best option when looking for a cost-effective, highly sensitive spectrometer. The back-thinned Hamamatsu detector features a signal-to-noise ratio of 500:1 and a quantum efficiency of up to 78%. The specific unit used in this experiment is fitted with an IB grating with a range of 600 nm to 1112 nm. An OSF-600 to reduce second-order effects is also implemented in this unit. The AvaSpec-ULS2048x64-EVO is useful for measuring the third overtone of the near-infrared (800-1100 nm) which provides for an economical means of analyzing grains that is far less expensive than an InGaAs array spectrometer.

The AvaSpec-NIR256-1.7-HSC-EVO is equipped with thermoelectric, Peltier-cooled 256-pixel InGaAs detector which supports cooling down to -25°C against ambient. The AvaSpec-NIR256/512-1.7-HSC-EVO spectrometers pair the same trusted InGaAs array detectors with our ultra-low-noise electronics board, featuring a USB3 and Giga-Ethernet connection port. The instruments are equipped with a Replaceable Slit. Digital and analog I/O ports enable external triggering and control over the shutter and pulsed light sources. Choose from two distinct software-controlled gain-setting modes: high-sensitivity mode (HS, default) and the low-noise mode (LN). Cooling ensures optimal noise conditions, even at longer integration times. All NIR-1.7 instruments are available with a choice of four different gratings, making it possible to choose the bandwidth fitting your application.

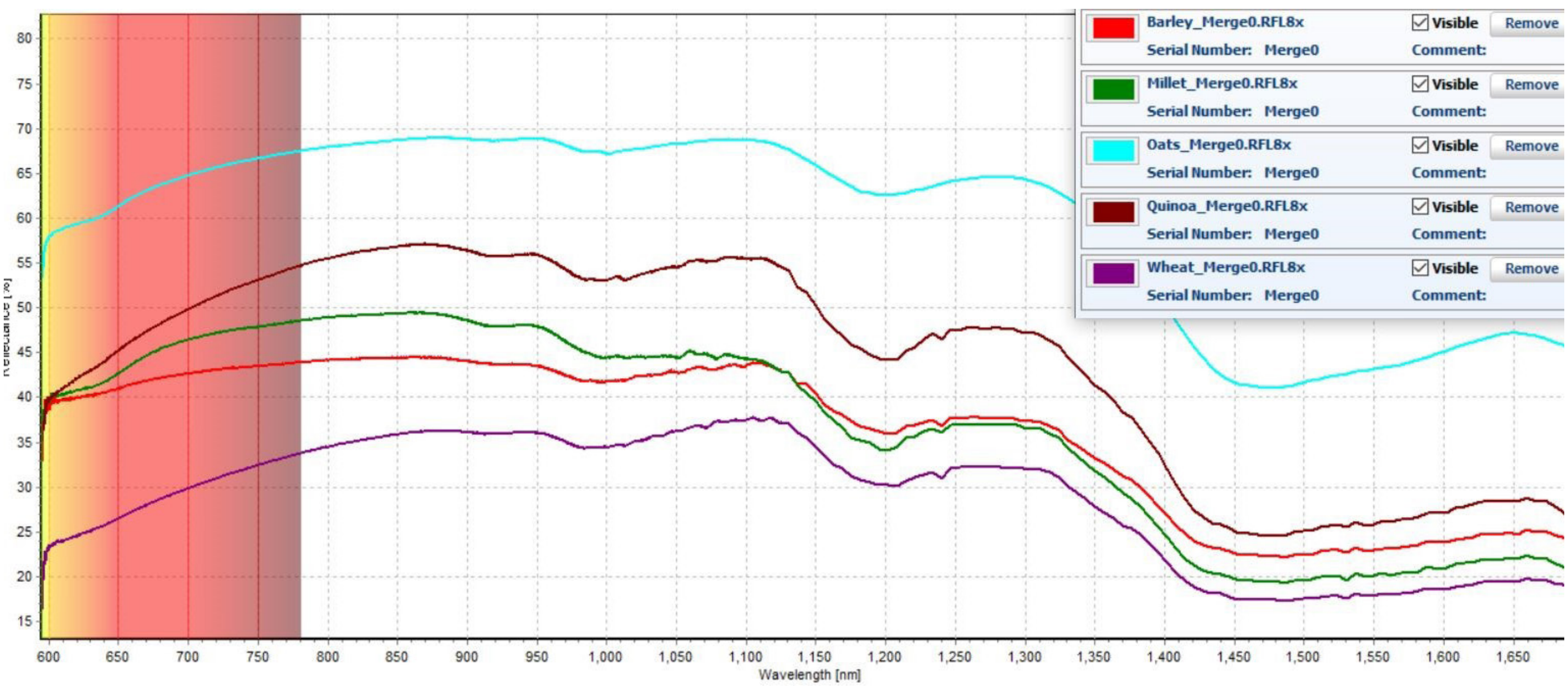
Description of Methodology

For this experiment, the Avantes software AvaSoft was utilized. Within AvaSoft, there are various modules for different types of spectroscopic measurements. One of the modules in AvaSoft is Absorbance Mode, which is specifically designed to collect absorbance related data.

Our dual-channel setup measured the absorbance spectrum from four different grain samples: barley, millet, quinoa, and wheat. A white WS-2 tile



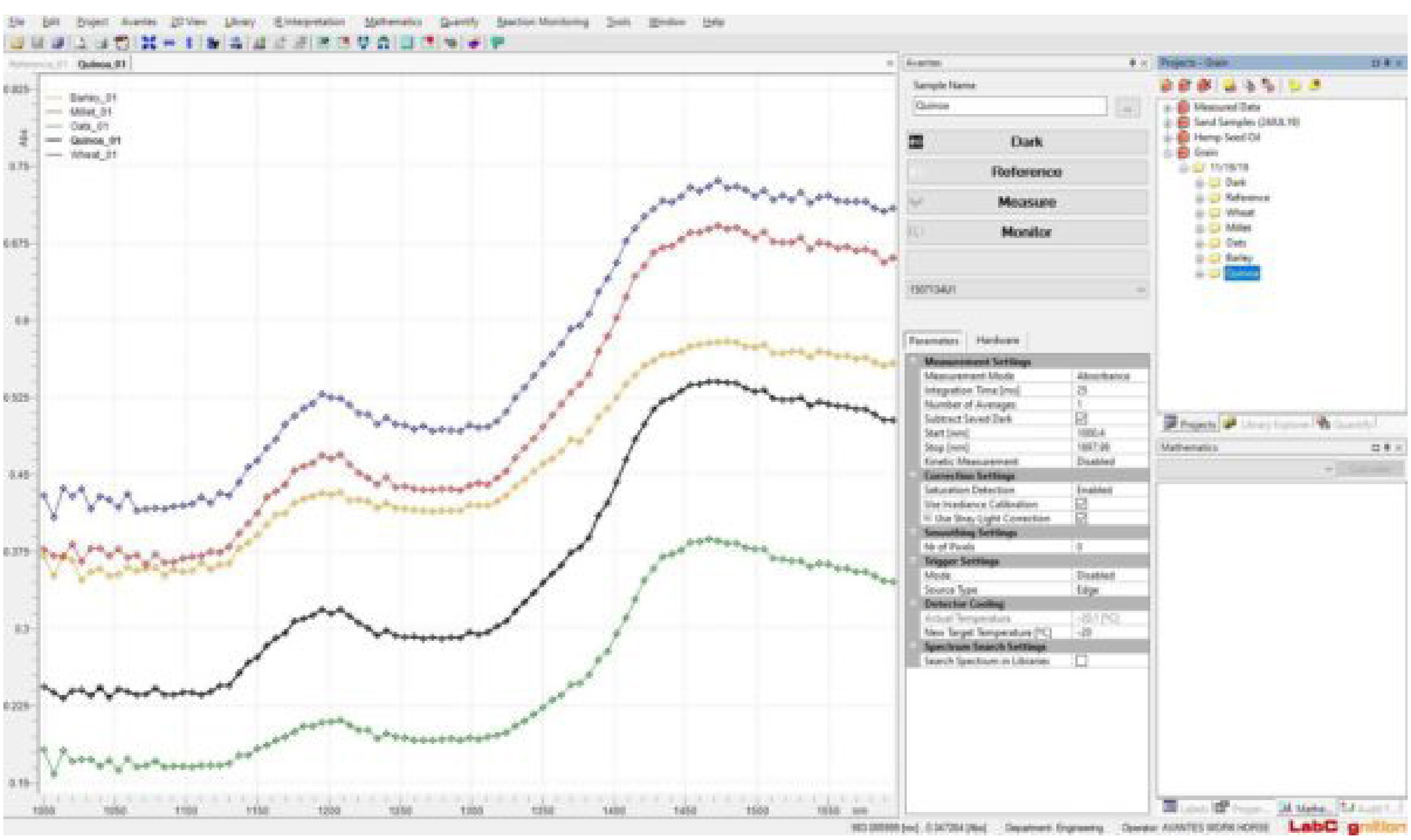
Combined Absorbance Spectra of all 5 samples



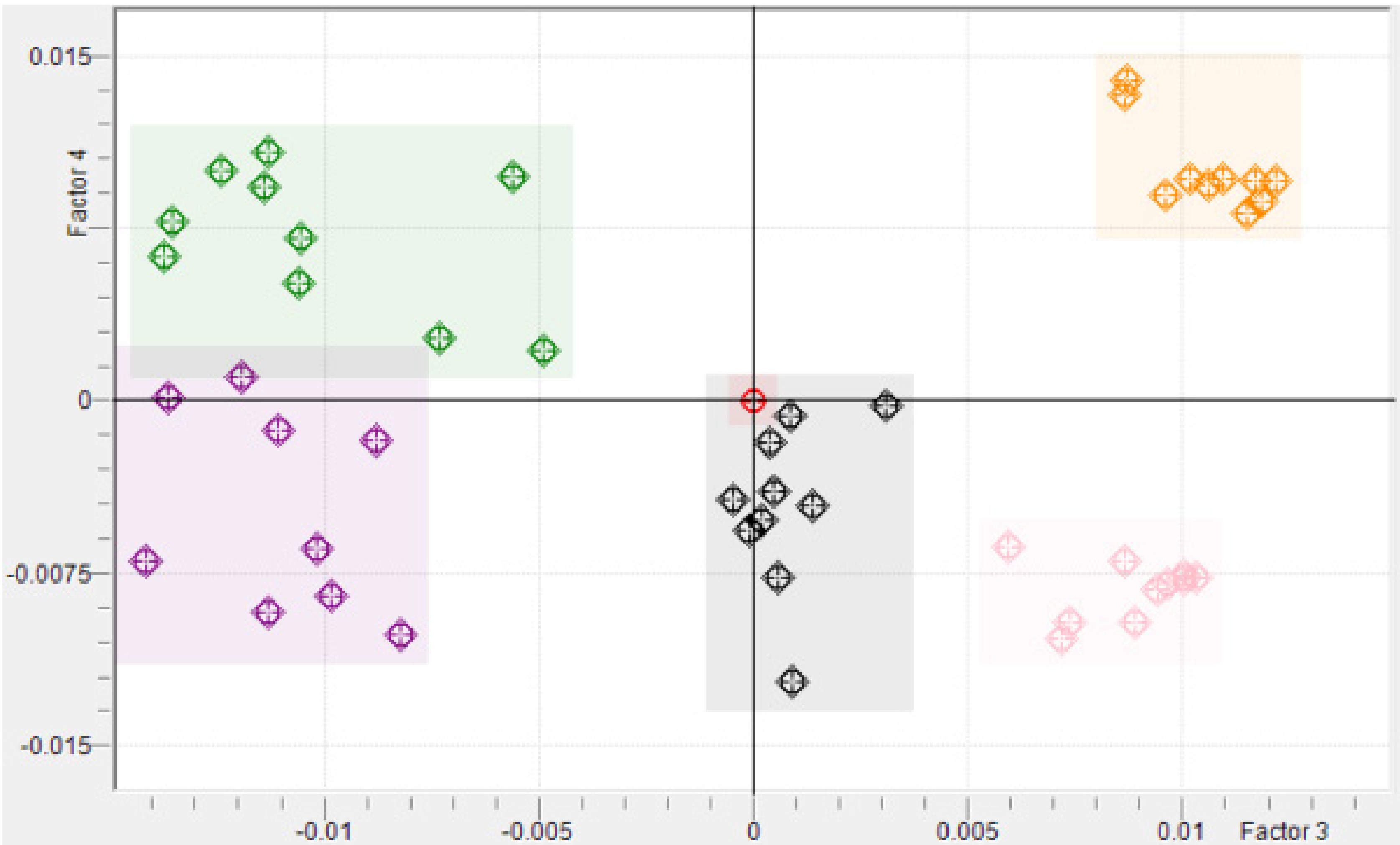
Combined Reflectance Spectra of all 5 samples

was placed on the port of the integrating sphere to optimize the integration time and averaging for each channel. This tile then served as a reference for collecting the absorbance spectrum of each of the four samples.

It is important to note that diffuse reflectance was measured in this experiment and not spectral reflectance. Diffuse reflectance refers to most of the colors we perceive from objects. Materials and objects with a rough surface display diffuse reflection, where light is reflected at a wide range of angles. Spectular reflectance refers to the phenomenon we see when looking at a mirror.



example of an absorption chemometric model developed for identifying various types of grains



factor score plot showcasing the difference and uniqueness of the spectra for all five samples.

The angle of reflection of the light is equivalent to the angle of incidence. Materials and surfaces that we perceive with a matte coating display diffuse reflectance, whereas samples with a glossy texture display a combination of diffuse and specular properties. Mirrors are an excellent example of a purely specular reflective material.

Test Data and Results

Displayed above is the reflectance and absorption spectrum collected from the four grain samples.

Integration time (AvaSpec-2048×16)= 5.50 ms

Integration time (AvaSpec-NIR256-1.7-HSC-EVO)= 27.20 ms, Low Noise Mode

Averaging= 20

Click Here to download the complete dataset

Analysis

While each grain sample appears similar to one another, such as sharing the same peaks and valleys, it is evident from observation that each sample has its own unique spectral fingerprint. This can be used to identify grains and test the grains for wellness and distribution. For example, a standard may be set that each sample must meet the specified parameters to pass a quality check.

Next steps could include developing a chemometric model of each grain sample, which can then be used to identify unknown grain samples. For the data collected on our five samples, a PCA report was compiled to identify the type of grain being examined according to our absorbance spectra. Ten spectra of each sample were used to compile the PCA report, resulting in an R^2 value of .999, allowing us to conclude our chemometric model is an accurate method to identify various grain samples. Our model also shows how each sample is unique from one another in ways that may not be visible at a first, top-level glance at the data. Chemometric software, such as LabCognition's Panorama, is a powerful tool that allows you to apply various mathematic methods to your data in order to generate a reliable model for future identification and quantification of your spectra.

Conclusion

In conclusion, the AvaSpec-ULS2048x64-EVO and AvaSpec-NIR256-1.7-HSC-EVO spectrometers in combination, in addition to AvaSoft and chemometric software, can collect extremely accurate reflection and absorbance data that can give you critical understanding of your sample. This technique on collecting reflection data can be applied to a wide range of industries and fields, including optics, medical diagnostics, food and agriculture, and biology.

08

NIR Absorption and Reflection Chemometrics with Flour

Near-infrared Absorption and Reflection measurements can be used to determine the properties of various samples, such as concentrations of chemicals and the quality of plastics. Not only can absorption spectra be used to identify the characteristics of many types of samples, but it can also be used to characterize the unique spectra of each sample to generate a chemometric model. NIR spectroscopy is leading the way for the future of agriculture and food production for both qualitative and quantitative measurements. The same goes for reflection measurements. Reflection spectra can characterize the unique properties of various

samples, such as grains, fruits, and plastics.

System Description

A halogen light source is ideal for absorption and reflection measurements because of its power and strong spectral energy output in the NIR range, which is the wavelength range many researchers use to characterize consumables, such as grains and food products. This aids in revealing properties not observable with the naked eye. The halogen light source used in this testing is the AvaLight-HAL-S-Mini. From visible light to near-infrared, that's where the AvaLight-HAL-S-Mini works best. It's a compact, stabilized halogen light source, with adjustable focusing of the fiber connection, maximizing output power at the desired wavelength. The light source also has an adjustable output power to provide extra power or longer bulb life. The light source is connected via SMA termination directly to the illumination leg of a reflection probe. The reflection probe is fixed on our reflection stage to illuminate and measure the samples. The spectrometer leg of the reflection probe is connected via SMA termination to our AvaSpec-NIR256-1.7-EVO.

For measurements in the near-infrared range up to 1.7 µm, Avantes offers a new series of uncooled spectrometer configurations. The AvaSpec-NIR256-1.7-EVO and the AvaSpec-NIR512-1.7-EVO offer the same high-sensitivity optical bench, but with the next generation of electronics. Both instruments deliver the same exceptional performance specifications, such as a sample speed of only 0.53 ms/scan and integration times as fast as 10 µs. For applications where resolution is key, or more data points for modeling are required, the 512-pixel detector will be the best choice. The AvaSpec-NIR256/512-1.7-EVO spectrometers pair the same trusted ultra-low-noise electronics board featuring USB3 and Giga-Ethernet connection port with our InGaAs array detectors. Digital and analog I/O ports enable external triggering and

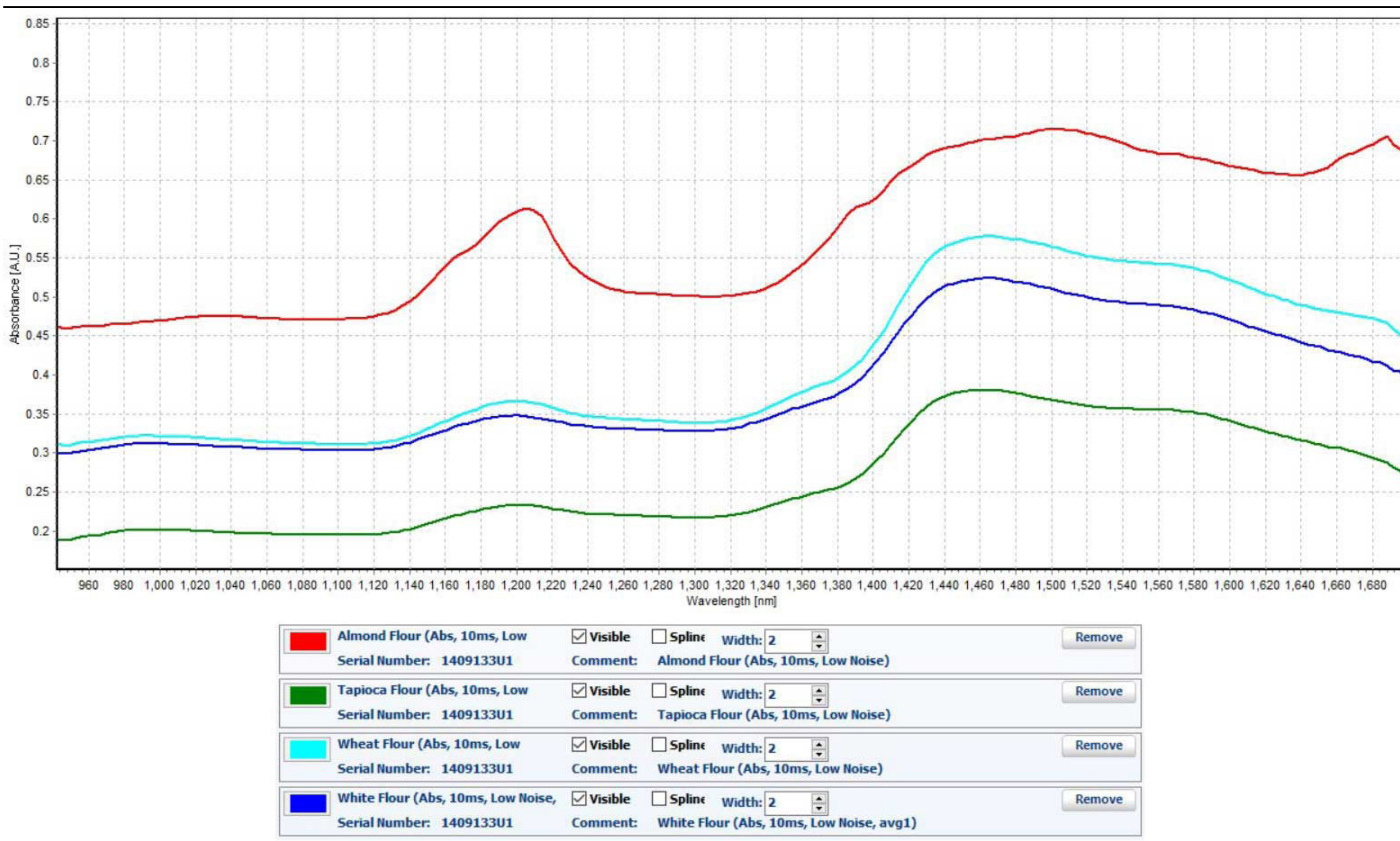


Figure 2: The overlay of the absorption spectrum of all four samples.

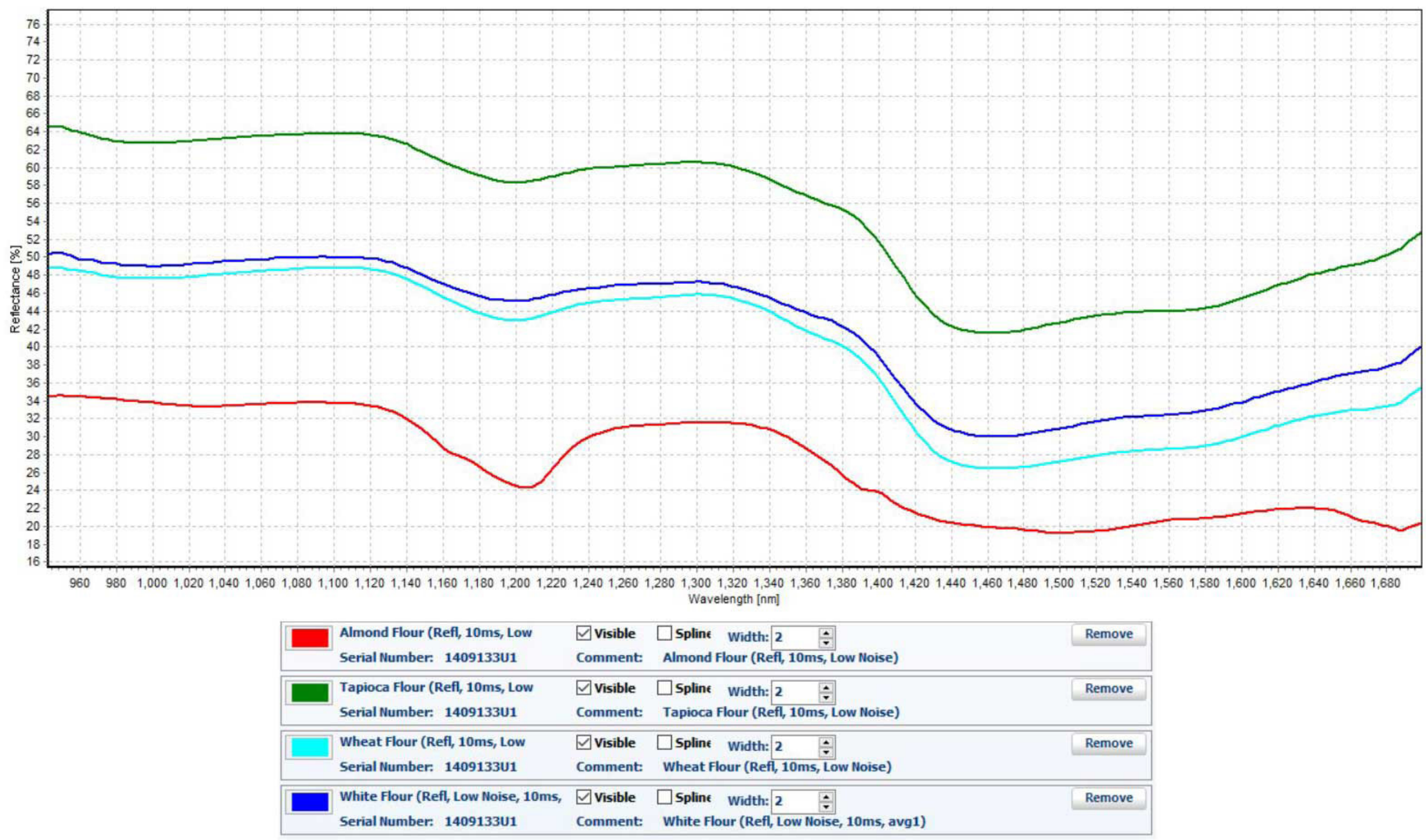


Figure 3: The variance of our model, displaying that only a second factor model is needed.

control over the shutter and pulsed light sources and choose from two distinct software-controlled gain-setting modes, high-sensitivity mode (HS, default) and the low-noise mode (LN). The unit used in this testing is configured with a slit-50 and OSF-850.

Description of Near-infrared Absorption and Reflection Methodology

For this experiment, we used the absorbance and reflection modes in AvaSoft. These modes are built to capture the absorbance of samples in absorbance units and the reflectance of samples in percent, respectfully.

Our setup will be used to measure the absorbance and reflection spectrum of four different types of flour: white flour, wheat flour, almond flour, and tapioca flour. Both the white and wheat flour types contain gluten, while the almond and tapioca flours are gluten-free. A WS-2 reflection tile will be used as our reference. With the tile, we will use this to optimize the integration time and averaging for the spectrometer.

Test Data and Results

Displayed below is near-infrared absorption and reflection spectrum collected from the four grain samples.

Integration time: 10 ms

Averaging: 50

Click Here to download the complete dataset

Analysis

While each flour sample appears similar to one another at an initial look at the spectra, such as sharing the same peaks and valleys, it is visible that each sample has its own unique spectral fingerprint. Upon scaling the y-axis, it is clearly visible that each type of flour has a unique spectrum. The white flour and wheat flour samples both contain gluten, while the almond flour and tapioca flour are gluten free. For the next steps, it can be possible to put together a chemometric model for identifying gluten levels in the flours of baked goods and characterize the traits. Avantes frequently works with LabCognition and their software, Panorama, for these types of near-infrared absorption and reflection applications.

Conclusion

In conclusion, the Avantes NIRLine of spectrometers provides a reliable and effective way of measuring many types of food samples and their ingredients. The accuracy of the NIRLine is a strong advantage in developing reliable chemometric models and for collecting reliable data. Additionally, the fit for use of NIRline instruments in process control environments is evident from the 10 ms integration time sample rate on diffuse flour samples. Avantes AvaSpec instruments also facilitate process control through the industrial communication protocols (Ethernet), onboard data processing capabilities and digital/analog I/O. Combined with the powerful capabilities of Panorama or other multivariate data modeling tools, a highly accurate model capable of predicting the levels of gluten in baked goods can be developed. In order to further improve this model, additional samples can be added to the calibration.

Plant Health, Fertlizer, & Soil Management

09

NIR Spectroscopy for Fungal Infection/ Disease Detection

Grain producers are very concerned about plant health as it directly affects grain yields and consequently profits. Plant health is also a concern for consumers because grain contamination can potentially have severe health consequences.

NIR Spectroscopy relies on the absorption or reflection of near-infrared light to facilitate qualitative and quantitative analysis of chemical and physical properties of the test sample. NIR spectroscopy is widely used in agricultural operations to determine crop parameters such as water content, sugar content, and other indicators of ripeness, as well as measuring chlorophyll fluorescence to determine the need for nitrogen-based fertilizers, or to look for bruising not visible to the human eye. This non-destructive and fast method of inspection has a place in every step of the food production cycle from production to grading and sorting.

Direct leaf measurement provides for the characterization of a variety of plant health parameters. The AvaSpec-Mini2048CL is an ideal instrument for handheld agricultural measurements such as leaf reflection or transmission.

Close-up of stem rust. Photo by Yue Jin via Wikimedia Commons

Numerous plant biologists have deployed the AvaSpec-ULS2048CL-EVO spectrometers into the field for in-situ reflection measurements of fruit and flower specimen measurements using the AvaLight-XE pulsed Xenon source for an excitation source and a fiber-optic reflection probe for sampling.

Detecting Fusarium Infection in Barley

A joint research project sponsored by the U.S.

Department of Agriculture (USDA) and the National Academy of Agricultural Sciences, Rural Development Administration of South Korea, investigated the use of Near-Infrared Spectroscopy to identify Fusarium infection in barley. The fungus Fusarium reduces grain yields and generates a toxin that can be harmful to humans and livestock that ingest infected grains.

To measure in the wavelength range of 1175-2170 nm, this group used the AvaSpec-NIR256/512-2.5-HSC-EVO instrument with an InGaAs (Indium, Gallium, and Arsenide) thermoelectric cooled detector with an integration time of 20 milliseconds. Using partial least squares analysis and regression modeling, a discrimination prediction model was developed that offered 98-100% accuracy in identifying grains contaminated with Fusarium spores.

Rice Blast Symptoms on Rice Stalks. Photo by Donald Groth via Wikimedia Commons

Researchers observed a reflectance peak between 1555-1575 nm for all samples as well as rising peaks at 1305 and 2000 nm and a falling peak in the 1900 nm wavelength range. The largest differences were in reflective intensity. For the normal (uninfected) hulled barley, intensity of reflectivity was 8000 counts while infected grains showed an average intensity of 9600 counts.

To test their discrimination model, researchers tested hundreds of samples. In testing uninfected samples, their model returned only one false positive with a discrimination accuracy of 99.8% and of the infected samples, returned zero false negatives for a discrimination accuracy of 100%. Future researchers will investigate similar models for detecting Fusarium infections in other grains as well.

Identifying Rice Blast Fungus

Rice blast is caused by the fungus Magnaporthe oryzae and its anamorphs such as pyricularia grisea. It is considered a major threat to food safety and stability in many parts of the world due to the severe yield loss that it causes, but until recently, the method used to detect rice blast was a physical inspection on the ground. It was time-consuming and nearly impossible for large-scale operations to perform comprehensive visual inspections. The alternative, the use of large amounts of pesticides and fungicides, has its own risks to health and the environment as well as increasing the costs of production.

Near-infrared spectroscopy has been proven a cost-effective and accurate method for detecting

fungal diseases on the ear of brewing barley

other plant diseases at the leaf and canopy levels. Proving a correlation between rice blast disease index and IR spectra can lead to early detection technologies suitable for large-scale operations allowing for more efficient use of agrichemicals and a more sustainable method of crop management.

Researchers at the China National Rice Research Institute and the Academy of Agricultural Sciences in Hangzhou, China employed neural networks to analyze reflectance spectra in the development of their modeling for rice blast detection. Their aim was to detect spectral regions where rice reflectance changed dependent on rice neck blast disease index and to select the key wavelength bands with the sensitivity to analyze disease severity and validated their neural network-based spectral model for qualifying disease severity.

In this study, rice showing a moderate disease index exhibited high raw reflectance in the 805-1000 nm range while rice with a higher disease index demonstrated a lower raw reflectance under 940 nm but higher reflectance in the 960-1000 nm range. This was similar to an earlier study that correlated moderate fungus infection with high reflectance in the SWIR 1135-2400 nm range and low reflectance in the NIR 709-1134 nm range and a more serious fungal infection with low reflectance under 1297 nm and a high reflectance between 1298 and 2400 nm.

The re-engineered AvaSpec-NIR256/512-2.5-HSC-EVO was not available yet at the time this research was conducted but is the ideal instrument for grain analysis available today.

Proven Use of NIR Spectroscopy in Disease Detection

There are numerous applications for NIR spectroscopy in the detection of plant diseases and biological contaminants in agricultural production. Some examples include the detection of aflatoxins in corn, late blight disease, or yellow leaf curl virus in tomatoes, leaf spot or powdery mildew in sugar beets, yellow rust in wheat, and countless other crop diseases that affect yield and quality.

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Lim, Jong Guk, et al. "Rapid and nondestructive discrimination of Fusarium Asiaticum and Fusarium Graminearum in hulled barley (Hordeum vulgare L.) using near-infrared spectroscopy." Journal of Biosystems Engineering 42.4 (2017): 301-313.

10

Spectroscopy for Fertilizer Management

Organic fertilizers, including manures and compost, are used in agriculture to provide nutrition to crops. To properly administer these fertilizers to the soil, knowledge of the nutrient content is required. Overapplication of nutrients is known to cause environmental damage, such as water pollution, while underapplication can reduce crop quality and yield.

NIR spectroscopy can be used to analyze mineral and nutrient contents, including nitrogen, carbon, ammonia and potassium in various types of manure samples. This analysis can then be utilized to create insight on the composition of the manure administered to the crops and to adjust the used

amount accordingly.

Compared to the conventional method of using chemical analysis to determine nutrient content in manure, NIR spectroscopy is faster, more efficient, less labor intense and non-destructive, which decreases waste of product. It also makes the use of harmful chemicals obsolete, which makes it a much more environmentally friendly option.

Intelligent Fertilizer Application

Chlorophyll measurements in the visible and near-infrared regions are often utilized in agriculture. They can be used to approximate plant health using reflection techniques on plant foliage. The AvaSpec-ULS2048CL-EVO spectrometer is particularly well suited to this application due to its high speed and quantum efficiency. Integrated systems have been developed with the AvaSpec-ULS2048CL-EVO to measure chlorophyll in real time and intelligently apply fertilizers to crops based upon sophisticated chemometric models while driving through a field at 40 kilometers per hour.

The third and second overtone of the near-infrared range can be used to determine organic nitrogen and protein through the characterization of the C-H, N-H, and O-H stretching vibrations in these spectral regions. These measurements are often used in the agricultural industry to analyze grians.

The AvaSpec-Mini-NIR is an ideal instrument for this measurement. For even higher performance into the second overtone, the AvaSpec-NIR256-1.7-EVO spectrometer is a very affordable InGaAs sensor instrument.

11

Spectroscopy for Sustainable Soil Management

Introduction

Agricultural research of today goes into feeding the world's population tomorrow. Year after year, farmers try to produce more food out of the same resources, and rapidly changing climate conditions only heighten the pressure on the world's food supply. Changing weather patterns means droughts deepen, floods are more frequent, extremes of heat and cold swing wider, and so inevitably we must produce more with less. Shorter growing seasons, fewer resources such as clean water, and even the soil itself can become depleted. Right now, scientists are hard at work developing the tools and technologies that will make the future of farming possible.

Spectroscopy is a key enabling technology for many of those tools and technologies in development today. From innovative research to integration in sensors and analytics, spectroscopy is everywhere. And so is Avantes. Trusted in labs, production lines and field research outposts, Avantes instruments deliver proven results around the world.Plant Physiology Research.

Soil Management

Soil is a compound mixture of organic matter, minerals, gases, liquids, and even living organisms. In addition to supporting the plant life we need for crops, soil also functions as a means of storing, transporting, and purifying water; it helps to modify the atmosphere we all depend on, and even serves as habitat for organisms large and small. Sustainable soil management is as critical for future food production as it is for life on Earth.

Soil health is elemental to sustainable land management and is an important consideration for farms of all sizes. Anything from erosion to contamination, loss of biodiversity, soil compaction, and everything in between, can be detrimental to crop production and the viability of the farm itself.

Numerous studies and technologies are in development for analyzing and managing soil health and Avantes is at the forefront of research and technology development, protecting our future food supply.

Moisture Measurements

Historically, measurements of soil moisture have employed a device called a tensiometer which uses a hollow tube with a porous reservoir of water on top and a gauge. The tube is inserted into the soil and the water is drawn into the soil from the cup, creating a vacuum, until it reaches equilibrium. The gauge allows the user to gather a reading based on that vacuum that correlates to water carrying potential in the soil matrix. This data allows farmers to determine the need for irrigation, but there are drawbacks. The tensiometer is slow, requiring a period of time for water to reach equilibrium which limits the scale of use.

As early as 1978, researchers have been interested in the effects of soil moisture on, first the visible spectrum, but as spectroscopy techniques improves, eventually extending into the near- and mid-infrared. [2] In 2014, researchers in Hungary were working to calibrate spectral data intended to develop algorithms that would allow fast, field-scale measurements of soil moisture content [3].

The development of algorithms that will one day allow for field-scale deployment of spectroscopy-based moisture measurements begins first in the laboratory with data collection. Soil samples collected from orchards with varying soil characteristics from around the region were first kiln dried in the lab to a consistent aridity. Water was then reintroduced slowly, with spectra collected each 2.5ml until the samples were fully saturated. They identified the wavelengths 1450-1460 nm and 1920-1930 nm as the most sensitive for quantifying soil moisture.

The AvaSpec-NIR256-2.5-HSC-EVO and AvaSpec-NIR256-1.7-EVO allow the range and sensitivity for this type of application in the laboratory. Future developments in compact NIR spectrometers could one day lead to replacing the tensiometer with handheld field instruments. These handheld instruments allow for rapid assessment of moisture content and integration with irrigation systems. They can also be used to calibrate and authenticate (ground truth) airborne hyperspectral imaging technology. [3]

Soil Characterization

Soil is not a homogenous mixture, differences in minerals, organic matter, and particle size, as just a few examples, can alter any number of soil characteristics. [4] Soil type will determine everything from irrigation schedules to types of crops likely to prosper. The US Department of Agriculture recognizes 12 types of soil with sand at one end of the spectrum and clay at the other. [5] Each type has predictable characteristics, including color. In fact, the most common method for determining soil type relies on subjective (and fallible) personal experience to compare against a specially designed color chart from the Munsell Corporation. [2]

Other methods for soil classification require chemical processes that might have adverse effects on data interpretation. [3] They are also time-consuming and require more advanced technical skills to perform. Optical spectral sampling, on the other hand, requires little or no sample preparation and no harsh chemicals, and several parameters can be analyzed from the same spectral data.

Researchers in Hamadan, Iran investigated UV/VIS/NIR spectroscopy to analyze a number of soil parameters including color, pH, electrical conductivity, moisture content, available organic carbon, total nitrogen, and exchangeable cations, as well as identifying minerals such as iron, titanium oxides, calcium, magnesium, potassium, and sodium, just to name a few. [3] Samples were collected, randomized, and kiln-dried then ground and sieved before being divided into calibration and validation sets. A full battery of chemometric data was collected from the set of validation samples.

An average of more than 24 broadband spectral scans were collected per sample in the calibration set using the spectrometer to cover the UV-VIS range from 200-1100 nm at 1 nm resolution. For the 1000-2400 nm range, the allows measurements in the NIR. Spectral analysis performed on the calibration set allowed a series of operations for statistical analysis based on principal component analysis (PCA) and least partial squares regression analysis (LPS-R) to relate spectral reflectance measurements to observable soil properties. Based on their results, these scientists determined that they could sufficiently validate soil classification using a fraction of available variables.

Bulk Density and Soil Compaction

Soil compaction is the compression of spaces between soil particles that would normally hold air or water. It leads to poor root development, oxygen deficiency, and other deficiencies. These factors ultimately reduce crop quality and yields. Compaction can be man-made or the result of natural processes, but is a serious environmental and agricultural problem. [1] Common causes include extensive use of heavy machinery, repeated plowing to uniform depth, and use by large animal populations. Sustainable agricultural systems must work to manage soil compaction beginning with the measurement of key parameters associated with soil compaction.

Bulk soil density (BD), representing the ratio of volumetric moisture (Θv) content to gravimetric moisture (ω) [expressed as BD = Θv/ω], is positively correlated with soil compaction, i.e. the higher the soil density, the greater the degree of compaction. [1] Current technology for measuring soil compaction is the penetrometer, an instrument that, at its heart, hasn't advanced a great deal beyond pointy stick. The penetrometer is meant to mimic a growing plant root and involves a pressure gauge atop a graduated driving shaft tipped with a wider 30-degree stainless steel cone.

Research published in 2018 in the journal Computers and Electronics in Agriculture unveiled a prototype measuring system that combines a traditional penetrometer with fiber-coupled NIRS sensor. [1] The system operated in situ to combine measurement of soil penetration resistance, frequency domain reflectometry to analyze volumetric moisture content, and near-infrared diffuse reflectance for the measurement of gravimetric moisture content, to allow calculation of bulk density (BD) with one easy-to-manage probe system. [1]

This novel probe design combined a penetrometer for the measurement of soil penetration resistance, with a hollow shaft housing optical fibers coupled to a sapphire window in the shaft body at one end, and on the other, to the 20 watt halogen lamp for input, and to the AvaSpec-NIR256-2.5-HSC-EVO spectrometer for NIR reflection data output and capture. Time domain reflectometry measurements quantify volumetric moisture content (Θv) achieved by integrating an electrode in the shaft of the probe in the form of a copper ring insulated from the probe body. Hundreds of measurements were used to train an artificial neural network (ANN) to model the fusion of data and produce encouraging results for the future development of bulk density solutions for rapid results in field applications. [1]

System Design Challenges

The need for affordable, efficient, and reliable data is not without challenges. Many available systems are not suitable for field deployment. Data collection can also be compromised because of operator errors and inconstancies. Much of the work of designing all-in-one spectroscopy-based solutions appears to focus on eliminating opportunities for user error or inconsistencies in deployment. [2] Working with an experienced partner in spectroscopy can help the system design engineer to discover solutions to any number of field deployment challenges.

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Food Adulteration & Quality Measurements

12

NIR Spectroscopy in Dairy and Milk Production

There are several uses for spectrology in the dairy industry. Fluorescence spectroscopy is used to analyze milk content for proteins, fat, water content, carbohydrates and minerals. The traditional chemical methods of analysis require specialized personnel, laboratory equipment and are often destructive in methodology. The constituents of milk products are typically studied in the UV (185-210 nm) and NIR (800-2500 nm) wavelength ranges. Research by a team at the University of Food Technologies in Plodiv, Bulgaria is aimed, in part, at giving inspectors a tools to curb the proliferation of milk products adulterated with the addition of vegetable fats, sugars, and foreign proteins[10].

The French company Spectralys Innovation, in partnership with Actalia, the center of expertise for the food industry, has developed the Amaltheys, a commercial fluorescence analyzer for assessing denatured whey proteins in cheese milk. This systems allows cheese producers to monitor curd coagulation and standardize cheese production yields[11].

Dairy Product Characterization

Dairy operations are some of most demanding for spectroscopic process control in agriculture. Near-infrared spectroscopy is a non-destructive method to analyze milk content for proteins, fat, water content, carbohydrates and minerals, among other constituents. The traditionally used chemical methods of analysis require specialized personnel and laboratory equipment, and are often destructive in methodology and thus wasteful.

NIR spectroscopy is also utilized to curb an increase in adulteration of milk products with substances such as vegetable fats, sugars, and foreign proteins as well as to monitor and standardize production yields.

Avantes NIRLine instruments are ideally suited to this application with thermoelectric cooling and fast numerical apertures optical designs to maximize spectral acquisition speeds. The AvaSpec-NIR256/512-1.7-HSC-EVO instruments are ideal candidates for this application.

For easy integration into different machines, we offer the AvaSpec-Mini-NIR. This compact, versatile near-infrared spectrometer is very well suited for different agricultural applications, including grain analysis and dairy product characterization.

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13

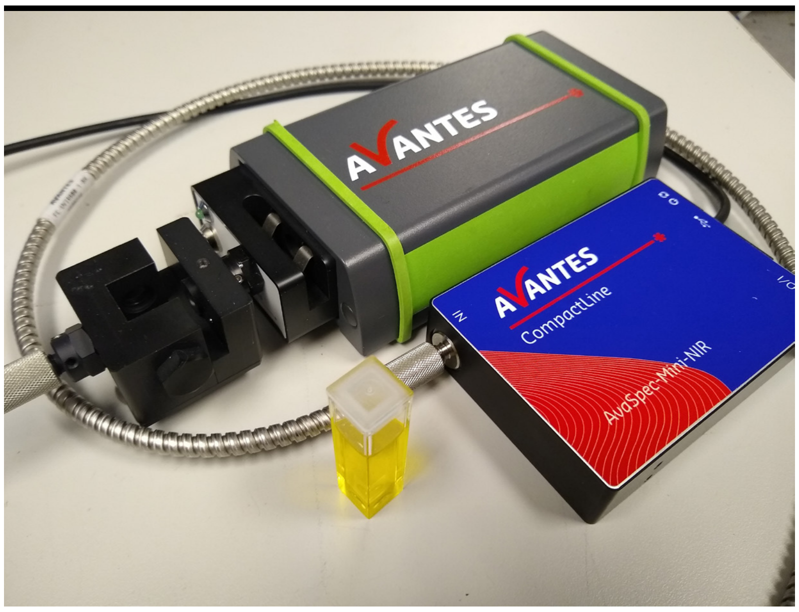
NIR Spectroscopy Measurements of Edible Oils for Chemometric Modeling

Background

Absorption measurements can be used to determine the properties of various samples, such as concentrations of chemicals and the quality of plastics. Not only can absorption spectra be used to identify the characteristics of many types of samples, but it can also be used to characterize the unique spectra of each sample to generate a chemometric model. NIR spectroscopy is leading the way for the future of agriculture and food production for both qualitative and quantitative measurements.

Description of System

A halogen light source is ideal for absorption measurements because of its power and good output in the NIR range, which is the wavelength range many researchers use in agriculture to study and characterize consumables, such as oils. This aids in revealing properties not observable with the naked eye. The halogen light source used in this testing is the AvaLight-HAL-S-Mini. From visible light to near-infrared, that's where the AvaLight-HAL-S-Mini works best. It's a compact, stabilized halogen light source, with adjustable focusing of the fiber connection, maximizing



NIR spectroscopy system for chemometric modeling index

output power at the desired wavelength. The light source also has adjustable output power to provide extra power or longer bulb life. The light source is connected via SMA termination directly to a direct attach cuvette holder (CUV-DA). All CUV-DA cuvette holders feature two 90-degree and one 180-degree threads that allow the COL-UV/VIS collimating lens to be connected for absorbance or fluorescence setups. Each of the CUV-DA series cuvette holders includes two SiO2 aluminum mirrors to further enhance fluorescence signals. These are mounted at 90 degrees to the excitation source and emission output. The CUV-DA has a 5 mm wide filter slot. The opposite end of the CUV-DA is attached to a 600um fiber, which will feed the absorption spectra directly to the latest addition to our CompactLine: the AvaSpec-Mini-NIR.

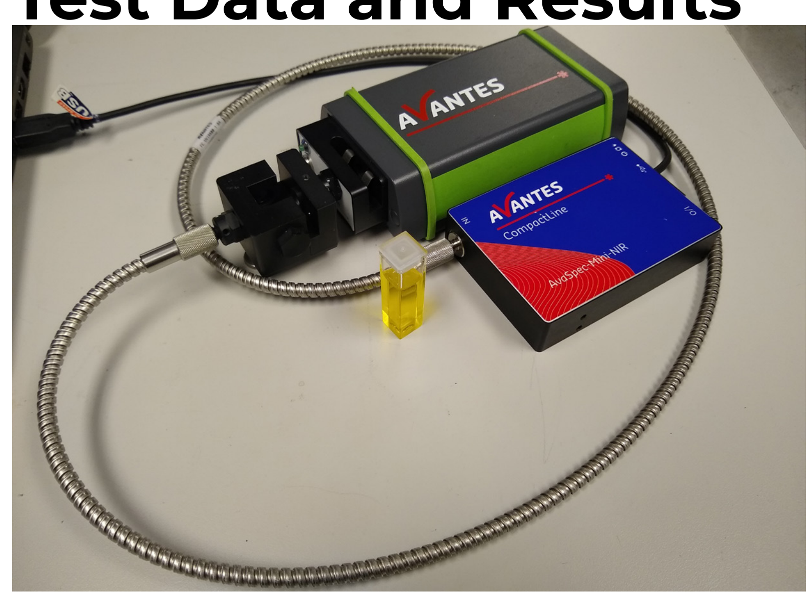
The AvaSpec-Mini-NIR is a compact near-infrared spectrometer, based on a combination of our popular AvaSpec-NIR256-1.7 and Mini-series. The AvaSpec-Mini-NIR's size and robustness are its greatest strengnths.. Like our other CompactLine spectrometers, this device is only the size of a deck of cards and USB powered, which makes it easy to integrate into other devices, including but not limited to OEM handheld applications. This versatile miniature NIR spectrometer is well suited for various applications, including food analysis and the recycling industry. For this testing, the configuration used has a useable range of 950 nm to 1700 nm. It is also fitted with a Slit-50 and an OSF-850.

Methodology

For this experiment, we used the software application Panorama, developed by LabCognition. Panorama is a powerful spectroscopic tool capable of fully controlling Avantes instruments to give the user the ability to not only collect and save data but compile this data into a multivariate chemometric calibration that is generated through the software and can be used for identification and quantitative prediction. To create this PCA model, each sample was measured a total of ten times.

Our setup will be used to measure the absorbance spectrum of five different consumable oil samples: sesame oil, canola oil, Spanish extra virgin olive oil, peanut oil, and garlic-infused extra virgin olive oil. A CUV-DA cover will be placed over the top of the cuvette holder in order to block out all ambient light. Air will be used as our reference. With air, we will use this to optimize the integration time and averaging for the spectrometer.

Test Data and Results



Displayed below is the reflectance and absorption spectrum collected from the four grain samples.

Integration time: 0.2 ms

Averaging: 10

Click here to download the complete dataset

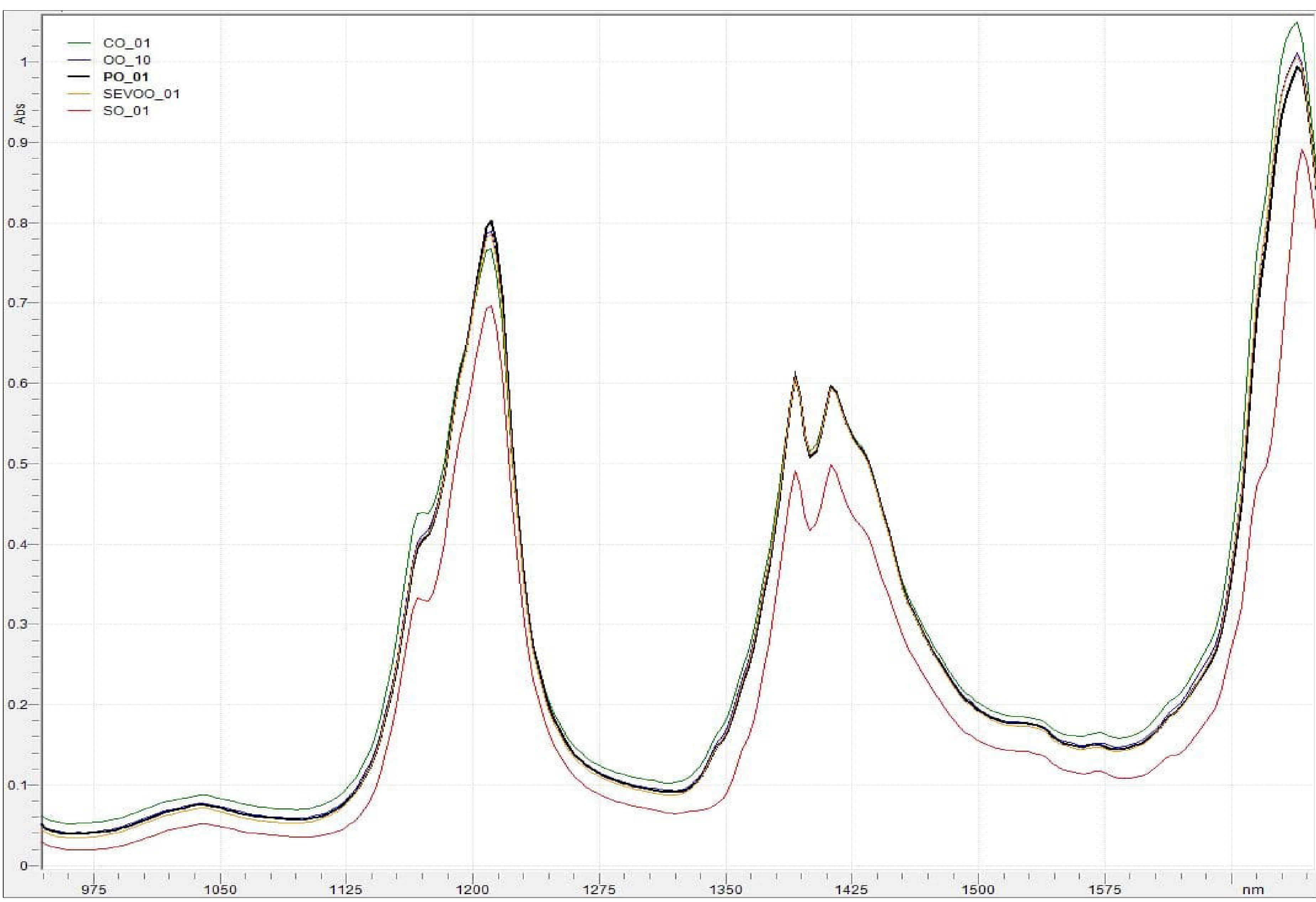
Analysis

While each oil sample appears similar to one another at an initial look at the spectra, such as sharing the same peaks and valleys, it is visible that each sample has its own unique spectral fingerprint. This can be used to identify oils and for verification. For example, a standard may be set that each sample must meet the specified parameters to pass a quality check.

Panorama also demonstrates the capability of determining high-resolution differences in each spectra. Even though several of the samples appear to overlay one another, our simple chemometric model is able to identify the unique properties of each sample. The next steps would include applying more mathematical methods to our model in order to further refine the ability to identify oils.

Conclusion:

In conclusion, the AvaSpec-Mini-NIR high spectrometer combined with the powerful capabilities of Panorama can produce a highly accurate model capable of predicting the type of consumable oil. In order to further improve this



Spectral signature of oil samples in aggregate model, additional samples can be added to the calibration. This model development could be applied to a variety of nutraceuticals products in liquid or powder form with the caveat that sample homogeneity is critical to success with these types of samples.

14

Egg and Beef Quality Inspection

Work is underway to develop methods for quality assessment of numerous other food products. Among the more interesting recent examples are the use of VIS/NIR spectroscopy to assess egg freshness and beef tenderness.

Researchers working with beef from China Agricultural University, College of Engineering, Beijing, China are working with the AvaSpec-NIR256-2.5spectrometertomeasurecharacteristics of meat quality, among them: water content, fat content, color, pH, and tenderness. In addition to studying the constituent macronutrients, this team also considered the use of NIR spectroscopy to look for common contaminants such as total volatile basic nitrogen[12].

Eggs are another popular source of protein, and monitoring freshness from inside the shell was problematic, however, researchers from the egg quality and Incubation Research Group studied the NIR and visible light transmission spectra obtained from eggs. Using the AvaSpec-ULS2048L, the EQIRG discovered a strong connection between the transmission spectra collected and traditional measurements of egg freshness, such as pH and Haugh Units which measure protein quality based on the height of the albumin, or egg white[13]. NIR spectroscopy has also been used effectively in the detection of abnormalities and freshness in eggs.

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15

Spectroscopy in Grapes and Wine Production

Wine production is a very important industry in many parts of the world, especially in Italy. Researchers from the department of Agricultural Engineering at the University of Milan, Italy applied Vis/NIR spectroscopy to characterization of grape composition at harvest. They sampled an astonishing 156 grape varieties throughout 2005 and 2006 while working toward a rapid in-line means of predicting ripening parameters identified to affect wine quality[1].

Grape composition at harvest is the primary determinant of future wine quality. Several factors are considered in grape composition including familiar ripeness indicators such as soluble sugar content and acidity as well as phenolic compounds anthocyanins (as in the cherries study) and polyphenols.

This study conducted with the aid of the AvaSpec-ULS2048C-EVO showed promise for the development of a portable VIS/NIR optical measurement system working in the 450-980 nm wavelength range for quick, non-destructive grape quality measurements with a 95% validation rate at the time the study was completed in 2010. Since that time, spectrometer technology has advanced to the point that these applications are a "ripe" opportunity for the development of commercial systems.

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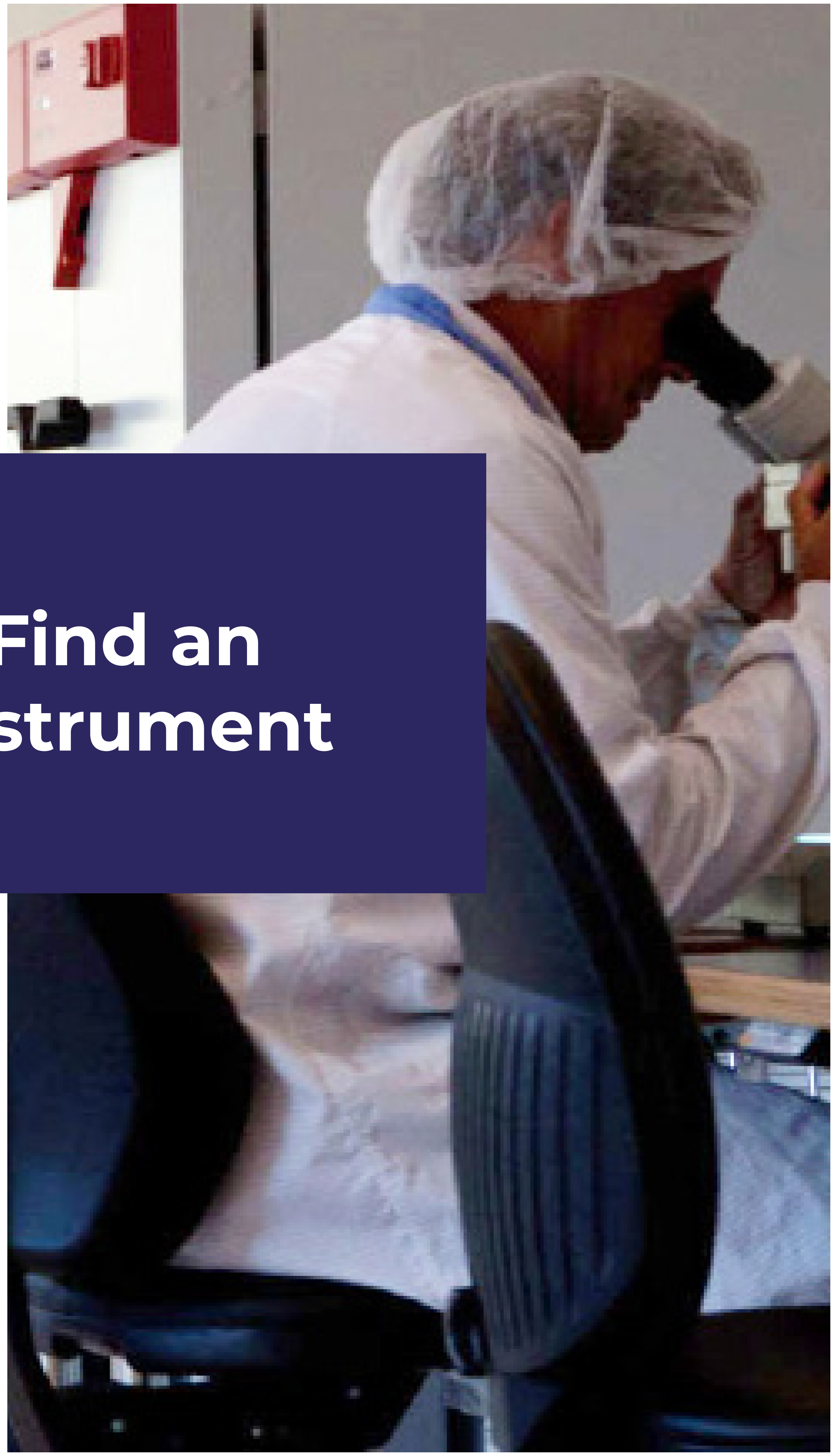

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SensLine for NIR 800-1160 nm

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- Resoloution of 0.09-20 nm, depending on configuration
- Sensitivity of 460,000 counts/µW per ms integration time
- Integration time of 2 µs-20 sec
- USB 3.0 high speed, 5 Gbps, Gigabit Ethernet 1 Gbps interface
- 2.44 ms/scan sample speed with store to RAM

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AvaSpec-ULS2048x64-EVO

- Ultra-low stray light (ULS) symmetrical Czerny-Turner, 75 mm focal length optical bench
- Back-thinned CCD detector with 2048×64 pixels (height: 0.89 nm)
- Wavelength rage: 200-1160 nm
- Resoloution of 0.09-20 nm, depending on configuration
- Sensitivity of 650,000 counts/µW per ms integration time
- Integration time of 2.4 ms-25 sec
- USB 3.0 high speed, 5 Gbps, Gigabit Ethernet 1 Gbps interface
- 2.44 ms/scan sample speed with store to RAM

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NIRLine up to 1750 nm

AvaSpec-NIR256-1.7-HSC-EVO

- Symmetrical Czerny-Turner, 100 mm focal length, 1 stage TE cooled optical bench
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- Wavelength range: 900 – 1750 nm
- Resolution: of 1.9-32 nm, depending on configuration
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 160,000 (integral 1000-1750 nm) counts/µW per ms integration time
- HS Sensitivity of 4,800.000 (integral 1000-1750 nm) counts/µW per ms integration time
- 20 µs-20 seconds integration time
- Sample speed of 0.13 ms/scan with store to RAM

AvaSpec-NIR512-1.7-HSC-EVO

- Symmetrical Czerny-Turner, 100 mm focal length, 1 stage TE cooled optical bench
- TE-cooled InGaAs linear array detector with 512 pixels, 25 µm x 500 µm
- Wavelength range: 900 – 1750 nm
- Resolution: of 1.7-32 nm, depending on configuration
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 83,000 (integral 1000-1750 nm counts)/µW per ms integration time
- HS Sensitivity of 2,500,000(integral 1000-1750 nm) counts/µW per ms integration time
- 20 µs-20 seconds integration time
- Sample speed of 0.13 ms/scan with store to RAM

Click here for complete instrument specifications

NIRLine up to 2500 nm

AvaSpec-NIR256-2.5-HSC-EVO

- TE-cooled symmetrical Czerny-Turner, 100 mm focal length optical bench
- InGaAs linear array detector with 2 stage TE-cooling, 256 pixels
- Wavelength range: 1000 – 2500 nm
- 4.4-85.0 nm resolution, grating and slit dependent
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 55,000 counts/µW per ms integration time
- HS Sensitivity of 990,000 counts/µW per ms integration time
- 10 µs – 5 ms integration time
- Sample speed of 0.54 ms/scan with onboard averaging

AvaSpec-NIR256-2.5-HSC-EVO

- TE-cooled symmetrical Czerny-Turner, 100 mm focal length optical bench
- InGaAs linear array detector with 2 stage TE-cooling, 512 pixels
- Wavelength range: 1000 – 2500 nm
- 2.6-85.0 nm resolution, grating and slit dependent
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 26,600 counts/µW per ms integration time
- HS Sensitivity of 480,000 counts/µW per ms integration time
- 10 µs – 5 ms integration time
- Sample speed of 0.54 ms/scan with onboard averaging

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CompactLine up to 175-0 nm

AvaSpec-Mini-NIR

- Symmetrical Czerny-Turner, 75 mm focal length
- 256 pixel InGaAs array detector
- Wavelength rage: 900-1750 nm
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 38,000 (integral 1000-1750 nm) counts/µW per ms integration time
- HS Sensitivity of 665,000 (integral 1000-1750 nm) counts/µW per ms integration time
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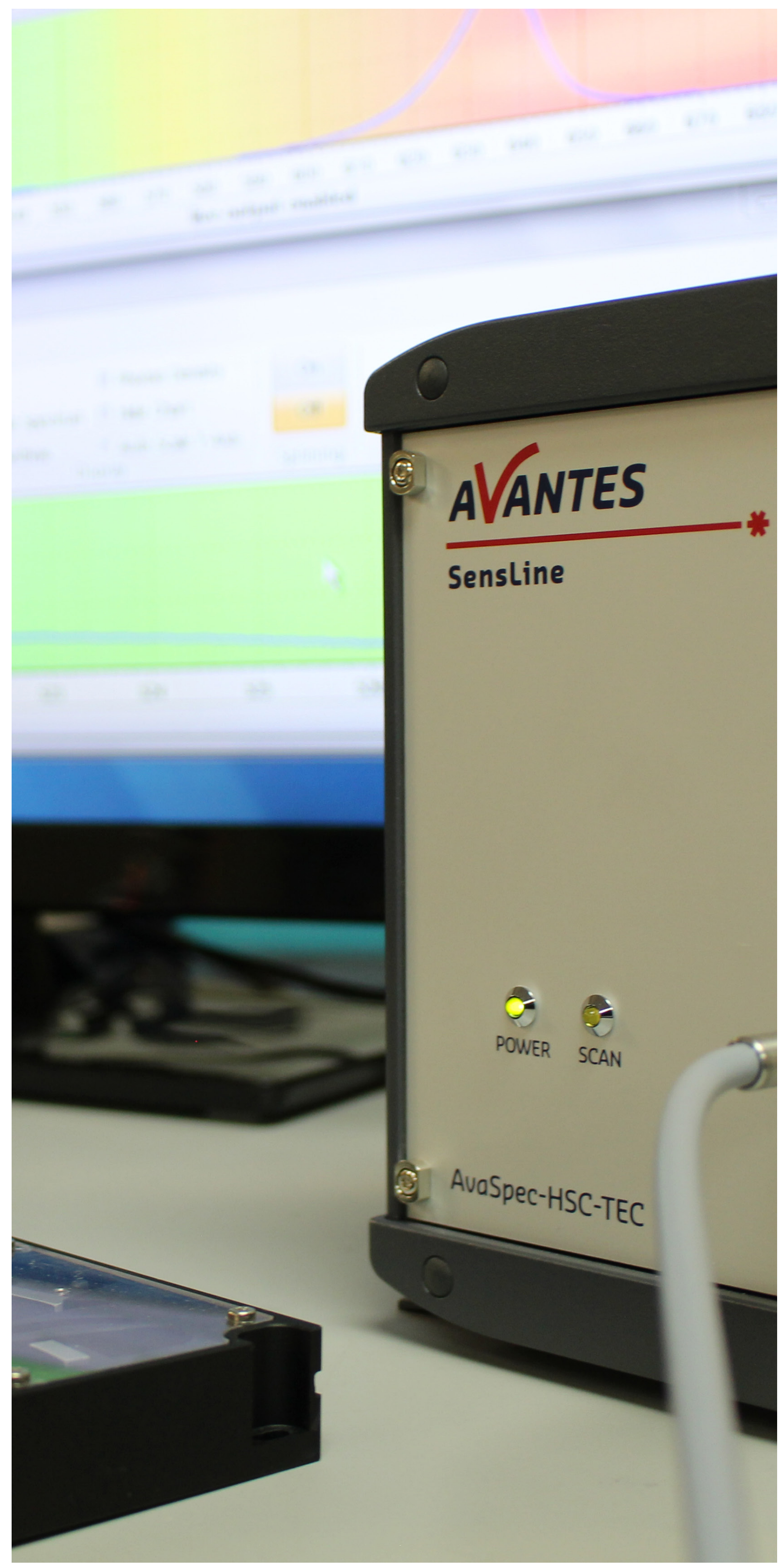

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