IEEE Sensors Letters VOL. 9, NO. 10, OCTOBER 2025 6011004 IEEE Sensors Council

Sensor applications

Machine Learning Models for Classifying Tomato Plants Exposed to Metal Nanoparticles Through Reflectance Spectroscopy

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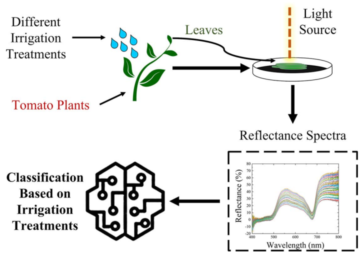
Manuscript received 3 August 2025; revised 1 September 2025; accepted 17 September 2025. Date of publication 19 September 2025; date of current version 6 October 2025.



Abstract—Nanotechnology has recently found applications in agriculture to optimize crop production, but the contact with plants may also occur as a result of the accidental introduction of nanoparticles into the environment. In this sense, the development of reliable and nondestructive methods capable of identifying and distinguishing plants exposed to nanoparticles is becoming of interest. In this study, machine learning models are used to classify plants irrigated with water containing gold and silver nanoparticles. k-nearest neighbors, random forest, and support vector machine models were trained and tested with the reflection spectra of leaves in the 400–800 nm range. The support vector machine model achieved the best performance, reaching an F1-score above 0.99, correctly classifying 483 of 486 samples in the test set. The findings demonstrated the effectiveness of machine learning, combined with leaf reflectance spectroscopy, in identifying plants exposed to gold and silver nanoparticles. The method may assist the study of the nanoparticles effects in plants development representing a powerful tool in agriculture.

Index Terms—Sensor applications, classification models, machine learning (ML), nanoparticles, reflectance spectroscopy, tomato.

I. INTRODUCTION

Tomatoes are one of the most important vegetable crops in the world and are grown in almost all regions of the planet. In addition to its commercial relevance in the fresh produce market and the processing industry, tomato is an excellent source of essential nutrients, including antioxidants and vitamins. In 2023, global tomato production exceeded 192 million tons, with a cultivated area of more than 5.4 million hectares. Due to its global importance, tomato production must be continuously improved and protected against contamination and environmental threats to ensure its safety and sustainability [1].

Nanotechnology, which involves materials and objects ranging from 1 to 100 nm in size, has achieved significant advances in recent decades, drastically transforming the landscape of modern science and technology [2]. Currently, nanoparticles are incorporated into various industrial and commercial products, such as biomedical materials, household appliances, and agricultural products. There has been a global effort in agriculture to intentionally apply nanoparticles to plants to improve agricultural productivity [3]. However, contact between nanoparticles and plants can also occur unintentionally, as agricultural soils are one of the leading sinks for nanoparticles accidentally introduced into the environment [2]. Thus, exposure of plants to nanoparticles is highly, likely, raising concerns since their effects can be positive or negative, potentially influencing plant growth and physiological processes, such as photosynthesis. Furthermore, studies on nanoparticle–plant interactions have yielded different or even contradictory conclusions [4]. More studies are needed to develop efficient, robust, and cost-effective methodologies to identify and differentiate nanoparticles and their effects on plants [5].

Among the various techniques used to study the interaction between nanoparticles and plants, reflectance spectroscopy in the visible region stands out. In this spectral range, leaf reflectance results from light absorption by leaf pigments, mainly chlorophylls and carotenoids, which absorb at different wavelength bands [6]. This phenomenon generates reflectance signatures that enable the monitoring of physiological processes in plants, such as nutritional status and stress levels, providing valuable insights about their condition [7].

These spectral signatures often require the application of machine learning (ML) algorithms for analysis and interpretation owing to their effectiveness in extracting complex patterns. However, there is no consensus on the best ML technique to use, as the choice of algorithm depends on various factors. Given this variability, a comparison of ML algorithms is conventionally employed as a standard method to assess the efficiency of different algorithms in solving a specific problem [6].

In the literature, several studies employ reflectance spectroscopy, combined with ML, as a nondestructive technique to classify leaves from a variety of plants, such as sugar beet, soybean, corn, thale cress, and maize, as well as roots and stems [6], [8], [9], [10], [11], [12]. However, the use of metallic nanoparticles as abiotic stress-inducing or treatment agents, followed by the classification of leaf samples using ML and reflectance spectroscopy, is a much less explored area in the literature [5], [13]. In addition, in both studies using nanoparticles in plants and those employing other stress or treatment methods, the dataset is typically limited to less than 400 spectra in total.

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Associate Editor: Chang-Hee Won.
Digital Object Identifier 10.1109/LSENS.2025.3611983