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## SPECTROPHOTOMETRY AND ITS APPLICATION IN FRUIT CROP ANALYSIS

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### ABSTRACT

Spectrophotometry is a key analytical technique in fruit crop analysis, measuring light absorption to assess quality, composition, and health. This non-destructive method is essential for evaluating pigments, nutrients, phenolics, quality control, pesticide residues, and shelf-life. Advances like UV-Vis, NIR, FTIR, Raman, and nanoparticle-based spectrophotometry have enhanced accuracy and sensitivity. These techniques offer detailed insights into the biochemical properties of fruits, aiding in the assessment of ripeness, nutritional value, and potential health benefits. The future prospects of spectrophotometry in fruit crop analysis are promising, with ongoing research and development focusing on enhancing its capabilities through integration with emerging technologies. Machine learning and remote sensing are expected to revolutionize the field by improving the accuracy of disease diagnosis and quality assessment. Additionally, portable and handheld spectrophotometers are becoming increasingly popular, allowing for on-site analysis in orchards and farms. This accessibility enables real-time decision-making, empowering farmers to implement precision agriculture practices and improve crop management.

### INTRODUCTION

Spectrophotometry is an analytical technique that measures the intensity of light absorbed by a sample at various wavelengths. This method has gained prominence in various scientific disciplines, including chemistry, biology, and environmental science. In recent years, it has also become a critical tool in horticulture, particularly in the analysis of fruit crops. Spectrophotometry provides a non-destructive, rapid, and precise means of assessing the quality, composition, and health of fruits, making it invaluable for researchers, agronomists, and food scientists (Wang et al. 2016). The technique operates on the principle that different substances absorb light at specific wavelengths. By measuring the intensity of light before and after it passes through a sample, spectrophotometry can determine the concentration of particular compounds within the sample.

Fruit crops are essential to global agriculture and nutrition, significantly contributing to the dietary intake of vitamins, minerals, and antioxidants. The quality and nutritional content of fruits can vary widely based on factors such as variety, growing conditions, and post-harvest handling. To improve fruit production and ensure consumer satisfaction, accurate and efficient methods for analyzing these factors are crucial. Spectrophotometry offers several

advantages in this context. It provides non-destructive analysis, allowing continuous monitoring of the same fruit throughout its growth and maturation. This method delivers rapid and precise measurements, making it suitable for large-scale screening of fruit crops. Additionally, spectrophotometry's versatility enables it to measure a wide range of compounds, including pigments, sugars, organic acids, and phytochemicals, thus providing comprehensive data on fruit quality and composition.

### PRINCIPLE OF SPECTROPHOTOMETRY

Spectrophotometry is a technique used to measure the amount of light absorbed by a solution. The basic principle involves passing a beam of light through a sample and measuring the intensity of light reaching a detector. The amount of light absorbed by the sample is directly proportional to the concentration of the absorbing species, according to Beer-Lambert's law (Brown *et al.*, 1997) This relationship can be used to determine the concentration of solutes in the solution by comparing the measured absorbance to a standard curve created from known concentrations. Key components include a light source, monochromator, sample holder, and detector shown in Figure 1

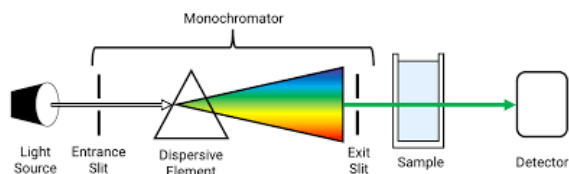


Figure 1 Key components of Spectrophotometer

### INSTRUMENTATION OF A SPECTROPHOTOMETER

The key components of a spectrophotometer include:

#### Radiant Energy Source:

- The source should be reliable and inexpensive.
- Materials that can be excited to high energy states by a high voltage electric discharge or by electrical heating are ideal.

#### Monochromator:

- This device separates polychromatic radiation into its individual wavelengths or bands of wavelengths.
- It resolves polychromatic light into distinct wavelengths and isolates them into narrow bands.

#### Prisms:

- Prisms disperse polychromatic light into its constituent wavelengths by reflecting different wavelengths to varying extents.
- Two types of prisms commonly used in commercial instruments are the 600 Cornu quartz prism and the 300 Littrow prism.

#### Grating:

- Gratings are often used in monochromators for spectrophotometers operating in the ultraviolet, visible, and infrared regions.

#### Transport Vessels (Cuvettes):

- Cuvettes hold the sample to be analyzed.
- Samples for the ultraviolet or visible region are usually in glasses or solutions and are placed in cuvettes.
- Cuvettes for the visible region are typically made of ordinary glass or sometimes quartz.

### Photosensitive Detector and Readout System:

- Most detectors operate based on the photoelectric effect.
- The generated current is proportional to the light intensity, providing a measure of it.
- Radiation detectors produce electronic signals proportional to the transmitted light.
- These signals are translated into an interpretable form using amplifiers, ammeters, potentiometers, and potentiometric recorders.

### RECENT ADVANCES IN SPECTROPHOTOMETRY

#### Microfluidic Spectrophotometry:

Microfluidic devices have been integrated with spectrophotometry, allowing for miniaturized and automated analysis of small volumes of samples. These devices offer benefits such as reduced reagent consumption, faster analysis times, and increased sensitivity. They have applications in various fields, including biomedical diagnostics, environmental monitoring, and chemical analysis.

#### Ultraviolet-Visible (UV-Vis)

**Spectrophotometry:** This technique measures absorbance in the ultraviolet and visible regions of the electromagnetic spectrum. It is widely used for quantifying pigments like chlorophyll and carotenoids, which are important indicators of fruit ripeness and quality.

#### Near-Infrared (NIR) Spectrophotometry:

NIR spectrophotometry is a non-destructive method that provides detailed information about the molecular composition of fruits. It is particularly useful for assessing parameters

such as moisture content, sugar levels, and internal defects without damaging the fruit.

#### Fourier-Transform Infrared (FTIR)

**Spectrophotometry:** FTIR spectrophotometry offers high-resolution spectral data, making it ideal for identifying complex chemical compounds in fruit crops. It is commonly used for analyzing sugars, organic acids, and other metabolites.

#### Raman Spectrophotometry:

Raman spectrophotometry, based on inelastic scattering of monochromatic light, is gaining traction for its ability to provide molecular-level information about fruit composition, including phytonutrients and structural changes.

#### Nanoparticle-based Spectrophotometry:

Nanoparticles have been utilized to enhance the sensitivity and selectivity of spectrophotometric measurements. Nanoparticles (NPs) are useful as matrixes for the analyses of several types of biomolecules (including aminothiols, peptides, and proteins) and for mass spectrometric imaging through surface-assisted laser desorption/ionization mass spectrometry (SALDI-MS), mainly because of their large surface area, strong absorption in the ultraviolet-near-infrared region, and ready functionalization. Functionalized nanoparticles can act as probes for specific analytes, allowing for ultrasensitive detection. They capture the analytes and absorb the laser light, transferring its energy to the analytes, leading to their desorption and ionization, enabling rapid and sensitive analysis in fields like bioassays, environmental monitoring, and food safety.

#### Multidimensional Spectrophotometry:

Multidimensional spectrophotometry involves acquiring spectral data in multiple dimensions,

such as wavelength, time, and spatial coordinates. This approach provides more comprehensive and detailed information about the sample, enabling the identification of complex mixtures or dynamic processes. It has applications in areas like chemical analysis, environmental monitoring, and material characterization.

**Time-Resolved Spectrophotometry:** Time-resolved spectrophotometry involves measuring the spectral changes of a sample over extremely short time intervals. This technique allows for the investigation of fast kinetic processes, such as chemical reactions and fluorescence dynamics. Time-resolved spectrophotometry enables the characterization of reaction rates, energy transfer processes, and excited-state lifetimes of molecules, providing insights into various chemical and biological phenomena.

**Hyperspectral Imaging:** Hyperspectral imaging combines spectroscopy and imaging, capturing both spatial and spectral information of a sample simultaneously. It allows for the identification and mapping of multiple analytes within a complex sample, even when their spectral signatures overlap. Hyperspectral imaging has applications in fields like biomedical imaging, remote sensing, agriculture, and food quality control.

**Portable and Handheld Spectrophotometry:** Advances in miniaturization and portable technologies have led to the development of handheld spectrophotometers. These compact devices offer portability and ease of use, making them suitable for field-based applications. Portable spectrophotometers have found applications in environmental monitoring, on-site analysis in industries, and point-of-care diagnostics.

**Data Analysis and Chemometrics:** Advanced data analysis methods, including chemometrics, have been integrated with spectrophotometry to improve data interpretation and extract meaningful information from complex spectral data. Chemometric techniques involve mathematical and statistical methods for data processing, pattern recognition, and multivariate analysis. These methods help in identifying relevant spectral features, detecting outliers, and performing qualitative and quantitative analysis with improved accuracy and precision.

### APPLICATIONS IN FRUIT CROP ANALYSIS

Spectrophotometry has become an indispensable tool in the field of fruit crop analysis, offering precise and non-destructive methods for evaluating various quality and safety parameters (Rajkumar et al. 2012). The advancements in this technology have significantly enhanced the ability to monitor and improve fruit crop production, quality, and safety. Here's a detailed exploration of its applications:

#### • Pigment Analysis

Spectrophotometry is widely used to determine the concentration of pigments such as chlorophyll, carotenoids, and anthocyanins in fruits. These pigments are crucial for understanding the ripening process, nutritional content, and overall quality of the fruit. By measuring absorbance at specific wavelengths, researchers can quantify these pigments accurately. This information helps in selecting the optimal harvest time and ensuring the desired color and quality in fruit products.

### **Nutrient Content Analysis**

The technique is also used to measure nutrient levels in fruits, including vitamins, minerals, and sugars. For instance, spectrophotometry can determine the concentration of vitamin C and other essential nutrients, which are indicators of the fruit's nutritional value. This application is particularly important for ensuring that fruits meet nutritional standards and for breeding programs aimed at enhancing the nutrient content of fruit crops.

### **Phenolic Content Estimation**

Phenolic compounds are vital for the antioxidant properties of fruits. Spectrophotometry enables the estimation of these compounds, contributing to the evaluation of the fruit's health benefits. By measuring absorbance in the UV/Vis regions, researchers can assess the levels of phenolics and their potential health impacts.

### **Quality Control**

Spectrophotometry is essential for quality control in the fruit industry. It helps monitor parameters such as ripeness, sugar content, and acidity, which are critical for consumer acceptance and marketability. The technique provides a rapid and reliable method to ensure that fruits meet the desired quality standards.

### **Pesticide Residue Detection**

Ensuring food safety is a top priority, and spectrophotometry plays a significant role in detecting and quantifying pesticide residues in fruits. By analyzing changes in absorbance, it is possible to identify the presence of harmful chemicals and ensure that fruit products are safe for consumption.

### **Shelf-Life Studies**

Evaluating changes in fruit composition during storage is crucial for extending shelf life and reducing post-harvest losses. Spectrophotometry allows for the monitoring of biochemical changes over time, providing valuable insights into the factors affecting fruit longevity.

### **Disease Detection**

Identifying and quantifying biochemical markers associated with fruit diseases is another important application of spectrophotometry. By detecting specific absorbance peaks, researchers can diagnose diseases early and take preventive measures to protect fruit crops.

### **Flavor Compound Analysis**

The technique is also used to measure volatile and non-volatile compounds that contribute to fruit flavor. This application is essential for breeding programs aimed at enhancing flavor profiles and for quality control in the food industry.

### **Stress Response Studies**

Spectrophotometry helps analyze biochemical changes in fruit under various stress conditions, such as drought or salinity. Understanding these responses is key to developing stress-resistant fruit varieties and improving crop management practices.

### **Genetic Modification Studies**

Evaluating the impact of genetic modifications on fruit composition is critical for advancing agricultural biotechnology. Spectrophotometry provides a non-destructive method to study these changes and their effects on fruit quality and nutritional content.

## Environmental Impact Assessment

Spectrophotometry aids in assessing the impact of environmental factors on fruit crops, contributing to sustainable agriculture practices. For example, it can measure how different light conditions (e.g., intensity and spectrum), soil types, and water availability affect fruit quality and yield. This information guides farmers in optimizing growing conditions and resource management practices, thereby enhancing productivity while minimizing environmental impact.

## CONCLUSION

Spectrophotometry has emerged as a powerful tool in the analysis of fruit crops, offering a range of applications that enhance quality control, nutritional assessment, disease detection, and more. With continuous advancements in technology, spectrophotometry is set to play an even more significant role in the future, driving innovations in fruit crop research and production. Its ability to provide precise, non-destructive, and rapid analysis makes it indispensable for ensuring the health and quality of fruit crops, ultimately benefiting both producers and consumers.

As spectrophotometry continues to evolve, its integration with emerging technologies and its increasing accessibility will further solidify its role as a cornerstone of modern horticultural science. This will not only improve the quality and yield of fruit crops but also contribute to sustainable agricultural practices and better food security worldwide.

## FUTURE PROSPECTS

The future of spectrophotometry in fruit crop analysis looks promising, with ongoing research and development focusing on enhancing its capabilities. Integration with

other technologies, such as machine learning and remote sensing, is expected to further revolutionize the field. For instance, combining spectrophotometric data with machine learning algorithms can improve the accuracy of disease diagnosis and quality assessment.

Moreover, portable and handheld spectrophotometers are becoming increasingly popular, allowing for on-site analysis in orchards and farms. This accessibility enables real-time decision-making, empowering farmers to implement precision agriculture practices and improve crop management. Additionally, advancements in miniaturization and cost reduction are making spectrophotometry more accessible to small and medium-sized farms, promoting widespread adoption of this technology.

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