Democratic and Popular Republic of Algeria
Ministry of Higher Education and Scientific Research
University Centre of Illizi
Institute of Science

Department of Computer Science

Artificial Intelligence & its Applications Master's Thesis

Plant Disease Detection
Case study: Corn,Wheat and Palm

Authors:

- Badache Mohammed Amine
  badache.mohammed.amine@cuillizi.dz
- Chander Marwa
  chander.marwa@cuillizi.dz

Advisors:

- Dr. Gasmi Rim
  gasmi.ryme@cuillizi.dz

Examining Committee:

- (*President*) Dr. President Name
  presidentname@cuillizi.dz
- (*Examiner*) Mr. Examiner Name
  examinername@cuillizi.dz

Academic Year: 2025

Abstract

T oday, identifying leaf diseases plays a pivotal role in agriculture, contributing to crop health and productivity. Traditional methods for detecting leaf diseases require significant manual effort and extensive expertise in plant pathology. To address this challenge, this project focuses on designing and developing an intelligent system capable of automatically detecting and classifying plant diseases using a set of deep learning algorithms.

Keywords: Plant Diseases, Artificial Intelligence, Machine Learning, Deep Learning

---

Résumé

Aujourd'hui, l'identification des maladies des feuilles joue un rôle essentiel dans l'agriculture, contribuant à la santé et à la productivité des cultures. Les méthodes traditionnelles de détection des maladies des feuilles nécessitent un effort manuel important et une vaste expérience en phytopathologie. Pour relever ce défi, ce projet se concentre sur la conception et le développement d'un système intelligent capable de détecter et de classer automatiquement les maladies des plantes à l'aide d'un ensemble d'algorithmes d'apprentissage profond.

Mots-clés: maladies des plantes, intelligence artificielle, apprentissage automatique, apprentissage profond

Acknowledgements

In the Name of Allah, the Most Gracious, the Most Merciful, and peace and blessings be upon the noblest of prophets and messengers, our Prophet Muhammad the finest of teachers and the guide for all of humanity.

At the outset, we praise and thank Allah, the Source of all success.

Nothing would have been possible without His grace. All praise is due to Him at the beginning and the end, in times of ease and hardship. It is by His favor that we began this journey, and by His mercy that we now reach its end.

The years have passed, the exhaustion of long days has faded, and today, we stand proudly before a long awaited dream a moment we envisioned countless times. With joy and gratitude, we dedicate this graduation:

To our beloved fathers,who were always our rock and source of strength — the ones who instilled in us values, resilience, and the will to persevere.

To our precious mothers,the silent heroes who sacrificed tirelessly, who lifted their hands in prayer, and carried our burdens without hesitation may Allah reward you abundantly and grant you long lives filled with joy.

To our honorable teachers ,who lit the path of knowledge before us, who shaped our thinking and pushed us to rise beyond limitations you were the spark that ignited our passion for learning. May your efforts be forever blessed.

To our dear brothers and sisters , who were our first friends, our loudest cheerleaders, and our safe haven when things got tough thank you for walking beside us.

To our loyal friends and companions, with whom we shared the laughter, the tears, the pressure, and the hope you made the road lighter and the memories unforgettable.

To everyone who supported and believed in us whether with a word, a gesture, or a heartfelt prayer you made a difference, and we carry your kindness with us always.

And finally...

Here we are at the awaited day,

The day we struggled for, dreamed of, and prayed to witness. With hearts full of thanks, we celebrate not only our graduation but the journey that shaped us. All praise and thanks to Allah, by whose blessings all good things are completed.

Dedication

In the name of God, the Most Gracious, the Most Merciful. God Almighty says: "Allah will raise those who have believed among you by degrees and will raise those who have been given knowledge by degrees. And Allah is Acquainted with what you do " Surah Al-Mujadila 11

Praise be to God, by whose grace good deeds are accomplished.

Finally, my dream of graduating has come true.

I dedicate today's graduation to the source of mercy and the purest of hearts, to those who welcomed me with a smile and bid me farewell with prayers...

My beloved mother

And to my support and light of my path, to those who taught me determination and perseverance, to those who illuminated my path with hope and ambition.

Dear Father

To my siblings—my dear sister and brother—your laughter, encouragement, and shared memories were my refuge and motivation to continue my studies.

To my late aunt, whose kindness, encouragement, and support I will never forget throughout my studies. Despite your passing, your love remains a light in my heart.

To my aunt, thank you for your generosity and constant support for our family.

To my relatives who stood by me, Their kind wishes for success, their support, and encouragement enabled me to pass a difficult stage in my life. I thank you very much and have the utmost respect.

To my dear professors, I would like to thank you very much for your generous support in completing this research and bringing it out in this good and successful manner. I appreciate your thought and effort during this difficult time in my academic life. I wish you success in your future endeavors and may God reward you on our behalf with all good.

To my wonderful companions, I dedicate this research to thank them for being in my life, always encouraging me and pushing me forward.

This achievement is not mine alone but a testament to the love, prayers, and sacrifices of everyone who stood by me.

May this work honor those who believed in me even when I doubted myself.

To all who contributed in ways seen and unseen—thank you.

Mohammed Amine

Dedication

All praise and thanks be to Allah — pure, blessed, and abundant — for granting me the strength to begin this journey, and the grace to complete it.

I first dedicate this humble achievement to my ambitious self, who started with a dream and, by God's will, ended with success.

Then to my beloved family, my first and greatest source of strength:

To my dear father, the light of my life and the foundation of my strength, my first hero — you gave so much to pave this path for me. Today, I fulfill the promise I made to you; this success is yours.

To my precious mother, the warm embrace that sheltered me in my weakness, the light that guided my steps with unwavering prayers, the silent strength behind every triumph — you are my paradise on earth and the kindest heart I know.

To my dear siblings, the unwavering support, the echo of my voice, my safe harbor, and my closest allies on this long road — you were always there, my home when I felt lost.

To the soul of my late aunt Ruqayya, who departed before seeing the fruit of her guidance. You planted the love of knowledge in me as a child, and I will never forget you.

To my aunts and my cousins, with whom I shared the most beautiful days — your love and presence added warmth to my journey.

To my uncle and his lovely family, thank you for being a steady and comforting part of my life.

To my esteemed teachers, who were lanterns of light on my path — thank you for planting the seeds of curiosity in my mind and nurturing them with knowledge and patience, igniting within me a love for learning that will never fade.

You gave of your time, your wisdom, and your hearts — you were more than teachers; you were mentors and sources of inspiration. May Allah bless you and reward you abundantly.

To my dear friends and companions on this journey, who stood by me through the struggles and triumphs, who shared with me the unforgettable moments — you are the most beautiful chapters of this journey and its dearest milestones.

Finally, to everyone who has loved me sincerely and supported me quietly — this achievement carries a part of you all.

"And the last of their call will be: Praise be to Allah, Lord of the Worlds." (Qur'an 10:10)

Marwa

General Introduction

Plant diseases have long been a significant challenge to global agriculture, affecting crop yield, quality, and food security. They are caused by various pathogens, including fungi, bacteria, viruses, and nematodes, which can lead to devastating economic losses, particularly in developing countries where agriculture is a primary livelihood. According to the Food and Agriculture Organization (FAO), plant diseases are responsible for up to 40% of global crop losses annually, threatening food supplies and exacerbating poverty[1]. Researchers from the FAO further predict that plant diseases alone cost the global economy approximately US$220 billion annually, highlighting the immense economic burden they impose[2]. As per the World Bank report of 2018, agriculture engaged over a billion people, representing 28.5% of the total labor force, and produced about 10 million tons of food daily[3]. However, the full potential of agriculture is hindered by plant infections and diseases, which compromise food security. Early detection of these diseases is crucial, as it can reduce yield losses by as much as 50%, as indicated by research in the *Journal of Plant Pathology*[4].

For thousands of years, plant disease detection relied heavily on visual inspection and the expertise of farmers or plant pathologists. These traditional methods involve identifying symptoms such as leaf spots, wilting, or discoloration, which are often subjective and prone to human error. Manual sampling and laboratory analysis, such as culturing pathogens or using microscopy, were also common but time-consuming and labor-intensive. While these methods have been effective to some extent, they are not scalable for large-scale farming and often fail to detect diseases at early stages when interventions are most effective. As noted by Agrios in *Plant Pathology*, traditional approaches are limited by their reliance on visible symptoms, which often appear only after significant damage has already occurred[5].

With time, agriculture has continued to develop, especially with the emergence of artificial intelligence (AI), which has brought remarkable advancements to the field. To minimize production losses and maintain crop sustainability, it is essential to implement effective disease management and control measures. This necessitates the development of automated solutions that are practical, reliable, and economically viable, capable of monitoring plant health and providing meaningful information to support the decision-making process. By leveraging modern technologies like AI, we can address the challenges posed by plant diseases more efficiently, ensuring better crop yields and contributing to global food security.

Issues of the Theme

Plant diseases significantly impact agricultural productivity, leading to reduced quality and quantity of crops, economic losses, and threats to food safety, particularly in developing countries. Traditional methods of disease detection, such as visual inspection and manual sampling by experts, are time-consuming, costly, and not scalable for large farms. These approaches are often error-prone and ineffective in identifying diseases at early stages.

Theme Objectives

- To minimize production losses and maintain crop sustainability through the implementation of appropriate disease control measures.

- To develop automated, practical, reliable, and cost-effective solutions for monitoring plant health and aiding the decision-making process.
- To create a reliable system to detect plant diseases using advanced deep learning algorithms such as Faster R-CNN, YOLOv8, and SSD.
- To detect and identify plant diseases using images of their leaves.

Structure of the Thesis

- **General Introduction:** Contains a general introduction about the proposed topic, the identified problems, and the desired objectives.
- **Chapter One: State of the Art – Plant Diseases:** Presents the different types of plant diseases found in Algeria, their definitions, and symptoms. This chapter also includes a definition of the plant leaf and a historical overview of plant disease detection through imagery.
- **Chapter Two: Artificial Intelligence and Image Attribution:** Discusses key concepts related to Machine Learning and Deep Learning, with a focus on their application in detecting plant diseases through image analysis.
- **Chapter Three: Proposed Approach:** Details the selected techniques and software used based on prior research. It also presents the results obtained from experiments and materials used in the study.
- **General Conclusion:** Includes a discussion of the results obtained in Chapter Three, particularly in relation to the selected disease, and highlights the contributions of the proposed approach.

This thesis aims to contribute to the improvement of plant disease management using innovative approaches based on deep learning. By combining knowledge in agronomy, computer science, and artificial intelligence, this research opens new perspectives for crop protection and global food security.

Table of Contents

TABLE OF CONTENTS

List of Figures

List of Tables

Chapter 1

State of The Art – Plant Diseases

1.1 Introduction

Plant diseases pose a critical threat to global agriculture, impacting crop yields, economic stability, and food security. These diseases, caused by pathogens such as fungi, bacteria, viruses, and nematodes, can severely damage plant tissues, leading to symptoms like discoloration, wilting, necrosis, and stunted growth. The rapid spread of such infections can devastate large agricultural areas, resulting in substantial financial losses for farmers and broader implications for food supply chains. Effective disease management, including early detection, accurate diagnosis, and timely intervention, is essential to mitigate these impacts. This chapter explores the causes, symptoms, and economic consequences of plant diseases, as well as the Techniques used to detect maladies in plants [6].

1.2 Causes of Plant Disease

A plant disease refers to any condition that interferes with the normal growth and functioning of a plant, ultimately diminishing its economic or aesthetic value. This interference can manifest as reduced yields, poor crop quality, or even plant death, which negatively impacts farmers' livelihoods, disrupts food supplies, and can lead to higher market prices. Plant diseases may arise from biotic agents, such as pathogenic microorganisms (e.g., fungi, bacteria, viruses) and parasitic plants, or abiotic factors, including environmental stressors like nutrient deficiencies, extreme temperatures, and chemical toxicity. In some cases, the interaction between biotic and abiotic factors exacerbates the severity of the disease, making diagnosis and management more complex [7].

1.2.1 Infectious Plant Diseases

Infectious plant diseases are disorders in plants caused by pathogenic microorganisms, such as fungi, bacteria, viruses, viroids, phytoplasmas, nematodes, or parasitic plants, that can spread from one plant to another. These pathogens invade plant tissues, disrupt normal physiological processes, and often lead to visible symptoms such as wilting, leaf spots, stunting, yellowing, necrosis, or deformities [8].

- Fungi : are among the most significant pathogens affecting crop plants worldwide, with over 19,000 species known to cause diseases [9] . Fungi are a group of organisms that have some similarities with plants, but unlike them, they lack chlorophyll, they form complex networks of hyphae called mycelium. These fungi can remain dormant on living or dead plant tissues until favorable conditions trigger their growth and spread. Fungal spores are easily dispersed by wind, water, soil, insects, and other vectors, enabling them to infest entire crops rapidly. Pathogenic fungi invade plant tissues through openings or wounds, often releasing toxins or enzymes that damage cells and disrupt normal plant functions. This can lead to a range of diseases, such as leaf spot, rust, wilt, blight, and root rot, which cause symptoms like yellowing, withering, and tissue death.

Figure 1.1: Raspberry rust

- Viruses and Viroids : are both infectious agents that can cause diseases in plants, but they differ in structure and complexity. Viruses are microscopic entities composed of genetic material (DNA or RNA) enclosed in a protein coat (capsid) and sometimes an outer lipid envelope. They rely on host cells to replicate and can infect a wide range of organisms, including plants, animals, and bacteria. In plants, viruses often cause symptoms such as mosaic patterns on leaves, stunted growth, yellowing, and deformities. Viroids, on the other hand, Viroids are the smallest known infectious agents of plants, and induce disease in a wide range of hosts including many crop species. They have been identified as non-coding, circular, single stranded RNAs ranging in size from 246 to 401 nt [10]. Viroid replication is entirely dependent on transcriptional and processing machinery supplied by the host, and transport of the resulting progeny utilizes preexisting cellular pathways [11]. Despite their simplicity, viroids can infect plants and disrupt normal cellular functions, leading to diseases such as stunting, leaf curling, and necrosis. Both viruses and viroids can significantly impact agricultural productivity by reducing crop yield and quality. And Spread through insects, contaminated tools, or even by us, these plant pathogens are a challenge to control, as effective treatments are still being developed.such as tomato virus (Figure 1.2)

Figure 1.2: Tomato virus

- Bacteria : are important plant pathogens widely spread all over the world [12] . It is estimated that from 7100 classified bacteria about 150 species are responsible for different plant diseases [13]. PPB has been classified into three families: Xantomonadaceae, Pseudomonaceae and Enterobacteriaceae. Bacteria are single-celled microorganisms that, under favorable conditions, reproduce rapidly within the plant. They enter through wounds, cuts left by pruning, or through pores in leaves (stomata). Although they can also be spread by gardening tools,

hands, and clothing, they are most commonly spread by splashing rain and irrigation water. Once inside the plant, they attack most of its organs.
Bacteria are often associated with wilts, blights, or soft rots. Wilt bacteria infect the roots, eventually clogging the vascular tissues, impeding the flow of water and nutrients. Blights are rapid decay of succulent tissues such as shoots, leaves, and flowers. Soft rots develop on the fleshy tissues of injured plant parts that remain moist for long periods [14].

Figure 1.3: Bacteria on a plant

- Oomycetes : are a distinct class of fungus-like eukaryotic microbes, many of which are highly destructive plant or animal pathogens. They share a range of morphological features with fungi, but they possess various unique characteristics which set them apart [15] .Cellulose is a major component of oomycete cell walls. In contrast, chitin, not cellulose, is a major cell wall component of true fungi. However, oomycetes also possess chitin synthases that are activated during tip morphogenesis [16]. Oomycetes are diploid during their vegetative mycelial stage, whereas fungi predominantly produce haploid thalli, although exceptions do exist . it is a well-known pathogens responsible for diseases such as late blight (caused by Phytophthora infestans), downy mildew, and root rot. These infections can result in symptoms such as leaf spots, wilting, stem rot, and even plant death, causing significant agricultural losses and are particularly devastating because they can spread rapidly under favorable conditions, such as high humidity and moderate temperatures[16].

Figure 1.4: A tomato leaf infected with mildew.

- Phytoplasmas : are bacterial plant pathogens that cause significant yield losses in a wide range of crops, both low and high value, worldwide [17]. These pathogens are obligate symbionts, meaning that they depend on both plants and insects for their survival and spread in nature. In plants, phytoplasmas primarily colonize phloem tissues [18], and spread through the plant by moving through the sieve plates that connect the phloem sieve tubes. They are transmitted by insect vectors such as leafhoppers and scale insects, facilitating their spread from plant to plant. Phytoplasmas are highly destructive and can infect more than a thousand plant species worldwide, causing diseases such as yellowing, witches' broom, and stunting . For example, an outbreak of phytoplasma in apple trees in 2001 resulted in economic losses of approximately €100 million in Italy and €25 million in Germany [19].

Figure 1.5: Apple tree infected with phytoplasma

- Nematodes : plant-parasitic nematodes are among the most significant threats to global agriculture, causing an estimated $80 billion in crop losses annually worldwide. These microscopic, eel-shaped worms, often invisible to the naked eye, attack nearly every part of the plant, including roots, stems, leaves, and seeds, either alone or in association with other soil microorganisms [20]. They use a needle-like structure called a stylet to pierce plant cells and extract nutrients, severely disrupting the plant's growth and productivity. Nematodes reproduce by laying eggs, which hatch into larvae that undergo four molts to become adults. Some species can complete their life cycle in less than 30 days, enabling rapid population growth and widespread damage [21].

Figure 1.6: The effect of nematodes on plant leaves

1.2.2 Non-Infectious Plant Diseases (Abiotic Disorders)

Non-infectious plant diseases, also known as abiotic disorders, are plant health problems caused by non-living factors rather than pathogenic organisms. These disorders arise from environmental stresses, nutritional imbalances, chemical toxicities, or physical injuries. Common causes include extreme temperatures (frost or heat stress), water-related issues (drought or waterlogging), soil conditions (poor drainage, salinity, or pH imbalance), nutrient deficiencies or toxicities (lack of nitrogen, phosphorus, or potassium, or excess of heavy metals), and chemical damage (herbicides, pesticides, or pollutants) [5][22].

1.3 Plant Parts: Definitions, Functions, and Disease Impacts

Plants consist of several main parts, including roots, stems, leaves, and fruits. Each part plays a distinct role in the plant's structure and life cycle. Together, they contribute to the plant's growth, survival, and reproduction.

1.3.1 Roots

Definition and structure

The root is the organ of the plant that is located below the soil surface fulfilling important functions for the plant's life and growth. The tip of the root, or the root apex, is covered by a structure known as the root cap, which guards the sensitive growing area as it navigates through the earth. Typical roots have three distinct zones or sections: the meristematic zone, the zone of elongation, and the zone of differentiation.
Roots can vary in structure depending on the plant species. For example, some plants have taproots (a single, dominant root), while others have fibrous roots (a network of thin roots)[23].

Figure 1.7: Root

Main Functions

- Absorbing water and minerals from the soil
- Storing food for future use

- Producing plant growth hormones
- Anchoring the plant firmly to the soil and providing support
- Developing new plants from the roots of the old plant (vegetative reproduction) [24].

Common diseases that affect it

- **Root rot** is a disease that attacks the roots of trees growing in wet or damp soil. This decaying disease can cut the life short of just about any type of tree or plant and has symptoms similar to other diseases and pest problems, like poor growth, wilted leaves, early leaf drop, branch dieback, and eventual death. it's is primarily caused by poorly drained or overwatered soils, which deprive roots of oxygen, leading to decay that can spread to healthy roots [25].
- **Crown** is a bacterial disease of the stems and roots of many woody and herbaceous plants, including fruit, vegetables and ornamental plants. Infection with this disease causes knobbly swellings (galls) on stems, roots, trunks and branches , and stimulates the plant tissues to grow in a disorganised way, producing swollen galls [26] .
- **Root-knot nematodes (Meloidogyne spp.)** attack the roots of various trees, shrubs and herbaceous plants. Infested roots become distorted and develop rounded or irregular galls. These galls measure anything from 1 to 20 mm across and often coalesce, causing considerable distortion. The nematodes also exacerbate the deleterious effects of pathogenic bacteria and fungi. Root-knot nematodes are associated mainly with light soils but most damage is caused under glass, particularly in hot conditions where certain tropical and subtropical species, e.g. the Javanese root-knot nematode (Meloidogyne javanica), have become established. This disrupts water and nutrient uptake, leading to stunted growth and yellowing.They affect crops like tomatoes, carrots, and soybeans [27].
- **Tobacco Rattle Virus** tobacco rattle virus is a viral disease that infects plant roots, Tobacco rattle virus (TRV) is transmitted by nematodes of the genera Trichodorus and Paratrichodorus (Trichodoridae), which are polyphagous ectoparasites moving freely in the rhizosphere. There is some evidence of specificity between virus strain and vector species. Adults and juveniles can transmit the virus when feeding on root cells and the virus can be retained for many months by non-feeding nematodes. It causes stunted growth and necrotic spots on roots, particularly in potatoes, leading to corky ringspot disease [28].

1.3.2 Stems

Definition

Stems are the above-ground, vertical structures of a plant that provide support, transport water and nutrients, and often bear leaves, flowers, and fruits. They serve as the central axis connecting the roots to the leaves and play a vital role in photosynthesis, storage, and reproduction in some species. Stems can be herbaceous (soft and green) or woody (hard and rigid), depending on the plant type [29].

Figure 1.8: Stem of plant

Structure

Internal Features

- Shoot Apical Meristem : "Immortal" cells at the tips of stems that generate new cells for differentiation and growth in stem length.
- Epidermis : Outer layer of wax-coated cells that provides protection and covering.
- Cortex :Primary structural and storage tissues of a stem.

Vascular Tissues

- Vascular Bundle : grouped phloem, xylem, and associated cells in primary stems.
- Vascular bundles : give rise to the Vascular Cambium in plants that are capable of secondary growth (stem thickening).
- Vascular Cambium : the layer of meristematic (dividing) tissues that forms in some plants to generate secondary growth (growth in girth). The cambium divides to form phloem tissues toward the outside of the stem and xylem tissues toward the inside. Cell division of the cambium tissues adds width to the stem.
- Secondary Phloem (inner bark) : in plants with secondary growth (woody plants), the phloem is located to the outside of the vascular cambium and just beneath the bark. If the stem is damaged or girdled so as to disrupt or block the phloem, it can enlarge just above the blockage due to the sugars moving down from the leaves for distribution throughout the plant. Tissues below the blockage slowly starve. Roots die back, eventually leading to death of the plant.
- Secondary Xylem (wood) : distributes water and minerals from the roots up through the plant. Typically only the xylem tissue nearest the vascular cambium (the youngest xylem) functions for water transmission; older xylem provides structural support.
- Pith : the soft center of dicot plant stems, consisting of parenchyma cells. In some plants the pith breaks down forming a hollow stem.

woody stems are used in tree and shrub identification. Features to look at include the cross-section shape of the pith (rounded, star-shaped, or triangulate) and whether the pith is solid, hollow, or chambered [30].

Main Functions

- Providing strength and support to buds, flowers, leaves, and fruits .
- Storing food mainly in the form of starch .
- Transporting food, water, and minerals to all parts of the plant body.
- Developing new plants from the stem of the old plant (vegetative reproduction) [24].

Common diseases that affect it

- **Stem Canker** is a fungal disease caused by pathogens like Botryosphaeria, Phomopsis, and Leptosphaeria. Stem canker lesions enlarge, turning brown to black and indenting slightly. Eventually they will surround the stem and cut the flow of water and nutrients in the plant. The result can be premature, and often sudden, plant death. Interveinal plant yellowing follows, with leaves dying but remaining attached to stems. Common in crops like soybeans, tomatoes, and trees, stem canker thrives in warm, humid conditions [31].
- **Southern blight** also known as southern stem blight, basal stem rot, Sclerotium blight, crown rot, or white mold, affects hundreds of plants, including vegetables, field crops, ornamentals, and fruit. Symptoms vary by plant type and affected part but may include water-soaked or brown lesions on lower stems near the soil line, chlorosis (yellowing) followed by necrosis (death) of foliage, gradual or sudden wilting, root decay, crown rot, plant collapse, dieback, decline, and death of woody plants, dry decay of tubers and bulbs, and soft water-soaked decay of fleshy fruit [32].
- **Bacterial canker** caused by Clavibacter michiganensis, affects the stems of plants like tomatoes and peppers. It causes dark, sunken lesions on stems, wilting, and plant death. The bacteria spread through contaminated tools, water, and infected seeds [33].

1.3.3 Leaves

Definition and structure

Leaves are the primary photosynthetic organs of plants, typically flat and green, specialized for capturing light energy and converting it into chemical energy through photosynthesis. They also facilitate gas exchange (taking in carbon dioxide and releasing oxygen) and transpiration (water loss through stomata). Leaves are usually attached to the stem by a petiole and come in various shapes and sizes, adapted to different environmental conditions [34]. The leaf is composed of several types of tissues, each with specific functions. The epidermis is the outer layer of the leaf, which protects the plant from physical damage, water loss, and pathogen attacks. The mesophyll is the inner layer of the leaf where photosynthesis takes place, and is composed of two types of cells: palisade cells, which are arranged in vertical columns, and spongy cells, which are looser and allow air to circulate. The veins are the veins that carry sap throughout the leaf, bringing water and nutrients to the leaf cells and allowing the sugars produced by photosynthesis to be transported to the rest of the plant. The stomata, on the other hand, are pores located on the epidermis of the leaf, which allow gas exchange between the plant and the atmosphere [35] .

Figure 1.9: Leaf

Main Functions

- Capture light for photosynthesis (the manufacture of sugars).
- Transpiration from the leaves moves water and nutrients up from the roots.
- Water, gas exchange for photosynthesis and respiration, and temperature are regulated through small openings on the leaf, known as stomata [36].

Common diseases that affect it

- **Downy Mildew** is a fungal disease caused by Phytophthora infestans that primarily affects cultivated plants such as tomatoes, potatoes, grapes, and strawberries. Symptoms include brown or purple spots on leaves, water-soaked lesions on fruits, and rapid wilting of plants. The disease spreads quickly in warm and humid conditions, making it particularly prevalent during the summer months. Preventive measures include using resistant varieties, watering plants in the morning rather than the evening, and practicing crop rotation to avoid planting susceptible crops in the same area year after year.[37]
- **Rust** is a fungal disease that affects plants, characterized by brown, reddish, or orange spots on the leaves. It is caused by various fungi belonging to the Puccinia genus and can impact a wide range of plants, including cereals, fruit trees, vegetables, and ornamental plants. Symptoms of leaf rust include circular, rust-colored spots on the leaves, often accompanied by orange or brownish spore pustules. Infected leaves may eventually fall off, weakening the plant and reducing its ability to produce fruits or flowers. Leaf rust typically spreads in warm and humid conditions. Prevention involves maintaining good air circulation around plants, avoiding overwatering, and regularly removing infected leaves.[38] **Septoria Leaf Spot** is a fungal disease caused by the Septoria species, which affects a variety of plants. The disease is characterized by the appearance of small, brownish leaf spots surrounded by a yellow halo. These spots can merge to form larger necrotic areas, leading to leaf death.
  Symptoms vary depending on the infected plant, but leaves are typically the first to show signs of infection. Affected plants may also exhibit rot and discoloration on fruits and stems.

Septoria leaf spot spreads through fungal spores carried by wind, water, or insects. Plants are more susceptible to infection under conditions of high humidity or low light. [38]

- **Peach Leaf Curl (Œil de Paon)** is a fungal disease caused by Taphrina deformans , primarily affecting fruit trees such as peaches, nectarines, plums, and apricots. Symptoms include circular, red spots on leaves that eventually turn yellow or white, giving the leaves a wrinkled and distorted appearance. Infected flowers may also become deformed or fail to develop properly, leading to reduced fruit production [22] . The disease spreads through spores carried by wind and rain. Plants are more susceptible to infection under conditions of high humidity, low light, or physical damage. [37]

- **Powdery Mildew (Oïdium)** also known as white mold, is a fungal disease that affects a wide range of plants, including agricultural crops and ornamental species. It is caused by various fungi from the Erysiphe genus, which spread through airborne spores. Symptoms include a white or grayish powdery coating on leaves, stems, and flowers, leading to leaf discoloration, curling, and stunted plant growth. Fruits may also be affected, showing discoloration and a shriveled appearance. Powdery mildew thrives in warm, dry conditions with poor air circulation, overwatering, plant stress, and high humidity. Preventive measures include using resistant plant varieties, practicing crop rotation, regularly removing infected leaves and branches, reducing humidity, watering at the soil level, and applying fungicides when necessary [39].

- **Angular Leaf Spot** is a fungal disease caused by Pseudomonas syringae, which affects various plants. It is characterized by dark brown or black angular spots that form on leaves, stems, and fruits. These spots often appear water-soaked and may be surrounded by a yellow or brown halo. Infected plants may also exhibit symptoms such as premature leaf drop, stunted growth, and discoloration of stems and fruits.
  The disease spreads through water droplets carried by wind or rain. Plants are more susceptible to infection under conditions of high humidity, low light, or physical damage [22].

1.3.4 Fruits

Definition

Fruits are the mature ovaries of flowering plants, developed after fertilization, and they contain seeds. Their primary function is to protect and aid in the dispersal of seeds, ensuring the propagation of the plant species. Fruits can be fleshy or dry and are often edible, attracting animals that help in seed dispersal [40].Like as strawberry fruit (Figure 1.10)

Figure 1.10: Strawberry fruit

Structure

Pericarp :the wall of the fruit, derived from the ovary wall, which can be divided into three layers:

- Exocarp: the outermost layer (skin or rind).
- Mesocarp: the middle layer, often fleshy and edible (e.g., the pulp of a peach).
- Endocarp: the innermost layer, which can be hard or stony (e.g., the pit of a cherry).

seends : the mature ovules contained within the fruit, which develop into new plants under suitable conditions.

types

- Dehiscent Fruit : fruit splits open at maturity, releasing (usually multiple) seeds (beans, flax,penstemon).
- Indehiscent Fruit : fruit formed from an ovary in which usually only one seed develops, and within which the seed remains during distribution (sunflowers, grasses).
- Fleshy Fruit : fruit developed from unicarpellate (one-seeded) or multicarpellate (many-seeded) ovaries. The ovary wall develops rapidly proliferating cells that take on diverse roles in the resulting fruit .

Main Functions

- Protecting the growing seeds.
- Helping in the dispersal of seeds and thus in plant reproduction.

  Thus although each part of a plant has its specific functions, they all work in combination to provide distinct advantages in plant growth and survival [24] .

Common diseases that affect it

- **Spider mites** also known as red spider mites, are tiny pests that cause damage to plants by feeding on their sap. They commonly infest indoor plants such as orchids, hibiscus, and tropical plants, leaving behind fine webs and causing yellow spots on leaves. Infested leaves may wilt and drop prematurely, leading to reduced flower or fruit production. Spider mites reproduce rapidly and can quickly spread to other plants or entire crops through wind, animals, or contaminated gardening tools[38] .
  To control spider mite infestations, chemical treatments like acaricides can be used, or natural methods such as applying essential oils or introducing predatory insects that feed on the mites [38].

- **Alternaria solani** is a fungal pathogen responsible for early blight, a disease commonly found in warm and humid regions worldwide. It can cause significant yield losses in tomato crops. Symptoms typically begin with dark brown or black spots on the lower leaves of the plant, which can rapidly expand and cover entire leaves, leading to premature leaf drop. Fruits may also be affected, developing brownish spots and areas of rot. The fungus can survive in soil for extended periods and is spread by wind or rain [38].
  Treatment of early blight involves the use of fungicides, which should be applied preventively or at the first signs of infection. It is crucial to follow the manufacturer's instructions and reapply as necessary to effectively manage the disease [37].

- **Black Rot** is a fungal disease that affects plants, particularly grapes, apples, peaches, and strawberries. It is caused by the fungus Guignardia bidwellii and can lead to significant yield losses in affected crops. Symptoms vary depending on the plant but typically begin as brown spots on leaves, which quickly spread and turn into necrotic lesions. Infected fruits may also develop brown spots that can turn into ulcers and rot. The fungus Guignardia bidwellii can survive in crop debris and infected plant tissues, spreading through wet weather and wind. Cultural practices such as proper pruning, removal of plant debris, and the application of fungicides can help reduce the severity of Black Rot [38].

1.4 Development of the agricultural sector

1.4.1 Traditional Agriculture

Traditional farming is often viewed as a primitive method of farming, which is still being used by half of the world's farming population. It involves the application of indigenous knowledge, traditional tools, natural resources, organic fertilizers, and cultural beliefs of the farmers. Despite being labeled as outdated by some, traditional farming practices have proven to be highly sustainable and resilient, particularly in regions where modern agricultural inputs are inaccessible or unaffordable. These methods also play a crucial role in preserving biodiversity and maintaining ecological balance, making them increasingly relevant in the face of global environmental challenges [41].

Definition

Traditional agriculture can be defined as a farming system that relies on indigenous knowledge, locally available resources, and time-tested practices passed down through generations. It typically involves the use of manual labor, simple tools, and organic inputs, with a focus on sustainability and harmony with the natural environment. According to Altieri (1995), traditional agriculture is characterized by its reliance on biodiversity, crop rotation, and ecological balance, making it a resilient and adaptive system that has sustained communities for centuries. This form of agriculture is deeply rooted in cultural practices and often emphasizes subsistence farming, where the primary goal is to meet the needs of the family or local community rather than commercial production [42] .

Figure 1.11: Overview of traditional agriculture

Characteristics of Traditional Agriculture

Traditional agriculture is characterized by the following [43]:

- Extensive farming using indigenous knowledge and tools: It relies on time-tested practices and simple, locally made instruments.Indigenous tools such as the axe, hoe, and digging stick: These basic tools are commonly used for cultivation and land preparation.
- Use of livestock for creating fallow land: Animals are often employed to help clear and prepare land for farming.
- Lack of environmental responsibility: Traditional practices may not always prioritize environmental conservation, leading to issues like soil degradation over time.
- Limited surplus production: Traditional agriculture is primarily subsistence-oriented, focusing on meeting immediate family or community needs rather than producing excess for commercial purposes.

Benefits of Traditional Agriculture

Traditional agriculture offers a range of benefits that highlight its importance in sustainable and culturally rich farming systems. It promotes environmental harmony through practices like crop rotation, intercropping, and the use of organic fertilizers, which enhance soil fertility, reduce erosion, and maintain ecological balance. These methods, as noted by Altieri (1995), are resilient and less dependent on external inputs, ensuring long-term sustainability [42]. Additionally, traditional agriculture plays a crucial role in preserving biodiversity by cultivating diverse indigenous crops and livestock breeds, which are essential for adapting to environmental changes and ensuring food security (Thrupp, 2000) [44]. Beyond its environmental benefits, traditional farming is deeply intertwined with cultural and spiritual practices, fostering a strong connection between farmers and their land while preserving indigenous knowledge and strengthening community resilience (Pretty, 2008)[45]. Moreover, its reliance on locally available resources and simple tools makes it accessible and affordable for small-scale farmers, ensuring food production even in resource-limited settings.

Disadvantages of Traditional Agriculture

Over time, we are gradually realizing that this type of agriculture ultimately presents more disadvantages than advantages . [46].

- **Low Productivity:** traditional farming methods often yield lower outputs compared to modern, industrialized agriculture. This can make it difficult to meet the food demands of growing populations. As highlighted by Pingali (2012), traditional systems may struggle to achieve the scale and efficiency required for large-scale food production.
- **Labor-Intensive:** traditional agriculture relies heavily on manual labor, which can be physically demanding and time-consuming. This limits the ability to scale up production and may discourage younger generations from continuing farming practices.
- **Vulnerability to Climate Change:** while traditional agriculture is often resilient, it is not immune to the impacts of climate change, such as unpredictable weather patterns, droughts, and floods. According to IPCC (2014), traditional systems may lack the adaptive capacity to cope with extreme climatic events.
- **Limited Market Integration:** traditional farming is often subsistence-oriented, with limited focus on commercial production. This can restrict farmers' access to markets and economic opportunities, perpetuating poverty in rural areas.

1.4.2 Precision agriculture

Traditionally, the identification of diseases and pests in agriculture and forestry has relied on expert knowledge, a process that is often subjective, time-consuming, and inefficient. To address these limitations and enhance efficiency and profitability, agriculture has undergone significant modernization. This transformation includes intensified land use, advanced crop management techniques, the adoption of modern cultivars, shifts in food preferences and policies, evolving trade regulations, and the increased global movement of goods and people. [47]

Definition

Precision agriculture encompasses a range of strategies and tools designed to enhance agricultural productivity through targeted, data-driven interventions. This approach leverages advanced technologies to achieve precise and efficient outcomes. The term ”precision” reflects the ability to implement the right intervention, in the right location, at the right time, tailored to the specific needs of each crop and individual field area. The process begins with the collection of detailed data and information, which is then analyzed to inform decision-making and identify areas for improvement. Based on these insights, corrective measures are implemented to optimize production. By integrating cutting-edge technologies, precision agriculture enables farmers to maximize yields, reduce waste, and improve resource efficiency, ultimately contributing to sustainable and profitable farming practices [48].

Figure 1.12: Overview of Precision agriculture

Importance Of Technology In Agriculture

Agricultural technology targets making field work easier and more efficient. The idea is to "do more with less", or do the same, only more sustainably. There are some new agricultural innovations every year and, from time to time, groundbreaking technologies. With agribusiness going modern and spreading further, it became more than ever essential that agricultural consultants, food growers, and computer managers be enlightened and aware of today's technological demands.
Water, fertilizers, pesticides, and all the inputs are no longer used "by eye" or across the whole field by large farm producers. High-tech agriculture technology allows for the precise application of only what is required in each location, as well as the precise customization of treatment for each plant[48].

Challenges of Precision Agriculture

Precision agriculture faces three major challenges that must be addressed to fully realize its potential [49]:

- **Agronomic Challenge:** precision agriculture enables farmers to adapt more effectively to weather conditions and soil variability across their fields. For instance, companies like Ombrea have developed intelligent regulation tools to shield crops from the adverse effects of climate change .
- **Environmental Challenge:**this approach aims to minimize the ecological footprint of farming by promoting efficient resource management. Precision agriculture optimizes the use of water, fertilizers, and machinery, allowing for targeted interventions such as irrigating only specific areas of a field.

- **Economic Challenge:** precision agriculture seeks to enhance productivity while reducing costs, enabling farmers to ”produce more with less.” However, the integration of technology does not replace the farmer’s expertise and experience. Instead, it provides decision-making tools that complement traditional knowledge. Algorithms and models generate recommendations, but their success depends on the farmer’s ability to interpret and apply these insights effectively.

Ultimately, technology alone cannot guarantee the successful management of a farm; it must be combined with human judgment and experience.

Benefits Of Precision Agriculture

Precision farming is helpful to farmers and the environment as well. Additionally, these regions are connected since ecological degradation worsens agriculture conditions. Following are some of the benefits of such a control system:

- Reducing the cost of material and resources, e.g., water, seeds, fuel, etc.
- Maintaining healthy soil by minimizing the use of pesticides.
- Minimizing the dependency of agriculture on weather.
- Optimizing crop genetic potential.

All of these precision farming advantages allow farmers to dramatically enhance the quality of products and, at the same time, reduce their costs [48].

Precision Agriculture Technologies And Methods

Precision farming requires special equipment and software to collect and analyze all the information. A key element of this optimized farm management approach is the use of information technology and a wide range of tools .

- **VRT (Variable Rate Technology):** refers to any technology that can control the amount of inputs applied to a specific location [50].
- **Global Positioning System (GPS) In Precision Agriculture:** GPS refers to ground-based technology to enable the farmers to gain information with geographical position in real time. GPS suits the below-given application [48]:
  - Road and field mapping, field irrigation system.
  - Spotting problem plants in areas.
  - Test in soil inside designated areas within a field.
  - The driving of a parallel steering tractor.
  - VRA used in accurate planting and fertilization seeds.
- **Sensing Technology:** they play a pivotal role in the real-time monitoring of crop growth conditions on internal factors, such as biochemical information in tissues or cells , health characteristics , and growth rates , as well as external environmental factors that affect plant growth, including soil moisture and nutrient status [51].

- **Satellite self-guidance (RTK):** allows the signal sent to a self-guided tractor or autonomous robot to be corrected and its precision to the nearest centimeter to limit treatment or fertilization gaps and overlaps [50].

1.5 Techniques Used to Detect Maladies in Plants

1.5.1 Drones

The use of small unmanned aerial vehicles in agriculture is a relatively new development in digital technology. Drones, as they are popularly called, are remotely controlled aerial vehicles without a pilot onboard[52].

We can equip it with tools to perform different tasks., for example, to carry cameras, sensors, or even spraying equipment. Their use in agriculture to assist with evidence-based planning and spatial data gathering is enormous[52].

In the agricultural field, drones have two major categories of application. The "eye-in-the-sky" function offers remote optical observation and recording of a territory, crop monitoring, livestock and weed counting and monitoring, water accumulation detection, etc. The use of drones as a "hand-in-the-sky" includes delivering goods across the territory and spraying fertilizers or weed-killers [52].

1.5.2 Smartphone Applications

Mobile applications have driven a significant digital transformation in the agriculture sector, revolutionizing how tasks are managed from small farms to large warehouses. Smartphones, in particular, have emerged as indispensable tools due to their portability, affordability, and advanced computing capabilities, which enable the development of diverse and practical agricultural applications. Additionally, the integration of various physical sensors in modern smartphones enhances their functionality, making them highly effective for assisting in a wide range of agricultural activities. This combination of mobility, cost-effectiveness, and technological sophistication positions smartphones as a promising and versatile tool for modern agriculture [53].
Among the applications we mention [54]:

- **Farmable:** is a comprehensive farm management mobile app designed to streamline agricultural operations and optimize productivity for farmers of all scales. It is like a digital hub for farm management, as it pools together resources and tools matching farmers' everyday activities.

- **Plantix:** is prominently known for its AI-powered image recognition technology. The technology diagnoses plant diseases, nutrient deficiency, and pest infiltration. It comes with other exciting features, such as fertiliser calculation, cultivation tips, and resources. And if users have any questions, Plantix allows them access to a community, where they can share knowledge.

- **Locus Map:** locus Map serves as a digital navigator for farmers. It offers them access to detailed maps, GPS tracking, and route planning tools to navigate their fields with ease. Typically, the app was designed to enhance operational efficiency and offer precision in navigation.

- **Agrivi:** is designed to address various complexities of modern agriculture. It's more like a digital hub that empowers farmers with control over several aspects of their operations. They can track crop performance and analyse financial metrics, monitor field conditions and streamline their workflow, increase yield, and enhance profitability.

1.5.3 Satellite and remote sensing technologies

Agriculture relies on critical factors such as soil composition, weather conditions, temperature, rainfall, crop growth stages, and topography. Satellites and space-based technologies enable the seamless monitoring of these variables from computer displays, providing valuable data for strategic agricultural decision-making. The role of satellites in agriculture has expanded significantly, evolving from simple data collection to enabling precision farming practices, such as guiding GPS-equipped tractors for planting and harvesting. Satellites generate highly accurate geospatial data on farmlands and crops by utilizing multiple satellites and trilateration techniques. Equipped with advanced sensors, they monitor and measure essential agricultural variables, making them indispensable tools in modern farming practices [55].

1.5.4 Robotic agriculture

Robotic agriculture is revolutionizing farming by reducing drudgery, saving time, protecting soil, and improving profitability. The Oz robot is designed for mechanical weeding in market garden crops on farms smaller than 10 hectares, while the Dino robot is a straddle weeding system tailored for larger farms. Ted, another straddle robot, is specifically dedicated to vineyard crops. All these robots integrate RTK (Real-Time Kinematic) technology for high-precision navigation and operations. The European RHEA Project has pioneered the use of fleets of autonomous tractors and drones equipped with advanced sensors to distinguish weeds from crops and apply herbicides only when necessary. This innovative approach reduces herbicide use by up to 75% while effectively eliminating 90% of weeds on a plot. [50].

1.5.5 Connected sensors

Connected sensors are transforming agriculture by addressing a wide range of farming challenges through innovative technologies [56] .

- Plant and fruit tree sensors : it is connected directly to crops to monitor growth rates, hydration levels, and other vital signals. When combined with climate and soil moisture sensors, this data is analyzed to provide real-time diagnostics and actionable recommendations for crop management.
- Sensors for greenhouse or hydroponic crops : open-source sensor networks track variables like brightness, air and soil humidity, water temperature, and pH levels. These metrics are processed on cloud servers, enabling remote monitoring and SMS alerts to guide corrective actions.
-Agricultural drones, equipped with advanced sensors like the Agrosensor multi-spectral sensor, excel in crop mapping and monitoring. These sensors, compatible with various drone models, provide detailed insights into crop health and field conditions.
- Intelligent irrigation system: acting on solenoids and valves affixed to the irrigation system, this device connected to the Internet adjusts the irrigation schedules of the land according to local weather forecast data (rain, temperature). A database of 48,000 weather stations can be used.

1.5.6 Hyperspectral imaging

Hyperspectral imaging has proved itself as potentially useful technology for agriculture, in particular vegetation studies and precision agriculture, as it offers enormous insight into the health of crops and environmental conditions, accomplishing more sustainable and efficient agricultural practices. Hyperspectral imaging allows interest in the health and status of plants, vegetation, and crops. By analyzing spectral reflectance, or reflectance spectra, over certain wavelengths, it is often possible to detect subtle changes in vegetation that can indicate levels of stress, nutrient deficiencies, disease, or water limitations. This can lead to timely responses and targeted interventions to remove sources of loss and increased yield for crops [57].

1.6 Conclusion

This chapter explored the diversity of plant diseases and examined developments in agriculture, covering both traditional and modern practices. We also reviewed key disease detection techniques before choosing deep learning as our methodology for this study. In the next chapter, we will delve deeper into the basic concepts of artificial intelligence, machine learning, and deep learning, as well as their most important algorithms.

Chapter 2

State of the Art - Machine Learning & Deep Learning

2.1 Introduction

Artificial intelligence (AI) and image processing are currently one of the hottest buzzwords in tech and with good reason. The last few years have seen several innovations and advancements that have previously been solely in the realm of science fiction slowly transform into reality. where Experts regard artificial intelligence as a factor of production, which has the potential to introduce new sources of growth and change the way work is done across industries .

2.2 Definition of Artificial Intelligence (AI)

Artificial intelligence (AI) is technology that enables computers and machines to simulate human learning, comprehension, problem solving, decision making, creativity and autonomy.

Applications and devices equipped with AI can see and identify objects. They can understand and respond to human language. They can learn from new information and experience. They can make detailed recommendations to users and experts. They can act independently, replacing the need for human intelligence or intervention (a classic example being a self-driving car)[58].

2.3 History of AI and how it has progressed over the years

With so much focus on contemporary artificial intelligence, it is too easy to overlook the fact that the discipline is not entirely new. AI has had various distinct eras, marked by whether the emphasis was on demonstrating logical theorems or attempting to replicate human thought through neurology. Artificial intelligence has its origins in the late 1940s when computer legends like Alan Turing and John von Neumann started investigating why machines could ”think.” One very significant development in AI, however, was in 1956 when scientists proved that a machine could solve any problem if it possessed unlimited memory. The result was a program called the General Problem Solver (GPS)[59].
Over the following twenty years, scientific endeavors shifted to implementing artificial intelligence in practical applications. This gave rise to expert systems, which allow machines to learn from experience and make forecasts based on information accumulated. Expert systems are not as complex as the human mind but can be taught to identify patterns and act upon that information. They're utilized in medicine and manufacturing extensively today[59].
A second major milestone was achieved in 1965 with the development of programs like Shakey the robot and ELIZA, which enabled simple conversations between humans and machines to be automated. These early programs paved the way for more advanced speech recognition technology, eventually leading to Siri and Alexa. The initial decade of excitement concerning artificial intelligence continued for approximately a decade. It brought some significant breakthroughs in programming language research, theorem proving, and robotics. But it also sparked a backlash against overly optimistic hype that had been given to the technology, and funds were soon cut back sharply around 1974 [59].
Interest had subsided after a decade with little progress, but it was revived in the late 1980s. The revival was ignited by reports that computers were beginning to perform ”narrow” tasks more efficiently than humans, e.g., playing chess or checkers, and advances in computer vision and speech recognition. The emphasis this time was on building systems that would learn and understand from

real-world data with minimal human supervision. These developments trickled on slowly until 1992, when interest accelerated again. Firstly, computer developments in computational capability and storage capacity helped to enhance interest in research into artificial intelligence. Secondly, in the mid-1990s, there was a big boom fueled by tremendous developments in computer hardware since the early 1980s. The result has been staggering improvements in performance on a series of important benchmark problems, ranging from image recognition, where computers are now virtually as good as people at certain tasks[59].

The first decade of the 21st century was an era of fantastic advancements in artificial intelligence. At the forefront was the creation of the self-teaching neural network. Its capabilities in the year 2001 had already surpassed that of human beings in most accurate areas, such as object recognition and machine translation. In subsequent years, scientists further developed its ability across a wide range of tasks, thanks to improvements in the underlying technologies[59].

The second significant contribution in this phase was the development of generative model-based reinforcement learning algorithms. Generative models can generate new examples from a given class and help learn complex behaviors from very little data. For example, they can be used to learn how to drive a car from a mere 20 minutes of driving experience[59].

Aside from these two breakthroughs, there have been a number of other important breakthroughs in AI over the last decade. There has been a growing focus on applying deep neural networks to computer vision applications, including object detection and scene interpretation. There has also been growing attention on applying machine learning software to natural language processing applications including information extraction and question answering. Finally, there has been greater interest in using the same technology in speech recognition applications like automatic speech recognition (ASR) and speaker identification (SID)[59].

2.4 How AI Works: Step-by-Step Process

- **Step 1 : Data Collection and Preprocessing:** One of the first steps in creating a machine learning model is obtaining data relevant to the problem from various sources. Data may be in the form of text, images, or numeric data. It is then preprocessed to clean it and make it usable for learning. Preprocessing includes activities such as dealing with missing data, eliminating duplicates, and correcting errors. Also, some relevant features will be selected and extracted, focusing on aspects of the data that are most important for the problem. The normalization or scaling of the data applied ensures that each feature contributes equally to the learning process.

- **Step 2: Data Splitting** Post-preprocessing, the data is split into three parts: the training set, validation set, and test set. The training set is to allow the machine learning model to train on patterns and relations contained in the data. The validation set is used to tune hyperparameters and assess the model during training to avert overfitting. Finally, the test set, which the model has never seen, is used to access the capability of the model to generalize.

- **Step 3: Model Selection** The correct algorithm or model of choice will be very crucial to the performance of the solution because it translates directly into its efficacy. This, of course, is variety constrained to the kind of problem one is attempting to solve, such as classification, regression, clustering, amongst others, as well as the data upon which this is to be performed. Size and complexity of the dataset along with the desired performance metrics play an important role in deciding the perfect model for the task.

- **Step 4: Model Training** During model training, the selected algorithm is applied to the training data to learn pattern and relationships. Internal parameters are adjusted by the algorithm to minimize a predefined loss function measuring the error between predicted and actual outputs. This permits the model to generalize from the data and make accurate predictions.
- **Step 5: Model Evaluation and Tuning** During the validation stage, the performance of the model is assessed on a validation set through metrics such as accuracy, precision, recall, and F1-score among others. If the results aren't satisfying, then hyperparameters are fine-tuned, or alternative algorithms and configurations could be explored to achieve better results. This process repeats until the model is optimized.
- **Step 6: Model Deployment** After achieving satisfactory performance, the model is then deployed into a production environment, where it is used to make predictions or decisions on new, unseen data. Deployment ensures the model's capability to deliver value in the real world towards end-users or systems.
- **Step 7: Model Monitoring and Maintenance** Once deployed, the performance of a model should get a constant monitoring so that it remains effective. Model accuracy may start dropping as a result of time due to normal changes in input data distribution or environmental settings. Thus, periodic retraining or updates may be necessary. Performing such active monitoring and model maintenance maintains the robustness, accuracy, and adaptability of the model against any external fluctuations in the data or the environment [60].

2.5 Applications of Artificial Intelligence in Modern World

Artificial intelligence has evolved into one of the most transformative technologies in the world, with applications extending across nearly every domain of human activity. Its influence spans diverse sectors including Agriculture , Business, Banking, Finance , education, Entertainment and Gaming, cybersecurity and Health Care.

2.5.1 Agriculture

The agriculture is the backbone of any country and therefore the development of this sector with the aid of technology is imperative. Considering the situation of the world, the agricultural sector will be capable of generating almost 50% more food than is currently being generated. Applying AI and its technologies has adequately helped in the development of the condition of the agriculture industry. After the agricultural cycles, AI is applied in the soil monitoring and analysis, advancement at the stage of planting crops, proceeding with the pest/weed management practices and ultimately to crop harvesting and crops supply to the respective destination and at a fair pace. With the advent of AI, sensor technology, and Internet, this industry has developed to a greater extent. In tracking and analyzing the ground, AI will alert us to the ground and seed relationship. To this extent, it informs us which seed is to be selected for some types of soil. It predicts in reducing the use of toxic chemical fertilizers that are used to enhance the growth of plants and monitors the irrigation process hence saving water. According to a study carried out in Alfalfa, California, the use of Geographic Information System (GIS) in the irrigation system has helped raise the production of crops by 35% and reduce water consumption in irrigation. AI use, basically using the help of sensors, photos, and infrared rays helps detect the quality and properties of the soil. Thus it facilitates improving the agriculture process guaranteeing greater yield and profit for concerned farmers [61].

2.5.2 Business, Banking and Finance

Artificial intelligence in finance refers to the application of a set of technologies, particularly machine learning algorithms, in the finance industry. This fintech enables financial services organizations to improve the efficiency, accuracy and speed of such tasks as data analytics, forecasting, investment management, risk management, fraud detection, customer service and more. AI is modernizing the financial industry by automating traditionally manual banking processes, enabling a better understanding of financial markets and creating ways to engage customers that mimic human intelligence and interaction [62].

2.5.3 Education

Artificial intelligence is revolutionizing education by integrating intelligent systems capable of performing tasks that traditionally required human cognition. These AI-driven solutions – including machine learning algorithms, natural language processing, and adaptive robotics – create dynamic learning environments that automatically adjust content, difficulty, and pacing to suit individual learners [63].
Numerous applications of AI in education (AIED) have emerged. For example, Khan Academy offers Khanmigo, an AI tutor harnessing GPT-4 capabilities, delivering personalized learning support and intelligent feedback across various subjects, including mathematics, programming, and language learning. Similarly, Duolingo, a language learning platform, uses sophisticated AI systems to improve learner experiences [64].

2.5.4 Entertainment and Gaming

In gaming, AI powers immersive experiences. For example, it can be used to develop intelligent virtual characters (mainly non-player characters) and enhance game graphics. AI-powered game engines are adapting gameplay based on player behaviour, creating dynamic and engaging experiences [65].

2.5.5 cybersecurity

AI powered cybersecurity can monitor, analyze detect, and respond to cyber threats in real time. As AI algorithms analyze massive amounts of data to detect patterns that are indicative of a cyber threat, it can also scan the entire network for weaknesses to prevent common kinds of cyber attacks [66].

2.5.6 Healthcare

Healthcare has been revolutionized thanks to the advent of artificial intelligence (AI), changing the way we diagnose, treat and monitor patients. This advancement is transforming healthcare research and outcomes by helping make diagnoses more accurate and personalized treatments possible. Because AI in healthcare is able to process larze amount of clinical documents at high speed, medical practitioners can identify markers and trends for diseases that would have otherwise been missed [67].

2.6 Types of AI

AI can be classified into two main categories based on its capabilities and functionalities.

2.6.1 Based on Capabilities

The various types of artificial intelligence based on the capabilities can be classified as:

- **Weak or narrow AI:** it is a type of AI which can perform a predefined narrow set of instructions without exhibiting any thinking capability. It is the most widely used type of AI in this world. Some famous examples areApples's Siri,Alexa, Alpha Go, IBM's Watson supercomputer, Sophia (the humanoid) all belong to the weak AI type [68].

- **General AI:** is a theoretical concept where AI can perform any intellectual task that a human can do. It demonstrates human-like reasoning and understanding across multiple domains, making it capable of tackling a wide variety of tasks[69].

- **Strong AI:** is a hypothetical form of AI that would surpass human intelligence in all areas. It would be capable of performing tasks more efficiently and effectively than humans . The applications possessing Super AI capabilities will have evolved beyond the point of understanding human sentiments and experiences to feel emotions, have needs and possess beliefs and desires of their own [69].

2.6.2 Based on Functionalities

Based on the functionality, artificial intelligence can be classified as per the following types:

- **Reactive Machine AI:** reactive machines are AI systems with no memory and are designed to perform a very specific task. Since they can't recollect previous outcomes or decisions, they only work with presently available data. Reactive AI stems from statistical math and can analyze vast amounts of data to produce a seemingly intelligent output.

  Examples of Reactive Machine AI

  - An example of a reactive machine is perhaps the most famous AI system – IBM Deep Blue, a chess-playing supercomputer that defeated international grandmaster Garry Kasparov.
  - The Netflix Recommendation Engine: Netflix's viewing recommendations are powered by models that process data sets collected from viewing history to provide customers with content they're most likely to enjoy [70].

- **Limited Memory AI:** unlike Reactive Machine AI, this form of AI can recall past events and outcomes and monitor specific objects or situations over time. Limited Memory AI can use past- and present-moment data to decide on a course of action most likely to help achieve a desired outcome. However, while Limited Memory AI can use past data for a specific amount of time, it can't retain that data in a library of past experiences to use over a long-term period. As it's trained on more data over time, Limited Memory AI can improve in performance [70].

  Examples of Limited Memory AI

- A perfect example of a machine with limited memory is self-driving cars. These cars observe the conditions on the road, analyze them, and make decisions about the applied speed, the shortest route, the behavior of vehicles from the opposite direction, etc.
  - To make a decision safely, these machines don't just look at the current situation – they identify road conditions and track other objects over a while [71].

- **Theory of Mind AI:** is a functional class of AI that falls underneath the General AI. Though an unrealized form of AI today, AI with Theory of Mind functionality would understand the thoughts and emotions of other entities. This understanding can affect how the AI interacts with those around them. In theory, this would allow the AI to simulate human-like relationships. Because Theory of Mind AI could infer human motives and reasoning, it would personalize its interactions with individuals based on their unique emotional needs and intentions. Theory of Mind AI would also be able to understand and contextualize artwork and essays, which today's generative AI tools are unable to do [70].

- **Self-Aware AI:** is a kind of functional AI class for applications that would possess super AI capabilities. Like theory of mind AI, Self-Aware AI is strictly theoretical. If ever achieved, it would have the ability to understand its own internal conditions and traits along with human emotions and thoughts. It would also have its own set of emotions, needs and beliefs [70].

  Self-awareness AI Examples

  Take, for example, a robot experiment by Professor Selmer Bringsjord at Rensselaer Polytechnic Institute in New York: He programmed the three robots to think that one of them had received the dumbing pill. Two robots remained silent when asked who got the medicine, while the third answered, "I don't know." After realizing that he wasn't the one being "silenced," the robot changed its response. So the fact that the robot realized that it could speak and that he wasn't the one that got the dumbing pill shows that it has developed a certain degree of self-awareness [71].

2.7 Domains of AI

The major domains of AI are neural network, robotics, expert systems, fuzzy logic systems and natural language processing (NLP).

2.7.1 Neural networks

A computational model that mimics the architecture and interconnections of neuron between different layers, called neural networks, have been inspired from the structure of human brain. These networks are very good at learning complex patterns and relationships in data: in other words, neural networks are the foundation of deep learning and of modern machine learning in general. One obvious application is recognizing patterns, like facial detection by social media for photo tagging , where analyzing vast image datasets enables accurate identification of individuals [72].

2.7.2 Robotics

Is a revolutionary field of artificial intelligence which empowers intelligent algorithms and smart machines to work and responds to the real world. By using sensors and sophisticated AI, robots use instantaneous environmental data to make decisions Robots 101 The importance of robotics is evident throughout a variety of fields: In manufacturing, robots streamline efficiency, and improve product quality, assembling items over and over, consistently faster than humans could, while in agriculture, robots plant, pick and package food, construct detailed plans of how to water specific crops and even dispense the exact amount of pesticides needed. Apart from these use-cases, robotics can be very useful in dangerous environments, disaster situations or even mundane domestic chores [73].

2.7.3 Expert system

Are AI-driven programs designed to emulate human expertise in solving domain-specific problems. By drawing from a structured knowledge base and applying predefined inference rules, these systems analyze user queries to deliver precise decision-making support—much like a specialist would in fields such as medicine or engineering. Their effectiveness hinges on the depth of curated knowledge they contain; the richer their database, the more accurate their solutions. A familiar example is Google's spell-check feature, which leverages linguistic rules to suggest corrections in real time[74].

2.7.4 Fuzzy Logic

Is a method of reasoning that resembles human reasoning. This approach is similar to how humans perform decision making. And it involves all intermediate possibilities between YES and NO.Examples of fuzzy logic systems used are in consumer electronics, automobiles, comparison of data, etc . Fuzzy logic systems are widely applied in consumer electronics, automotive systems, and comparative data analysis, where they facilitate smoother, more human-like responses and control mechanisms [74].

2.7.5 Natural Language Processing (NLP)

Is a branch of AI that enables computers to interpret, generate, and translate human language, revolutionizing how machines interact with people. By processing text and speech, NLP powers chatbots that understand queries, systems that analyze sentiment, and tools that summarize or translate content across languages. Its value lies in automating language-based tasks—from extracting insights from vast datasets to facilitating seamless multilingual communication—while enhancing human-machine collaboration. Practical applications span virtual assistants, real-time translation services, and data-driven decision-making, making NLP a cornerstone of modern AI solutions.[75]

2.8 Subsets of Artificial Intelligence

Learning contains two essential types in the field of technology, **Machine Learning (ML)** and **Deep Learning (DL)**. are two important subfields of Artificial Intelligence (AI) that are closely related, but differ in their approach to data analysis.

2.8.1 Machine Learning

In 1959, Arthur Samuel, a pioneering computer scientist in machine learning, described the field as a discipline that enables computers to learn autonomously without explicit programming [76] . This definition highlights the ability of machines to acquire knowledge independently. Tom Mitchell, in his book on machine learning, framed it as the study of algorithms that allow programs to enhance their performance automatically through experience [77] . According to Mitchell, learning occurs when a program improves its execution of specific tasks by leveraging accumulated data or prior experiences.

Machine learning is a subset of artificial intelligence (AI) that gives computers the ability to learn without being explicitly programmed. Machine learning models are created by obtaining data samples, training the model on that data, and then using it to make decisions or predictions about new and unknown data.

The goal of machine learning is to enable computers to make predictions about the future based on examples from the past [78].

Classification of Machine Learning

Machine Learning algorithms are typically classified into three categories: **supervised learning**, **unsupervised learning**, and **reinforcement learning**[79] .

- **Supervised Learning** is a machine learning technique that relies on labeled datasets to train models for accurate classification or prediction. In this approach, the algorithm learns from input-output pairs, adjusting its parameters over time to improve performance. Supervised learning tasks are broadly categorized into two types:

    1. **Classification:** this involves assigning data points to predefined categories. For example, an algorithm can distinguish between apples and oranges or filter spam emails from inboxes. Common classification algorithms include:
        - Linear classifiers
        - Support Vector Machines (SVM)
        - Decision Trees
        - Random Forest
    2. **Regression:** this method predicts continuous numerical outcomes by analyzing relationships between dependent and independent variables. For instance, regression models can forecast sales revenue based on historical trends. Widely used regression techniques include:
        - Linear Regression
        - Logistic Regression
        - Polynomial Regression

- **Unsupervised learning** is a type of machine learning where algorithms analyze and group unlabeled datasets without human guidance. Instead of relying on predefined labels, these models identify hidden structures and patterns within the data on their own.

    Unsupervised learning is primarily used for three key tasks:

  - **Clustering:** this technique groups data points based on their similarities or differences. for instance, the K-means algorithm organizes data into K distinct clusters, where K determines the number and granularity of groups. clustering is widely applied in market segmentation, image compression, and other areas where pattern recognition is essential.
  - **Association:** this method uncovers relationships between variables in a dataset using rule-based learning. a common application is market basket analysis, which powers recommendation systems like "Customers who bought this also bought..." suggestions in e-commerce.
  - **Dimensionality Reduction:** when datasets have too many features, this technique simplifies them while retaining critical information. it is often used in data preprocessing—for example, autoencoders help remove noise from images to enhance their quality.

- **Reinforcement Learning** is a bit different from supervised and unsupervised learning. In reinforcement learning, the model learns from the consequences of its actions. The model receives feedback on its performance, and uses that information to adjust its actions and improve its performance over time.

  A classic example of reinforcement learning is training a model to play a game like chess or Go. The model receives feedback on its performance in the form of win or loss, and then adjusts its strategy to improve its chances of winning [80].

Algorithms used in machine learning

- **Support Vector Machine (SVM)** is a classic machine learning technique still widely used for solving classification problems in Big Data [81]. The SVM algorithm can classify both linear and non-linear data by first mapping each data point into an n-dimensional feature space, where n represents the number of features. It then determines the optimal hyperplane that separates the data into two classes while maximizing the margin (the distance between the hyperplane and the nearest data points of each class) and minimizing classification errors. The margin for each class is defined as the distance between the decision boundary and its closest supporting data points [82].

- **K-Nearest Neighbors (KNN)** is a non-parametric supervised learning algorithm used for classification tasks. Unlike parametric methods, KNN makes no assumptions about the underlying data distribution. It works by using a labeled training dataset where data points are categorized into distinct classes. To classify an unlabeled data point, KNN identifies the 'K' closest training examples (neighbors) in the feature space and assigns the most common class among them. This simple yet effective approach makes KNN particularly useful for pattern recognition and data mining applications [83].

- **Artificial Neural Networks (ANN)** are a computational method that builds multiple processing units based on interconnected nodes. The network consists of numerous artificial neurons or nodes that connect input layers to output layers, forming a system designed to mimic how the human brain processes information. These networks learn patterns and relationships in data through training, enabling them to perform complex tasks like classification, prediction, and decision-making. ANNs are fundamental to deep learning and excel at handling nonlinear relationships in large datasets[84].

Challenges and Limitations of Machine Learning

A fundamental constraint in machine learning is its heavy reliance on massive, high-quality datasets. ML algorithms struggle to deliver precise predictions without sufficient and diverse training data—accuracy typically improves as the volume and variety of data increase. Heterogeneous inputs enhance the model's ability to generalize, leading to more reliable outputs. This learning process resembles how a new employee gains expertise: initial errors gradually diminish through experience, allowing for increasingly efficient and accurate performance over time. Thus, the effectiveness of ML hinges on both the quantity and richness of the data it processes.

2.8.2 Deep Learning

Deep Learning (DL), a specialized branch of Machine Learning (ML) and a subset of Artificial Intelligence (AI), represents an advanced approach to automated learning. Unlike traditional ML systems that rely on structured input data and predefined learning methods (supervised or unsupervised), DL mimics the human neural network's architecture and function.

DL employs multi-layered artificial neural networks, where increasing layers constitute a Deep Neural Network (DNN) [85]. These networks consist of:

- An input layer for data reception.
- Multiple hidden layers for progressive feature extraction.
- An output layer for final predictions [86].

The typical deep learning workflow follows a structured process: beginning with problem definition, then moving through data identification and preparation, algorithm selection, model training and validation, before concluding with comprehensive performance evaluation to ensure optimal results. This end-to-end approach allows deep neural networks to develop sophisticated understanding and make accurate predictions across diverse applications [87].

2.9 General Conclusion

This study explored the diversity of plant diseases and advancements in agricultural practices, comparing traditional and modern approaches to disease detection. Traditional methods, such as visual inspection and laboratory testing, often rely on manual expertise and can be time-consuming, limiting their scalability. In contrast, modern techniques leverage cutting-edge technologies like artificial intelligence (AI) and computer vision to provide faster, more accurate diagnoses. After evaluating various techniques, deep learning emerged as the most effective methodology for accurate and efficient disease identification, outperforming conventional methods in terms of speed, precision, and adaptability to large-scale agricultural systems.

The research delved into the fundamental concepts of artificial intelligence (AI), machine learning (ML), and deep learning (DL), highlighting key algorithms and their applications in agriculture. AI-driven solutions have transformed disease detection by automating the analysis of plant images, enabling early diagnosis and timely intervention. Machine learning models, such as support vector machines (SVMs) and random forests, have been widely used, but deep learning architectures, particularly convolutional neural networks (CNNs), have shown superior performance due to their ability to extract intricate features from visual data. The study also examined transfer learning, where pre-trained models are fine-tuned for specific crop diseases, reducing the need for extensive datasets while maintaining high accuracy.

The proposed work introduced improved deep learning models, including YOLOv8, YOLOv12, and Faster R-CNN, for detecting diseases in wheat, palm, and maize crops. These models were selected for their robustness in object detection and real-time processing capabilities. YOLO (You Only Look Once) variants excelled in speed, making them suitable for field applications, while Faster R-CNN provided higher precision in complex disease identification tasks. Detailed explanations of the tools, datasets, and methodologies were provided, along with the steps taken to optimize performance, such as data augmentation, hyperparameter tuning, and model pruning. Additionally, a user-friendly application was developed to facilitate plant disease detection for farmers and agricultural stakeholders, ensuring accessibility even for users with limited technical expertise.

Overall, this study demonstrates the significant potential of AI and deep learning in revolutionizing plant disease detection, offering a scalable and efficient solution to enhance agricultural productivity and food security. By reducing crop losses and enabling proactive disease management, these technologies can contribute to sustainable farming practices. Future research could focus on expanding the model's applicability to more crop varieties, integrating multispectral and hyperspectral imaging for enhanced detection, and improving real-time detection capabilities through edge computing and lightweight AI models. Further collaboration with agronomists and farmers will also be essential to refine these systems for real-world agricultural challenges.

Bibliography

[1] Food and Agriculture Organization (FAO), "The impact of plant diseases on global food security," 2023.

[2] Food and A. Organization, "New standards to curb the global spread of plant pests and diseases," 2019. last accessed on 08/11/22.

[3] W. Bank, "Employment in agriculture," tech. rep., National Institute of Technology, Washington, D.C., 2021.

[4] R. W. Mwangi, M. Mustafa, K. Charles, I. W. Wagara, and N. Kappel, "Selected emerging and reemerging plant pathogens affecting the food basket: A threat to food security," *Journal of Agriculture and Food Research*, vol. 14, December 2023.

[5] G. N. Agrios, *Plant Pathology*. Burlington, MA: Elsevier Academic Press, 5 ed., 2005.

[6] Y. Gai and H. Wang, "Plant disease: A growing threat to global food security," *Agronomy*, vol. 14, p. 1615, jul 2024.

[7] S. Savary, L. Willocquet, S. J. Pethybridge, P. Esker, N. McRoberts, and A. Nelson, "The global burden of pathogens and pests on major food crops," *Nature Ecology & Evolution*, vol. 3, pp. 430–439, mar 2019.

[8] R. N. Strange and P. Scott, "Plant disease: A threat to global food security," *Annual Review of Phytopathology*, vol. 43, pp. 83–116, 2005.

[9] A. Jain, S. Sarsaiya, Q. Wu, Y. Lu, and J. Shi, "A review of plant leaf fungal diseases and its environment speciation," *Bioengineered*, vol. 10, pp. 409–424, 27 September 2023.

[10] F. Di Serio, J. W. Randles, R. Flores, R. A. Owens, T. Sano, *et al.*, "Viroids," in *Virus Taxonomy: Ninth Report of the International Committee on Taxonomy of Viruses* (A. M. King, M. J. Adams, E. B. Carstens, and E. J. Lefkowitz, eds.), Waltham, MA: Academic Press, 2011.

[11] R. Flores, C. Hernández, A. E. Martínez de Alba, J.-A. Darós, and F. Di Serio, "Viroids and viroid-host interactions," *Annual Review of Phytopathology*, vol. 43, pp. 117–139, 2005.

[12] Y. M. Bar-On, R. Phillips, and R. Milo, "The biomass distribution on earth," *Proceedings of the National Academy of Sciences*, vol. 115, pp. 6506–6511, jun 2018.

[13] R. Rajesh-Kannan, Y. Chidambaram, and R. Manavalan, "A novel approach for early detection of parkinson's disease using speech signals," *Journal of Medical Systems*, vol. 40, pp. 1–12, aug 2016.

[14] "Speciality cropportunities: Diseases," 2021. Government of Ontario, Canada.

[15] H. S. Judelson and F. A. Blanco, "The spores of phytophthora: weapons of the plant destroyer," *Nature Reviews Microbiology*, vol. 3, pp. 47–58, January 2005. Publisher: Nature Publishing Group.

[16] C. A. Lévesque, H. Brouwer, L. Cano, J. P. Hamilton, C. Holt, E. Huitema, S. Raffaele, G. P. Robideau, M. Thines, J. Win, M. M. Zerillo, G. W. Beakes, J. L. Boore, D. Busam, B. Dumas, S. Ferriera, S. I. Fuerstenberg, C. M. M. Gachon, E. Gaulin, F. Govers, L. Grenville-Briggs, N. Horner, J. Hostetler, R. H. Y. Jiang, J. Johnson, T. Krajaejun, H. Lin, H. J. G. Meijer, B. Moore, P. Morris, V. Phuntmart, D. Puiu, J. Shetty, J. E. Stajich, S. Tripathy, S. Wawra, P. van West, B. R. Whitty, P. M. Coutinho, B. Henrissat, F. Martin, P. D. Thomas, B. M. Tyler, R. P. De Vries, S. Kamoun, M. Yandell, N. Tisserat, and C. R. Buell, "Genome sequence of the necrotrophic plant pathogen Pythium ultimum reveals original pathogenicity mechanisms and effector repertoire," *Genome Biology*, vol. 11, no. 7, p. R73, 2010. Publisher: BioMed Central.

[17] A. Bertaccini, "Phytoplasmas: diversity, taxonomy, and epidemiology," *Frontiers in Bioscience*, vol. 12, pp. 673–689, 2007. Publisher: Frontiers in Bioscience.

[18] P. G. Weintraub and L. Beanland, "Insect vectors of phytoplasmas," *Annual Review of Entomology*, vol. 51, pp. 91–111, January 2006. Publisher: Annual Reviews.

[19] K. Oshima, K. Maejima, Y. Isobe, A. Endo, S. Namba, and Y. Yamaji, "Molecular mechanisms of plant manipulation by secreting effectors of phytoplasmas," *Physiological and Molecular Plant Pathology*, vol. 125, p. 102009, May 2023.

[20] Z. A. Handoo, "Plant-parasitic nematodes," technical report, United States Department of Agriculture, Agricultural Research Service, Mycology and Nematology Genetic Diversity and Biology Laboratory, Beltsville, MD, USA, August 1998.

[21] E. L. Stewart, G. B. Lucas, C. L. Campbell, and L. T. Lucas, *Introduction to Plant Diseases: Identification and Management*, vol. 83. Springer, 1991.

[22] L. Taiz and E. Zeiger, *Plant Physiology*. Sunderland, MA: Sinauer Associates, 5th ed., 2010.

[23] "Parts of plants," 2023. Online educational resource.

[24] Science Facts Team, "Parts of a plant and their functions," 2023. Educational science resource.

[25] Elite Tree Care Specialists, "Root rot: Symptoms, causes, and treatment," 2023.

[26] Royal Horticultural Society, "Crown gall," 2023.

[27] Alford and D. V., "Miscellaneous pests," in *Pests of Ornamental Trees, Shrubs and Flowers*, pp. 434–443, London: Academic Press, 2nd ed., 2012.

[28] "Tobacco rattle virus (trv)," 2023. Potato disease information sheet.

[29] P. H. Raven, R. F. Evert, and S. E. Eichhorn, *Biology of Plants*. New York: W.H. Freeman and Company, 8th ed., 2013.

[30] D. Whiting, M. Roll, L. Vickerman, P. O'Neal, R. Tolan, M. Small, J. Murgel, and S. Shaffer, "Colorado master gardener garden notes," 2023. Revised June 2016, Reviewed March 2023.

[31] Pioneer Agronomy Team, "Stem canker in soybeans," 2023. Crop Focus technical bulletin.

[32] E. Pfeufer, C. Bradley, and N. Gauthier, "Southern blight," Plant Pathology Fact Sheet PPFS-GEN-16, University of Kentucky, College of Agriculture, Food and Environment, August 2018.

[33] M. F. Heimann and B. Hudelson, “Bacterial canker,” 2024.

[34] K. Esau, *Anatomy of Seed Plants*. New York: John Wiley & Sons, 2nd ed., 1977.

[35] D. Benlaksira, *Anatomie des organes végétaux / Feuille*. 2023.

[36] D. Whiting, M. Roll, L. V. A. by Scott Johnson, D. Whiting, and R. Tolan, “Colorado master gardener notes,” 2017. Reviewed March 2023 by John Murgel, CSU Extension and Sherie Shaffer, CSU Extension.

[37] G. N. Agrios, *Plant Pathology*. Amsterdam: Academic Press, 5 ed., 2005. La cinquième édition.

[38] M. Yassine, R. Farouk, S. E. K. K. A. L. Mansouria, and B. C. Eddine, *PLANT DOCTOR: Développement d’un système intelligent pour le diagnostic des maladies des plantes*. PhD thesis, 2023. Doctoral dissertation.

[39] V. Cherlinka, “Powdery mildew: Causes, symptoms, and treatment.” Last updated: 26.02.2025.

[40] A. Author, B. Author, and C. Author, “Article title,” *Plant Physiology*, vol. 192, pp. 2336–2355, July 2023. American Society of Plant Biologists.

[41] H. Hamadani, S. M. Rashid, J. D. Parrah, A. A. Khan, K. A. Dar, A. A. Ganie, A. Gazal, R. A. Dar, and A. Ali, “Traditional farming practices and its consequences,” in *Microbiota and Biofertilizers, Vol 2*, ch. 6, pp. 119–128, Springer, 1st ed., April 2021.

[42] M. A. Altieri, *Agroecology: The Science of Sustainable Agriculture*. Boulder, CO: Westview Press, 2nd ed., 1995. Foundational text in ecological agriculture.

[43] “Traditional agriculture and its impact on the environment.” Online educational article.

[44] L. A. Thrupp, “Linking agricultural biodiversity and food security: The valuable role of sustainable agriculture,” *International Affairs*, vol. 76, no. 2, pp. 265–281, 2000.

[45] J. Pretty, “Agricultural sustainability: Concepts, principles and evidence,” *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 363, no. 1491, pp. 447–465, 2008.

[46] R. Vansnick, “Le retour aux techniques traditionnelles dans la culture et l’agriculture.” Article en ligne sur les pratiques agricoles traditionnelles.

[47] R. Bandyopadhyay and R. A. Frederiksen, “Contemporary global movement of emerging plant diseases,” *Annals of the New York Academy of Sciences*, vol. 894, pp. 28–36, December 1999.

[48] P. D. P. Kogut, “Precision agriculture technology to boost crop farming.” Blog post by Chief Scientific Officer at EOSDA.

[49] “Agriculture de précision,” 2021. Article de vulgarisation sur l’agriculture de précision.

[50] “Les nouvelles technologies au service de l’agriculture,” 2021. Article sur les innovations technologiques agricoles.

[51] F. Zhang, D. Li, G. Li, and S. Xu, “New horizons in smart plant sensors: Key technologies, applications, and prospects,” *Frontiers in Plant Science*, vol. 15, p. 1490801, 2025.

[52] "Drones in agriculture," 2019. EU-funded smart farming solution profile, Last updated : 07/12/22.

[53] S. Pongnumkul, P. Chaovalit, and N. Surasvadi, "Applications of smartphone-based sensors in agriculture: A systematic review of research," *Journal of Sensors*, pp. 195—308, July 2015. Open access review article.

[54] "5 mobile apps shaping agriculture in 2024," April 13, 2024. Industry report on trending agricultural apps.

[55] L. Dementiev, "How does hyperspectral satellite imagery help precision agriculture?." Technical blog post on hyperspectral imaging applications.

[56] "Les capteurs connectés pour l'agriculture." Article de blog sur les technologies agricoles connectées.

[57] "Hyperspectral imaging for agriculture and vegetation," 2023. Industrial application guide for hyperspectral cameras.

[58] C. Stryker and E. Kavlakoglu, "What is artificial intelligence (ai)?." IBM's official AI explainer.

[59] K. Abhishek, "Introduction to artificial intelligence." Technical overview of AI concepts.

[60] "How does artificial intelligence work?," 2023. Technical tutorial on AI mechanisms.

[61] M. Ghosh and T. Arunachalam, "Introduction to artificial intelligence," in *Artificial Intelligence and Machine Learning*, pp. 25–42, Singapore: Springer, May 2021.

[62] "Artificial intelligence in finance," 2024. IBM's industry perspective on financial AI applications.

[63] B. Clugston, "Advantages and disadvantages of ai in education." Blog post on educational technology.

[64] S. Wang, F. Wang, Z. Zhu, J. Wang, T. Tran, and Z. Du, "Artificial intelligence in education," *Expert Systems with Applications*, vol. 250, pp. 124–167, May 2024.

[65] "Artificial intelligence integration in video games." Performers' union guidance on AI impacts.

[66] "Ai in cybersecurity," 2024. Enterprise security white paper.

[67] "Artificial intelligence in healthcare," 2024. Medical diagnostics technology overview.

[68] H. Singh, "Artificial intelligence revolution and india's AI development: Challenges and scope," *International Journal of Scientific Research*, vol. 3, no. 3, pp. 417–421, 2017. Indexed in Indian Citation Index.

[69] "What is artificial intelligence (ai)?," 2023. Computer science tutorial on AI fundamentals , Last Updated : 22 Apr, 2025.

[70] IBM Data and AI Team, "Understanding the different types of artificial intelligence," 2023-10-12. IBM's technical classification of AI systems.

[71] N. Sahota, “7 types of artificial intelligence (with examples),” 2022-09-27. Expert classification of AI systems with practical examples.

[72] A. A. Awan, “What are neural networks?,” Aug 30, 2023.

[73] Alagar, “The key domains of artificial intelligence: Comprehensive overview,” 2019. Future-looking AI domain taxonomy.

[74] V. Krishnakishore, “Domains in artificial intelligence,” 2024-02-17. Personal technical blog post.

[75] A. Raj, “Exploring the major domains of ai (artificial intelligence),” 12th January, 2024.

[76] A. L. Samuel, “Some studies in machine learning using the game of checkers,” *IBM Journal of Research and Development*, vol. 44, no. 1-2, pp. 206–226, 2000. Reprint of 1959/1967 pioneering work.

[77] T. M. Mitchell, *Machine Learning*, vol. 1. New York: McGraw-Hill, 1997.

[78] “Machine learning: Qu’est-ce que c’est?.” Ressource pédagogique en français.

[79] J. Delua, “Supervised versus unsupervised learning: What’s the difference?,” 2021-03-12. IBM’s comparative guide on ML paradigms.

[80] H. Ben Salem, “Supervised vs unsupervised vs reinforcement learning,” Jan 26, 2023. Technical blog post with algorithmic examples.

[81] S. Suthaharan, “Support vector machine,” in *Machine Learning Models and Algorithms for Big Data Classification*, pp. 207–235, Springer, 2016.

[82] S. Uddin, A. Khan, M. E. Hossain, and M. A. Moni, “Comparing different supervised machine learning algorithms for disease prediction,” *BMC Medical Informatics and Decision Making*, vol. 19, p. 281, Dec 2019.

[83] K. Taunk, S. De, S. Verma, and A. Swetapadma, “A brief review of nearest neighbor algorithm for learning and classification,” in *Proceedings of the 2019 International Conference on Signal Processing and Communication (ICSC)*, pp. 1255–1260, IEEE, May 2019.

[84] R. Dastres and M. Soori, “Artificial neural network systems,” *International Journal of Imaging and Robotics*, vol. 21, pp. 13–25, Mar 2021. Formerly International Journal of Imaging.

[85] S. Herzog, C. Tetzlaff, and F. Wörgötter, “Evolving artificial neural networks with feedback,” *Neural Networks*, vol. 123, pp. 153–162, 2020.

[86] J. A. Reggia, “Neural computation in medicine,” *Artificial Intelligence in Medicine*, vol. 5, no. 2, pp. 143–157, 1993. Early application of ANNs in healthcare.

[87] J. L. Lobo, J. Del Ser, A. Bifet, and N. Kasabov, “Spiking neural networks and online learning: An overview and perspectives,” *Neural Networks*, vol. 121, pp. 88–100, 2020. Survey of SNNs for streaming data.