ADVANCES IN PHYSICAL MUTAGENIC SEED TREATMENT: UV radiation and Corona discharge

Mrs.V.Divyaprabha
Dr. N.Vairam
Ms.B.Jananee
Dr.N.Murugan

sky fox

Advances in physical mutagenic seed treatment: UV radiation and Corona discharge

Mrs.V.Divyaprabha, B.Tech (Agriculture Engineering),
M.E. in Irrigation and Water Management.
Dr. N. Vairam, M.Sc. (Agri.,)., Ph.D.,
Ms.B.Jananee B.Tech (Agricultural Engineering)
Dr. N. Murugan, M.Sc. (Agri.,)., Ph.D.,

Skyfox Publishing Group,
Skyfox Press #1789, Medical College Road
Thanjavur - 613004

2026

Book Name: Advances in Physical Mutagenic Seed Treatment: UV Radiation and Corona Discharges
ISBN Number: 978-93-90357-48-2

Publisher Information:
Publisher Contact & Support
Skyfox Publishing Group
Skyfox Press #1789,
Medical College Road
Thanjavur-613004
Tamil Nadu, India.
Phone: +918300123232
Email: skyfoxpublishing@gmail.com/
skyfox@skyfox.org.in
Website: www.skyfox.co

ISBN 978-93-90357-48-2
9 789390 357482

http://dx.doi.org/10.22573/spg.026.978-93-90357-48-2/S/053

Published on 17.07.2026

PREFACE

Agriculture is continuously evolving to meet the increasing demand for food production while maintaining environmental sustainability. Seed quality plays a crucial role in crop establishment, growth, and yield. In recent years, physical mutagenic seed treatment technologies have gained attention as eco-friendly alternatives to conventional chemical treatments. Among these technologies, UV radiation and corona discharge have shown promising results in improving seed germination, seedling vigour, and overall crop productivity.

This book, Advances in Physical Mutagenic Seed Treatment: UV Radiation and Corona Discharge, provides a comprehensive understanding of these emerging technologies. It covers the fundamentals of seed germination, working principles, mechanisms of seed treatment, and applications in various crops. Case studies and comparative analyses are also included to highlight the practical importance of these techniques in modern agriculture.

This book is specially designed for B.Sc. Agriculture and B.Tech. Agricultural Engineering students, along with researchers and academicians interested in seed technology. The content is presented in a simple and systematic manner to support academic learning and research. We hope this book serves as a valuable reference and contributes to the advancement of sustainable agricultural practices.

V.Divyaprabha

N.Vairam

B.Jananee

N.Murugan

INDEX

1. INTRODUCTION

Agriculture forms the foundation of global food production, and seed quality plays a crucial role in determining crop establishment, plant growth, and final yield. High-quality seeds exhibit good viability, uniform germination, and strong seedling vigour, enabling crops to perform well even under unfavourable environmental conditions. Since seed germination is the first and most critical stage of plant development, improving seed performance has become an important area of research in modern agriculture.

Traditionally, chemical seed treatments have been used to protect seeds from pests, diseases, and adverse environmental conditions. Although these treatments have proven effective, their excessive use has raised concerns regarding environmental pollution, chemical residues, human health risks, and the development of resistant pathogens. As a result, there is an increasing need for sustainable and eco-friendly alternatives that can enhance seed quality without causing environmental harm.

Physical mutagenic seed treatment technologies have emerged as promising alternatives to conventional chemical methods. These technologies utilize physical agents such as ultraviolet (UV) radiation and corona discharge to induce beneficial changes in seeds. UV radiation enhances seed performance by stimulating metabolic activity, activating enzymes, and reducing microbial contamination. Similarly, corona discharge treatment modifies seed surface properties, improves wettability, and enhances water absorption during germination.

Research studies have demonstrated that these technologies can significantly improve germination percentage, seedling vigour, plant growth, and crop productivity. In addition to enhancing seed performance, they offer environmentally friendly solutions by reducing dependence on chemical treatments. Their ability to improve seed quality while maintaining sustainability has attracted considerable attention from researchers and agricultural professionals worldwide.

This book focuses on the advances in physical mutagenic seed treatment, with particular emphasis on UV radiation and corona discharge technologies. It discusses their principles, mechanisms, equipment, applications in different crops, and effects on seed germination and plant growth.

.

2. SEED GERMINATION AND SEED VIGOUR

2.1 Seed Germination

Seed germination is the process by which a seed develops into a new plant under favorable environmental conditions. It is the first and most critical stage in crop establishment. Successful germination depends on several factors, including seed viability, moisture, temperature, oxygen, and light. When these conditions are suitable, the seed absorbs water and activates metabolic processes that initiate growth.

The germination process begins with water absorption, also known as imbibition. This is followed by enzyme activation and the breakdown of stored food materials. The radicle emerges first, forming the primary root, followed by the plumule, which develops into the shoot. These stages ultimately lead to the formation of a healthy seedling.

Seed germination plays a vital role in determining crop establishment and final yield. Poor germination results in uneven plant growth, reduced plant population, and lower productivity. Therefore, improving seed germination is an important objective in modern agriculture.

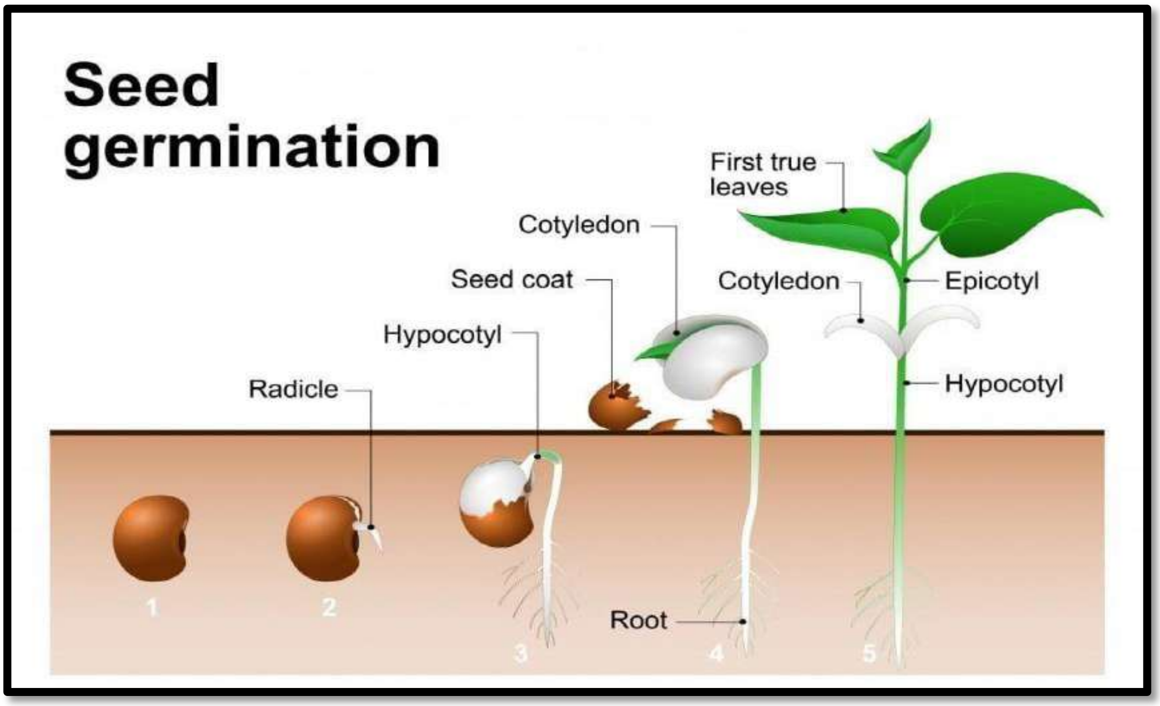

Figure 1. Stages of seed germination from seed to seedling.

2.2 Factors Affecting Seed Germination

Seed germination is a critical stage in the plant life cycle that determines crop establishment, growth, and final productivity. Successful germination depends on a combination of environmental, biological, and physical factors. These factors influence the activation of metabolic processes, enzyme activity, and early seedling development. Understanding these factors is essential for improving seed performance and ensuring uniform crop establishment.

Moisture

Water is one of the most important factors affecting seed germination. During germination, seeds absorb water through a process known as imbibition. This absorption activates enzymes, initiates metabolic activities, and softens the seed coat, allowing the embryo to grow. Adequate moisture is required for dissolving nutrients stored in the seed and transporting them to the growing embryo.

However, excessive water can also negatively affect germination. Waterlogged conditions reduce oxygen availability and may lead to seed decay or fungal growth. On the other hand, insufficient moisture delays germination and reduces seedling vigour. Therefore, optimal moisture conditions are essential for successful seed germination.

Temperature

Temperature plays a crucial role in regulating biochemical reactions during seed germination. Each crop species has a specific temperature range for optimal germination. Temperature affects enzyme activity, metabolic processes, and growth rate of the embryo.

Low temperatures slow down germination by reducing enzyme activity, while excessively high temperatures may damage seed tissues and reduce germination percentage. For most agricultural crops, moderate temperature conditions promote faster and uniform germination. Maintaining proper temperature is especially important in nursery management and controlled cultivation systems.

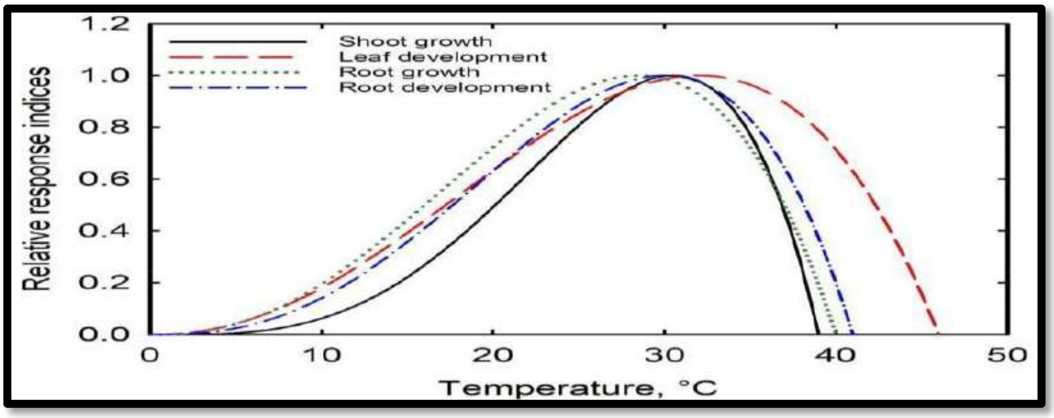

Figure 2. Temperature influence on shoot, leaf, and root growth showing optimum plant development around 25–30°C.

Oxygen

Oxygen is essential for respiration during seed germination. Seeds require oxygen to convert stored food into energy for embryo growth. Proper soil aeration ensures sufficient oxygen supply to seeds.

Poorly aerated soil conditions, such as compacted or waterlogged soils, reduce oxygen availability and slow down germination. In such conditions, seeds may fail to germinate or produce weak seedlings. Proper soil structure and drainage help maintain adequate oxygen levels for seed germination.

Light

Light influences germination in certain seeds. Some seeds require light for germination, while others germinate better in darkness. Light-sensitive seeds respond to specific wavelengths, which trigger physiological changes within the seed. For example, small seeds such as lettuce and some grasses require light for germination. In contrast, many crop seeds germinate well in dark conditions under soil. Light conditions should be carefully managed, especially in controlled environments such as nurseries and greenhouses.

Seed Quality

Seed quality is a major factor affecting germination. High-quality seeds with good viability and vigor show better germination and uniform growth. Seed quality depends on factors such as seed maturity, storage conditions, and genetic characteristics. Old or damaged seeds often show poor germination and weak seedling growth. Proper seed storage under controlled temperature and humidity conditions helps maintain seed quality and improves germination performance.

Soil Conditions

Soil properties such as texture, structure, pH, and nutrient availability influence seed germination. Well-drained and fertile soils provide favorable conditions for seed growth. Soil compaction may restrict seedling emergence, while poor soil fertility may reduce seedling vigor. Maintaining suitable soil conditions ensures proper seedling development and early plant growth.

Seed Treatment

Seed treatments such as physical, biological, or chemical methods influence germination performance. Physical seed treatments like UV radiation and corona discharge improve seed surface characteristics, enhance water absorption, and activate enzymes. These treatments reduce microbial contamination and improve germination percentage and seedling growth. Seed treatment is an effective method for improving crop establishment.

Environmental Stress

Environmental stress conditions such as drought, salinity, and extreme temperatures can negatively affect seed germination. Stress conditions reduce water absorption and metabolic activity, leading to delayed or poor germination. Physical seed treatment technologies help improve seed tolerance to stress conditions, enhancing germination and plant growth under adverse environments.

Genetic Factors

Genetic characteristics of seeds also influence germination. Different crop varieties have different germination rates, growth patterns, and environmental tolerance. Selecting high-quality varieties improves germination and crop establishment.

2.3 Seed Vigour

Seed Vigour refers to the ability of seeds to germinate rapidly and produce healthy seedlings under different environmental conditions. Seeds with high vigour show faster emergence, uniform growth, and better stress tolerance.

High seed vigour is important for:

- Better plant growth
- Improved nutrient uptake
- Increased crop yield.

Seeds with low vigour often produce weak seedlings, resulting in poor crop performance. Therefore, improving seed vigour is an important goal in seed technology and crop production.

Figure 3. Comparison between high vigour and low vigour seedlings.

Physical Dormancy

Physical dormancy occurs due to the presence of a hard and impermeable seed coat. The seed coat prevents water and oxygen from entering the seed, thereby restricting germination. Seeds with hard coats require physical or mechanical treatment to break dormancy. This type of dormancy is common in crops such as Groundnut (*Arachis hypogaea*), Soybean (*Glycine max*), and Cotton (*Gossypium hirsutum*). Physical seed treatment technologies such as UV radiation and corona discharge help modify the seed coat structure, improving permeability and promoting germination.

Physiological Dormancy

Physiological dormancy occurs due to internal biochemical conditions within the seed. In this case, the embryo is mature but cannot germinate due to hormonal imbalance or presence of chemical inhibitors. Seeds require specific environmental conditions such as temperature variation or light exposure to overcome this type of dormancy. Physiological dormancy is observed in crops such as Wheat (Triticum aestivum) and Rice (Oryza sativa) under certain conditions.

Morphological Dormancy

Morphological dormancy occurs when the embryo inside the seed is not fully developed at the time of seed maturity. These seeds require additional time for embryo development before germination can occur. This type of dormancy is common in certain horticultural crops and ornamental plants.

Chemical Dormancy

Chemical dormancy occurs when growth-inhibiting substances are present in the seed. These inhibitors prevent germination until they are removed or broken down. Environmental factors such as rainfall, temperature, or microbial activity help in removing these inhibitors naturally.

Factors Influencing Seed Dormancy

Seed dormancy is influenced by a combination of genetic, physiological, and environmental factors that prevent seeds from germinating even under favourable conditions. One of the major factors is the seed coat, which may be hard and impermeable, restricting the entry of water and oxygen necessary for germination.

Hormonal balance within the seed also plays a crucial role; high levels of abscisic acid (ABA) promote dormancy, while gibberellins stimulate germination. Environmental conditions during seed development, such as temperature, moisture availability, and light exposure, can significantly affect the degree of dormancy. Additionally, the presence of chemical inhibitors within the seed, immature embryo development, and genetic characteristics of the crop species contribute to dormancy. Storage conditions and seed age may also influence dormancy levels by altering physiological and biochemical processes within the seed. Understanding these factors is essential for developing effective methods to overcome dormancy and improve seed germination**.** Several factors influence seed dormancy, including:

- Seed coat thickness
- Moisture content
- Temperature
- Oxygen availability
- Hormonal balance
- Genetic characteristics

Environmental conditions during seed development also affect dormancy. Seeds formed under stress conditions may exhibit stronger dormancy compared to those formed under favorable conditions.

Methods to Break Seed Dormancy

1. Scarification

Scarification is a method used to break physical dormancy caused by hard and impermeable seed coats. In this process, the seed coat is scratched, cracked, or weakened to allow water and oxygen to enter the seed. Scarification can be performed mechanically using sandpaper or blades, chemically using acids, or thermally using hot water. This method is commonly used in seeds with hard coats, where water absorption is restricted. Improved permeability accelerates germination and promotes uniform seedling emergence.

The effectiveness of scarification depends on the degree of seed coat hardness and the method employed. Excessive scarification may damage the embryo, while insufficient scarification may fail to break dormancy. Therefore, proper treatment is essential to achieve optimum germination. This method is widely used in legumes and several tree species that possess hard seed coats.

2. Stratification

Stratification involves exposing seeds to specific temperature and moisture conditions for a certain period before sowing. This treatment mimics natural seasonal changes and helps overcome physiological dormancy. Cold stratification is the most common method, where seeds are stored in moist conditions at low temperatures. The treatment stimulates embryo development and activates biochemical processes necessary for germination.

Stratification helps reduce the concentration of germination inhibitors present within the seed. It also promotes hormonal changes that favour embryo growth and development. Seeds subjected to proper stratification often exhibit improved germination percentage and more uniform seedling emergence. This technique is commonly used in temperate fruit crops and forest species.

3. Water Soaking

Soaking seeds in water is a simple and effective method for breaking dormancy. The process softens the seed coat and promotes rapid water absorption. As water enters the seed, metabolic activities are activated, leading to faster germination. Depending on the crop species, seeds may be soaked in normal or warm water for several hours before planting.

Water soaking also enhances enzyme activity and accelerates the mobilization of stored food reserves. The method is inexpensive, easy to perform, and suitable for a wide range of agricultural crops. Farmers commonly use this technique to improve field emergence and reduce the time required for germination.

4. Chemical Treatment

Chemical treatments are used to overcome dormancy caused by physiological or chemical inhibitors within the seed. Chemicals such as gibberellic acid (GA_3), potassium nitrate, and thiourea stimulate germination by activating enzymes and promoting embryo growth. These treatments help overcome internal restrictions that prevent germination.

Chemical treatments are highly effective when applied at appropriate concentrations. They can significantly improve germination percentage and seedling vigour in dormant seeds. However, excessive concentrations may damage seeds or affect seedling growth. Therefore, proper dosage and treatment duration are important for successful results.

5. Physical Seed Treatment

Modern physical seed treatment technologies such as UV radiation and corona discharge are increasingly used to break seed dormancy. These treatments modify the seed coat, improve water absorption, and stimulate metabolic activity within the seed.

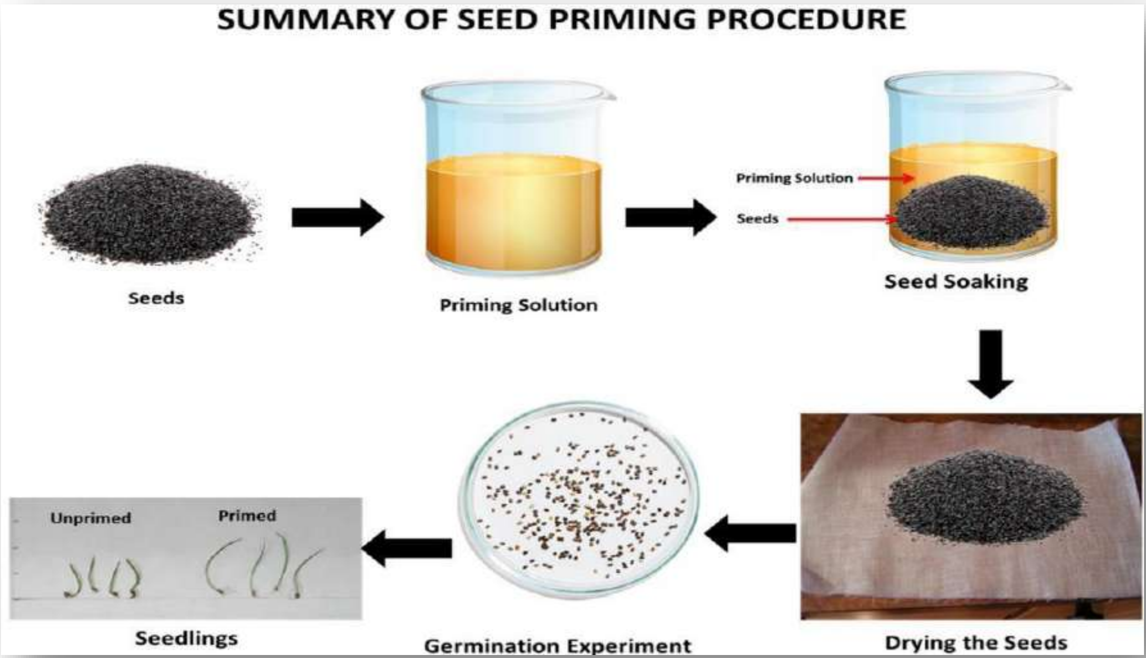

Figure 4. Physical seed treatment technologies used to break seed dormancy and promote uniform seedling growth.

UV radiation can activate enzymes and reduce microbial contamination, while corona discharge improves seed surface wettability. Physical treatments are considered environmentally friendly because they do not leave harmful chemical residues. They also improve seed vigour and enhance tolerance to environmental stress conditions. Due to their sustainability and effectiveness, these technologies are gaining importance in modern agriculture and seed technology research.

6. Temperature Treatment

Temperature treatment involves exposing seeds to controlled hot or cold conditions to overcome dormancy. Some seeds require exposure to high temperatures to weaken the seed coat, while others need low temperatures to activate physiological processes. Temperature treatment helps improve germination by promoting embryo growth and reducing dormancy-related barriers.

This method is widely used for seeds that naturally experience seasonal temperature variations before germination. Proper temperature treatment can significantly improve germination speed and uniformity. It is also useful for reducing seed-borne pathogens and improving seed health in certain crop species.

7. Light Treatment

Certain seeds require exposure to light to initiate germination. In such cases, providing the appropriate light intensity and duration helps break dormancy. Light influences hormonal balance and activates physiological processes that stimulate embryo growth. Conversely, some seeds germinate better in darkness. Light treatment regulates various biochemical activities associated with germination. Exposure to suitable light conditions improves seedling establishment and enhances plant development. Understanding crop-specific light requirements is important for maximizing germination and achieving healthy seedling growth.

8. Combined Treatments

In some cases, a single method may not be sufficient to overcome dormancy. Therefore, two or more methods are combined to achieve better results. For example, scarification may be followed by soaking, or stratification may be combined with chemical treatment. Combined treatments often provide higher germination percentages and more uniform seedling emergence.

These integrated approaches help overcome multiple dormancy barriers simultaneously. They improve seed performance more effectively than individual treatments alone. Combined methods are particularly useful for seeds exhibiting complex dormancy mechanisms and are widely used in advanced seed technology programs.

2.5 Role of Seed Treatment in Germination

Role of Seed Treatment in Germination

Seed treatment plays a vital role in improving germination, seedling establishment, and early plant growth. Germination is the first stage of plant development, and any improvement at this stage directly influences crop performance and yield. Seed treatment involves the application of physical, chemical, or biological agents to seeds before sowing to enhance their performance and protect them from environmental stress and pathogens. Proper seed treatment ensures uniform germination, strong seedlings, and better crop establishment.

One of the primary roles of seed treatment in germination is to improve seed viability and vigour. Seeds may lose their vigour during storage due to environmental conditions such as temperature and humidity. Seed treatment helps restore seed activity by stimulating metabolic processes and activating enzymes. These processes improve the ability of seeds to germinate quickly and produce healthy seedlings.

Seed treatment also plays an important role in protecting seeds from seed-borne diseases. Seeds often carry harmful microorganisms such as fungi and bacteria that reduce germination percentage and cause seedling diseases. Seed treatment helps eliminate or reduce these pathogens, thereby improving seed health. Healthy seeds germinate more efficiently and produce stronger seedlings. Another important function of seed treatment is enhancing water absorption. Germination begins with water uptake, which activates metabolic processes within the seed. Some seeds have hard seed coats that restrict water absorption. Seed treatment modifies the seed coat, improving permeability and allowing faster water absorption. This leads to quicker germination and uniform seedling emergence.

Seed treatment also improves enzyme activity during germination. Enzymes such as amylase, protease, and lipase break down stored food materials in the seed into simple nutrients. These nutrients provide energy for embryo growth and seedling development. Seed treatment stimulates enzyme activity, resulting in faster germination and improved seedling vigour. In addition, seed treatment helps in breaking seed dormancy. Some seeds remain dormant even under favourable conditions.

Physical seed treatments such as UV radiation and corona discharge help overcome dormancy by modifying seed structure and activating metabolic processes. This leads to improved germination and uniform crop establishment. Seed treatment also enhances tolerance to environmental stress. Seeds treated before sowing often show improved resistance to drought, temperature fluctuations, and soil salinity. These treatments prepare the seed for adverse environmental conditions, ensuring successful germination and seedling survival. Furthermore, seed treatment promotes uniform germination. Uniform germination is important for proper crop management, irrigation, and harvesting. When seeds germinate at the same time, plants grow uniformly, resulting in better crop performance and higher yield.

Seed treatment is widely used in various crops such as Wheat (*Triticum aestivum*), Rice (*Oryza sativa*), Maize (*Zea mays*), Sunflower (*Helianthus annuus*), and Soybean (*Glycine max*). These crops have shown improved germination and better seedling growth after seed treatment. Physical seed treatment methods such as UV radiation and corona discharge are gaining popularity due to their eco-friendly nature. These treatments improve seed germination without the use of harmful chemicals. They enhance seed metabolism, improve water absorption, and reduce microbial contamination.

Overall, seed treatment plays a significant role in improving germination, enhancing seedling vigour and promoting early plant growth. By improving seed health and performance, seed treatment contributes to better crop establishment and increased agricultural productivity.

3. PHYSICAL SEED TREATMENT TECHNOLOGIES

3.1 Overview of Physical Seed Treatment

Seed treatment plays an important role in improving seed germination, seedling vigour, and crop productivity. Traditionally, chemical treatments have been widely used to protect seeds from pests and diseases. However, increasing concerns about environmental pollution, chemical residues, and health risks have encouraged researchers to explore safer alternatives.

Physical seed treatment technologies have emerged as eco-friendly approaches that use different forms of physical energy to enhance seed performance. These methods improve seed germination, stimulate metabolic activity, and reduce microbial contamination without the use of harmful chemicals. As a result, physical seed treatments are gaining attention in sustainable agriculture.

Common physical seed treatment technologies include ultraviolet (UV) radiation, corona discharge, plasma treatment, magnetic field exposure, and laser treatment. Among these, UV radiation and corona discharge have shown promising results in improving seed germination and crop yield.

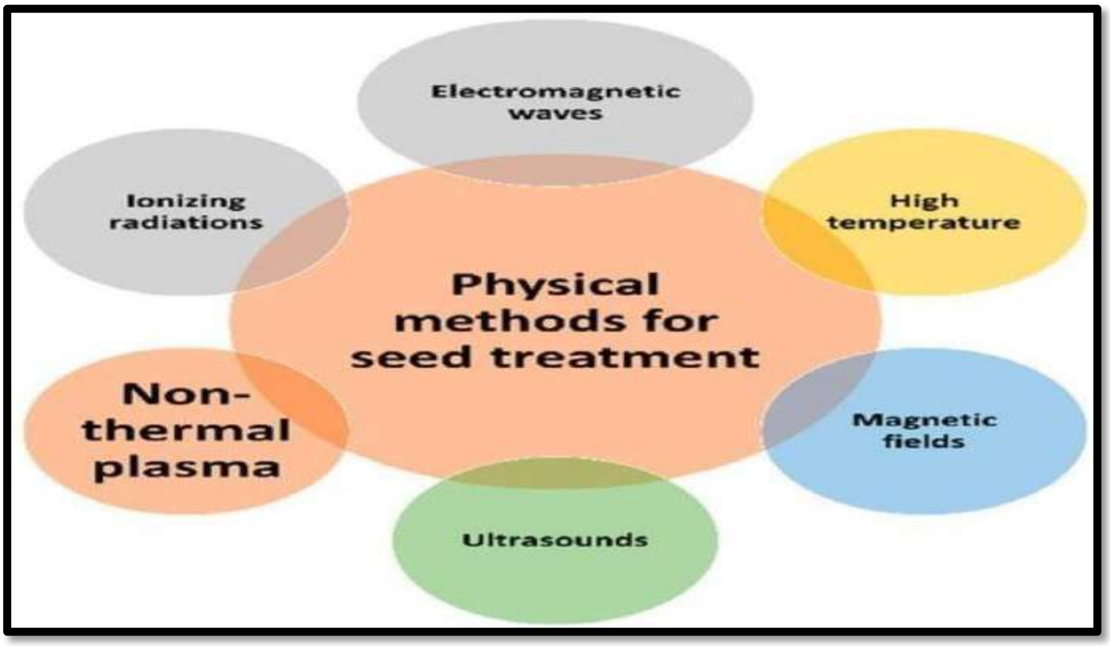

Figure 5. Different physical seed treatment technologies used in Agriculture.

3.2 Types of Physical Seed Treatment Technologies

Physical seed treatment technologies use physical agents such as radiation, plasma, magnetic fields, lasers, and temperature treatments to improve seed germination, seedling vigour, and crop productivity. Unlike chemical treatments, these methods do not leave harmful residues and are considered environmentally friendly. The major physical seed treatment technologies are discussed below.

1. Ultraviolet (UV) Radiation Treatment

Ultraviolet (UV) radiation is one of the most widely studied physical seed treatment methods. In this technique, seeds are exposed to controlled UV light for a specific duration. UV radiation modifies the seed coat, stimulates enzyme activity, and enhances metabolic processes within the seed. It also helps reduce microbial contamination by destroying harmful fungi and bacteria present on the seed surface. As a result, treated seeds often exhibit improved germination percentage, stronger seedlings, and better plant growth.

The effectiveness of UV treatment depends on factors such as exposure time, radiation intensity, and seed type. Properly treated seeds show increased vigour and improved resistance to environmental stress. Due to its simplicity and eco-friendly nature, UV radiation is increasingly being investigated as an alternative to chemical seed treatments in sustainable agriculture.

2. Corona Discharge Treatment

Corona discharge treatment involves exposing seeds to ionized air generated by a high-voltage electric field. The reactive particles produced during corona discharge interact with the seed surface and modify its physical properties. This increases seed wettability and improves water absorption during germination. The treatment also helps reduce microbial contamination and enhances root and shoot development.

The technology improves the hydrophilic nature of the seed coat, allowing seeds to absorb moisture more efficiently. Improved water uptake accelerates the germination process and promotes uniform seedling emergence. Because it does not require chemicals, corona discharge treatment is considered a safe and environmentally sustainable method for seed enhancement.

3. Cold Plasma Treatment

Cold plasma treatment is an advanced physical seed treatment technology that utilizes ionized gases containing reactive oxygen and nitrogen species. When seeds are exposed to cold plasma, the seed surface undergoes physical and chemical modifications that improve water uptake and metabolic activity. Cold plasma also possesses antimicrobial properties that help eliminate seed-borne pathogens.

Research studies have shown that cold plasma treatment can significantly improve seed germination, seedling vigour, and crop productivity. The technology can also enhance plant tolerance to environmental stress conditions such as drought and salinity. Because of its effectiveness and environmental safety, cold plasma is emerging as one of the most promising technologies in modern seed science.

4. Magnetic Field Treatment

Magnetic field treatment involves exposing seeds to magnetic energy before sowing. The magnetic field influences physiological and biochemical activities within the seed, leading to improved germination and plant growth. Research has shown that magnetic treatment can enhance enzyme activity, increase water absorption, and promote nutrient uptake.

Seeds treated with magnetic fields often exhibit stronger root systems and faster seedling development. In addition, magnetic treatment may improve plant resistance to environmental stress factors. Since the method is non-destructive and chemical-free, it has attracted interest as a sustainable technology for crop improvement.

5. Laser Irradiation Treatment

Laser seed treatment uses low-intensity laser beams to stimulate biological processes within seeds. The energy from laser irradiation activates enzymes, enhances cellular metabolism, and promotes cell division. These effects contribute to improved germination and seedling development.

Laser treatment has been reported to increase chlorophyll formation and photosynthetic efficiency in plants. Improved photosynthesis results in better growth and higher biomass production. Due to its precision and controllability, laser irradiation is considered a valuable tool for enhancing seed quality and crop productivity.

6. Electron Beam Treatment

Electron beam treatment is a non-chemical seed treatment method that uses high-energy electrons to sterilize seeds and eliminate pathogens. The treatment helps reduce fungal and bacterial contamination while maintaining seed viability. Electron beam technology is particularly useful for improving seed health and reducing disease incidence.

The method provides rapid treatment without leaving chemical residues on seeds. It can also improve storage quality by reducing microbial activity during storage. Because of these advantages, electron beam treatment is gaining attention as a modern alternative to chemical disinfectants.

7. Gamma Radiation Treatment

Gamma radiation treatment involves exposing seeds to low doses of gamma rays to induce beneficial genetic and physiological changes. Controlled exposure can stimulate germination, improve plant growth, and create useful mutations for crop improvement programs. Gamma radiation is widely used in mutation breeding to develop new crop varieties.

Many improved crop varieties have been developed using gamma radiation-induced mutations. These varieties often possess desirable traits such as disease resistance, drought tolerance, and higher yield potential. However, treatment doses must be carefully optimized to prevent harmful effects on seed viability.

8. X-Ray Treatment

X-ray treatment is another radiation-based technology used for seed improvement. Low doses of X-rays can stimulate metabolic processes and enhance germination, while higher doses are used in mutation breeding programs. X-ray treatment has been applied in agricultural research to study seed physiology and improve crop characteristics. The treatment can induce genetic variability that may be useful for crop improvement. Researchers use X-ray exposure to develop new plant traits and investigate plant responses to radiation. Its controlled application offers opportunities for enhancing agricultural productivity.

9. Ultrasound Treatment

Ultrasound treatment utilizes high-frequency sound waves to improve seed performance. The sound waves create microscopic vibrations that enhance water penetration into seeds and stimulate metabolic activity. This treatment accelerates germination and promotes uniform seedling growth.

Ultrasound treatment can also improve nutrient mobilization within seeds, leading to stronger seedlings. The technology is considered environmentally safe and can be applied to a wide range of crop species. Its ability to improve germination without chemical inputs makes it attractive for sustainable agriculture.

10. Thermal Treatment

Thermal treatment involves exposing seeds to controlled temperatures to improve germination and eliminate pathogens. Hot water treatment and dry heat treatment are commonly used methods. Thermal treatments help break seed dormancy, reduce microbial contamination, and improve seedling establishment.

In addition to disease control, thermal treatment enhances seed health and improves germination uniformity. The method is widely used in vegetable and horticultural crops where seed-borne diseases are a major concern. Proper temperature control is essential to ensure effective treatment without damaging the seeds**.**

3.3 Advantages of Physical Seed Treatment

Physical seed treatment methods such as ultraviolet radiation, magnetic field exposure, microwave treatment, and corona discharge have gained increasing attention in modern agriculture. These methods improve seed performance without the use of harmful chemicals, making them safer and more sustainable alternatives to conventional seed treatment techniques.

One of the major advantages of physical seed treatment is its eco-friendly nature. Unlike chemical treatments, physical methods do not leave harmful residues on seeds or in the soil. This helps in maintaining soil health and reducing environmental pollution. As agriculture moves toward sustainable and organic farming practices, physical seed treatment technologies are becoming more important. Another important advantage is improved seed germination. Physical treatments modify seed coat properties, allowing better water absorption and oxygen diffusion. These changes activate metabolic processes and enzyme activity, resulting in faster and uniform germination. Uniform germination helps in achieving proper crop establishment and improved field performance.

Physical seed treatment also enhances seedling vigour. Treated seeds produce stronger seedlings with better root and shoot development. Improved root growth allows plants to absorb nutrients and water more efficiently, leading to better plant growth and productivity. Furthermore, physical treatments help in reducing microbial contamination. Many physical methods, especially ultraviolet radiation and plasma treatment, destroy harmful microorganisms present on seed surfaces. This reduces seed-borne diseases and improves plant health without the need for chemical fungicides. Physical seed treatment technologies offer several advantages over traditional chemical treatments:

- Eco-friendly and sustainable
- No chemical residues
- Improved germination rate
- Enhanced seedling vigour
- Reduced microbial contamination
- Improved crop productivity

These benefits make physical seed treatment technologies suitable for sustainable agricultural practices.

3.4 Limitations of Physical Seed Treatment

Physical seed treatment technologies such as ultraviolet (UV) radiation and corona discharge offer several advantages, including eco-friendly operation and improved seed performance. However, despite these benefits, certain limitations restrict their widespread adoption in agricultural practices. Understanding these limitations is important for improving these technologies and promoting their effective use in modern agriculture.

Sensitivity to Treatment Parameters

One of the major limitations of physical seed treatment is the sensitivity to treatment parameters such as exposure time, intensity, and distance from the treatment source. Seeds treated with insufficient exposure may not show significant improvement in germination or growth. On the other hand, excessive exposure may damage seed tissues, reduce viability, and negatively affect germination.

Different crops and seed varieties require different treatment conditions. Therefore, determining optimal treatment parameters becomes essential but also challenging. Improper parameter selection may result in inconsistent outcomes, limiting the reliability of physical seed treatments.

Variation Among Crop Species

Not all seeds respond similarly to physical treatments. Some crop seeds show significant improvement in germination and growth, while others may show minimal or no response. This variation occurs due to differences in seed size, seed coat thickness, moisture content, and genetic characteristics. For example, seeds with hard seed coats may require longer exposure, whereas delicate seeds may be damaged easily. This variability makes it difficult to apply a standard treatment procedure across all crops and requires crop-specific research.

Equipment Cost and Availability

Physical seed treatment technologies often require specialized equipment such as UV chambers, corona discharge units, and plasma generators. These systems may involve high initial investment, which can limit adoption by small-scale farmers. In addition, maintenance and calibration of equipment require technical expertise. Limited availability of such equipment in rural areas also restricts widespread implementation. Developing low-cost and portable systems remains an important challenge.

Limited Large-Scale Application

Most research on physical seed treatment technologies has been conducted under laboratory or small-scale conditions. Large-scale field application is still limited. Treating large quantities of seeds uniformly remains a challenge, particularly in commercial agricultural operations.

Industrial-scale seed treatment systems require automation and precise control mechanisms. Until such systems become widely available and cost-effective, large-scale adoption may remain limited.

Risk of Seed Damage

Although physical treatments are generally safe, improper treatment can cause seed damage. Excessive UV radiation may damage cellular structures, reduce enzyme activity, and decrease seed viability. Similarly, high-intensity corona discharge may alter seed surface properties excessively and negatively affect germination. Therefore, careful monitoring and control of treatment conditions are necessary to avoid seed damage.

Limited Awareness Among Farmers

Physical seed treatment technologies are still emerging and not widely known among farmers. Lack of awareness and technical knowledge limits adoption. Farmers often prefer traditional seed treatment methods due to familiarity and ease of use. Training programs and demonstration studies are required to improve awareness and encourage adoption of these technologies.

Energy Requirement

Some physical seed treatment systems require electricity and controlled operating conditions. In rural areas where power supply is inconsistent, this may become a limitation. Energy-efficient equipment is needed to improve practical usability.

4. UV RADIATION SEED TREATMENT TECHNOLOGY

4.1 Introduction to UV Radiation

Ultraviolet (UV) radiation is a form of electromagnetic radiation with wavelengths shorter than visible light and longer than X-rays. In recent years, UV radiation has gained significant attention as an emerging physical seed treatment technology. It is considered an eco-friendly method because it does not involve chemical use and does not leave harmful residues on seeds.

UV radiation treatment enhances seed performance by stimulating physiological and biochemical processes. It activates enzymes, improves metabolic activity, and reduces microbial contamination on the seed surface. These effects result in improved germination, better seedling growth, and increased crop productivity. UV radiation treatment is widely studied in crops such as wheat, rice, maize, sunflower, and vegetables. Research findings indicate that controlled UV exposure improves seed vigour and plant development.

4.2 Types of UV Radiation

Ultraviolet (UV) radiation is a part of the electromagnetic spectrum with wavelengths shorter than visible light and longer than X-rays. Based on wavelength and energy level, UV radiation is classified into three main types: UV-A, UV-B, and UV-C. Each type possesses distinct characteristics and biological effects on seeds, plants, and microorganisms. In agriculture, understanding these categories is important because different UV wavelengths produce different responses in seed germination and plant growth.

UV-A (315–400 nm)

UV-A radiation has the longest wavelength and the lowest energy among all ultraviolet radiations. It constitutes the largest portion of ultraviolet radiation reaching the Earth's surface because it is not significantly absorbed by the atmosphere. Due to its lower energy, UV-A causes minimal damage to plant tissues and is mainly associated with physiological and metabolic stimulation. In seed treatment, UV-A radiation can enhance certain biological activities by influencing enzyme function and cellular metabolism. Studies have shown that controlled exposure to UV-A may improve seedling growth, chlorophyll production, and photosynthetic activity. However, its ability to eliminate microorganisms is relatively limited compared to UV-C radiation. Therefore, UV-A is generally used for growth stimulation rather than seed disinfection.

UV-B (280–315 nm)

UV-B radiation has a shorter wavelength and higher energy than UV-A. A significant portion of UV-B is absorbed by the ozone layer, while a smaller amount reaches the Earth's surface. UV-B has a stronger biological effect on plants and seeds due to its increased energy. Controlled UV-B exposure can stimulate germination by activating metabolic processes and enhancing enzyme activity. It may also promote the synthesis of protective compounds that help plants tolerate environmental stresses. In some crops, moderate UV-B treatment has been reported to improve seedling vigor and growth. However, excessive exposure can damage DNA, reduce germination percentage, and negatively affect plant development. Therefore, careful regulation of treatment duration and intensity is essential.

UV-C (100–280 nm)

UV-C radiation possesses the shortest wavelength and the highest energy among all ultraviolet radiations. Under natural conditions, UV-C does not reach the Earth's surface because it is completely absorbed by atmospheric gases. Therefore, artificial UV-C lamps are used for seed treatment applications. UV-C is the most important type of UV radiation in physical seed treatment technology. Its strong antimicrobial properties enable it to destroy bacteria, fungi, viruses, and other harmful microorganisms present on seed surfaces. By reducing microbial contamination, UV-C treatment improves seed health and reduces seed-borne diseases. In addition to its disinfecting effect, controlled UV-C exposure stimulates metabolic activity, enzyme activation, and water absorption in seeds. These changes often result in improved germination percentage, enhanced seedling vigor, and better crop establishment. Due to these advantages, UV-C radiation is the most commonly used UV source in agricultural seed treatment systems.

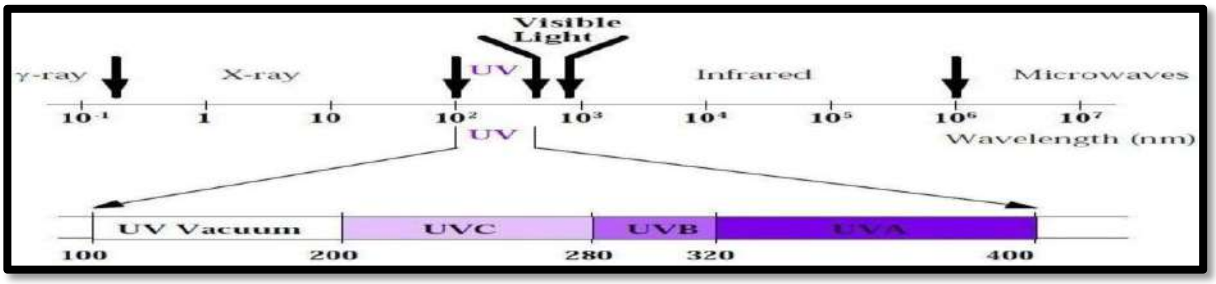

Figure 6. Ultraviolet radiation spectrum showing UV-A, UV-B, and UV-C Region

4.3 UV Radiation Equipment

UV seed treatment involves exposing seeds to controlled ultraviolet (UV-C) radiation using a specially designed disinfection chamber. The given setup consists of a closed treatment system integrated with monitoring and control components to ensure uniform exposure and safe operation. The major components of the UV radiation equipment shown in the figure include:

- **Disinfection Chamber:** The disinfection chamber is the primary component of the UV seed treatment system where seeds are placed for controlled exposure to ultraviolet radiation. It is designed as a completely enclosed structure to prevent the leakage of harmful UV rays into the surrounding environment, thereby ensuring operator safety. The chamber provides a stable and controlled treatment environment, allowing uniform distribution of UV radiation across the seed surface. Its enclosed design also minimizes external interference and helps maintain consistent treatment conditions throughout the process. By ensuring safe and effective UV exposure, the disinfection chamber plays a crucial role in improving seed germination and seedling development.
- **UV-C Lamps (8W): T**he UV-C lamps serve as the primary source of ultraviolet radiation in the seed treatment system. Two 8W UV-C lamps are strategically positioned inside the disinfection chamber to ensure uniform exposure of seeds placed on the treatment tray. These lamps emit ultraviolet radiation within the germicidal wavelength range, which is highly effective in reducing microbial contamination and stimulating beneficial physiological changes in seeds. The arrangement of the lamps helps achieve even distribution of radiation across the entire seed surface, minimizing untreated areas. Controlled exposure to UV-C radiation enhances seed germination, improves seedling vigour, and contributes to better overall seed performance.
- **Seed Holder/Tray:** The seed holder or tray is designed to securely hold the seeds during the UV treatment process and ensure uniform exposure to ultraviolet radiation. In the experimental setup, corn seeds are placed in a single layer on the tray positioned between the UV-C lamps. This arrangement allows all seeds to receive nearly equal radiation intensity, minimizing variations in treatment. The tray prevents seed overlapping, which could otherwise block UV rays and result in uneven exposure. Proper positioning of seeds on the tray contributes to consistent treatment outcomes, improved germination, and reliable experimental results.
- **Lighting Bulb:** The lighting bulb is installed inside the disinfection chamber to provide adequate illumination for observing seed placement and monitoring the treatment process.

It enables researchers to visually inspect the arrangement of seeds on the tray and ensure proper positioning before UV exposure begins. The bulb also facilitates routine observation of equipment operation without affecting the treatment conditions. By improving visibility within the chamber, it helps maintain accuracy and consistency during experiments. Proper illumination supports efficient monitoring and contributes to the overall effectiveness of the UV seed treatment system.

- **Webcam:** The webcam is installed inside the disinfection chamber to capture images and continuously monitor seed conditions during the UV treatment process. It enables real-time observation of the seeds without opening the chamber, thereby preventing disruption of treatment conditions. The captured images can be used to assess seed appearance, monitor treatment progress, and document experimental observations. In advanced systems, the webcam data may also be utilized for image processing and analysis, such as contour detection and colour evaluation. This feature enhances monitoring accuracy and supports reliable data collection throughout the seed treatment experiment.
- **Sensors (SCD30 and AST331):** The SCD30 and AST331 sensors are integrated into the UV treatment system to continuously monitor important environmental parameters within the disinfection chamber. These sensors measure conditions such as temperature, humidity, and air quality, which can influence the effectiveness of UV treatment and seed response. Accurate monitoring helps maintain a stable treatment environment and ensures consistency throughout the experiment. The collected sensor data can be stored and analyzed to evaluate treatment performance and optimize operating conditions. By providing real-time environmental information, these sensors improve the reliability and precision of seed treatment studies.
- **Electronic Components Board:** The electronic components board serves as the central control unit of the UV seed treatment system. It consists of components such as the Arduino Nano microcontroller, relay modules, and logic level converters that regulate the operation of UV lamps, sensors, and other electronic devices. The board automates treatment procedures by controlling exposure time and coordinating communication between different system components. This automation reduces human error and enhances treatment accuracy. The electronic control system ensures smooth operation and reliable performance throughout the seed treatment process.
- **Raspberry Pi System:** The Raspberry Pi system functions as an advanced computing and data management platform within the UV treatment setup. It provides a graphical user interface (GUI) for monitoring treatment conditions, collecting sensor data, and controlling

system operations. The Raspberry Pi also stores experimental information and generates reports based on treatment results. In addition, it supports image processing and data analysis applications that help researchers evaluate seed responses. This intelligent system enhances automation, improves data management, and increases the overall efficiency of the UV seed treatment process.

- **Computer Interface:** The computer interface is connected to the treatment system through USB or serial communication and serves as a platform for data visualization and analysis. It receives information from sensors, cameras, and control units, allowing researchers to monitor treatment conditions in real time. Advanced image analysis techniques such as contour detection, colour detection, and histogram calculation can be performed using specialized software. These analyses provide valuable information regarding seed characteristics and treatment effectiveness. The computer interface therefore plays an important role in experimental monitoring, data processing, and result interpretation.

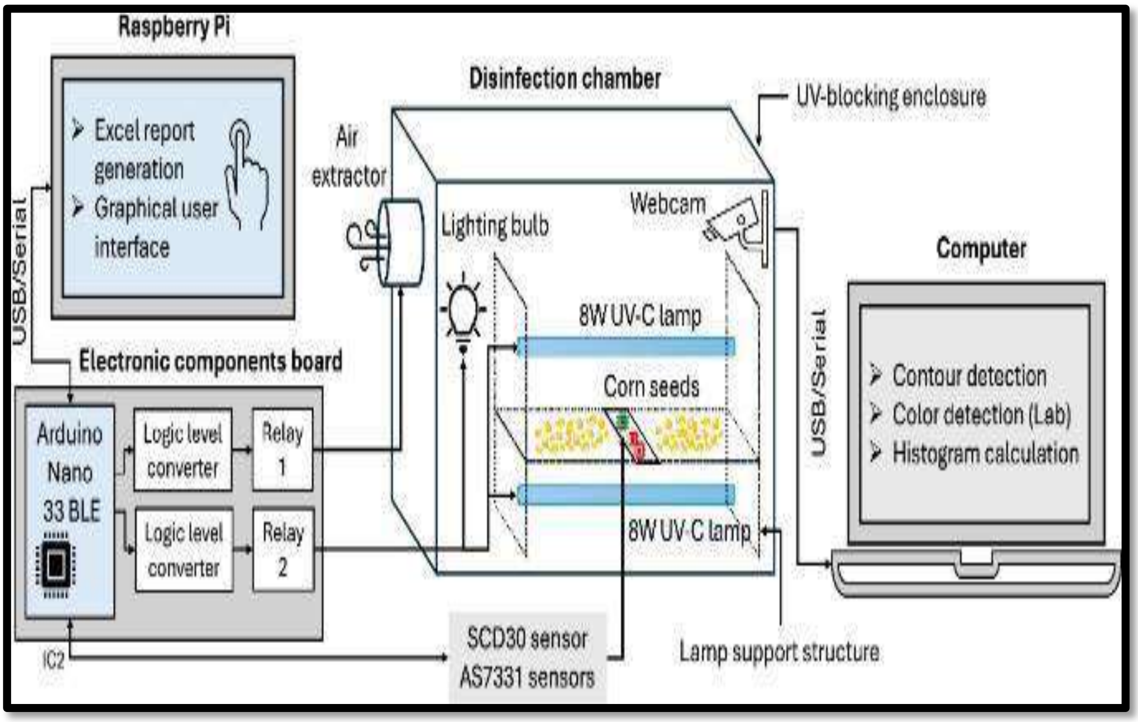

Figure 7. UV radiation seed treatment setup showing disinfection chamber, UV-C lamps, seed tray, sensors, Raspberry Pi, and computer-based monitoring system.

- **Air Extraction Unit:** The air extraction unit is designed to remove excess heat generated by UV lamps and maintain suitable environmental conditions inside the treatment chamber. Continuous operation of UV lamps can increase chamber temperature, which may affect seed quality and experimental accuracy. The extraction system improves air circulation and helps maintain a stable temperature and humidity level throughout the treatment process.

By preventing overheating, it protects seeds from thermal stress and ensures consistent treatment conditions. This component contributes significantly to the safety, efficiency, and reliability of the UV seed treatment system. This integrated system ensures controlled UV exposure, uniform seed treatment, and accurate monitoring, thereby improving seed germination and seedling growth.

4.4 Mechanism of UV Seed Treatment

Ultraviolet (UV) seed treatment is a physical method that uses ultraviolet radiation to improve seed germination, seedling growth, and overall plant development. This technique works by inducing physical, chemical, and biological changes in seeds that stimulate metabolic activity and enhance physiological processes. UV radiation influences seed performance by modifying theseed surface, activating enzymes, and reducing microbial contamination.

When seeds are exposed to UV radiation, energy from the radiation interacts with the seed coat and internal tissues. This interaction causes slight structural changes in the seed coat, making it more permeable to water and oxygen. As a result, seeds absorb moisture more efficiently during imbibition, which is the first step in germination. Improved water absorption accelerates metabolic processes and promotes faster germination. UV radiation also plays a significant role in activating enzymes within the seed. During germination, enzymes such as amylase, protease, and lipase break down stored food materials into simple nutrients. These nutrients provide energy for embryo growth and seedling development. UV exposure stimulates enzyme activity, which enhances the conversion of stored food into usable energy.

Another important mechanism of UV seed treatment is the stimulation of metabolic activity. UV radiation influences cellular processes within the seed, including respiration and protein synthesis. Increased respiration provides additional energy for embryo development, while improved protein synthesis supports cell division and tissue growth. These biochemical changes contribute to improved seed vigour and uniform seedling growth. UV radiation also helps in reducing microbial contamination on the seed surface. Seeds often carry harmful microorganisms such as fungi and bacteria that affect germination and early plant growth. UV treatment destroys or inactivates these microorganisms, reducing the chances of seed-borne diseases. This leads to healthier seedlings and improved crop establishment.

Additionally, UV radiation affects plant hormones that regulate seed germination and growth. Exposure to UV radiation can stimulate the production of growth-promoting hormones such as gibberellins and auxins. These hormones enhance cell elongation, root growth, and shoot development. As a result, treated seeds produce stronger and more vigorous seedlings.

UV seed treatment also improves seedling development by enhancing root and shoot growth. Treated seeds often develop stronger root systems, which allow plants to absorb water and nutrients more efficiently. Improved nutrient uptake supports better plant growth and increases crop productivity.

Environmental stress tolerance is another important effect of UV seed treatment. Seeds treated with UV radiation often show improved resistance to stress conditions such as drought, temperature variation, and soil salinity. This improved tolerance helps plants establish successfully under adverse environmental conditions.

4.5 Effect of UV Radiation on Seed Germination

Ultraviolet (UV) radiation has gained considerable attention as an effective physical seed treatment method for improving seed germination. Germination is a complex physiological process that begins with water absorption and ends with the emergence of the seedling. UV radiation influences this process by inducing beneficial physical and biochemical changes within the seed. When applied under controlled conditions, UV treatment enhances germination percentage, accelerates emergence, and improves uniformity in seedling development.

UV radiation also enhances enzyme activity within the seed. Germination requires enzymes to break down stored food materials such as starch, proteins, and lipids into simpler compounds. These compounds serve as energy sources for embryo growth. UV exposure stimulates enzymes such as amylase, protease, and lipase, leading to faster mobilization of nutrients. This increased enzymatic activity contributes to improved germination rate and seedling vigour.

Another important effect of UV radiation is the activation of metabolic processes. UV-treated seeds often show increased respiration rate and improved cellular activity. Enhanced respiration provides more energy for embryo growth, while increased cellular activity promotes rapid development of root and shoot structures. These physiological changes lead to improved germination and early plant growth. UV radiation also plays a role in reducing seed-borne pathogens. Seeds may carry microorganisms such as fungi and bacteria that affect germination. UV radiation helps in reducing microbial contamination on the seed surface, resulting in healthier seeds. Reduced pathogen load improves germination percentage and promotes uniform seedling development. In addition, UV radiation influences plant hormone activity during germination. Growth-regulating hormones such as gibberellins and auxins are responsible for embryo growth and seedling development. UV exposure can stimulate the production and activity of these hormones, resulting in improved germination and faster seedling emergence.

The positive effects of UV radiation on seed germination have been reported in various crops including Wheat (*Triticum aestivum*), Rice (*Oryza sativa*), Maize (*Zea mays*), Sunflower (*Helianthus annuus*), and Tomato (*Solanum lycopersicum*). These studies indicate that UV-treated seeds often exhibit faster germination, improved seedling vigour, and better plant establishment compared to untreated seeds. However, it is important to apply UV radiation carefully. Excessive exposure may damage seed tissues and reduce germination. Therefore, proper optimization of exposure time and intensity is essential for achieving beneficial effects. Each crop species may require different treatment conditions for optimal results.

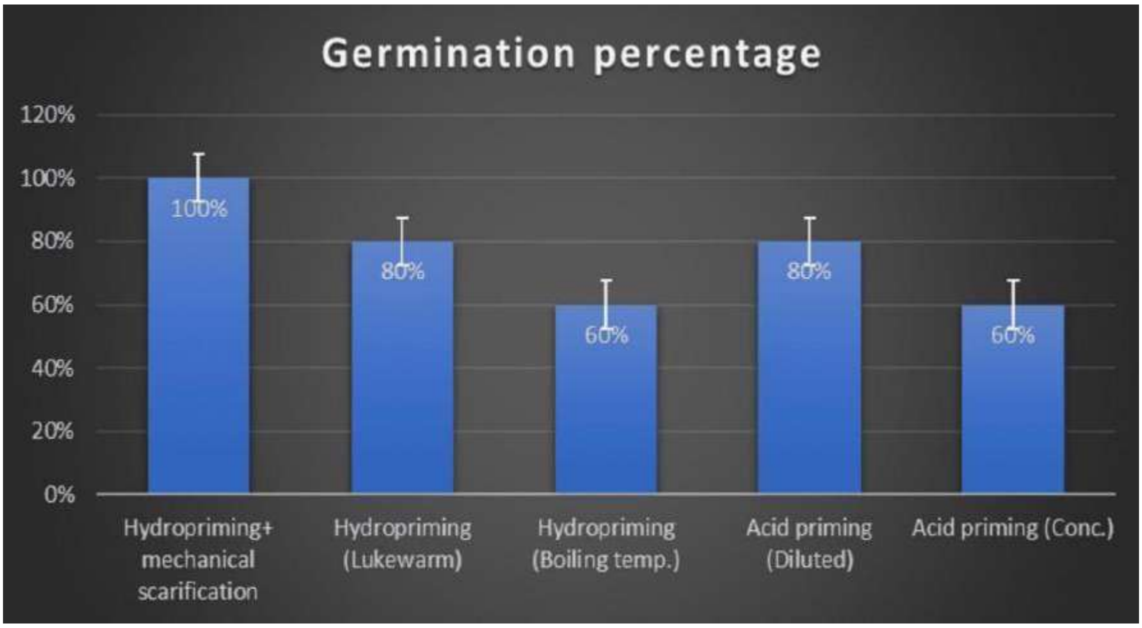

Figure 8. Effect of UV radiation on seed germination percentage.

4.6 Effect on Seedling Growth

UV-treated seeds produce stronger seedlings with better root and shoot growth. Improved seedling vigour helps plants establish quickly and grow efficiently.

Benefits of UV treatment:

- Increased root length: UV treatment stimulates physiological and biochemical activities inside the seed, which enhances early root development. When seeds are exposed to controlled ultraviolet radiation, it activates enzymes responsible for cell division and elongation. This results in faster root emergence and deeper root penetration into the soil. A longer root system helps plants absorb more water and nutrients from the soil, especially during early growth stages. As a result, plants become stronger, more stable, and more resistant to drought conditions.
- Increased shoot length: UV radiation at optimal levels promotes faster shoot growth by enhancing photosynthetic efficiency and stimulating plant hormones such as auxins and gibberellins. These hormones play a crucial role in stem elongation and leaf development. When shoot length increases, seedlings emerge faster above the soil surface and gain better access to sunlight. This leads to improved photosynthesis, healthier leaves, and overall better plant growth during early development stages.
- Improved biomass: UV-treated seeds often show improved overall biomass production. Biomass refers to the total weight of the plant, including roots, stems, and leaves. UV exposure enhances metabolic activities and nutrient uptake efficiency, which supports better plant growth. As plants grow larger and healthier, they accumulate more dry matter. Increased biomass is directly associated with improved crop yield and better productivity. This is particularly beneficial in agricultural crops where higher biomass contributes to stronger plants and better harvest output.
- Better plant establishment: UV-treated seeds generally show improved germination and stronger seedling vigour. This helps plants establish themselves quickly in the soil. Strong seedlings are more resistant to environmental stress such as drought, temperature variation, and soil nutrient deficiency. Better plant establishment also reduces seedling mortality and ensures uniform crop growth across the field. Uniform growth is important for efficient crop management and higher agricultural productivity.

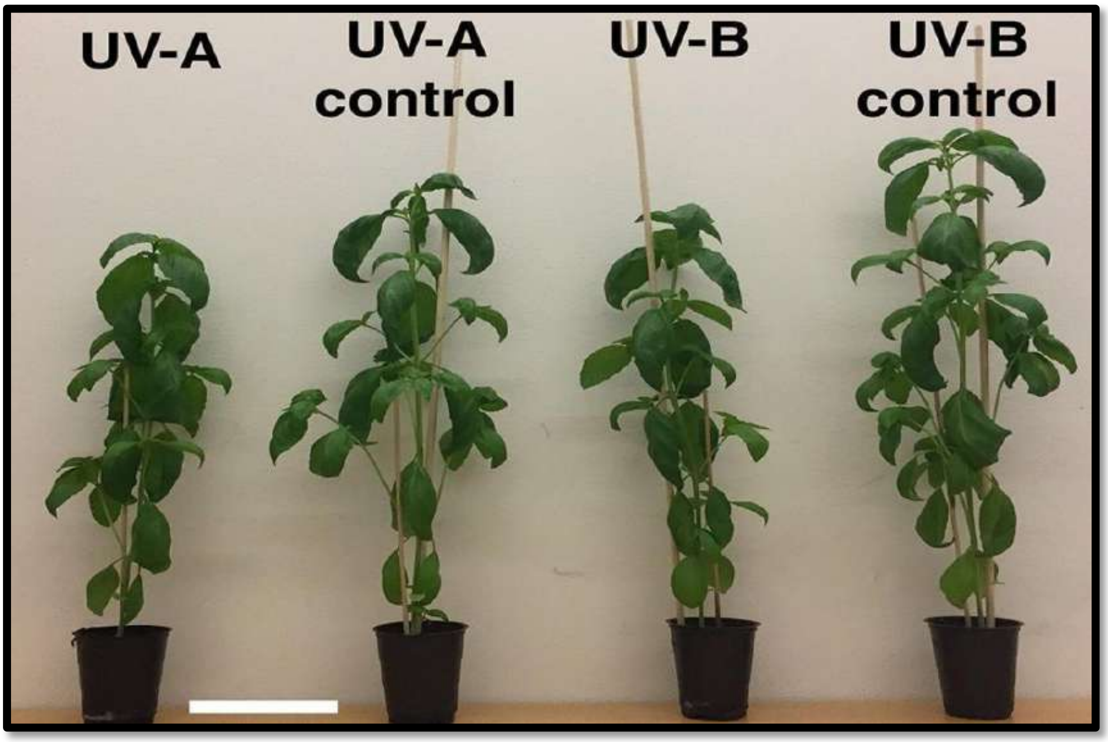

Figure 9. Seedling growth comparison between UV-treated and untreated seed.

4.7 Effect on Crop Yield

UV seed treatment plays an important role in improving overall crop yield. When seeds are exposed to controlled ultraviolet radiation, it enhances germination rate and improves seedling vigour. Healthy and vigorous seedlings grow into strong plants, which ultimately increases agricultural productivity. Better early growth helps plants utilize available resources such as sunlight, water, and nutrients more efficiently. As a result, UV-treated crops often show improved yield compared to untreated seeds.

Increased Plant Population

UV treatment improves seed germination percentage, which results in more seeds developing into healthy plants. Higher germination ensures better plant population per unit area. When more plants grow successfully in the field, it leads to increased crop density and better land utilization. A well-maintained plant population contributes significantly to improving total crop yield. In addition, a dense and healthy crop stand helps suppress weed growth by reducing the availability of space, light, and nutrients for weeds. Improved plant establishment also enhances the efficient utilization of available resources such as water, fertilizers, and sunlight. Consequently, the crop can achieve its full growth potential and produce higher yields under favourable conditions.

Uniform Crop Growth

Seeds treated with UV radiation often germinate at the same time, leading to uniform crop growth. Uniformity in growth is beneficial for proper crop management practices such as irrigation, fertilization, and pest control. When crops grow evenly, it reduces competition among plants and allows them to develop properly. Uniform growth also helps in synchronized maturity, making harvesting easier and more efficient. Furthermore, uniform crops exhibit consistent plant height and canopy development, which improves light interception and photosynthetic efficiency. Even growth facilitates mechanized farming operations and minimizes losses during harvesting. Uniform crop stands are easier to monitor and manage throughout the growing season. They also ensure that all plants receive similar amounts of nutrients and water. As a result, farmers can achieve better crop performance and improved overall productivity.

Better Flowering

UV-treated plants often show improved flowering due to enhanced physiological and biochemical activities. Better flowering increases the chances of successful pollination and fertilization. Increased flower formation leads to more fruits, grains, or seeds depending on the crop type. This directly contributes to improved productivity and better yield. Enhanced flowering also extends the reproductive capacity of plants and increases the number of productive structures. Improved nutrient uptake and metabolic activity support the development of healthy flowers with higher viability. UV treatment may also stimulate hormonal activities that regulate flower initiation and development. Stronger plants are capable of sustaining more flowers without significant flower drop. Consequently, the chances of successful fruit and seed set are significantly increased, resulting in greater agricultural output.

Increased Grain Yield

UV treatment improves plant health, which leads to better grain formation and filling. Strong plants produce more grains with improved size and weight. Increased grain yield is one of the most important benefits of UV seed treatment. Studies have shown that crops grown from UV-treated seeds often produce higher yield compared to untreated seeds, making UV treatment a useful technique for improving agricultural production. In addition, improved photosynthetic activity enables plants to synthesize and store more carbohydrates that are later transferred to developing grains. Better nutrient utilization contributes to enhanced grain quality and uniform grain development. Increased root growth allows plants to absorb water and minerals more efficiently during critical growth stages. UV-treated plants often maintain better physiological activity throughout the crop cycle, supporting higher productivity. These improvements collectively result in increased harvestable yield and greater economic returns for farmers.

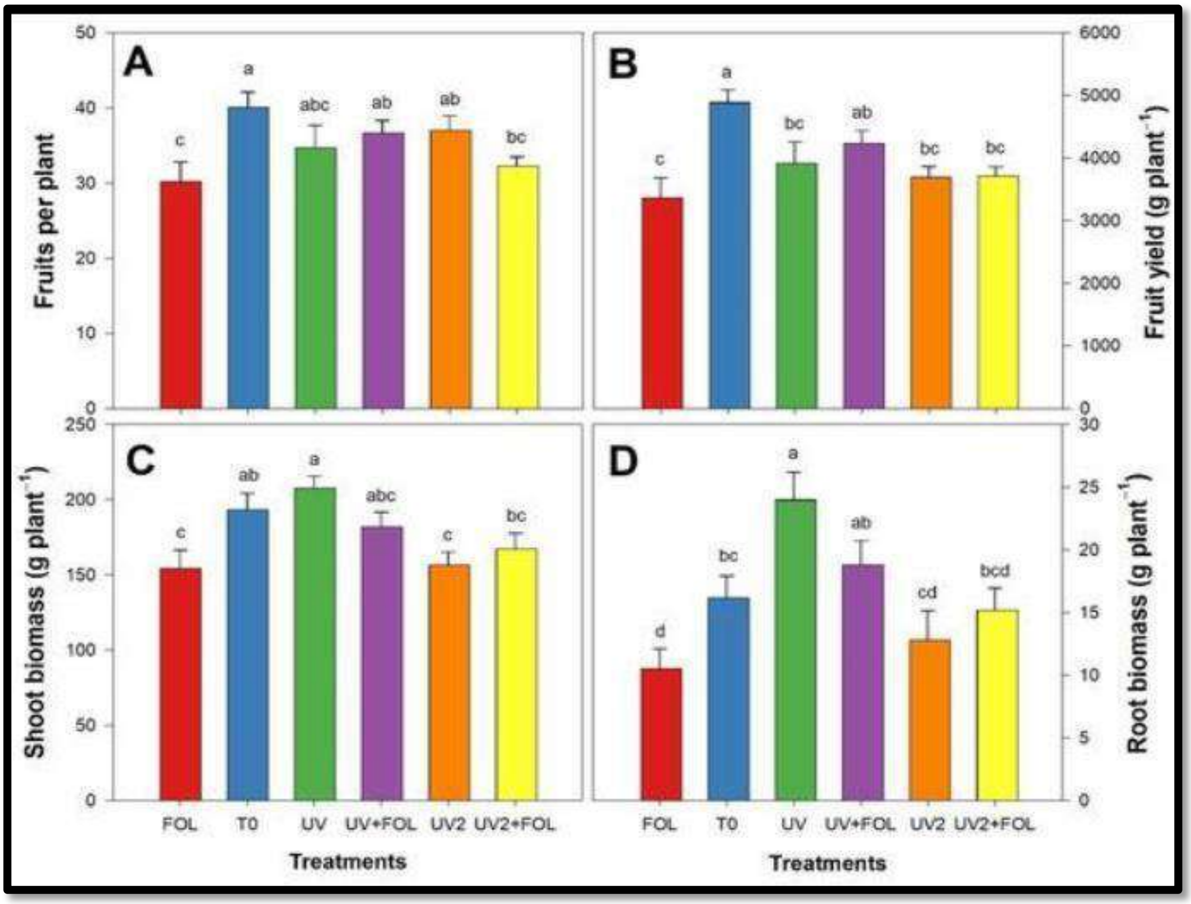

Figure 10. Crop yield improvement after UV seed treatment.

4.8 Advantages of UV Seed Treatment

Ultraviolet (UV) seed treatment has emerged as an effective and environmentally friendly alternative to conventional chemical seed treatment methods. By exposing seeds to controlled levels of UV radiation, several beneficial physiological, biochemical, and microbiological changes occur within the seed. These changes improve seed performance, enhance plant growth, and contribute to increased agricultural productivity. Due to its non-chemical nature and sustainable approach, UV seed treatment is gaining increasing attention in modern agriculture and seed technology.

Improved Seed Germination

One of the major advantages of UV seed treatment is its ability to improve seed germination. UV radiation enhances seed coat permeability, allowing water and oxygen to enter the seed more efficiently during imbibition. This activates metabolic processes and stimulates enzyme activity necessary for germination. As a result, treated seeds often germinate faster and more uniformly than untreated seeds. Improved germination ensures better crop establishment and contributes to higher productivity.

Enhanced Seedling Vigour

UV-treated seeds generally produce stronger and healthier seedlings. The treatment stimulates enzyme activity and promotes efficient utilization of stored food reserves within the seed. Consequently, seedlings develop longer roots, taller shoots, and greater biomass accumulation. Enhanced seedling vigour improves plant establishment and enables young plants to withstand environmental stress conditions more effectively during the early stages of growth.

Reduction of Seed-Borne Pathogens

UV radiation possesses strong antimicrobial properties that help reduce fungal and bacterial contamination on seed surfaces. Seed-borne pathogens often cause poor germination, seedling diseases, and crop losses. UV treatment damages the DNA and cellular structures of harmful microorganisms, reducing their ability to survive and reproduce. This improves seed health and decreases the incidence of diseases without the need for chemical fungicides or disinfectants.

Improved Water Absorption

Another important advantage of UV treatment is the enhancement of water absorption. Exposure to UV radiation can create microscopic changes in the seed coat that improve its permeability. Increased water uptake accelerates the germination process and promotes uniform seedling emergence. Efficient water absorption also supports metabolic activities and nutrient mobilization required for healthy seedling development.

Increased Enzyme Activity

UV treatment stimulates the activity of important enzymes such as amylase, protease, and lipase. These enzymes break down stored carbohydrates, proteins, and lipids into simpler compounds that provide energy for embryo growth. Enhanced enzyme activity improves nutrient mobilization and supports faster germination and seedling growth. This biochemical stimulation contributes significantly to improved seed performance.

Better Plant Growth and Development

Plants grown from UV-treated seeds often exhibit improved vegetative growth and overall development. Increased chlorophyll content, enhanced photosynthetic efficiency, and improved nutrient uptake have been reported in many studies. These physiological improvements result in healthier plants with stronger root systems and better growth characteristics. Improved plant growth ultimately contributes to higher crop productivity.

Increased Crop Yield

UV seed treatment can positively influence flowering, fruit formation, grain filling, and yield production. Better germination and vigorous seedling growth provide a strong foundation for subsequent plant development. Treated plants frequently produce more flowers, fruits, pods, or grains compared to untreated plants. Improved yield is one of the most important economic benefits of UV seed treatment for farmers.

Enhanced Stress Tolerance

Research studies have shown that UV-treated plants often exhibit greater tolerance to environmental stresses such as drought, salinity, temperature fluctuations, and nutrient deficiency. Enhanced physiological and biochemical responses help plants adapt to adverse growing conditions. Improved stress tolerance increases crop survival and productivity under challenging environments.

Environmentally Friendly Technology

Unlike chemical seed treatments, UV radiation does not leave harmful residues on seeds, soil, or agricultural produce. The technology reduces dependence on synthetic chemicals and minimizes environmental pollution. Because no toxic substances are involved, UV treatment is considered a sustainable and eco-friendly approach for improving seed quality and crop performance**.**

Cost-Effective and Sustainable

Once the UV treatment equipment is installed, operating costs are relatively low compared to repeated chemical applications. The technology is simple, efficient, and suitable for integration into modern seed processing systems. Its ability to improve seed quality while reducing chemical use makes UV seed treatment a sustainable option for future agricultural production.

4.9 Factors Affecting UV Treatment

The effectiveness of UV seed treatment depends on several important factors. Proper control and optimization of these factors are essential to achieve the desired results. If the exposure conditions are not properly maintained, UV treatment may not produce beneficial effects and, in some cases, may even damage the seeds. Therefore, understanding the factors affecting UV treatment helps in improving seed germination, seedling growth, and overall crop productivity.

- Exposure Time

  Exposure time is one of the most critical factors in UV seed treatment. It refers to the duration for which seeds are exposed to ultraviolet radiation. Short exposure time may not produce sufficient stimulation in seeds, while excessive exposure can damage seed tissues and reduce germination. Optimal exposure time varies depending on the crop type and UV radiation level. Therefore, determining the correct exposure duration is essential to obtain positive results such as improved germination and better seedling growth.

- UV Intensity

  UV intensity refers to the strength or power of ultraviolet radiation used during treatment. Low UV intensity may not significantly affect seed performance, whereas very high intensity may cause harmful effects such as damage to seed coat or internal tissues. Moderate and controlled UV intensity helps stimulate biological activities inside the seed. The correct intensity level enhances enzyme activity, promotes cell division, and improves seed vigour.

- Seed Type

  Different types of seeds respond differently to UV treatment. Seed size, seed coat thickness, and genetic characteristics influence the effect of UV radiation. For example, seeds with thick seed coats may require slightly longer exposure, while small or delicate seeds may need shorter exposure time. Crop species such as cereals, pulses, and vegetables each have different responses to UV radiation. Therefore, seed type must be considered when planning UV treatment.

- Distance from UV Source

  The distance between the seeds and the UV lamp plays a major role in treatment effectiveness. Seeds placed closer to the UV source receive higher radiation intensity, while seeds placed farther away receive lower intensity. Uneven distance may lead to non-uniform treatment. Maintaining proper and uniform distance ensures consistent exposure and better treatment results. Most UV treatment setups include adjustable trays to maintain the required distance.

- Seed Moisture Content

  Seed moisture content also affects UV treatment efficiency. Seeds with very high moisture content may absorb UV radiation differently and may become more sensitive to damage. On the other hand, extremely dry seeds may not respond effectively to UV treatment. Moderate moisture content is generally preferred for better results. Proper drying and conditioning of seeds before treatment helps improve the effectiveness of UV radiation.

4.10 Research Studies on UV Seed Treatment

Research on ultraviolet (UV) seed treatment has demonstrated its significant potential to improve seed germination, seedling vigour, plant growth, and crop productivity. Scientists have investigated the effects of different UV wavelengths and exposure durations on various crop species, and the results indicate that controlled UV treatment can stimulate physiological and biochemical processes while reducing microbial contamination. One of the major findings of early research was the antimicrobial effect of UV radiation, particularly UV-C, which effectively reduces fungal and bacterial populations present on seed surfaces. By minimizing seed-borne pathogens, UV treatment improves seed health, reduces disease incidence, and enhances the chances of successful germination. Studies conducted on crops such as wheat, rice, and maize have shown that UV-treated seeds exhibit improved water absorption, enhanced metabolic activity, faster seedling emergence, and higher germination percentages compared to untreated seeds.

Several investigations have also highlighted the positive effects of UV radiation on seedling growth and plant development. Research on sunflower seeds revealed that controlled UV exposure resulted in higher germination rates, greater root and shoot length, improved seedling vigour, enhanced chlorophyll content, and increased biomass accumulation. Similar beneficial effects have been reported in vegetable crops such as tomato, cucumber, and lettuce, where UV-treated seeds produced stronger seedlings and demonstrated improved tolerance to environmental stress conditions. Researchers have attributed these improvements to increased enzyme activity, particularly enzymes such as amylase and protease, which accelerate the breakdown of stored food reserves and provide energy for embryo growth. UV radiation has also been shown to stimulate protein synthesis and other metabolic activities that support healthy plant development.

Recent studies have focused on optimizing treatment conditions to maximize the benefits of UV seed treatment while preventing potential damage. Researchers emphasize that treatment effectiveness depends on factors such as UV wavelength, exposure duration, radiation intensity, seed moisture content, and crop species. While excessive exposure may reduce seed viability, carefully controlled treatments can significantly improve seed performance and crop establishment. As concerns about environmental pollution and chemical residues continue to increase, UV seed treatment is gaining recognition as an environmentally friendly alternative to conventional chemical treatments. Overall, research findings consistently demonstrate that UV radiation can enhance germination, improve seedling vigour, reduce microbial contamination, and contribute to sustainable agricultural production.

5. CORONA DISCHARGE SEED TREATMENT TECHNOLOGY

5.1 Introduction to Corona Discharge

Corona discharge is a physical phenomenon that occurs when a high voltage is applied between two electrodes separated by air or another gas. When the voltage exceeds a certain level, the surrounding air becomes ionized, forming charged particles such as ions, electrons, and free radicals. This ionized region around the electrode is known as corona discharge. Unlike electric sparks or arcs, corona discharge occurs without producing high heat, making it suitable for treating biological materials like seeds without causing thermal damage.

In seed treatment technology, corona discharge is used as a non-thermal and eco-friendly method to improve seed performance. When seeds are exposed to corona discharge, the reactive particles generated in the ionized air interact with the seed surface. These interactions cause physical and chemical changes that improve seed quality and enhance germination. The treatment modifies the seed coat structure, making it more favourable for water absorption and gas exchange, which are essential for seed germination. Corona discharge treatment improves several seed characteristics. One of the major improvements is seed surface wettability. The ionized particles increase the surface energy of the seed coat, allowing water to spread more easily across the seed surface. Improved wettability enhances water penetration into the seed, which is necessary for initiating metabolic activities. Another important benefit is increased water absorption. When seeds absorb water more efficiently, the germination process begins faster. Water activates enzymes and biochemical reactions inside the seed, which leads to faster and more uniform germination. This results in healthier seedlings and better crop establishment.

Corona discharge also enhances enzyme activity within seeds. The reactive species generated during treatment stimulate biochemical processes that activate growth-related enzymes. These enzymes help break down stored food materials in the seed and convert them into energy required for seedling growth. Increased enzyme activity supports faster root and shoots development.

As a result of these improvements, seed germination is significantly enhanced.

Treated seeds often show higher germination percentage, reduced germination time, and uniform seedling emergence. This leads to stronger plant growth and better crop performance. In addition, corona discharge treatment promotes seedling growth by improving early plant development. Treated seedlings typically show increased root length, shoot growth, and overall vigour. Strong seedlings are more resistant to environmental stress and establish more successfully in the field.

Corona discharge produces reactive species such as ions, electrons, free radicals, and excited molecules. These particles interact with seed surfaces and alter their physical and chemical properties without damaging the seed structure. Because this method is chemical-free, energy-efficient, and environmentally friendly, corona discharge is increasingly used in seed technology research and agricultural applications.

Overall, corona discharge is a promising modern technique that improves seed quality, enhances germination, and supports better plant growth, making it valuable for sustainable agriculture and crop productivity.

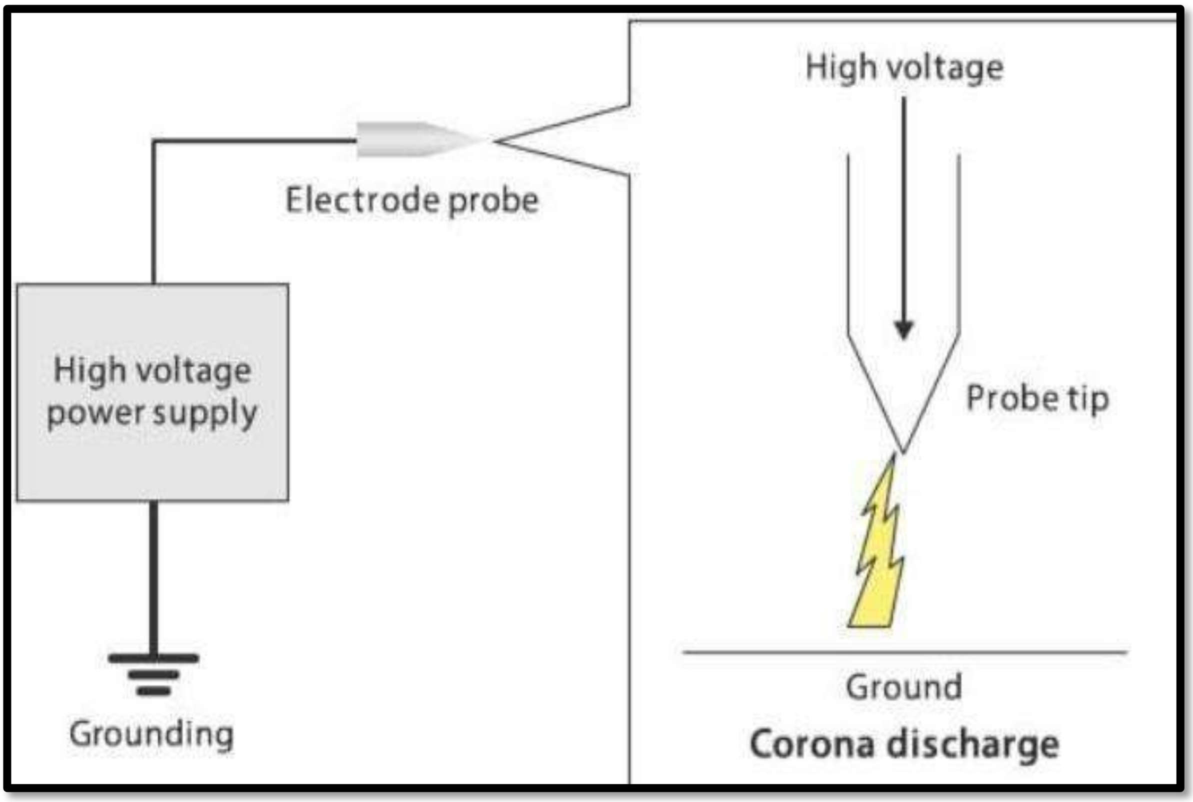

Figure 11. Corona discharge phenomenon using high voltage electrodes.

5.2 Corona Discharge Equipment

Corona discharge equipment is used in physical seed treatment to improve seed surface properties, enhance water absorption, and promote better germination and plant growth. This equipment generates ionized air or plasma using high-voltage electrical energy, which interacts with the seed surface and produces beneficial physical and chemical changes. Corona discharge technology is gaining importance in agriculture due to its eco-friendly nature and effectiveness in improving seed performance. The basic working principle of corona discharge equipment involves the generation of a high-voltage electric field between two electrodes. When the voltage exceeds a certain limit, the surrounding air becomes ionized and forms a corona discharge. This discharge produces reactive species such as ions, electrons, and free radicals. These reactive particles interact with the seed surface, modifying its physical characteristics and improving wettability. As a result, treated seeds absorb water more efficiently and germinate faster.

Corona discharge equipment typically consists of several key components that work together to ensure effective seed treatment. These components are carefully designed to provide uniform exposure and controlled treatment conditions.

High-Voltage Power Supply

The high-voltage power supply is the main component of corona discharge equipment. It generates the electrical energy required to produce corona discharge. The voltage level is carefully controlled to ensure effective treatment without damaging seeds. Proper voltage control is essential for maintaining treatment efficiency and seed safety.

Electrodes

Electrodes are used to generate the corona discharge. Usually, one electrode is connected to high voltage, while the other is grounded. The space between the electrodes creates a strong electric field where ionization occurs. The design and arrangement of electrodes play an important role in ensuring uniform treatment of seeds.

Treatment Chamber

The treatment chamber is where seeds are placed during corona discharge treatment. It is designed to provide uniform exposure of seeds to ionized air. The chamber may include trays, conveyors, or rotating mechanisms to ensure even treatment. Proper chamber design improves treatment efficiency and reduces the risk of uneven exposure.

Seed Holder or Conveyor System

Seeds are placed on trays or passed through a conveyor system during treatment.

Conveyor systems are commonly used in large-scale operations. These systems ensure continuous seed movement and uniform exposure to corona discharge. Uniform exposure is important for achieving consistent results.

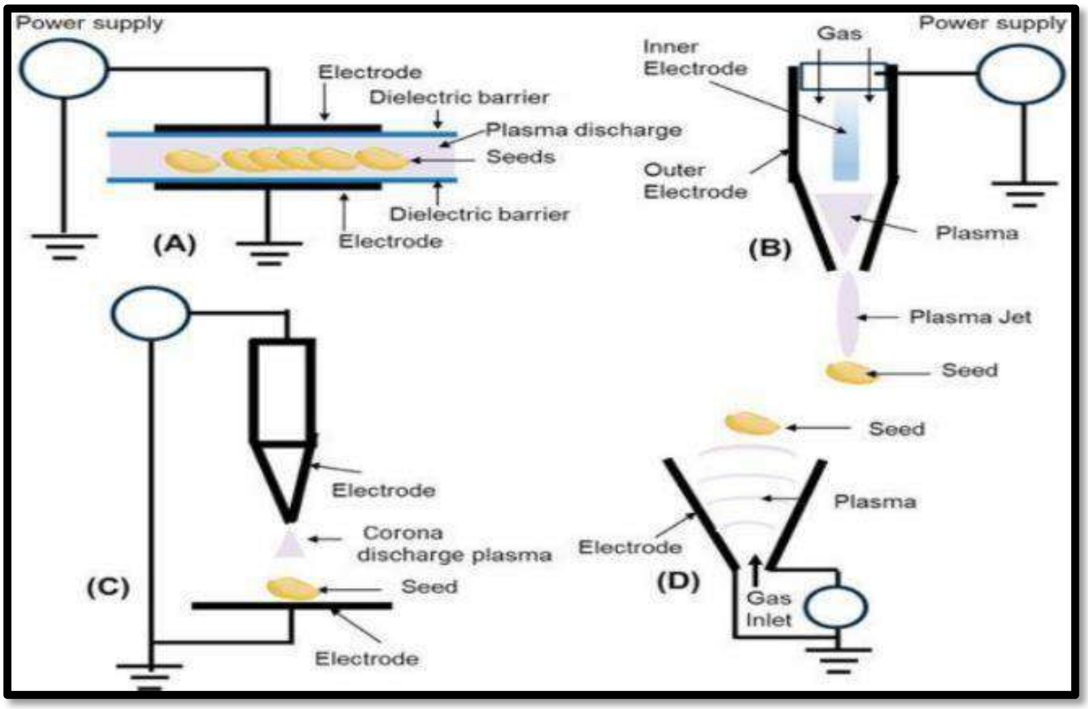

Figure 12. Corona discharge seed treatment experimental setup.

5.3 Working Principle of Corona Discharge

Corona discharge is generated when a high voltage is applied between two electrodes separated by a small air gap. When the applied voltage exceeds a critical level, the surrounding air becomes ionized, producing charged particles such as electrons, ions, and reactive species. These particles interact with the seed surface and bring about physical and chemical changes that improve seed performance.

Step-by-Step Working Process:

High Voltage Generation

The process begins with a high voltage power supply connected to electrodes. One electrode act as the high-voltage electrode, while the other acts as the ground electrode. When voltage is applied, an electric field is created between the electrodes.

This strong electric field is responsible for ionizing the air molecules surrounding the electrode. The ionization process leads to the formation of corona discharge.

Ionization of Air Molecules

When the electric field becomes strong enough, air molecules such as oxygen and nitrogen break down into charged particles. These include:

- Electrons
- Positive ions
- Negative ions
- Reactive oxygen species
- Reactive nitrogen species

These particles are highly reactive and interact with seed surfaces during treatment.

Interaction with Seed Surface

When seeds are placed in the corona discharge zone, reactive particles collidewith theseed surface. This interaction causes several beneficial changes:

- Removal of surface contaminants
- Modification of seed coat structure
- Increase in surface roughness
- Improved seed wettability

These changes enhance seed performance during germination.

Improvement in Surface Wettability

One of the main effects of corona discharge treatment is improved surface wettability. Treated seeds absorb water more easily compared to untreated seeds. This leads to faster germination and improved seedling growth.

Improved wettability results in:

- Faster water absorption
- Enhanced enzyme activation
- Improved metabolic activity

Reduction of Microbial Contamination

Corona discharge also helps reduce microbial contamination present on seed surfaces. Reactive particles destroy harmful microorganisms such as fungi and bacteria. This helps in:

- Preventing seed-borne diseases
- Improving seed health
- Promoting healthy seedling growth

Stimulation of Physiological Processes

Corona discharge treatment stimulates physiological and biochemical activities within seeds. These include:

- Increased enzyme activity
- Improved respiration
- Enhanced nutrient mobilization
- Faster germination

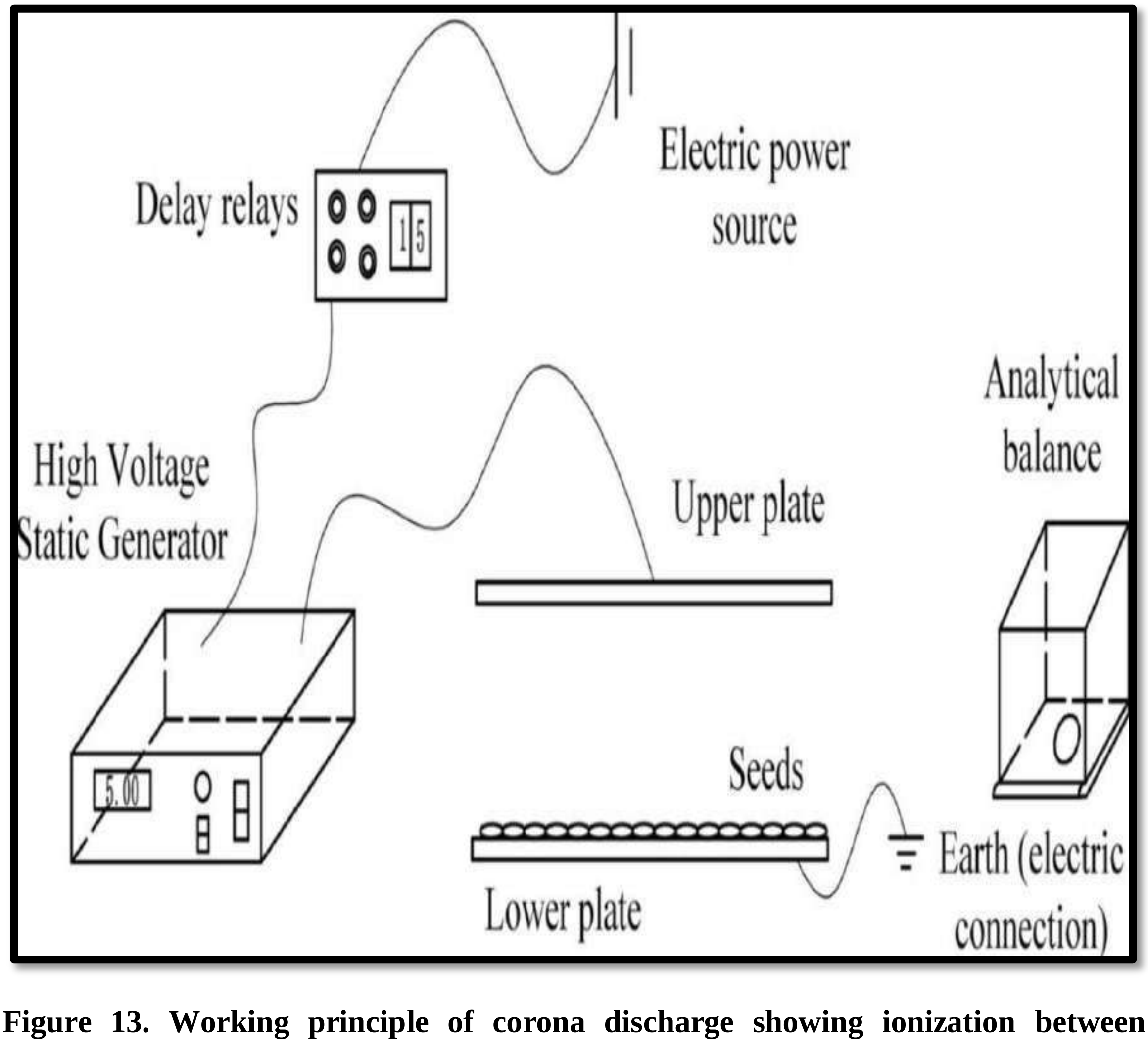

Figure 13. Working principle of corona discharge showing ionization between electrodes

5.4 Mechanism of Corona Discharge Seed Treatment

Corona discharge seed treatment improves seed performance through a combination of physical, chemical, and biological changes. When seeds are exposed to corona discharge, ionized air particles such as electrons, ions, and reactive radicals interact with the seed surface. These interactions bring beneficial modifications that enhance water uptake, activate metabolic processes, and promote faster germination and seedling growth.

Physical Changes:

Seed Coat Modification

Corona discharge treatment alters the structure of the seed coat. The high-energy charged particles gently etch or modify the outer surface of the seed without damaging the internal tissues. This modification reduces the hardness of the seed coat and makes it more permeable. As a result, water and oxygen can enter the seed more easily, which helps initiate germination faster. Seed coat modification is particularly beneficial for seeds with hard or thick outer coverings.

Increased Surface Roughness

During corona discharge treatment, reactive particles interact with the seed surface and create microscopic changes. These changes increase the surface roughness of seeds. A rougher surface improves the ability of the seed to absorb water and nutrients. Increased surface roughness also improves seed-to-soil contact after planting, which supports better seedling establishment and growth.

Enhanced Water Absorption

One of the most important effects of corona discharge treatment is improved water absorption. The physical modifications in the seed coat increase its wettability, allowing water to spread evenly across the seed surface. When seeds absorb water quickly, metabolic activities inside the seed start earlier. Faster water uptake leads to quicker germination and uniform seedling emergence.

Chemical Changes:

Formation of Reactive Oxygen Species

Corona discharge generates reactive oxygen species (ROS) such as oxygen radicals, ozone, and other reactive molecules. These reactive species interact with the seed surface and cause beneficial chemical changes. At controlled levels, reactive oxygen species help break seed dormancy and stimulate physiological processes that support germination and growth.

Increased Oxygen Availability

Corona discharge increases the availability of oxygen around the seed surface. Oxygen is essential for respiration, which provides energy required for seed germination. Improved oxygen diffusion into the seed enhances respiration rate and supports faster metabolic activity. Increased oxygen availability contributes to better seed vigour and improved plant growth.

Improved Metabolic Activity

The chemical changes produced by corona discharge activate metabolic pathways inside the seed. These pathways help convert stored food materials into energy needed for growth. Improved metabolic activity supports faster root and shoot development. As a result, seedlings become stronger and healthier during early growth stages.

Biological Changes

Enzyme Activation

Corona discharge treatment stimulates enzyme activity within seeds. Enzymes play an important role in breaking down stored nutrients such as starch, proteins, and fats. When enzymes become more active, nutrients are converted into simpler forms that can be used for growth. Increased enzyme activity supports faster germination and improved seedling vigour.

Improved Seed Respiration

Respiration is a key biological process that provides energy for seed germination. Corona discharge enhances respiration by increasing oxygen availability and activating metabolic processes. Improved respiration ensures that seeds receive enough energy for root and shoot development. This leads to stronger and healthier seedlings.

Faster Germination

The combined effect of physical, chemical, and biological changes results in faster germination. Seeds treated with corona discharge usually show reduced germination time and improved germination percentage. Faster germination helps seedlings establish quickly in the soil and improves crop performance.

5.5 Effect on Seed Germination

Corona discharge seed treatment has shown significant improvement in seed germination in many research studies. When seeds are exposed to corona discharge, the ionized particles produced during the process interact with the seed surface and trigger several beneficial changes. These changes improve seed vigour, enhance metabolic activity, and promote faster and more uniform germination. As a result, treated seeds often show higher germination percentage and stronger seedling development compared to untreated seeds.

Faster Water Absorption

One of the primary benefits of corona discharge treatment is improved water absorption. The treatment modifies the seed coat by increasing its surface energy and permeability. This allows water to penetrate the seed more easily and quickly. Water absorption is the first and most important step in the germination process because it activates metabolic activities inside the seed. Faster water uptake leads to early activation of enzymes and quicker seed swelling, resulting in faster germination.

Reduced Seed Dormancy

Seed dormancy is a condition in which seeds do not germinate even under favourable conditions. Corona discharge treatment helps reduce seed dormancy by altering the seed coat structure and stimulating physiological changes inside the seed. The reactive particles generated during the treatment weaken the seed coat and improve oxygen diffusion, which helps break dormancy. This results in improved germination percentage and uniform seedling emergence.

Enhanced Enzyme Activity

Corona discharge stimulates enzyme activity within the seed. Enzymes are essential for breaking down stored food materials such as starch, proteins, and lipids into simpler forms. These nutrients provide energy and support early seedling growth. Increased enzyme activity accelerates biochemical processes and promotes faster germination. This also leads to stronger and healthier seedlings

Improved Seed Metabolism

Corona discharge treatment enhances overall metabolic activity in seeds. Improved metabolism helps convert stored nutrients into energy required for germination and growth. Increased metabolic rate supports rapid cell division and elongation, which leads to faster root and shoot emergence. Enhanced metabolism also improves seedling vigour and growth.

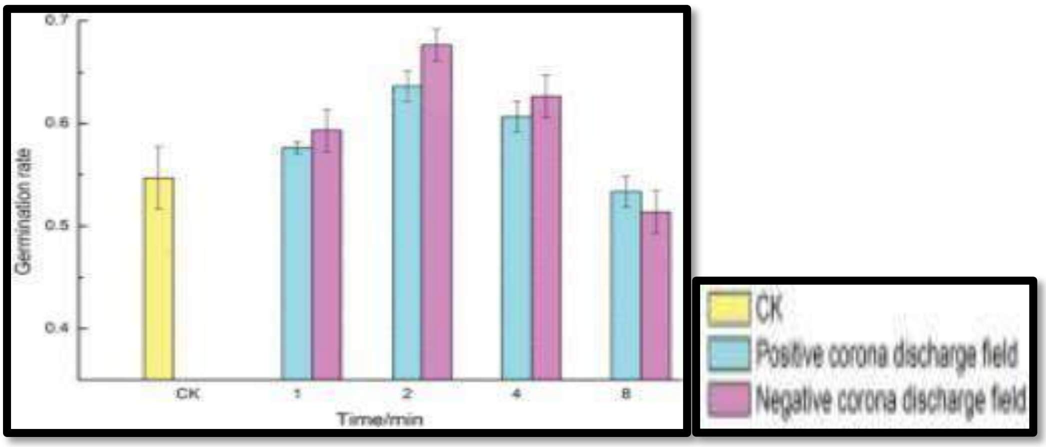

Figure 14. The treatment voltage was set to 14 kV and the Germination rate of the millet was shown.

5.6 Factors Affecting Corona Discharge Treatment

The effectiveness of corona discharge seed treatment depends on several important factors. Proper control of these factors is necessary to achieve uniform treatment and improve seed performance. If these factors are not properly managed, the treatment may not produce desired results or may even damage the seeds. Therefore, optimizing treatment conditions is essential for improving seed germination and seedling growth.

Applied Voltage

Applied voltage is one of the most important factors in corona discharge treatment. The voltage determines the strength of the corona discharge and the number of ionized particles produced. Low voltage may generate weak discharge, which may not produce significant effects on seeds. On the other hand, very high voltage may cause damage to the seed coat or internal tissues. Therefore, maintaining an optimal voltage level ensures effective treatment and improved seed performance.

Exposure Time

Exposure time refers to the duration for which seeds are exposed to corona discharge. Short exposure time may not allow sufficient interaction between reactive particles and seed surfaces. However, excessive exposure may lead to seed damage and reduced germination. Optimal exposure time depends on seed type and treatment intensity. Proper timing ensures beneficial effects such as improved germination and better seedling growth.

Distance Between Electrodes and Seeds

The distance between electrodes and seeds affects the intensity of corona discharge received by the seeds. Seeds placed closer to the electrodes receive stronger treatment, while seeds placed farther away receive weaker treatment. Uneven distance can lead to non uniform treatment results. Maintaining a proper and uniform distance ensures consistent exposure and better treatment efficiency.

Environmental Conditions

Environmental factors such as temperature, humidity, and air composition also influence corona discharge treatment. High humidity may affect ionization and reduce treatment efficiency. Similarly, temperature variations may influence seed response to treatment. Maintaining controlled environmental conditions helps achieve consistent results.

Seed Moisture Content

Seed moisture content plays an important role in treatment effectiveness. Seeds with high moisture content may become more sensitive to corona discharge, while very dry seeds may not respond effectively. Moderate moisture content is generally preferred for optimal results. Proper conditioning of seeds before treatment improves treatment efficiency.

5.7 Advantages of Corona Discharge Treatment

Corona discharge treatment is an advanced physical seed treatment technology that utilizes ionized air generated by a high-voltage electric field to improve seed performance. This technology modifies the physical and chemical properties of the seed surface without the use of harmful chemicals. Over the past few years, corona discharge treatment has gained considerable attention due to its ability to enhance seed germination, seedling vigor, and crop productivity while supporting sustainable agricultural practices. The numerous benefits associated with this technology make it a promising alternative to conventional chemical seed treatments.

Improved Seed Germination

One of the most important advantages of corona discharge treatment is its ability to improve seed germination. The treatment alters the seed coat surface and increases its permeability to water and oxygen. Enhanced water uptake activates metabolic processes and enzyme activity required for germination. As a result, treated seeds often germinate faster and exhibit higher germination percentages than untreated seeds. Improved germination contributes to better crop establishment and uniform plant growth.

Enhanced Water Absorption

Corona discharge treatment significantly improves the wettability of seed surfaces by introducing polar functional groups. These modifications increase the hydrophilic nature of the seed coat, allowing water to spread more easily and penetrate rapidly into the seed.

Enhanced water absorption accelerates imbibition, stimulates metabolic activity, and promotes uniform seedling emergence. Efficient water uptake is particularly beneficial under conditions where soil moisture availability is limited.

Increased Seedling Vigour

Seeds treated with corona discharge generally produce stronger and more vigorous seedlings. Enhanced water absorption and improved nutrient mobilization provide the energy required for rapid seedling development. Treated seedlings often exhibit greater root length, shoot length, and biomass accumulation compared to untreated seedlings. Increased seedling vigor improves plant establishment and enhances the ability of plants to withstand environmental stresses during early growth stages.

Reduction of Seed-Borne Pathogens

Another significant advantage of corona discharge treatment is its antimicrobial activity. The reactive ions, electrons, and free radicals generated during the discharge process help suppress or eliminate fungal and bacterial pathogens present on the seed surface. Reduced microbial contamination improves seed health and decreases the incidence of seed-borne diseases. This allows healthier seedlings to develop without relying heavily on chemical fungicides and disinfectants.

Improved Enzyme Activity

Corona discharge treatment stimulates various biochemical processes within seeds, including enzyme activation. Important enzymes such as amylase, protease, and lipase become more active following treatment. These enzymes break down stored food reserves into simple compounds that provide energy for embryo growth and seedling development. Enhanced enzyme activity contributes to faster germination, improved seedling growth, and better overall seed performance.

Better Plant Growth and Development

Research studies have demonstrated that plants grown from corona-treated seeds often show improved growth and development. Enhanced nutrient uptake, increased chlorophyll content, and improved photosynthetic efficiency contribute to vigorous vegetative growth. Stronger root systems allow plants to absorb water and minerals more effectively, supporting healthy development throughout the crop cycle. These physiological improvements result in stronger and more productive plants.

Increased Crop Yield

Corona discharge treatment can positively influence flowering, fruit formation, grain filling, and overall yield production. Better germination and vigorous seedling growth create a strong foundation for plant development. Treated plants frequently produce higher yields compared to untreated plants due to improved nutrient utilization and enhanced physiological performance. Increased yield contributes to greater profitability and economic benefits for farmers.

Enhanced Stress Tolerance

Plants grown from corona-treated seeds often exhibit greater tolerance to environmental stresses such as drought, salinity, temperature fluctuations, and nutrient deficiencies. Improved physiological and biochemical responses enable plants to adapt more effectively to adverse conditions. Enhanced stress tolerance helps maintain productivity even under challenging environmental situations.

Environmentally Friendly Technology

Unlike conventional chemical seed treatments, corona discharge treatment does not leave harmful residues on seeds, soil, or agricultural products. The technology reduces dependence on synthetic chemicals and minimizes environmental pollution. Because it relies on physical processes rather than chemical agents, it is considered an eco-friendly and sustainable approach to seed enhancement.

Suitable for Sustainable Agriculture

Corona discharge treatment supports sustainable agricultural practices by improving seed quality without harming the environment. The technology aligns with the growing demand for environmentally responsible farming methods and can be integrated into modern seed processing systems. Its ability to enhance crop performance while reducing chemical inputs makes it an important tool for future agricultural development.

5.8 Factors Affecting Corona Discharge Treatment

The effectiveness of corona discharge seed treatment depends on several important factors that influence the interaction between ionized particles and the seed surface. Proper optimization of these factors is essential to achieve maximum benefits such as improved germination, enhanced seedling vigour, and better plant growth. If treatment conditions are not carefully controlled, the desired effects may not be achieved, and excessive exposure may even damage the seeds. Therefore, understanding the factors affecting corona discharge treatment is crucial for successful application in agricultural seed technology.

Voltage Level

Voltage is one of the most critical factors affecting corona discharge treatment. It determines the intensity of the electric field and the amount of ionized particles generated during the process. Low voltage may produce insufficient ionization and limited seed surface modification, whereas excessively high voltage can damage the seed coat and internal tissues. Appropriate voltage levels enhance seed wettability, improve water absorption, and stimulate physiological activities within the seed. Therefore, selecting the optimum voltage is essential for obtaining positive treatment outcomes.

Exposure Duration

The duration of seed exposure to corona discharge significantly influences treatment effectiveness. Short exposure periods may not provide sufficient interaction between reactive particles and the seed surface, resulting in minimal improvement. Conversely, excessive exposure can cause structural damage to the seed coat and negatively affect germination. Different crop species require different exposure durations depending on seed characteristics. Therefore, careful optimization of treatment time is necessary to maximize benefits while avoiding seed injury.

Seed Moisture Content

Seed moisture content plays an important role in determining the response of seeds to corona discharge treatment. Seeds with appropriate moisture levels generally respond more effectively because moisture facilitates biochemical and physiological activities. Extremely dry seeds may show limited treatment effects, while excessively moist seeds may be more susceptible to damage during treatment. Maintaining optimum seed moisture content before treatment helps improve treatment efficiency and enhances germination performance.

Seed Type and Seed Coat Characteristics

Different crop species respond differently to corona discharge treatment due to variations in seed size, shape, structure, and seed coat properties. Seeds with thick or hard seed coats may require different treatment conditions than seeds with thin or soft seed coats. The composition and permeability of the seed coat influence how effectively reactive particles interact with the seed surface. Therefore, crop-specific treatment protocols are often necessary to achieve optimal results.

Distance Between Electrode and Seed Surface

The distance between the corona discharge electrode and the seed surface affects the intensity of treatment received by the seeds. Seeds positioned too close to the electrode may experience excessive exposure, while those located too far away may receive insufficient treatment. Maintaining a uniform and appropriate distance ensures consistent exposure across all seeds and promotes uniform treatment effectiveness. Proper electrode positioning is therefore essential for achieving reliable and reproducible results.

Electrode Configuration

The design and configuration of electrodes used in corona discharge equipment influence the generation and distribution of ionized particles. Different electrode shapes and arrangements produce varying electric field strengths and discharge patterns. Uniform distribution of the corona discharge ensures consistent treatment of all seeds. Well-designed electrode systems improve treatment efficiency and minimize variations in seed response.

Environmental Conditions

Environmental factors such as temperature, humidity, and air composition can affect the performance of corona discharge treatment. High humidity levels may influence the formation of reactive species, while temperature variations can affect seed physiology and treatment outcomes. Stable environmental conditions help maintain consistent treatment performance and improve the reliability of experimental results. Therefore, environmental parameters should be monitored and controlled during treatment.

Airflow and Gas Composition

The composition of air surrounding the seeds during treatment also affects corona discharge efficiency. The presence of oxygen, nitrogen, and moisture influences the formation of reactive oxygen and nitrogen species. These reactive molecules play a key role in modifying the seed surface and stimulating physiological processes. Proper airflow and gas circulation ensure uniform generation and distribution of reactive particles throughout the treatment chamber.

Equipment Design and Operating Conditions

The overall design of the corona discharge system, including power supply stability, treatment chamber configuration, and control mechanisms, significantly affects treatment effectiveness. Modern systems equipped with automated controls provide precise regulation of treatment parameters and improve consistency. Proper maintenance and calibration of equipment are essential for ensuring accurate and reproducible treatment results.

Optimization of Treatment Parameters

Successful corona discharge treatment requires the optimization of all operating parameters. Factors such as voltage, exposure duration, moisture content, electrode configuration, and environmental conditions must be carefully balanced. Optimization helps maximize the beneficial effects of treatment while minimizing the risk of seed damage. Continuous research is being conducted to identify ideal treatment conditions for different crop species and seed types.

5.9 Limitations of Corona Discharge Treatment

Although corona discharge treatment has shown considerable potential for improving seed germination and seedling growth, several limitations restrict its widespread adoption in agriculture. One of the major challenges is the need for precise control of treatment parameters such as voltage, exposure time, and electrode distance. If seeds are exposed to excessively high voltage or prolonged treatment durations, the seed coat and internal tissues may be damaged, leading to reduced germination and seed viability. Therefore, optimization of treatment conditions is essential for each crop species to ensure effective and safe application.

Another limitation is the variation in treatment response among different crops and seed varieties. Seeds differ in size, shape, moisture content, and seed coat characteristics, which influence the effectiveeness of corona discharge treatment. As a result, treatment protocols developed for one crop may not produce the same results in another. This variability makes it difficult to establish universal treatment standards and requires extensive crop-specific research before large-scale implementation.

The cost and availability of corona discharge equipment also present significant challenges. The technology requires specialized high-voltage power supplies, treatment chambers, and safety systems, which may involve considerable investment. Small-scale farmers often find it difficult to access such equipment due to financial constraints. In addition, operation and maintenance of the equipment require technical knowledge and skilled personnel, limiting its adoption in rural farming communities.

Limited large-scale commercial application is another concern. Most studies on corona discharge treatment have been conducted under laboratory or experimental conditions, while large-scale field evaluations remain relatively limited. Uniform treatment of large quantities of seed and integration into existing seed processing systems continue to be technical challenges. Furthermore, safety precautions are necessary because high-voltage equipment can pose risks to operators if proper protective measures are not followed.

Despite these limitations, ongoing research and technological advancements are helping to improve the efficiency, safety, and affordability of corona discharge systems. Future developments in automation, equipment design, and treatment optimization are expected to overcome many of these challenges and support wider adoption of corona discharge technology in sustainable agriculture.

5.10 Research Studies on Corona Discharge

Research on corona discharge seed treatment has demonstrated its effectiveness in improving seed germination, seedling vigour, and overall plant growth. Corona discharge technology utilizes ionized air generated by a high-voltage electric field to modify the physical and chemical properties of the seed surface. Several studies have reported that corona discharge treatment increases seed wettability, allowing seeds to absorb water more efficiently during the germination process. Enhanced water uptake activates metabolic activities within the seed and accelerates germination. Researchers working with crops such as wheat, maize, sunflower, and soybean observed that corona-treated seeds exhibited higher germination percentages and more uniform seedling emergence compared to untreated seeds. In addition, the treatment was found to reduce microbial contamination on the seed surface, thereby improving seed health and reducing the incidence of seed-borne diseases.

Numerous investigations have also highlighted the positive effects of corona discharge on seedling growth and plant development. Experimental studies revealed that treated seeds often produced longer roots, increased shoot length, and greater seedling biomass. These improvements were associated with enhanced enzyme activity, improved nutrient uptake, and increased metabolic efficiency. Research on sunflower and vegetable crops showed that corona discharge treatment promoted stronger root systems, enabling plants to absorb water and nutrients more effectively. As a result, treated plants demonstrated improved growth performance and better tolerance to environmental stress conditions. Some studies also reported increased chlorophyll content and photosynthetic activity, contributing to healthier plant development.

Recent research has focused on optimizing treatment parameters such as voltage, exposure time, and electrode configuration to maximize the benefits of corona discharge technology. Scientists have emphasized that treatment effectiveness varies among crop species and depends on seed characteristics and treatment conditions. While excessive exposure may damage seed tissues, properly controlled treatments consistently produce positive results. Due to its ability to improve germination, enhance seedling vigor, and reduce reliance on chemical treatments, corona discharge technology is increasingly being recognized as a promising and sustainable approach in modern seed treatment research and agricultural production systems.

6. MECHANISM OF PHYSICAL SEED TREATMENT

6.1 Physical Changes in Seeds

Physical seed treatment technologies such as UV radiation and corona discharge produce several structural and surface modifications in seeds that contribute to improved germination and seedling development. These treatments primarily affect the seed coat, which serves as the protective outer layer of the seed. Exposure to UV radiation or corona discharge can create microscopic changes on the seed surface, including the formation of tiny pores and cracks. These modifications increase the permeability of the seed coat, allowing water and oxygen to enter the seed more easily. Improved permeability accelerates the imbibition process and initiates metabolic activities necessary for germination.

Another important physical change is the enhancement of seed surface wettability. Corona discharge treatment alters the surface characteristics of seeds by introducing polar groups that increase hydrophilicity. As a result, water spreads more uniformly across the seed surface and penetrates the seed more efficiently. Enhanced water absorption promotes faster germination and uniform seedling emergence. In addition, these treatments may reduce the hardness of certain seed coats, helping to overcome physical dormancy and facilitating embryo growth.

Figure 15. Physical changes in seed coat after treatment.

Physical seed treatments also improve the overall condition of the seed surface by reducing microbial contamination and removing certain surface barriers that hinder germination. The modified seed structure allows for better gas exchange, ensuring adequate oxygen availability for respiration during germination. These physical changes collectively contribute to improved seed vigour, enhanced seedling establishment, and better crop performance. By modifying the external characteristics of seeds without the use of chemicals, physical seed treatment technologies provide an environmentally friendly approach to improving agricultural productivity.

6.2 Chemical Changes in Seeds

Physical seed treatment technologies such as UV radiation and corona discharge induce several chemical changes within seeds that contribute to improved germination and seedling growth. These treatments influence biochemical reactions, activate metabolic pathways, and alter the chemical composition of seeds. One of the most significant changes is the controlled production of reactive oxygen species (ROS). Although excessive ROS can be harmful, moderate levels act as signalling molecules that stimulate germination-related processes. They activate biochemical pathways responsible for breaking seed dormancy and initiating embryo growth, resulting in faster and more uniform germination.

Another important chemical change is the alteration of hormonal balance within the seed. Physical treatments often increase the levels of growth-promoting hormones such as gibberellins and auxins while reducing the concentration of abscisic acid (ABA), which is associated with seed dormancy. This favourable hormonal balance promotes root and shoot development during the early stages of growth. In addition, these treatments stimulate the breakdown of stored carbohydrates, proteins, and lipids into simpler compounds such as sugars, amino acids, and fatty acids. These nutrients provide the energy required for embryo development and vigorous seedling growth.

Physical seed treatments also enhance the antioxidant defense system and modify seed surface chemistry. Exposure to UV radiation or corona discharge stimulates the production of antioxidant enzymes that protect cells from oxidative damage and improve tolerance to environmental stresses.

Furthermore, corona discharge treatment introduces polar functional groups onto the seed surface, increasing its hydrophilicity and improving water absorption. UV treatment may also alter the chemical composition of the seed coat, making it more permeable to water and oxygen. Collectively, these chemical changes create favourable conditions for germination, seedling establishment, and healthy plant growth.

6.3 Biological Changes

Physical seed treatment technologies such as UV radiation and corona discharge bring about several biological changes within seeds that contribute to improved germination, seedling vigour, and plant growth. These treatments stimulate various physiological and cellular processes that enhance the biological activity of the seed. One of the most important biological effects is the activation of dormant cells within the embryo. As metabolic activities increase, cell division and cell elongation are accelerated, leading to faster germination and improved seedling emergence. This enhanced cellular activity supports the development of healthy and vigorous seedlings.

Another significant biological change is the stimulation of enzyme production and protein synthesis within the seed. Physical treatments activate enzymes responsible for mobilizing stored food reserves, which provide energy for embryo growth. Increased protein synthesis promotes the formation of new cells and tissues, supporting root and shoot development. In addition, these treatments can enhance the activity of beneficial microorganisms while reducing harmful microbial populations present on the seed surface. This creates a healthier environment for seed germination and early plant growth.

Physical seed treatments also influence plant physiological responses and stress tolerance mechanisms. Treated seeds often exhibit stronger root systems, improved nutrient uptake, and enhanced resistance to environmental stresses such as drought, salinity, and temperature fluctuations. The activation of various biological pathways improves overall plant health and growth performance. As a result, seedlings produced from treated seeds generally show better establishment, increased vigour, and higher productivity compared to untreated seeds. These biological changes play a crucial role in the effectiveness of physical seed treatment technologies in sustainable agriculture.

6.4 Enzyme Activation

Enzymes play a crucial role in seed germination by regulating the biochemical reactions required for embryo growth and seedling development. Physical seed treatment technologies such as UV radiation and corona discharge stimulate enzyme activity within seeds, thereby enhancing the germination process. When seeds absorb water during imbibition, enzymes become active and begin breaking down stored food materials into simpler compounds that can be utilized by the developing embryo. Physical treatments accelerate this activation process, resulting in faster and more uniform germination.

One of the most important enzymes activated during germination is amylase, which converts stored starch into simple sugars. These sugars serve as an energy source for the growing embryo. Similarly, enzymes such as protease break down proteins into amino acids, while lipase converts stored fats into fatty acids and glycerol. The increased activity of these enzymes ensures a continuous supply of nutrients and energy required for root and shoot development. As a result, treated seeds often exhibit improved seedling vigour and faster growth compared to untreated seeds.

Physical seed treatments also enhance overall metabolic efficiency by promoting enzyme synthesis and activity. Increased enzyme activity improves nutrient mobilization, accelerates cellular growth, and supports the development of healthy seedlings. Furthermore, efficient enzyme function helps seeds respond better to environmental conditions and stress factors during germination. Therefore, enzyme activation is considered one of the key mechanisms through which UV radiation and corona discharge treatments improve seed performance and contribute to higher crop productivity.

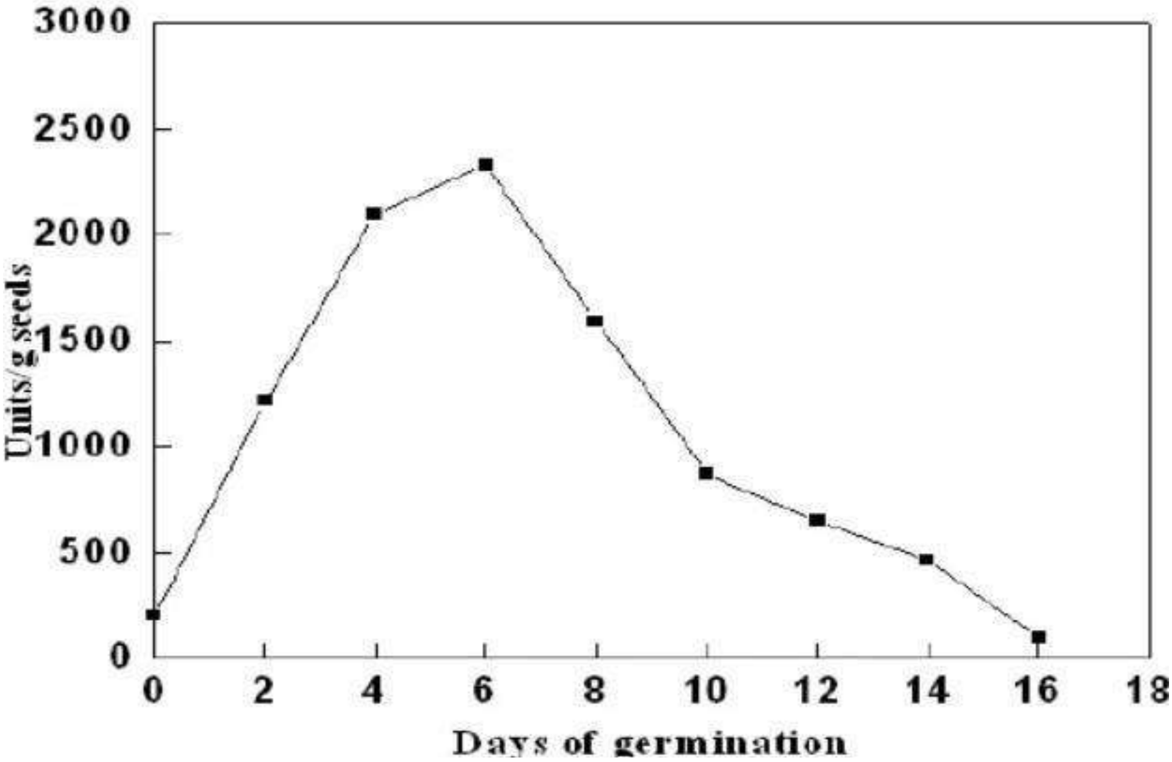

Figure 16. Enzyme activation in treated seeds.

6.5 Water Absorption

Water absorption is one of the most critical processes in seed germination, as it initiates the transition of a seed from a dormant state to an actively growing organism. Dry seeds contain very little moisture and remain metabolically inactive until they absorb sufficient water from the surrounding environment. The process of water uptake, known as imbibition, causes the seed to swell and soften the seed coat. This swelling creates favourable conditions for oxygen entry and activates the physiological mechanisms required for germination. Water also acts as a medium for biochemical reactions, allowing enzymes and nutrients to move freely within the seed. Therefore, the rate and extent of water absorption directly influence the speed and success of seed germination.

Physical seed treatment technologies such as UV radiation and corona discharge significantly improve the water absorption capacity of seeds by altering the structure and properties of the seed coat. UV treatment can create minor structural modifications that increase permeability, while corona discharge treatment changes the surface chemistry of seeds by introducing polar functional groups. These modifications increase the hydrophilic nature of the seed surface, enabling water to spread more evenly and penetrate more rapidly. Improved water uptake activates enzymes responsible for breaking down stored carbohydrates, proteins, and lipids into simpler compounds that provide energy for embryo growth. Consequently, treated seeds often exhibit faster germination, improved seedling vigour, and more uniform emergence compared to untreated seeds.

Water absorption also plays a vital role in activating cellular processes that support early plant development. As moisture enters the seed, cells regain their physiological activity and begin dividing and expanding. The embryo starts to grow, and the radicle, which develops into the primary root, emerges through the seed coat. Adequate water availability ensures efficient nutrient transport, supports respiration, and promotes the synthesis of proteins and other essential compounds. In addition, improved water absorption enhances the ability of seedlings to establish quickly in the soil, increasing their chances of survival under field conditions. Thus, water absorption serves as a fundamental mechanism through which physical seed treatments improve germination, seedling establishment, and overall crop productivity.

The efficiency of water absorption depends on several factors, including seed coat characteristics, seed size, temperature, and soil moisture conditions. Seeds with hard or thick seed coats generally absorb water more slowly than seeds with thinner coats. Environmental conditions such as low soil moisture or extreme temperatures can also limit water uptake and delay germination. Physical seed treatments help overcome some of these barriers by improving seed coat permeability and facilitating moisture penetration. As a result, treated seeds are often able to germinate successfully even under less favourable environmental conditions.

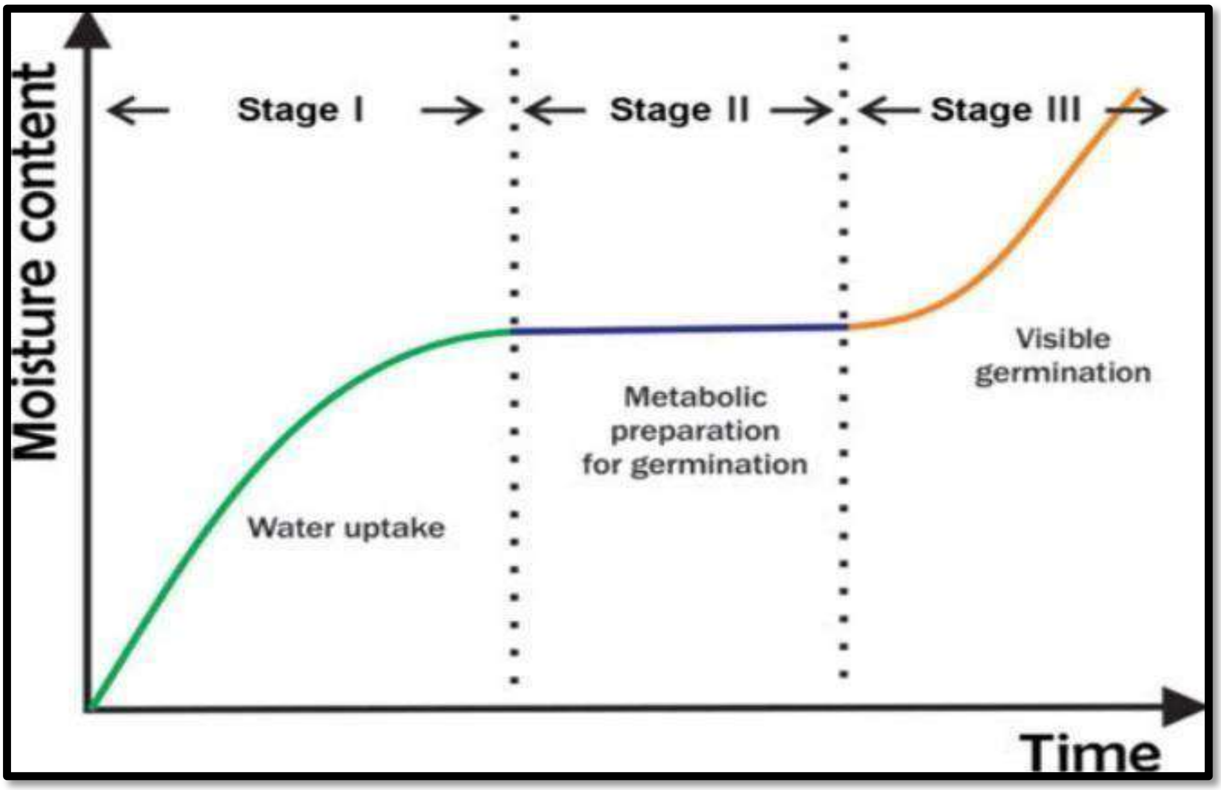

Figure 17. Water absorption (imbibition) during seed germination.

Another important aspect of water absorption is its role in breaking seed dormancy. Many dormant seeds fail to germinate because their seed coats restrict water entry. By modifying the seed surface and enhancing permeability, physical treatments allow water to reach the embryo more effectively. This stimulates metabolic activity and initiates the germination process. Therefore, improved water absorption not only accelerates germination but also contributes to overcoming dormancy-related constraints, making physical seed treatment an effective strategy for enhancing seed performance in modern agriculture

6.6 Reactive Oxygen Species (ROS) Generation in Seeds

Reactive Oxygen Species (ROS) are highly reactive oxygen-containing molecules that play an important role in seed germination, growth, and development. Common ROS include superoxide radicals (O_2^-), hydrogen peroxide (H_2O_2), hydroxyl radicals (OH•), and singlet oxygen ($^1O_2$). Although excessive ROS can cause cellular damage, controlled levels of ROS act as important signaling molecules that regulate various physiological and biochemical processes within seeds. Physical seed treatment technologies such as UV radiation and corona discharge stimulate the production of ROS, which contributes significantly to enhanced seed performance and germination.

During UV radiation and corona discharge treatment, energy from ultraviolet light or ionized particles interacts with oxygen molecules surrounding the seed surface. This interaction generates reactive oxygen species that accumulate on and within the seed coat. These ROS molecules initiate a series of beneficial biochemical reactions that promote seed germination and seedling development. The controlled generation of ROS acts as a signalling mechanism that activates metabolic pathways required for breaking dormancy and initiating growth processes.

One of the primary functions of ROS in seeds is the modification of the seed coat structure. Reactive oxygen species help weaken or partially degrade rigid seed coat components, increasing permeability to water and oxygen. Improved permeability enhances water absorption during imbibition and facilitates oxygen diffusion into the seed. These changes accelerate the activation of metabolic activities necessary for germination. Consequently, ROS generation contributes to faster and more uniform seed germination.

ROS also play a vital role in activating enzymes associated with seed germination. The presence of reactive oxygen species stimulates the synthesis and activity of enzymes such as amylase, protease, and lipase. These enzymes break down stored carbohydrates, proteins, and lipids into simpler compounds that provide energy and nutrients for embryo growth. Enhanced enzyme activity improves nutrient mobilization and supports rapid seedling development. Thus, ROS serve as important mediators linking physical seed treatment to improved metabolic performance.

Another important function of ROS is their involvement in breaking seed dormancy. Dormant seeds often contain physiological barriers that prevent germination even under favourable environmental conditions. Controlled ROS accumulation helps overcome these barriers by influencing hormonal balance and cellular signaling pathways. ROS can reduce the inhibitory effects of abscisic acid (ABA) while promoting the action of gibberellic acid

(GA), thereby creating conditions favourable for germination. This hormonal regulation contributes to the successful transition of seeds from dormancy to active growth.

Reactive oxygen species also enhance the plant's defense mechanisms against environmental stresses and microbial pathogens. Moderate ROS levels stimulate antioxidant systems within seeds and seedlings, preparing them to tolerate adverse conditions such as drought, salinity, and temperature stress. Additionally, ROS possess antimicrobial properties that help suppress fungal and bacterial pathogens present on the seed surface. This dual role improves both seed health and stress resilience.

While controlled ROS production is beneficial, excessive ROS accumulation can damage cellular membranes, proteins, nucleic acids, and other cellular components. Therefore, maintaining an optimal balance between ROS generation and antioxidant activity is essential. Physical seed treatment technologies are designed to generate ROS at levels that stimulate beneficial physiological responses without causing oxidative damage. Proper optimization of treatment conditions ensures that ROS contribute positively to seed performance and plant growth.

Overall, ROS generation is considered one of the key mechanisms through which UV radiation and corona discharge treatments improve seed germination, seedling vigour, and crop productivity. By enhancing seed coat permeability, activating enzymes, breaking dormancy, stimulating metabolic activity, and strengthening stress tolerance, reactive oxygen species play a central role in the success of modern physical seed treatment technologies.

6.7 Changes in Seed Coat Morphology after Treatment

The seed coat serves as the outer protective layer of the seed and plays a crucial role in regulating water absorption, gas exchange, and protection against environmental stresses and microbial attack. The structure and properties of the seed coat greatly influence seed germination and seedling establishment. Physical seed treatment technologies such as UV radiation and corona discharge can induce significant changes in seed coat morphology, resulting in improved seed performance. These modifications enhance seed permeability and facilitate the physiological processes necessary for successful germination.

One of the most important morphological changes observed after physical seed treatment is the formation of microscopic cracks, pores, and surface irregularities on the seed coat. UV radiation and corona discharge alter the outer layers of the seed surface, creating tiny openings that increase permeability. These structural modifications allow water and oxygen to penetrate the seed more easily during imbibition. Improved permeability accelerates the activation of metabolic processes and promotes faster germination. Microscopic observations using scanning electron microscopy (SEM) have confirmed the presence of these surface changes in many treated crop seeds.

Physical seed treatments also influence the surface roughness of the seed coat. Untreated seeds generally possess smooth and compact surfaces that may restrict water entry. Following treatment, the seed surface becomes rougher due to slight erosion and modification of outer protective layers. Increased surface roughness improves the contact area between the seed and surrounding moisture, facilitating faster water absorption. Enhanced water uptake supports efficient enzyme activation and nutrient mobilization during germination.

Another significant change involves the modification of waxy and hydrophobic compounds present on the seed surface. Many seeds possess natural wax layers that limit water penetration and protect against environmental stress. Corona discharge treatment, in particular, alters the chemical composition of these surface layers by introducing oxygen-containing functional groups. These changes increase the hydrophilic nature of the seed coat, making it more attractive to water molecules. Consequently, treated seeds absorb water more rapidly and germinate more efficiently than untreated seeds.

Physical treatments may also affect the thickness and integrity of certain seed coat layers. Controlled exposure to UV radiation or corona discharge can partially weaken rigid structural components without damaging the embryo. This weakening reduces mechanical resistance to radicle emergence during germination. As a result, the developing root can penetrate the seed coat more easily, contributing to faster and more uniform seedling emergence. Such modifications are particularly beneficial for seeds with hard or thick seed coats.

Research studies have shown that changes in seed coat morphology are closely associated with improved physiological and biochemical responses. Enhanced water absorption resulting from surface modifications stimulates metabolic activity, enzyme synthesis, and respiration. Increased oxygen diffusion into the seed further supports cellular processes necessary for germination. These combined effects lead to improved seedling vigor, stronger root development, and better crop establishment under field conditions.

The extent of seed coat modification depends on several factors, including treatment intensity, exposure duration, seed type, and seed coat characteristics. Moderate treatment levels generally produce beneficial changes, whereas excessive exposure may cause structural damage and reduce seed viability. Therefore, careful optimization of treatment conditions is necessary to achieve desirable morphological modifications while maintaining seed quality.

Overall, changes in seed coat morphology represent one of the key mechanisms through which UV radiation and corona discharge treatments enhance seed performance. By increasing surface roughness, improving permeability, modifying hydrophobic layers, and facilitating water and oxygen uptake, these treatments create favorable conditions for germination and seedling growth. Such morphological improvements contribute significantly to the effectiveness of modern physical seed treatment technologies.

7. APPLICATIONS OF SEED TREATMENT IN DIFFERENT CROPS

7.1 Cereals

Cereal crops form the backbone of global food security and are widely cultivated across different climatic regions. Major cereal crops include Rice (*Oryza sativa*), Wheat (*Triticum aestivum*), Maize (*Zea mays*), Barley (*Hordeum vulgare*), and Sorghum (*Sorghum bicolour*). These crops require high-quality seeds to ensure uniform germination, strong seedling establishment, and improved productivity. Physical seed treatment technologies such as ultraviolet (UV) radiation and corona discharge have shown promising results in improving cereal seed performance.

Cereal seeds often face challenges such as delayed germination, poor seedling vigour, and susceptibility to seed-borne diseases. These factors reduce crop establishment and ultimately affect yield. Physical seed treatment technologies help overcome these challenges by improving seed physiological and biochemical properties.

When cereal seeds are exposed to UV radiation, the seed coat undergoes slight structural changes. These modifications increase seed permeability, allowing better water absorption and oxygen exchange. Improved hydration initiates metabolic processes earlier, resulting in faster and uniform germination. Uniform germination is especially important in cereal crops, as it ensures even plant spacing and reduces competition among plants.

Similarly, corona discharge treatment enhances seed surface wettability. The treatment modifies the seed coat surface and increases its hydrophilic nature. This allows water molecules to spread evenly across the seed surface, improving moisture absorption. As a result, cereal seeds treated with corona discharge often show faster germination and improved seedling vigour.

Research studies conducted on cereal crops have reported significant improvements after physical seed treatment. Treated wheat seeds have shown increased germination percentage and improved root and shoot growth. Similarly, rice seeds exposed to UV radiation demonstrated enhanced seedling emergence and better early growth. Maize seeds treated with corona discharge have also shown improved plant vigour and increased biomass accumulation. Another important benefit of physical seed treatment in cereals is the reduction of microbial contamination. Cereal seeds are often affected by fungal and bacterial pathogens, which reduce germination and seedling growth. UV radiation has disinfecting properties that help eliminate harmful microorganisms present on seed surfaces. Corona discharge treatment also reduces microbial contamination by damaging pathogen cell walls. These effects improve seed health and reduce the incidence of seed-borne diseases.

Physical seed treatments also improve stress tolerance in cereal crops. Treated seedsoften perform better under unfavourable conditions such as drought, salinity, and temperature stress. Improved root development helps plants absorb water and nutrients more efficiently, which supports plant growth under stress conditions.

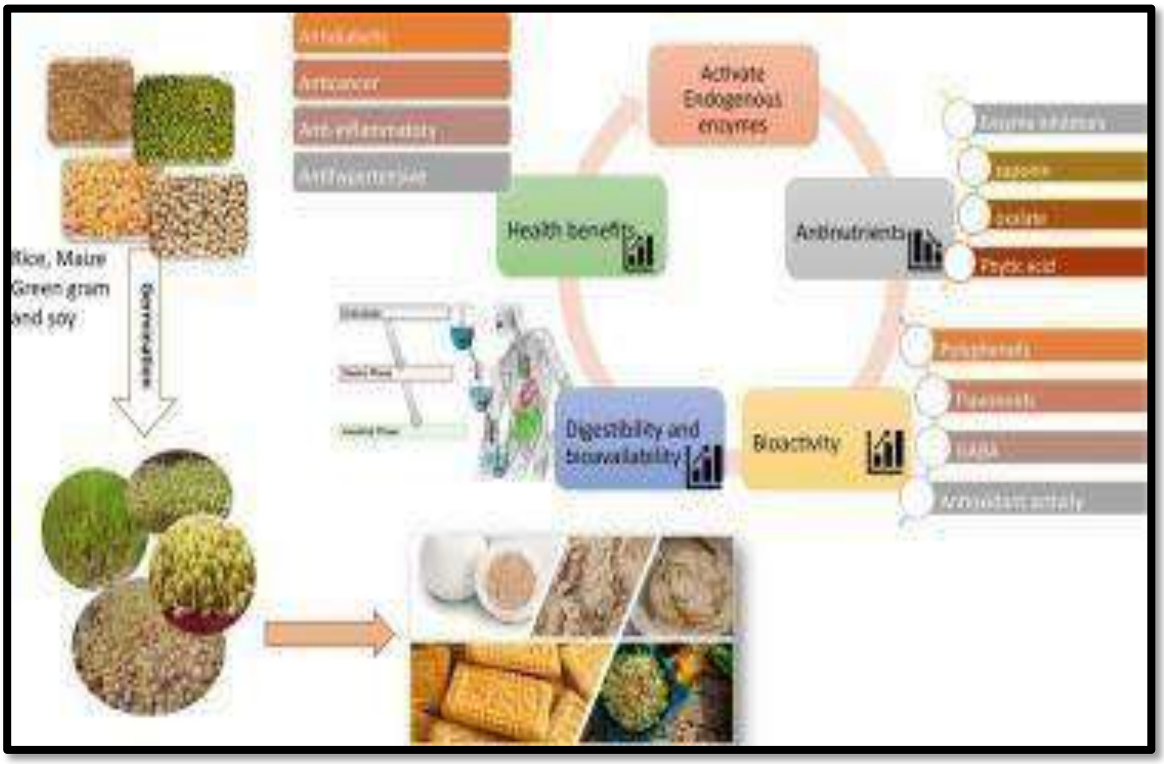

Figure 18. Effect of physical seed treatment on cereal crop germination and seedling growth.

In addition to improved germination and growth, physical seed treatment also contributes to increased crop yield. Uniform plant establishment improves nutrient utilization and reduces plant competition. Treated plants often show better tillering, improved leaf development, and enhanced photosynthesis. These factors collectively contribute to higher productivity in cereal crops.

Overall, the application of physical seed treatment technologies in cereal crops offers a sustainable and effective approach to improving seed quality, plant growth, and crop yield. As research continues, these technologies are expected to play an important role in enhancing cereal production and ensuring global food security.

7.2 Pulses

Pulse crops are an essential component of global agriculture and human nutrition. They are rich in protein, minerals, and vitamins, making them an important part of daily diets, especially in developing countries. Major pulse crops include Chickpea (*Cicer arietinum*), Green gram (*Vigna radiata*), Black gram (*Vigna mungo*), Pigeon pea (*Cajanus Cajan*), and Lentil (*Lens culinaris*). Despite their importance, pulse crops often face challenges related to poor germination, hard seed coats, and susceptibility to environmental stress. Physical seed treatment technologies such as UV radiation and corona discharge have emerged as promising solutions to improve pulse crop performance.

Pulse seeds typically have hard seed coats that limit water absorption during germination. This slow hydration delays germination and results in uneven plant growth. Physical seed treatments help overcome this limitation by modifying the seed surface. UV radiation causes slight structural changes in the seed coat, improving permeability and allowing better water absorption. This accelerates the germination process and promotes uniform seedling emergence.

Corona discharge treatment also improves seed surface properties. The treatment increases seed wettability and enhances the hydrophilic nature of the seed coat. This allows water molecules to spread evenly across the seed surface, leading to improved moisture uptake. As a result, pulse seeds treated with corona discharge often exhibit faster germination and improved seedling vigour. Another important advantage of physical seed treatment in pulses is enhanced root development. Pulse crops rely heavily on root systems for nutrient absorption and nitrogen fixation. Treated seeds often develop stronger roots and improved root length.

Figure 19. Various types of treated pulses seed.

Physical seed treatments also improve nodulation in pulse crops. Nodulation is an important process in which symbiotic bacteria form nodules on roots and fix atmospheric nitrogen. Improved root development and enhanced biological activity in treated seeds promote better nodulation. This results in improved nitrogen fixation and better plant growth.

Physical seed treatment also helps reduce microbial contamination in pulse seeds. UV radiation has antimicrobial properties that eliminate harmful fungi and bacteria present on seed surfaces. Similarly, corona discharge treatment reduces seed-borne pathogens. These effects improve seed health and reduce the chances of disease during early growth stages. In addition, treated pulse seeds often show improved tolerance to environmental stress conditions such as drought and salinity. Enhanced root growth helps plants absorb water efficiently, while improved metabolic activity supports plant survival under stress conditions. These advantages contribute to better plant establishment and increased productivity.

Several research studies have reported that pulse crops treated with UV radiation and corona discharge show improved germination percentage, increased seedling vigour, and better plant growth. Treated plants often exhibit uniform growth, improved flowering, and higher yield compared to untreated seeds. Overall, physical seed treatment technologies provide an effective and sustainable method for improving pulse crop performance. These treatments enhance germination, promote root development, improve nodulation, and increase crop productivity, making them valuable tools for modern pulse cultivation.

7.3 Oilseeds

Oilseed crops play a significant role in global agriculture as they are major sources of edible oil, industrial raw materials, and livestock feed. Improving seed germination and early plant growth in oilseed crops is essential for achieving higher productivity and better oil yield. Physical seed treatment technologies such as UV radiation and corona discharge have shown promising results in enhancing oilseed crop performance.

Major oilseed crops include Sunflower (*Helianthus annuus*), Groundnut (*Arachis hypogaea*), Soybean (*Glycine max*), Mustard (*Brassica juncea*), and Sesame (*Sesamum indicum*). These crops often require strong seedling establishment and uniform plant growth for better flowering and seed formation. Physical seed treatments help improve these characteristics by enhancing seed physiological activity. Oilseed seeds usually contain high amounts of stored lipids, which serve as energy sources during germination. UV radiation stimulates enzyme activity that helps break down these stored lipids into usable energy. This process supports faster germination and improved seedling growth. As a result, treated seeds often exhibit early emergence and improved plant establishment.

Corona discharge treatment improves seed surface properties by increasing wettability and water absorption. This is particularly beneficial for oilseed crops, where rapid hydration is necessary for activating metabolic processes. Improved water absorption accelerates germination and promotes uniform seedling growth.

Studies conducted on sunflower seeds have shown significant improvements in germination percentage, root length, and shoot growth after UV radiation and corona discharge treatment. Similarly, soybean seeds treated with physical methods exhibit enhanced seedling vigour and improved biomass accumulation. Groundnut seeds have also demonstrated improved emergence and plant development after treatment.

Another important benefit of physical seed treatment in oilseed crops is the reduction of microbial contamination. Oilseed seeds are often susceptible to fungal infections, which affect germination and seedling growth. UV radiation helps eliminate harmful microorganisms, while corona discharge treatment reduces pathogen presence on seed surfaces. These effects improve seed health and reduce disease incidence.

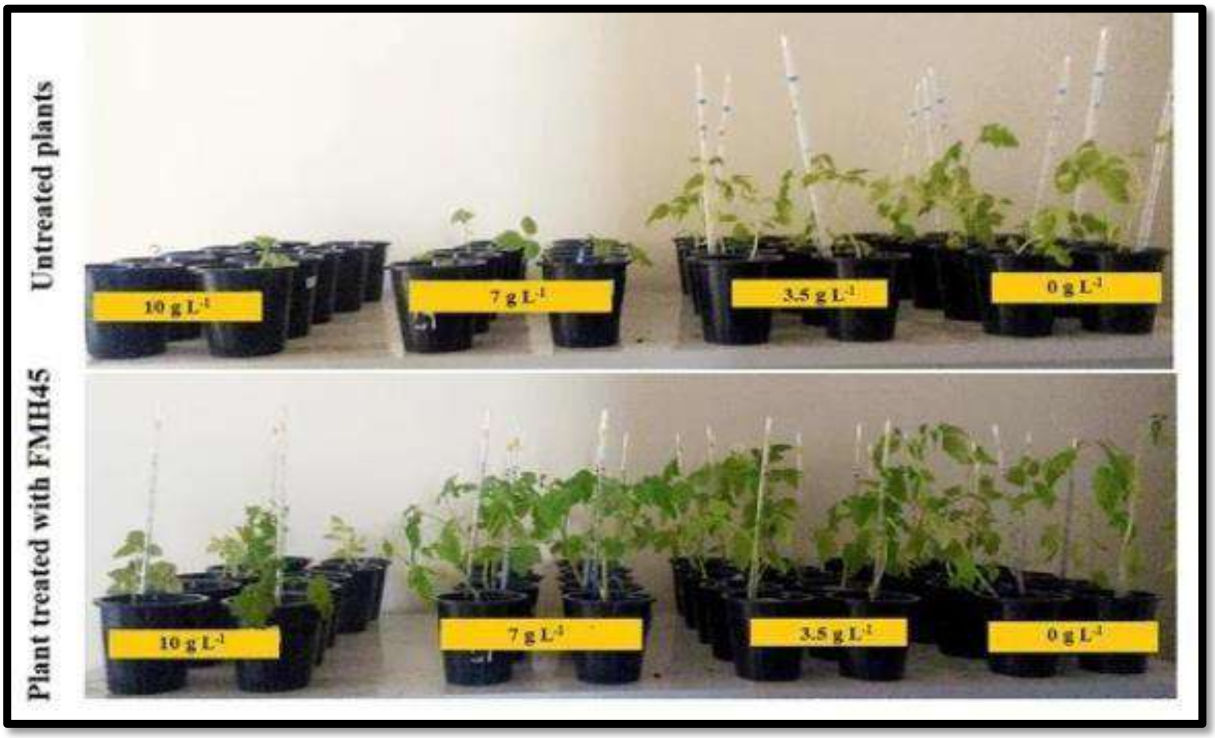

Figure 20. Effect of physical seed treatment.

Physical seed treatment also improves stress tolerance in oilseed crops. Treated seeds often perform better under drought and temperature stress conditions. Enhanced root development allows plants to absorb water and nutrients more efficiently, supporting plant growth under challenging environmental conditions.

In addition, treated oilseed crops often show improved flowering and seed formation. Uniform plant growth ensures better pollination and seed development, leading to increased yield and improved oil content. These improvements make physical seed treatment technologies valuable tools for enhancing oilseed crop productivity.

7.4 Vegetables

Vegetable crops are highly important in agriculture due to their nutritional value, economic importance, and short growth duration. Successful vegetable production largely depends on high seed germination, uniform seedling emergence, and strong early plant growth. However, vegetable seeds are often sensitive to environmental conditions and prone to poor germination and seedling diseases. Physical seed treatment technologies such as UV radiation and corona discharge have shown promising results in improving vegetable crop performance.

Common vegetable crops include Tomato (*Solanum Lycopersicon*), Brinjal (*Solanum melongena*), Chilli (*Capsicum annuum*), Cucumber (*Cucumis sativus*), and Cabbage (*Brassica oleracea*). These crops require uniform germination and healthy seedlings for better plant establishment and productivity. Physical seed treatment technologies help improve these parameters by enhancing seed physiological and biochemical activities.

Vegetable seeds are often small and delicate, making them vulnerable to environmental stress and microbial infection. UV radiation helps disinfect seed surfaces by eliminating harmful fungi and bacteria. This reduces seed-borne diseases and improves seed health. As a result, treated seeds produce healthier seedlings with better survival rates. UV radiation also stimulates enzyme activity within vegetable seeds. This improves metabolic processes and accelerates germination.

Seeds treated with UV radiation often show faster emergence and improved seedling vigour. Enhanced root and shoot development in treated seedlings further supports plant growth. Corona discharge treatment also plays an important role in improving vegetable seed performance. The treatment modifies seed surface properties, increasing wettability and water absorption. Improved hydration activates metabolic processes earlier, resulting in uniform germination and strong seedling development.

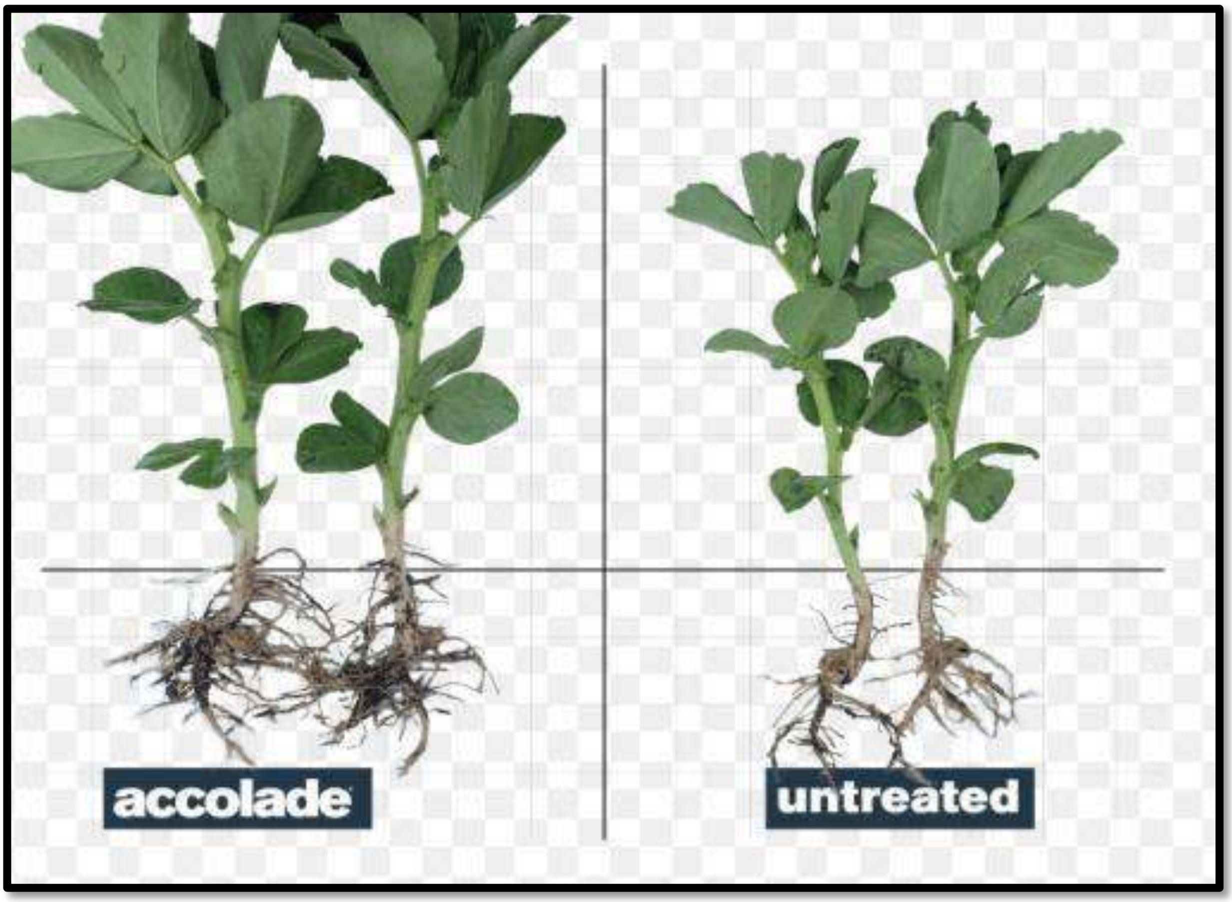

Figure 21. Growth stages of treated and untreated.

Studies conducted on tomato and chilli seeds have reported improved germination percentage and increased seedling vigour after UV radiation treatment. Similarly, cucumber and cabbage seeds treated with corona discharge have shown improved root length, shoot growth, and biomass accumulation. These improvements contribute to better plant establishment and crop productivity.

7.5 Horticultural Crops

Horticultural crops include fruits, flowers, plantation crops, and ornamental plants that require high-quality seeds for uniform growth and better productivity. Seed germination and early seedling establishment are particularly important in horticultural crops because these crops are often cultivated under controlled conditions and demand high-quality planting material. Physical seed treatment technologies such as UV radiation and corona discharge have shown promising results in improving germination, seedling vigour, and plant growth in horticultural crops.

UV radiation treatment enhances seed germination in horticultural crops by stimulating metabolic processes and activating enzymes responsible for growth. Treated seeds often show faster emergence and uniform seedling development. UV radiation also helps in reducing microbial contamination on seed surfaces, which is particularly beneficial for horticultural crops that are sensitive to diseases during early growth stages. Crops such as Tomato (*Solanum lycopersicum*), Chilli (*Capsicum annuum*), and Brinjal (*Solanum melongena*) have shown improved germination and seedling growth after UV seed treatment.

Corona discharge treatment improves seed surface characteristics by increasing wettability and water absorption. This leads to faster germination and improved root development in horticultural crops. Strong root systems help plants absorb nutrients efficiently and support better plant growth. Studies conducted on crops such as Cucumber (*Cucumis sativus*), Watermelon (*Citrullus lanatus*), and Okra (*Abelmoschus esculentus*) have reported improved germination and early plant growth following corona discharge treatment. Fruit crops also benefit from physical seed treatments. Seeds of Papaya (*Carica papaya*), Guava (*Psidium guajava*), and Pomegranate (*Punica granatum*) show improved germination and uniform seedling growth when treated with UV radiation or corona discharge. These treatments help overcome dormancy and improve seedling establishment, which is important for nursery production.

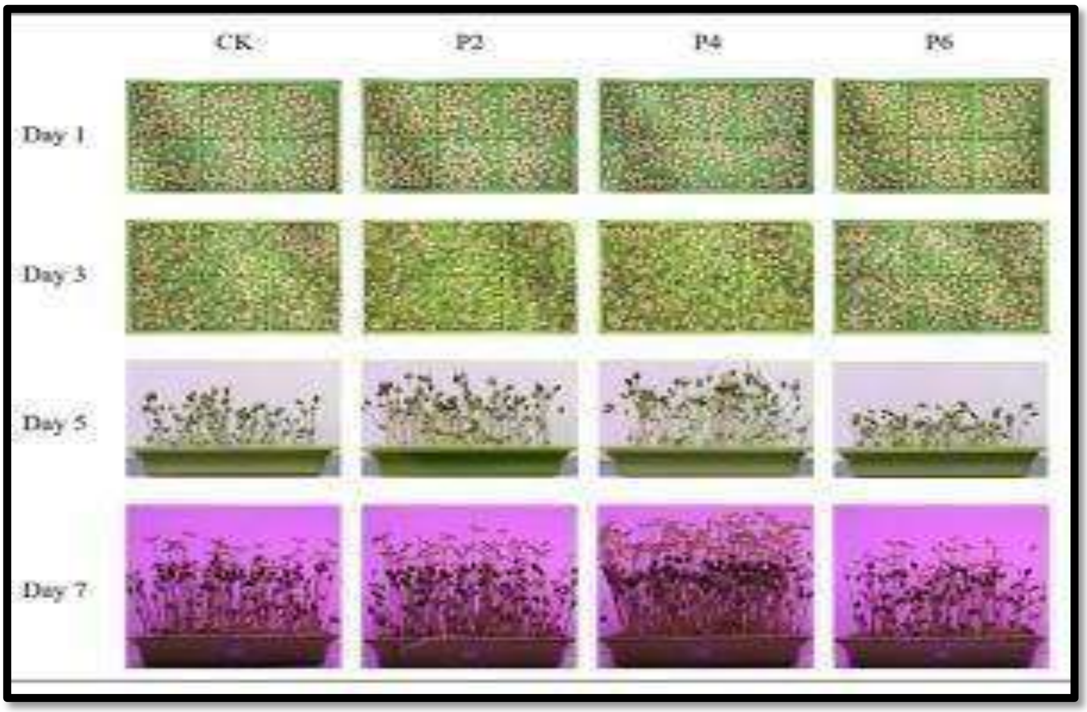

Figure 22. Application of physical seed treatment in horticultural crops

In ornamental crops, uniform germination and seedling growth are important for maintaining plant quality. Physical seed treatment improves germination rate and promotes healthy seedling development in ornamental plants such as Marigold (*Tagetes erecta*), Petunia (*Petunia hybrida*), and Zinnia (*Zinnia elegans*). These improvements help in producing uniform flowering plants with better growth performance. Overall, physical seed treatment technologies such as UV radiation and corona discharge offer significant advantages for horticultural crops. These treatments improve germination, enhance seedling vigour, promote root development, and increase plant growth. As a result, horticultural crops benefit from improved plant quality, uniform growth, and better productivity.

8. CASE STUDIES OF PHYSICAL SEED TREATMENT

8.1 Sunflower Seed Treatment

Sunflower (*Helianthus annuus*) is one of the most important oilseed crops cultivated worldwide for edible oil production. Achieving high germination rate and strong seedling growth is essential for improving sunflower productivity. However, sunflower seeds often face challenges such as delayed germination, poor seedling vigour, and susceptibility to microbial contamination. Physical seed treatment technologies such as ultraviolet (UV) radiation and corona discharge have shown promising results in improving sunflower seed performance.

Experimental Background

Several experimental studies have been conducted to evaluate the effect of UV radiation and corona discharge on sunflower seeds. In these studies, sunflower seeds were subjected to controlled UV exposure and corona discharge treatment for specific durations. Treated seeds were then compared with untreated seeds to evaluate germination percentage, seedling growth, and plant development. The results showed that treated seeds exhibited significant improvement in germination rate and seedling vigour. Both UV radiation and corona discharge treatments positively influenced early plant growth and development.

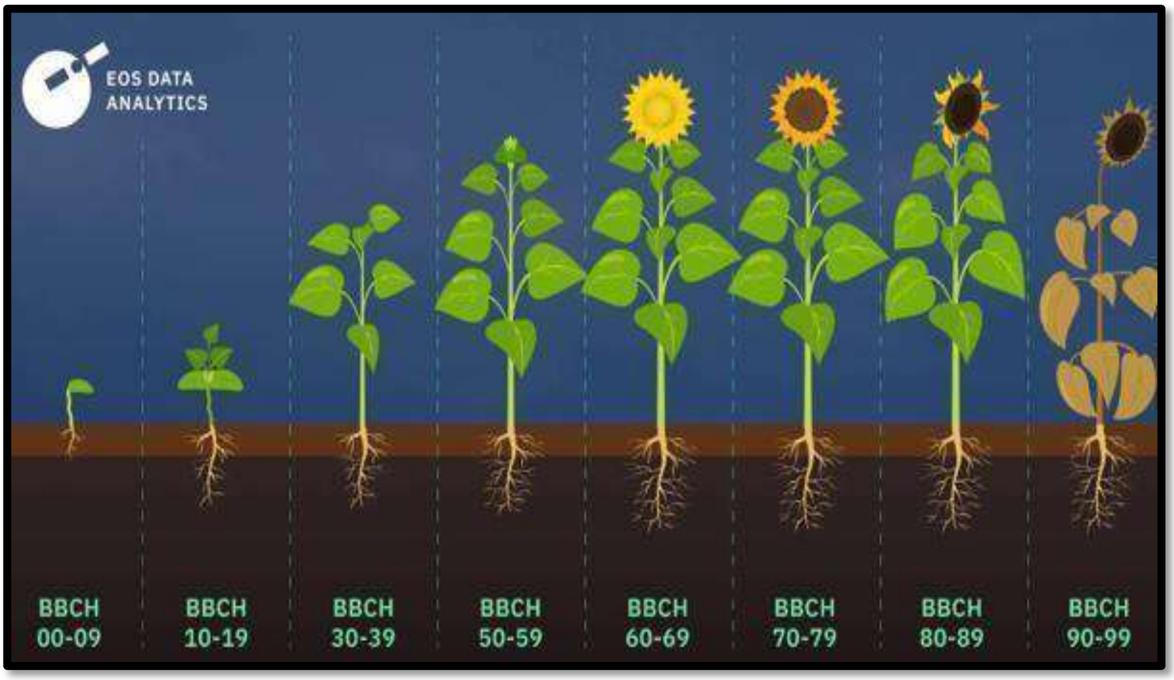

Figure 23. Growth stages of sunflower.

Effect of UV Radiation on Sunflower Seeds

One of the primary effects of UV radiation on sunflower seeds is the improvement of germination percentage and germination speed. UV treatment modifies the seed coat and enhances its permeability, allowing seeds to absorb water more efficiently during imbibition. Improved water uptake activates metabolic processes and stimulates enzyme activity, leading to faster germination. Several studies have reported that UV-treated sunflower seeds exhibit quicker emergence and more uniform germination compared to untreated seeds. Uniform germination is particularly important for achieving consistent crop establishment and efficient field management.

UV radiation also has a positive influence on seedling vigour and early plant development. Treated sunflower seeds often produce seedlings with greater root length, shoot length, and overall biomass. The enhanced growth is mainly attributed to increased enzyme activity and improved mobilization of stored food reserves within the seed. Enzymes such as amylase and protease become more active after UV exposure, providing the energy required for rapid embryo development. As a result, sunflower seedlings develop stronger root systems that improve nutrient and water uptake from the soil.

Another significant effect of UV radiation is the reduction of microbial contamination on sunflower seeds. Seeds often carry fungi and bacteria that can adversely affect germination and seedling growth. UV radiation possesses antimicrobial properties that help eliminate or suppress these microorganisms on the seed surface. Reduced pathogen load improves seed health, minimizes disease incidence, and promotes healthy seedling establishment. This advantage makes UV treatment an environmentally friendly alternative to certain chemical seed disinfectants.

Research has also shown that UV-treated sunflower plants exhibit improved physiological performance. Increased chlorophyll content, enhanced photosynthetic activity, and greater biomass accumulation have been observed in plants grown from treated seeds. These improvements contribute to better plant growth throughout the crop cycle. In some studies, UV treatment has been associated with increased flower head diameter, higher seed yield, and improved oil content, indicating its potential to enhance overall crop productivity.

The effectiveness of UV radiation depends on treatment conditions such as wavelength, intensity, and exposure duration. Moderate UV exposure generally produces positive effects, whereas excessive exposure may damage seed tissues and reduce viability.

Therefore, optimization of treatment parameters is essential to achieve maximum benefits without causing adverse effects.

Overall, UV radiation has demonstrated considerable potential as a physical seed treatment technology for sunflower cultivation. By improving germination, enhancing seedling vigor, reducing microbial contamination, and promoting plant growth, UV treatment contributes to better crop establishment and increased productivity These advantages make UV radiation a promising and sustainable tool for modern sunflower production systems.

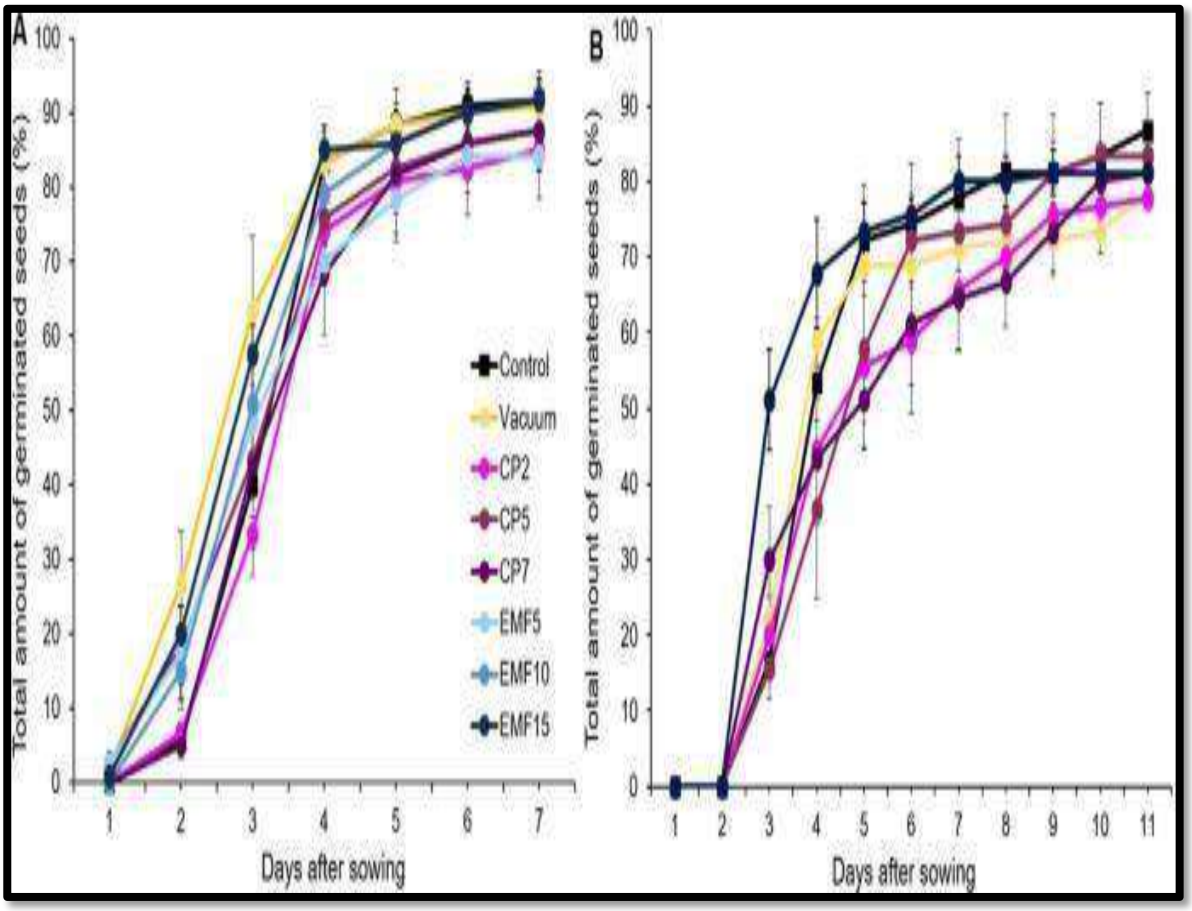

Figure 24. Effect of UV radiation on sunflower seed germination and growth effect of Corona Discharge on Sunflower Seeds

One of the most significant effects of corona discharge treatment on sunflower seeds is the improvement of seed surface wettability and water absorption. The treatment alters the physical and chemical characteristics of the seed coat by introducing polar functional groups and creating microscopic surface modifications. These changes increase the hydrophilic nature of the seed surface, allowing water to penetrate more rapidly during imbibition. Enhanced water uptake activates metabolic processes earlier, resulting in faster and more uniform germination. Experimental studies have shown that corona-treated sunflower seeds often exhibit higher germination percentages and reduced germination time compared to untreated seeds.

Corona discharge treatment also promotes seedling vigor and early plant growth. Improved water absorption and enhanced metabolic activity stimulate root and shoot development during the initial growth stages. Research findings indicate that treated sunflower seedlings frequently show increased root length, shoot length, and biomass accumulation. Stronger root systems improve nutrient and water uptake from the soil, enabling plants to establish more effectively and withstand environmental stress. Consequently, seedlings produced from corona-treated seeds tend to be healthier and more vigorous than those from untreated seeds.

Another important benefit of corona discharge treatment is its ability to reduce microbial contamination on seed surfaces. Sunflower seeds may carry fungal and bacterial pathogens that negatively affect germination and seedling health. The reactive ions and radicals generated during corona discharge can suppress or eliminate these microorganisms, thereby improving seed health and reducing the risk of seed-borne diseases. This antimicrobial effect contributes to healthier seedlings and better crop establishment without the need for chemical disinfectants.

Studies have further reported that corona discharge treatment enhances physiological and biochemical activities within sunflower seeds. Increased enzyme activity, improved nutrient mobilization, and enhanced respiration rates contribute to rapid embryo growth and seedling development. Some research has also observed increased chlorophyll content and photosynthetic efficiency in plants grown from treated seeds. These physiological improvements support stronger plant growth and may contribute to increased yield and productivity.

The effectiveness of corona discharge treatment depends on factors such as voltage level, exposure duration, electrode configuration, and seed characteristics. Proper optimization of these parameters is essential because excessive treatment may damage seed tissues and reduce viability. When applied under controlled conditions, corona discharge treatment provides significant benefits for sunflower seed germination and growth.

Overall, corona discharge treatment is an effective and environmentally friendly technology for improving sunflower seed performance. By enhancing water absorption, promoting seedling vigor, reducing microbial contamination, and stimulating physiological activity, it contributes to better crop establishment and increased agricultural productivity.

These advantages make corona discharge a valuable tool in modern sunflower cultivation and sustainable seed treatment practices.

Comparative Results

Experimental results indicated that both UV radiation and corona discharge treatments improved sunflower seed performance. However, the level of improvement depended on treatment duration and intensity. Optimized treatment conditions produced the best results.

Treated sunflower seeds showed:

- Higher germination percentage
- Increased seedling vigour
- Improved plant growth
- Better crop establishment

These improvements contributed to increased sunflower productivity.

Conclusion of Case Study

The sunflower seed treatment case study demonstrates that UV radiation and corona discharge technologies are effective in improving seed germination and seedling growth. These physical seed treatment methods offer eco-friendly alternatives to chemical seed treatments. The improved plant growth and productivity highlight the potential of these technologies for sustainable sunflower cultivation.

8.2 Wheat Seed Treatment

Wheat (*Triticum aestivum*) is one of the most widely cultivated cereal crops in the world and serves as a staple food for a large portion of the global population. Improving wheat seed germination and early plant establishment is essential for achieving higher productivity. However, wheat seeds often face challenges such as poor germination, seed-borne diseases, and uneven seedling growth. Physical seed treatment technologies such as ultraviolet (UV) radiation and corona discharge have shown promising potential in improving wheat seed performance.

Experimental Background

Several research studies have been conducted to evaluate the effect of physical seed treatment on wheat seeds. In these studies, wheat seeds were exposed to controlled UV radiation and corona discharge treatment. The treated seeds were compared with untreated seeds to evaluate parameters such as germination percentage, seedling growth, and plant vigour.

The results indicated that physical seed treatments significantly improved germination rate and seedling growth in wheat. Treated seeds showed faster emergence and stronger plant establishment compared to untreated seeds.

Effect of UV Radiation on Wheat Seeds

One of the primary effects of UV radiation on wheat seeds is the improvement of germination percentage and germination speed. UV treatment increases seed coat permeability, allowing water and oxygen to enter the seed more efficiently. Enhanced water absorption activates metabolic processes and stimulates enzyme activity, leading to faster germination and uniform seedling emergence. Several studies have reported that UV-treated wheat seeds exhibit higher germination rates and shorter germination periods compared to untreated seeds. Uniform germination contributes to better crop establishment and improved field performance.

UV radiation also positively influences seedling growth and vigor in wheat. Treated seeds often produce seedlings with longer roots, greater shoot length, and increased biomass accumulation. The treatment stimulates the activity of enzymes such as amylase and protease, which break down stored food reserves and provide energy for embryo growth. As a result, wheat seedlings develop stronger root systems capable of absorbing water and nutrients more effectively. Improved root development enhances plant stability and supports healthy growth during later stages of crop development.

Another important benefit of UV seed treatment is the reduction of microbial contamination. Wheat seeds frequently carry fungal and bacterial pathogens that can reduce germination and cause seedling diseases. UV radiation possesses strong antimicrobial properties that help eliminate or suppress these harmful microorganisms on the seed surface. Reduced pathogen populations improve seed health, minimize disease incidence, and promote healthy seedling establishment. This makes UV treatment an environmentally friendly alternative to certain chemical seed disinfectants.

Research studies have also reported improvements in physiological and biochemical characteristics of wheat plants grown from UV-treated seeds. Increased chlorophyll content, enhanced photosynthetic activity, and improved nutrient utilization have been observed in treated plants. These changes contribute to better plant growth, increased biomass production, and improved stress tolerance under adverse environmental conditions. Some studies have further indicated that UV treatment can positively influence grain yield and overall crop productivity when optimal treatment conditions are used.

The effectiveness of UV radiation depends on several factors, including wavelength, radiation intensity, exposure duration, and seed moisture content. Moderate exposure generally produces beneficial effects, while excessive treatment may damage seed tissues and reduce germination. Therefore, careful optimization of treatment parameters is necessary to achieve maximum benefits without adversely affecting seed viability.

Overall, UV radiation has demonstrated significant potential as a sustainable and eco-friendly seed treatment technology for wheat cultivation. By improving germination, enhancing seedling vigour, reducing microbial contamination, and promoting plant growth, UV treatment contributes to better crop establishment and higher agricultural productivity. These advantages make UV radiation an important tool in modern wheat production and sustainable farming practices.

Effect of Corona Discharge on Wheat Seeds

One of the most important effects of corona discharge treatment on wheat seeds is the improvement of seed surface wettability and water absorption. The treatment alters the physical and chemical properties of the seed coat, making it more hydrophilic and permeable to water. Enhanced water uptake accelerates the imbibition process, activates metabolic reactions, and initiates germination more rapidly. Studies have shown that corona-treated wheat seeds often exhibit higher germination percentages, faster emergence, and more uniform seedling establishment compared to untreated seeds. These improvements contribute to better crop stand and efficient field management.

Corona discharge treatment also enhances seedling vigor and plant growth in wheat. Increased water absorption stimulates enzyme activity and promotes the breakdown of stored food reserves within the seed. As a result, developing seedlings receive a greater supply of energy and nutrients necessary for growth. Research findings indicate that wheat seedlings produced from corona-treated seeds frequently exhibit longer roots, greater shoot length, and increased biomass accumulation. Stronger root systems improve nutrient and water uptake from the soil, supporting healthy plant development throughout the growing season.

Another significant benefit of corona discharge treatment is its antimicrobial effect. Wheat seeds may carry fungal and bacterial pathogens that reduce germination and affect seedling health. The reactive ions and radicals generated during corona discharge help suppress or eliminate these microorganisms from the seed surface. Reduced microbial contamination decreases the incidence of seed-borne diseases and promotes healthier seedlings. This environmentally friendly approach reduces dependence on chemical fungicides and supports sustainable agricultural practices.

Research studies have also reported positive physiological and biochemical changes in wheat plants grown from corona-treated seeds. Enhanced enzyme activity, increased respiration rates, and improved nutrient mobilization contribute to better seedling development. Some investigations have observed higher chlorophyll content and improved photosynthetic efficiency, which support greater plant growth and productivity. These physiological improvements may ultimately contribute to increased grain yield and improved crop performance under field conditions.

The effectiveness of corona discharge treatment depends on factors such as voltage level, exposure time, seed moisture content, and equipment configuration. Proper optimization of these parameters is essential because excessive treatment may damage seed tissues and reduce viability. When applied under controlled conditions, corona discharge treatment provides substantial benefits in terms of germination, seedling vigor, and crop establishment.

Overall, corona discharge treatment is a promising and sustainable technology for improving wheat seed performance. By enhancing water absorption, stimulating metabolic activity, reducing microbial contamination, and promoting plant growth, it contributes to improved germination and increased agricultural productivity. These advantages make corona discharge an important physical seed treatment method for modern wheat cultivation and sustainable farming systems.

Comparative Results

Experimental studies have shown that both UV radiation and corona discharge treatments improve wheat seed performance. Treated seeds showed improved germination and better seedling growth compared to untreated seeds. The improvements varied depending on treatment intensity and exposure duration.

Overall improvements observed in treated wheat seeds include:

- Higher germination percentage
- Stronger seedling growth
- Improved plant vigour
- Better crop establishment

These factors contribute to increased wheat productivity and improved crop yield.

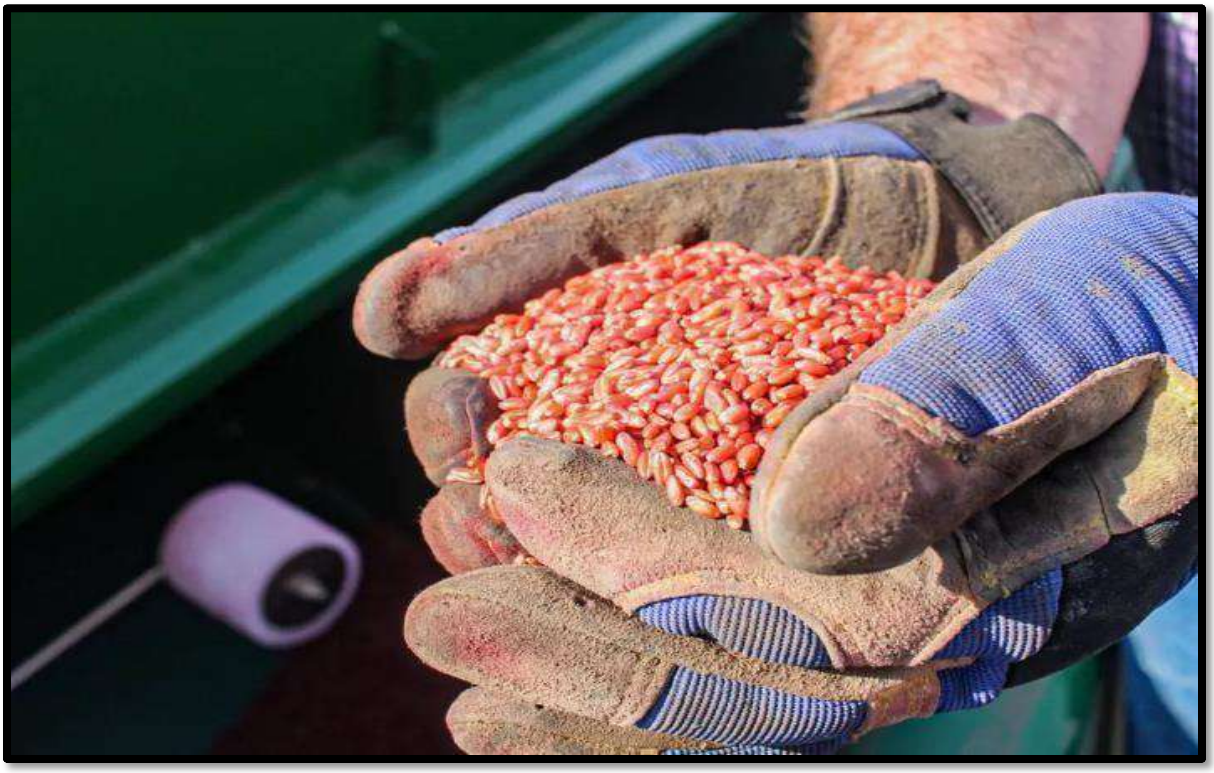

Figure 25. Treated Wheat Seed.

Conclusion of Case Study

The wheat seed treatment case study demonstrates that physical seed treatment technologies such as UV radiation and corona discharge effectively enhance germination and seedling growth. These eco-friendly methods reduce the need for chemical seed treatments and support sustainable wheat production.

8.3 Rice Seed Treatment

Rice (*Oryza sativa*) is one of the most important staple food crops in the world, particularly in Asian countries. High-quality seed germination and early seedling establishment are essential for achieving better rice productivity. However, rice seeds often face challenges such as poor germination, fungal contamination, and uneven seedling growth. Physical seed treatment technologies such as ultraviolet (UV) radiation and corona discharge have been increasingly studied as sustainable methods to improve rice seed performance.

Experimental Background

Several experimental studies have been conducted to evaluate the effects of UV radiation and corona discharge on rice seeds. In these experiments, rice seeds were exposed to controlled UV radiation and corona discharge treatment for specific durations. Treated seeds were then compared with untreated seeds based on germination rate, seedling growth, and plant vigour.

The results from these studies showed that physical seed treatment significantly improved germination percentage, seedling growth, and early plant development. Treated rice seeds demonstrated faster emergence and better uniformity compared to untreated seeds.

Effect of UV Radiation on Rice Seeds

One of the major effects of UV radiation on rice seeds is the enhancement of germination percentage and germination speed. UV treatment improves seed coat permeability, allowing water and oxygen to penetrate the seed more effectively during imbibition. This stimulates metabolic activity and activates enzymes responsible for the breakdown of stored food reserves. As a result, rice seeds germinate more rapidly and uniformly compared to untreated seeds. Uniform germination contributes to better crop establishment and facilitates efficient crop management practices in the field.

UV radiation also promotes seedling vigor and early plant growth in rice. Treated seeds often develop longer roots and shoots, greater seedling biomass, and stronger root systems. The increased activity of enzymes such as amylase enhances the conversion of starch into simple sugars, providing energy for embryo development and seedling growth. Stronger root systems improve water and nutrient uptake from the soil, enabling plants to establish successfully and withstand environmental stress during the early stages of growth.

Another important advantage of UV seed treatment is its antimicrobial effect. Rice seeds may carry various fungal and bacterial pathogens that negatively affect germination and seedling health. UV radiation effectively reduces microbial contamination on the seed surface by damaging the DNA of harmful microorganisms. This reduction in pathogen load improves seed health, decreases disease incidence, and promotes healthy seedling establishment. Consequently, UV treatment can serve as an environmentally friendly alternative to certain chemical seed disinfectants.

Figure 26. Effect of UV radiation on rice seed germination and growth.

Research studies have also reported improvements in physiological and biochemical characteristics of rice plants grown from UV-treated seeds. Increased chlorophyll content, enhanced photosynthetic activity, and improved nutrient utilization have been observed in treated plants. These improvements support better vegetative growth and may contribute to increased grain yield under favorable conditions. Some studies have further indicated that UV-treated rice plants exhibit greater tolerance to environmental stresses such as drought and salinity, improving crop resilience.

The effectiveness of UV radiation treatment depends on factors such as wavelength, exposure duration, radiation intensity, and seed moisture content. Moderate UV exposure generally produces beneficial effects, whereas excessive exposure may damage seed tissues and reduce germination. Therefore, proper optimization of treatment conditions is essential to maximize the benefits of UV seed treatment.

Overall, UV radiation has demonstrated considerable potential as a sustainable and eco-friendly seed treatment technology for rice cultivation. By improving germination, enhancing seedling vigor, reducing microbial contamination, and promoting plant growth, UV treatment contributes to better crop establishment and increased agricultural productivity. These benefits make UV radiation a valuable tool in modern rice production and sustainable agriculture.

Effect of Corona Discharge on Rice Seeds

One of the primary effects of corona discharge treatment on rice seeds is the improvement of seed surface wettability and water absorption. The treatment modifies the seed coat by increasing its hydrophilic properties and creating microscopic surface changes. These modifications allow water to penetrate the seed more rapidly and uniformly during imbibition. Enhanced water uptake activates metabolic processes and enzyme activity, leading to faster and more uniform germination. Several studies have reported that corona-treated rice seeds exhibit higher germination percentages and reduced germination time compared to untreated seeds, resulting in better crop establishment.

Corona discharge treatment also promotes seedling vigor and early plant development. Increased water absorption stimulates the breakdown of stored food reserves, providing energy for embryo growth. As a result, treated rice seedlings often develop longer roots, greater shoot length, and increased biomass accumulation. Strong root systems enable efficient uptake of water and nutrients from the soil, supporting healthy plant growth during the early stages of development. Improved seedling vigour contributes to better field establishment and increased tolerance to environmental stresses.

Another significant advantage of corona discharge treatment is its ability to reduce microbial contamination on rice seeds. Seed-borne fungi and bacteria can adversely affect germination and seedling health. The reactive ions and free radicals generated during corona discharge possess antimicrobial properties that help eliminate or suppress these harmful microorganisms. Reduced pathogen populations improve seed health, decrease disease incidence, and promote the development of healthy seedlings. This makes corona discharge an environmentally friendly alternative to conventional chemical seed disinfectants.

Research studies have also reported improvements in physiological and biochemical activities within rice plants grown from corona-treated seeds. Enhanced enzyme activity, increased respiration rates, and improved nutrient mobilization have been observed following treatment. Some investigations have shown higher chlorophyll content and improved photosynthetic efficiency in treated plants, leading to better vegetative growth and biomass production. These physiological improvements may contribute to increased grain yield and overall crop productivity under suitable growing conditions.

The effectiveness of corona discharge treatment depends on factors such as voltage level, exposure duration, seed moisture content, and equipment design. Proper optimization of these parameters is essential because excessive exposure may damage seed tissues and reduce viability. When applied under controlled conditions, corona discharge treatment consistently provides positive effects on rice seed germination and seedling growth.

Overall, corona discharge treatment is a promising and sustainable technology for improving rice seed performance. By enhancing water absorption, stimulating metabolic activity, reducing microbial contamination, and promoting seedling vigor, it contributes to improved crop establishment and productivity. These benefits highlight the potential of corona discharge technology as an important component of modern rice cultivation and sustainable agricultural practices.

Comparative Results

Research findings indicate that both UV radiation and corona discharge treatments improve rice seed performance. Treated seeds showed improved germination rate, stronger seedling growth, and better plant establishment. Key improvements observed include:

- Higher germination percentage
- Uniform seedling growth
- Improved plant vigour
- Better crop establishment

These improvements contribute to increased rice productivity and better yield.

Conclusion of Case Study

The rice seed treatment case study demonstrates that UV radiation and corona discharge are effective methods for improving rice seed germination and seedling growth. These eco-friendly technologies reduce reliance on chemical seed treatments and promote sustainable rice cultivation.

8.4 Tomato Seed Treatment

Tomato (*Solanum lycopersicum*) is one of the most widely cultivated vegetable crops in the world and is valued for its nutritional, economic, and industrial importance. Successful tomato production depends greatly on seed quality, germination rate, and seedling vigor. However, tomato seeds are often affected by seed-borne pathogens, poor germination under adverse conditions, and uneven seedling emergence. Physical seed treatment technologies such as ultraviolet (UV) radiation and corona discharge have emerged as environmentally friendly alternatives to chemical seed treatments for improving tomato seed performance.

Experimental Background

Several research studies have been conducted to evaluate the effects of UV radiation and corona discharge on tomato seeds. In these experiments, seeds were exposed to controlled levels of UV radiation or corona discharge for specific durations before sowing. The treated seeds were then assessed for germination percentage, germination speed, seedling growth, root and shoot development, and overall plant vigor. Results from these investigations demonstrated that physical seed treatments significantly improved tomato seed germination and early seedling establishment compared to untreated controls.

Researchers observed that treated seeds germinated more rapidly and uniformly, producing healthier seedlings with stronger root systems. Enhanced seed performance contributed to improved plant establishment and better adaptation to environmental stress conditions. These findings indicate that physical seed treatment technologies can play an important role in sustainable tomato cultivation.

Effect of UV Radiation on Tomato Seeds

One of the major effects of UV radiation on tomato seeds is the improvement of germination percentage and germination speed. UV treatment alters the physical characteristics of the seed coat, increasing its permeability to water and oxygen. Enhanced water absorption during imbibition activates metabolic processes and stimulates enzyme activity within the seed. As a result, treated tomato seeds germinate more rapidly and uniformly than untreated seeds. Uniform germination is particularly beneficial in tomato cultivation because it promotes synchronized seedling development and facilitates efficient nursery management.

UV radiation also enhances seedling vigor and early plant growth in tomato. Treated seeds often produce seedlings with longer roots, greater shoot length, and increased biomass accumulation. The activation of enzymes such as amylase and protease improves the mobilization of stored food reserves, providing the energy required for embryo growth and seedling development. Stronger root systems enable seedlings to absorb water and nutrients more efficiently, resulting in healthier plants and improved establishment after transplanting. Enhanced seedling vigour is especially important in tomato production, where vigorous seedlings contribute to better field performance and higher productivity.

Another significant advantage of UV treatment is its antimicrobial effect. Tomato seeds frequently carry fungal and bacterial pathogens that can reduce germination and cause seedling diseases. UV radiation helps eliminate or suppress these harmful microorganisms by damaging their cellular structures and genetic material. Reduced microbial contamination improves seed health, decreases disease incidence, and promotes healthy seedling growth. Consequently, UV treatment serves as an environmentally friendly alternative to chemical seed disinfectants commonly used in tomato seed production.

Research studies have also reported improvements in physiological and biochemical characteristics of tomato plants grown from UV-treated seeds. Increased chlorophyll content, enhanced photosynthetic efficiency, and improved nutrient utilization have been observed in treated plants. These improvements support vigorous vegetative growth, better flowering, and increased fruit development. Some studies have further indicated that UV-treated tomato plants exhibit greater tolerance to environmental stresses such as drought, salinity, and temperature fluctuations, enhancing crop resilience and productivity.

The effectiveness of UV radiation treatment depends on several factors, including wavelength, radiation intensity, exposure duration, and seed moisture content. Moderate UV exposure generally produces beneficial effects, whereas excessive exposure may damage seed tissues and reduce germination. Therefore, careful optimization of treatment parameters is necessary to maximize the benefits of UV treatment while maintaining seed viability.

Overall, UV radiation has demonstrated significant potential as a sustainable and eco-friendly seed treatment technology for tomato cultivation. By improving germination, enhancing seedling vigour, reducing microbial contamination, and promoting plant growth, UV treatment contributes to better crop establishment and increased tomato productivity. These advantages highlight the importance of UV seed treatment as an innovative tool in modern vegetable production systems.

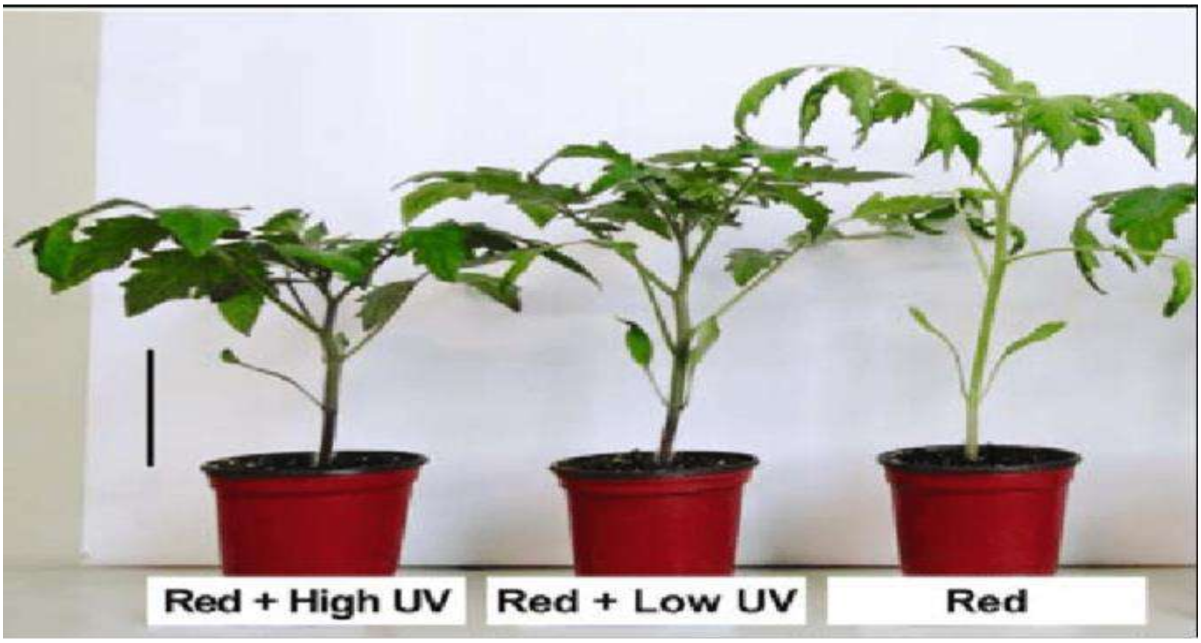

Figure 27. Effect of UV radiation on tomato seed germination and seedling growth.

Effect of Corona Discharge on Tomato Seeds

One of the primary effects of corona discharge treatment on tomato seeds is the improvement of seed surface wettability and water absorption. The treatment modifies the seed coat by creating microscopic surface changes and increasing its hydrophilic properties. These modifications allow water to penetrate the seed more rapidly and uniformly during imbibition. Enhanced water uptake stimulates metabolic processes and enzyme activity, resulting in faster and more uniform germination. Studies have shown that corona-treated tomato seeds often exhibit higher germination percentages and reduced germination time compared to untreated seeds, leading to improved seedling establishment.

Corona discharge treatment also promotes seedling vigor and early plant growth in tomato. Increased water absorption accelerates the mobilization of stored food reserves, providing energy for embryo growth and seedling development. Consequently, treated seedlings frequently exhibit greater root length, shoot length, and biomass accumulation. Strong root systems improve the uptake of water and nutrients from the growing medium, supporting healthy plant growth. Enhanced seedling vigor is particularly beneficial in tomato cultivation because vigorous seedlings establish more successfully after transplanting and perform better under field conditions.

Another important benefit of corona discharge treatment is its antimicrobial activity. Tomato seeds may carry fungal and bacterial pathogens that negatively affect germination and seedling health. The reactive ions and free radicals generated during corona discharge possess strong antimicrobial properties that help suppress or eliminate these microorganisms. Reduced pathogen populations improve seed health, decrease disease incidence, and contribute to healthier seedling development. This makes corona discharge an environmentally friendly alternative to chemical seed disinfectants used in tomato production.

Research studies have also reported positive physiological and biochemical changes in tomato plants grown from corona-treated seeds. Enhanced enzyme activity, improved respiration, and better nutrient mobilization contribute to vigorous plant growth. Some investigations have observed increased chlorophyll content and improved photosynthetic efficiency in treated plants, resulting in greater biomass production and improved vegetative development. These physiological improvements may also promote better flowering, fruit set, and fruit quality in tomato crops. The effectiveness of corona discharge treatment depends on factors such as voltage level, exposure duration, seed moisture content, and equipment configuration. Proper optimization of these parameters is essential because excessive treatment may damage seed tissues and reduce viability. When applied under controlled conditions, corona discharge treatment consistently produces positive effects on tomato seed germination and seedling growth.

Overall, corona discharge treatment is a promising and sustainable technology for improving tomato seed performance. By enhancing water absorption, stimulating metabolic activity, reducing microbial contamination, and promoting seedling vigour, it contributes to better crop establishment and increased productivity. These benefits highlight the potential of corona discharge technology as an effective physical seed treatment method for modern tomato cultivation.

Comparative Results

Research findings indicate that both UV radiation and corona discharge treatments significantly improve tomato seed performance compared to untreated seeds. Treated seeds exhibited higher germination percentages, faster germination rates, and better seedling vigor. Enhanced water absorption, increased enzyme activity, and reduced microbial contamination contributed to improved seedling establishment and early plant development. Both treatments also promoted stronger root and shoot growth, resulting in healthier seedlings capable of utilizing nutrients and water more efficiently.

Studies have shown that UV radiation is particularly effective in reducing seed-borne pathogens and stimulating physiological activities associated with germination. Corona discharge treatment, on the other hand, is highly effective in improving seed surface wettability and accelerating water uptake. Although the mechanisms differ, both technologies contribute to enhanced metabolic activity and improved seed performance. Experimental observations indicate that treated tomato plants often show better vegetative growth, increased stress tolerance, and improved productivity compared to plants grown from untreated seeds.

Key Improvements Observed

- Higher germination percentage
- Faster and more uniform germination
- Enhanced root and shoot growth
- Improved seedling vigour
- Reduced microbial contamination
- Better nutrient and water uptake
- Improved plant establishment after transplanting
- Increased tolerance to environmental stress
- Enhanced flowering and fruit development
- Higher crop productivity and fruit yield

These improvements collectively contribute to better tomato crop performance, improved fruit production, and greater economic returns for farmers.

Conclusion of Case Study

The tomato seed treatment case study demonstrates that both UV radiation and corona discharge are effective physical seed treatment technologies for improving seed germination, seedling growth, and overall plant performance. These treatments enhance water absorption, stimulate metabolic activity, reduce microbial contamination, and promote vigorous seedling development. As a result, treated tomato plants establish more successfully and exhibit improved growth throughout the crop cycle.

Furthermore, both technologies provide environmentally friendly alternatives to conventional chemical seed treatments. By reducing dependence on chemical disinfectants and promoting sustainable agricultural practices, UV radiation and corona discharge contribute to safer and more sustainable tomato production systems. The positive results obtained from various research studies highlight the potential of these technologies as valuable tools for improving vegetable crop productivity and supporting modern sustainable agriculture.

8.5 Chilli Seed Treatment

Chilli (*Capsicum annuum L.*) is one of the most important spice and vegetable crops cultivated worldwide. It is valued for its culinary uses, nutritional content, and economic importance. Chilli fruits are rich in vitamins, antioxidants, and bioactive compounds such as capsaicin, which gives the characteristic pungency. Successful chilli cultivation depends greatly on rapid seed germination, healthy seedling establishment, and vigorous plant growth. However, chilli seeds often exhibit slow and uneven germination due to seed coat characteristics, environmental stress, and microbial contamination. Poor germination can result in weak seedlings and reduced crop productivity.

Experimental Background

Several experimental studies have been conducted to evaluate the effects of UV radiation and corona discharge treatments on chilli seeds. In these studies, chilli seeds were exposed to controlled doses of UV radiation or corona discharge for specific durations before sowing. The treated seeds were then evaluated for germination percentage, germination speed, root and shoot growth, seedling vigor, and overall plant performance. Comparisons were made between treated and untreated seeds to determine the effectiveness of these physical treatment methods. The results of these investigations demonstrated significant improvements in seed germination and seedling development following treatment. Treated chilli seeds showed faster emergence, higher germination rates, and more uniform seedling growth compared to untreated seeds. Researchers also reported enhanced physiological and biochemical activities in treated seedlings, leading to stronger plant establishment and improved growth. These findings suggest that UV radiation and corona discharge can be effective technologies for improving chilli seed quality and supporting sustainable chilli production.

Effect of UV Radiation on Chilli Seeds

One of the major effects of UV radiation on chilli seeds is the improvement of germination percentage and germination speed. UV treatment enhances the permeability of the seed coat, allowing water and oxygen to enter the seed more effectively during imbibition. This activates various metabolic and biochemical processes necessary for germination. As a result, UV-treated chilli seeds often exhibit faster and more uniform germination compared to untreated seeds. Uniform germination is particularly important in chilli cultivation because it ensures synchronized seedling growth and facilitates efficient nursery management and transplanting operations.

UV radiation also promotes seedling vigor and early plant development in chilli.

Treated seeds frequently produce seedlings with longer roots, greater shoot length, and higher biomass accumulation. The treatment stimulates the activity of enzymes such as amylase and protease, which help convert stored food reserves into energy required for embryo growth. Enhanced root development improves the plant's ability to absorb water and nutrients from the soil, while increased shoot growth supports better photosynthetic activity. These improvements contribute to stronger seedlings that establish more successfully under field conditions.

Another significant benefit of UV treatment is its antimicrobial effect. Chilli seeds may carry various fungal and bacterial pathogens that can negatively affect germination and seedling health. UV radiation effectively reduces microbial contamination by damaging the DNA and cellular structures of these harmful microorganisms. Reduced pathogen populations improve seed health, decrease disease incidence, and promote healthy seedling establishment. This makes UV radiation a sustainable and environmentally friendly alternative to certain chemical seed disinfectants commonly used in chilli production systems.

Research studies have also reported positive physiological and biochemical changes in chilli plants grown from UV-treated seeds. Increased chlorophyll content, enhanced photosynthetic efficiency, improved nutrient uptake, and greater metabolic activity have been observed in treated plants. These improvements support vigorous vegetative growth and contribute to better flowering and fruit development. Some studies have further indicated that UV-treated chilli plants exhibit improved tolerance to environmental stresses such as drought, salinity, and temperature fluctuations, enhancing overall crop resilience.

The effectiveness of UV radiation treatment depends on factors such as wavelength, exposure duration, radiation intensity, and seed moisture content. Moderate UV exposure generally produces beneficial effects, whereas excessive exposure may damage seed tissues and reduce germination. Therefore, careful optimization of treatment conditions is necessary to maximize the advantages of UV seed treatment while maintaining seed viability and quality.

Overall, UV radiation has demonstrated considerable potential as an eco-friendly seed treatment technology for chilli cultivation. By improving germination, enhancing seedling vigour, reducing microbial contamination, and promoting plant growth, UV treatment contributes to better crop establishment and increased productivity. These benefits highlight the importance of UV radiation as a valuable tool for sustainable chilli production.

Effect of Corona Discharge on Chilli Seeds

One of the primary effects of corona discharge treatment on chilli seeds is the improvement of seed surface wettability and water absorption. The treatment modifies the outer seed coat by introducing polar functional groups and creating microscopic surface changes that enhance its hydrophilic nature. As a result, water penetrates the seed more rapidly and uniformly during imbibition. Enhanced water uptake activates metabolic processes and stimulates enzyme activity, leading to faster and more uniform germination. Several studies have reported that corona-treated chilli seeds exhibit higher germination percentages and reduced germination time compared to untreated seeds, resulting in improved seedling establishment and better nursery performance.

Corona discharge treatment also enhances seedling vigor and early plant growth in chilli. Increased water absorption promotes the breakdown of stored food reserves, providing the energy required for embryo development and seedling growth. Consequently, treated seedlings often exhibit greater root length, shoot length, and biomass accumulation. Strong root systems improve the absorption of water and nutrients from the soil, supporting healthy plant growth and development. Enhanced seedling vigor enables chilli plants to establish more effectively after transplanting and improves their ability to tolerate environmental stresses during the early growth stages.

Another significant benefit of corona discharge treatment is its antimicrobial activity. Chilli seeds may carry fungal and bacterial pathogens that adversely affect germination and seedling health. The reactive ions and free radicals generated during corona discharge possess strong antimicrobial properties that help suppress or eliminate these harmful microorganisms. Reduced microbial contamination improves seed health, decreases disease incidence, and promotes the development of healthy seedlings. This makes corona discharge an environmentally friendly alternative to conventional chemical seed disinfectants used in horticultural crop production.

Research studies have also reported positive physiological and biochemical changes in chilli plants grown from corona-treated seeds. Enhanced enzyme activity, increased respiration rates, improved nutrient mobilization, and greater chlorophyll content have been observed following treatment. These improvements contribute to vigorous vegetative growth, enhanced photosynthetic efficiency, and increased biomass production. Some investigations have further indicated that corona-treated chilli plants produce more flowers and fruits, thereby improving yield and overall crop productivity.

The effectiveness of corona discharge treatment depends on factors such as voltage level, exposure duration, seed moisture content, and equipment design. Proper optimization of these treatment parameters is essential because excessive exposure may damage seed tissues and reduce viability. When applied under controlled conditions, corona discharge treatment consistently produces beneficial effects on chilli seed germination, seedling growth, and plant performance.

Overall, corona discharge treatment is a promising and sustainable technology for improving chilli seed quality and crop productivity. By enhancing water absorption, stimulating metabolic activity, reducing microbial contamination, and promoting seedling vigor, it contributes to better crop establishment and improved yield. These advantages make corona discharge a valuable physical seed treatment method for modern chilli cultivation and sustainable horticultural production.

Comparative Results

Research findings indicate that both UV radiation and corona discharge treatments significantly improve chilli seed performance compared to untreated seeds. Treated seeds exhibited higher germination percentages, faster germination rates, and improved seedling vigor. Enhanced water absorption, increased enzyme activity, and reduced microbial contamination contributed to better seedling establishment and early plant development. Both treatment methods promoted stronger root and shoot growth, resulting in healthier seedlings capable of utilizing water and nutrients more efficiently. These improvements ultimately support vigorous plant growth and increased productivity in chilli cultivation.

Studies have shown that UV radiation is particularly effective in reducing seed-borne pathogens and stimulating physiological processes associated with germination and seedling growth. Corona discharge treatment, on the other hand, is highly effective in improving seed surface wettability and accelerating water uptake. Although the mechanisms of action differ, both technologies enhance metabolic activity, improve nutrient mobilization, and support healthy plant development. Experimental observations have indicated that chilli plants grown from treated seeds often exhibit improved vegetative growth, enhanced flowering, and greater tolerance to environmental stresses compared to untreated plants.

Key Improvements Observed

- Higher germination percentage
- Faster and more uniform germination
- Increased root and shoot growth
- Enhanced seedling vigor

- Reduced fungal and bacterial contamination
- Improved nutrient and water uptake
- Better plant establishment after transplanting
- Increased tolerance to drought and environmental stress
- Enhanced flowering and fruit set
- Higher fruit yield and crop productivity

These improvements collectively contribute to better crop performance, improved fruit production, and increased economic returns for chilli growers. Both UV radiation and corona discharge treatments demonstrate considerable potential as sustainable alternatives to conventional chemical seed treatments.

Conclusion of Case Study

The chilli seed treatment case study clearly demonstrates that UV radiation and corona discharge are effective physical seed treatment technologies for enhancing seed germination, seedling vigor, and plant growth. Both treatments improve water absorption, stimulate metabolic and enzymatic activities, reduce microbial contamination, and promote healthy seedling development. These benefits result in stronger plant establishment and improved crop performance throughout the growing season.

Furthermore, UV radiation and corona discharge offer environmentally friendly alternatives to chemical seed treatment methods. By reducing dependence on synthetic chemicals and supporting sustainable agricultural practices, these technologies contribute to safer crop production and environmental protection. The positive outcomes observed in various research studies highlight their potential for improving chilli cultivation and increasing horticultural productivity

.

8.6 Green Gram Seed Treatment

Green gram (*Vigna radiata L.*), commonly known as mung bean, is an important pulse crop cultivated in many tropical and subtropical regions of the world. It is highly valued for its rich protein content, digestibility, and nutritional benefits. Green gram plays a significant role in sustainable agriculture because of its ability to fix atmospheric nitrogen through symbiotic association with rhizobial bacteria, thereby improving soil fertility. Successful cultivation of green gram depends largely on rapid seed germination, healthy seedling establishment, and vigorous plant growth. However, factors such as hard seed coats, seed-borne pathogens, and unfavorable environmental conditions can negatively affect germination and crop productivity.

Experimental Background

Several experimental investigations have been conducted to evaluate the effects of UV radiation and corona discharge treatments on green gram seeds. In these studies, seeds were exposed to controlled UV radiation or corona discharge for specific durations and subsequently assessed for germination percentage, germination speed, root and shoot growth, seedling vigor, and overall plant performance. Comparisons between treated and untreated seeds were carried out to determine the effectiveness of these physical treatment technologies.

The results of these experiments revealed significant improvements in seed germination and seedling development following treatment. Treated green gram seeds exhibited faster germination, more uniform emergence, and stronger seedling growth than untreated seeds. Researchers also reported enhanced physiological and biochemical activities in treated plants, resulting in improved crop establishment and productivity. These findings suggest that UV radiation and corona discharge technologies have considerable potential for improving pulse crop production and supporting sustainable agricultural practices.

Effect of UV Radiation on Green Gram Seeds

One of the major effects of UV radiation on green gram seeds is the improvement of germination percentage and germination speed. UV treatment enhances the permeability of the seed coat, allowing water and oxygen to penetrate more effectively during imbibition. This increased water absorption activates metabolic activities and stimulates enzymes responsible for the breakdown of stored food reserves. As a result, UV-treated green gram seeds often germinate faster and more uniformly than untreated seeds. Uniform germination is particularly beneficial in pulse crops because it ensures synchronized seedling emergence and promotes better crop establishment in the field.

UV radiation also enhances seedling vigour and early plant growth in green gram. Treated seeds frequently produce seedlings with longer roots, greater shoot length, and increased biomass accumulation. The activation of enzymes such as amylase and protease accelerates the conversion of stored starch and proteins into usable nutrients, providing energy for embryo growth and seedling development. Enhanced root growth improves water and nutrient uptake from the soil, while stronger shoots support better photosynthetic activity. These improvements contribute to the development of healthy and vigorous plants capable of achieving higher productivity.

Another important benefit of UV treatment is its antimicrobial activity. Green gram seeds may carry fungal and bacterial pathogens that adversely affect germination and seedling health. UV radiation reduces microbial contamination by damaging the DNA of harmful microorganisms and preventing their multiplication. Reduced pathogen populations improve seed health, decrease disease incidence, and support healthy seedling establishment. Consequently, UV treatment serves as an environmentally friendly alternative to chemical seed disinfectants and contributes to sustainable pulse production.

Research studies have also reported positive physiological and biochemical changes in green gram plants grown from UV-treated seeds. Increased chlorophyll content, enhanced photosynthetic efficiency, improved nutrient utilization, and greater metabolic activity have been observed in treated plants. These improvements support vigorous vegetative growth and better flowering and pod development. Some investigations have further indicated that UV-treated green gram plants exhibit enhanced tolerance to environmental stresses such as drought, salinity, and temperature fluctuations, thereby improving crop resilience and yield stability.

The effectiveness of UV radiation treatment depends on factors such as wavelength, exposure duration, radiation intensity, and seed moisture content. Moderate UV exposure generally produces beneficial effects, whereas excessive exposure may damage seed tissues and reduce germination. Therefore, proper optimization of treatment conditions is necessary to maximize the benefits of UV treatment while maintaining seed viability and quality.

Overall, UV radiation has demonstrated significant potential as a sustainable and eco-friendly seed treatment technology for green gram cultivation. By improving germination, enhancing seedling vigor, reducing microbial contamination, and promoting plant growth, UV treatment contributes to better crop establishment and increased pulse productivity. These advantages highlight the importance of UV radiation as a valuable tool in modern pulse production and sustainable agriculture.

Effect of Corona Discharge on Green Gram Seeds

One of the primary effects of corona discharge treatment on green gram seeds is the improvement of seed surface wettability and water absorption. The treatment modifies the seed coat by introducing polar functional groups and creating microscopic surface changes that increase its hydrophilic nature. These modifications allow water to penetrate the seed more rapidly and uniformly during imbibition. Enhanced water uptake activates metabolic activities and enzyme systems responsible for initiating germination. As a result, corona-treated green gram seeds often exhibit higher germination percentages and faster germination rates than untreated seeds, leading to improved crop establishment and uniform field emergence.

Corona discharge treatment also promotes seedling vigour and early plant growth in green gram. Increased water absorption stimulates the breakdown of stored food reserves, providing energy for embryo development and seedling growth. Consequently, treated seedlings frequently exhibit greater root length, shoot length, and biomass accumulation. Strong root systems improve the uptake of water and nutrients from the soil, enabling plants to establish more effectively and grow vigorously. Enhanced seedling vigour is particularly important in pulse crops because it improves competitiveness against weeds and supports healthy crop development throughout the growing season.

Another significant advantage of corona discharge treatment is its antimicrobial effect. Green gram seeds may harbor fungal and bacterial pathogens that reduce germination and adversely affect seedling health. The reactive ions and free radicals generated during corona discharge possess strong antimicrobial properties that help eliminate or suppress these harmful microorganisms. Reduced microbial contamination improves seed health, decreases disease incidence, and promotes healthy seedling establishment. This environmentally friendly approach reduces reliance on chemical seed treatments and supports sustainable pulse production systems.

Research studies have also reported positive physiological and biochemical changes in green gram plants grown from corona-treated seeds. Enhanced enzyme activity, increased respiration rates, improved nutrient mobilization, and greater chlorophyll content have been observed following treatment. These improvements contribute to enhanced photosynthetic efficiency, vigorous vegetative growth, and improved flowering and pod development. Some studies have further indicated that corona-treated green gram plants exhibit increased tolerance to environmental stresses such as drought and salinity, helping to maintain productivity under challenging growing conditions.

The effectiveness of corona discharge treatment depends on several factors, including voltage level, exposure duration, seed moisture content, and equipment configuration. Proper optimization of these parameters is essential because excessive treatment may damage seed tissues and reduce viability. When applied under controlled conditions, corona discharge treatment consistently produces beneficial effects on green gram seed germination, seedling growth, and plant performance.

Overall, corona discharge treatment is a promising and sustainable technology for improving green gram seed quality and crop productivity. By enhancing water absorption, stimulating metabolic activity, reducing microbial contamination, and promoting seedling vigour, it contributes to better crop establishment and increased yield. These benefits highlight the potential of corona discharge as an effective physical seed treatment method for modern pulse cultivation and sustainable agriculture.

Comparative Results

Research findings indicate that both UV radiation and corona discharge treatments significantly improve green gram seed performance compared to untreated seeds. Treated seeds exhibited higher germination percentages, faster germination rates, and improved seedling vigour. Enhanced water absorption, increased enzyme activity, and reduced microbial contamination contributed to better seedling establishment and early plant development. Both treatment methods promoted stronger root and shoot growth, resulting in healthier seedlings capable of utilizing water and nutrients more efficiently. These improvements ultimately support vigorous plant growth and increased productivity in green gram cultivation.

Studies have shown that UV radiation is particularly effective in reducing seed-borne pathogens and stimulating physiological and biochemical activities associated with germination. Corona discharge treatment, on the other hand, is highly effective in improving seed surface wettability and accelerating water uptake. Although the mechanisms differ, both technologies enhance nutrient mobilization, enzyme activation, and metabolic efficiency within the seed. Experimental observations have indicated that green gram plants grown from treated seeds often exhibit improved vegetative growth, enhanced flowering, increased pod formation, and greater stress tolerance compared to untreated plants.

Key Improvements Observed

• Higher germination percentage
• Faster and more uniform germination
• Enhanced root and shoot growth
• Improved seedling vigor
• Reduced fungal and bacterial contamination
• Better water absorption and nutrient uptake
• Improved plant establishment and survival
• Increased tolerance to drought and salinity stress
• Enhanced flowering and pod development
• Increased grain yield and crop productivity

These improvements collectively contribute to stronger plant growth, improved pulse production, and greater economic returns for farmers. Both UV radiation and corona discharge treatments demonstrate considerable potential as sustainable alternatives to conventional chemical seed treatment methods.

Conclusion of Case Study

The green gram seed treatment case study demonstrates that UV radiation and corona discharge are highly effective physical seed treatment technologies for improving seed germination, seedling vigor, and plant growth. Both treatments enhance water absorption, stimulate metabolic and enzymatic activities, reduce microbial contamination, and promote healthy seedling establishment. These benefits contribute to improved crop performance and higher productivity throughout the growing season.

Furthermore, UV radiation and corona discharge provide environmentally friendly alternatives to conventional chemical seed treatments. By reducing dependence on synthetic chemicals and supporting sustainable agricultural practices, these technologies contribute to safer crop production and environmental conservation. The positive results obtained from various research studies highlight their potential for improving green gram cultivation and increasing pulse productivity. Therefore, physical seed treatment technologies can play an important role in achieving sustainable pulse production and ensuring future food security.

9. COMPARISON OF UV RADIATION AND CORONA DISCHARGE

9.1 Germination Comparison

Seed germination is one of the most important factors determining crop establishment and productivity. Physical seed treatment technologies such as UV radiation and corona discharge have been widely studied for their effects on seed germination. Both methods improve germination performance, but their mechanisms and effectiveness may vary depending on crop type and treatment conditions.

UV radiation enhances germination primarily by stimulating metabolic activity within the seed. When seeds are exposed to controlled UV radiation, slight structural changes occur in the seed coat. These changes improve water absorption and oxygen exchange, which activate enzymes involved in germination. As a result, seeds treated with UV radiation often show faster and more uniform germination.

Corona discharge treatment improves germination through surface modification. The treatment increases seed surface wettability, allowing water molecules to spread evenly across the seed surface. This improves hydration and accelerates germination. Corona discharge treatment is particularly effective for seeds with hard seed coats or poor water absorption capacity.

Several studies have compared the germination performance of seeds treated with UV radiation and corona discharge. In many cases, both treatments significantly improve germination percentage compared to untreated seeds. However, the degree of improvement depends on crop type, exposure time, and treatment intensity.

UV radiation is often more effective in reducing microbial contamination on seed surfaces. This disinfecting effect helps improve seed health and enhances germination. On the other hand, corona discharge treatment is more effective in improving seed wettability and water uptake. This leads to faster hydration and improved germination.

Experimental results generally indicate that both treatments improve germination rate, but the effectiveness may vary. In some crops, UV radiation shows slightly better germination improvement, while in others, corona discharge treatment provides better results. Combining both treatments has also shown promising outcomes in certain studies.

As a result, both UV radiation and corona discharge are effective methods for improving seed germination. While UV radiation enhances metabolic activity and reduces microbial contamination, corona discharge improves water absorption and seed surface properties. These complementary effects make both technologies valuable for improving seed performance and crop establishment.

9.2 Growth Comparison

Plant growth after germination is a critical factor influencing crop productivity. Seedling growth determines plant establishment, nutrient uptake, and resistance to environmental stress. Physical seed treatments such as UV radiation and corona discharge have shown significant improvements in seedling growth across various crops. However, the extent and nature of growth enhancement vary between these two technologies.

UV radiation promotes plant growth by stimulating physiological and biochemical processes within the seed. Exposure to controlled UV radiation activates enzymes responsible for mobilizing stored nutrients. This leads to improved root and shoot development during early growth stages. UV-treated seeds often produce seedlings with stronger stems, greener leaves, and improved biomass accumulation. These improvements contribute to better plant establishment and early vigour.

Corona discharge treatment enhances plant growth through modification of seed surface properties. The treatment increases water absorption and improves hydration during germination. This results in faster root development and improved nutrient uptake. Corona discharge-treated seeds often show longer roots and enhanced shoot growth compared to untreated seeds.

In many studies, UV radiation has been observed to improve shoot growth and leaf development, while corona discharge treatment has shown greater improvement in root development. A well-developed root system allows plants to absorb nutrients and water more efficiently, which supports overall plant growth. On the other hand, improved shoot growth enhances photosynthesis and biomass production.

Comparative studies conducted on crops such as Wheat (*Triticum aestivum*), Rice (*Oryza sativa*), and Sunflower (*Helianthus annuus*) have shown that both treatments significantly improve seedling growth. However, the degree of improvement varies depending on crop type, treatment duration, and environmental conditions.

UV radiation also helps reduce microbial contamination on seed surfaces, which indirectly improves plant growth by minimizing disease incidence. Corona discharge treatment enhances seed hydration and nutrient absorption, leading to stronger and healthier plants.

Overall, both UV radiation and corona discharge treatments improve plant growth and seedling vigour. UV radiation is often more effective in improving shoot growth and plant development, while corona discharge treatment shows greater improvement in root growth and nutrient uptake. These complementary effects highlight the importance of both technologies in enhancing crop growth and productivity.

9.3 Yield Comparison

Crop yield is the ultimate measure of success in agricultural production. Improvements in seed germination and seedling growth directly influence plant development, flowering, and final yield. Physical seed treatments such as UV radiation and corona discharge have shown considerable potential in increasing crop yield across various crop types.

UV radiation improves crop yield primarily by enhancing physiological and biochemical processes in plants. Seeds treated with UV radiation often develop into vigorous plants with better leaf area, improved photosynthesis, and enhanced biomass production. These factors contribute to improved flowering, seed formation, and grain filling. As a result, crops treated with UV radiation often show higher yield compared to untreated seeds.

Corona discharge treatment improves yield by enhancing root development and nutrient absorption. Treated seeds produce plants with stronger root systems, which allow efficient uptake of water and nutrients from the soil. This leads to improved plant growth, better flowering, and increased yield. In addition, corona discharge-treated plants often exhibit improved tolerance to environmental stress, which further supports yield improvement.

Comparative studies conducted on crops such as Wheat (Triticum aestivum), Rice (Oryza sativa), Sunflower (Helianthus annuus), and Soybean (Glycine max) have demonstrated that both UV radiation and corona discharge treatments contribute to yield improvement.

However, the level of improvement depends on treatment conditions and crop characteristics.

UV radiation is often associated with improved plant height, leaf area, and photosynthetic activity, which contribute to increased grain or seed production. On the other hand, corona discharge treatment enhances root development and nutrient uptake, which indirectly improves crop yield. In many cases, both treatments produce similar yield improvements, although their mechanisms differ.

Research findings suggest that combining both UV radiation and corona discharge treatments may further enhance yield. The combined effect improves both root and shoot growth, resulting in better plant performance and increased productivity.

9.4 Efficiency Analysis

Efficiency analysis is important for evaluating the practical application of UV radiation and corona discharge technologies in agriculture. While both treatments improve germination, plant growth, and crop yield, their efficiency depends on factors such as treatment time, energy consumption, cost, ease of operation, and suitability for different crops.

UV radiation is considered an efficient method because it requires relatively simple equipment and short treatment duration. UV treatment systems generally consist of UV lamps, a treatment chamber, and a control unit. These systems are easy to operate and can be used for different crop seeds. UV radiation treatment also requires less maintenance, making it suitable for laboratory and small-scale agricultural applications. In addition, UV radiation effectively reduces microbial contamination, which improves seed health and enhances overall efficiency.

Corona discharge treatment, on the other hand, is highly effective in modifying seed surface properties. It improves seed wettability and water absorption, leading to faster germination and better seedling growth. However, corona discharge equipment is generally more complex compared to UV systems. It requires high-voltage power supply and controlled operating conditions. Despite these requirements, corona discharge treatment is highly efficient for improving seed hydration and root development. Studies comparing the efficiency of UV radiation and corona discharge treatments have shown that both technologies provide significant improvements over untreated seeds. However, UV radiation is often considered more suitable for microbial control and metabolic activation, whereas corona discharge is more effective in improving water absorption and root growth.

Another important factor in efficiency analysis is treatment time. UV radiation usually requires shorter exposure time, which makes it suitable for rapid seed treatment. Corona discharge treatment may require slightly longer exposure depending on seed type and treatment intensity. However, both methods are significantly faster compared to traditional chemical seed treatment methods. Energy consumption is also an important consideration. UV radiation systems generally consume less energy and are easier to maintain. Corona discharge systems require high voltage, which may increase energy consumption. However, improvements in equipment design are helping reduce energy requirements for corona discharge treatment.

In terms of large-scale application, both technologies show potential. UV radiation systems are easier to scale for commercial seed treatment facilities. Corona discharge treatment is also gaining attention for industrial-scale applications due to its effectiveness in improving seed performance.

Also, both UV radiation and corona discharge treatments are efficient technologies for improving seed quality and crop productivity. UV radiation is simpler and more suitable for microbial control, while corona discharge offers better seed surface modification and water absorption. These complementary advantages make both technologies valuable for modern sustainable agriculture.

10. FUTURE PROSPECTS

10.1 Emerging Technologies

Physical seed treatment technologies are rapidly evolving with advancements in agricultural engineering, nanotechnology, and plasma science. While ultraviolet radiation and corona discharge are already showing promising results, several emerging technologies are being developed to further improve seed germination, plant growth, and crop productivity. These new technologies aim to enhance seed performance while maintaining environmental sustainability and reducing dependence on chemical treatments.

One of the most promising emerging technologies is cold plasma seed treatment. Cold plasma generates ionized gas containing reactive particles such as ions, electrons, and free radicals. These reactive species interact with seed surfaces and induce beneficial physical and biochemical changes. Cold plasma treatment improves seed wettability, enhances water absorption, and stimulates metabolic activity. Studies have reported improved germination rate, seedling vigour, and crop yield after cold plasma treatment.

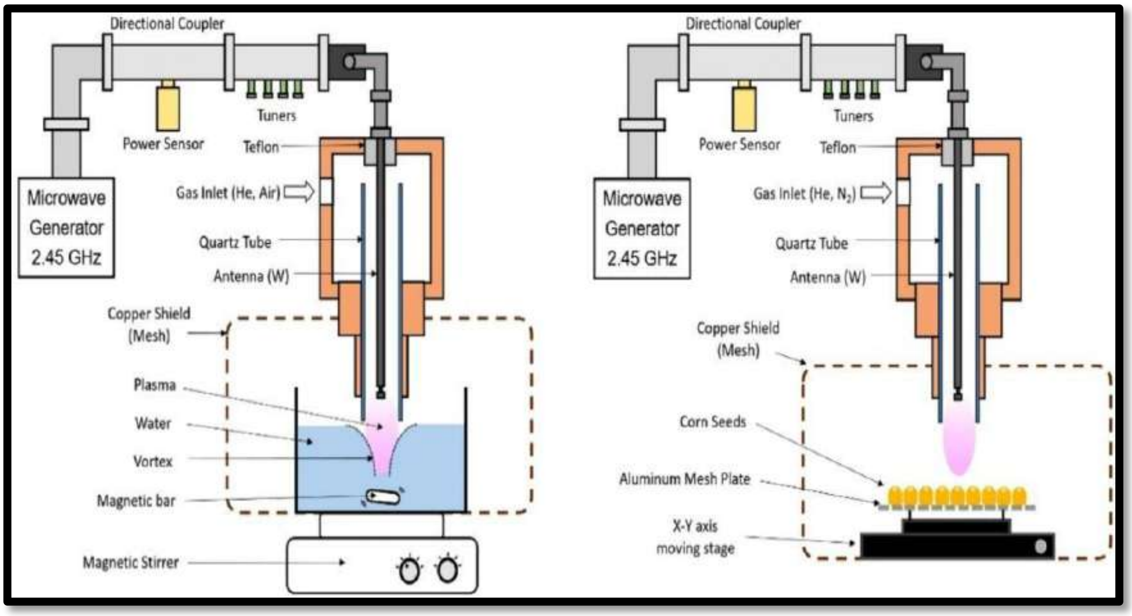

Figure 28. Growth of Plasma-Treated Corn Seeds under Realistic Conditions

Another emerging technology is laser seed treatment. Laser irradiation is used to stimulate seed metabolism and improve plant growth. Low-energy laser exposure enhances enzyme activity, promotes cell division, and accelerates germination. Laser seed treatment is gaining attention due to its precision and ability to control treatment intensity.

Magnetic field treatment is also being explored as a physical seed treatment technology. Seeds exposed to magnetic fields show improved germination, root growth, and plant development. Magnetic field treatment influences biochemical reactions and improves nutrient uptake efficiency. This technology is particularly useful for improving crop performance under stress conditions.

Ultrasound seed treatment is another emerging method. Ultrasound waves create micro-vibrations that improve seed hydration and activate metabolic processes. This treatment enhances germination rate and seedling growth. Ultrasound technology is considered safe, efficient, and environmentally friendly.

Nanotechnology is also being integrated into physical seed treatment. Nanoparticles can be used to enhance seed germination and improve nutrient delivery. Combined with physical treatment methods, nanotechnology can further improve seed performance and plant growth.

Automation and smart technologies are also shaping the future of seed treatment. Automated seed treatment systems can control treatment parameters such as exposure time, intensity, and environmental conditions. These smart systems improve efficiency and ensure uniform seed treatment.

10.2 Future Research Scope

Although physical seed treatment technologies such as UV radiation and corona discharge have demonstrated promising results, further research is required to fully utilize their potential in modern agriculture. Future research efforts should focus on improving treatment efficiency, optimizing parameters, and developing cost-effective systems suitable for large-scale agricultural use.

One of the major research areas involves optimization of treatment parameters. The effectiveness of UV radiation and corona discharge depends on exposure time, intensity, seed type, and environmental conditions. Excessive exposure may damage seeds, while insufficient exposure may not produce significant improvements. Therefore, determining optimal treatment conditions for different crops is essential for achieving consistent results.

Another important research direction is understanding the molecular and biochemical mechanisms involved in seed treatment. Although improvements in germination and growth have been observed, more studies are needed to understand how physical treatments influence gene expression, enzyme activity, and plant metabolism. This knowledge will help in developing more targeted and efficient seed treatment technologies.

Future research should also focus on combining physical treatments with other sustainable agricultural practices. For example, combining UV radiation with biological seed treatment or combining corona discharge with nutrient priming may further enhance seed performance. Such integrated approaches could provide greater improvements in crop productivity. Large-scale field trials are also necessary to validate laboratory findings. Most current studies are conducted under controlled laboratory conditions. However, environmental factors such as soil moisture, temperature, and climate conditions may influence treatment performance. Conducting field-level studies will help determine the practical feasibility of these technologies.

Another important research area is equipment development. Current treatment systems are often designed for laboratory use. Future research should focus on developing portable, low-cost, and farmer-friendly seed treatment devices. This will help in promoting adoption among small and medium-scale farmers. Additionally, research should explore the effects of physical seed treatment under stress conditions such as drought, salinity, and temperature extremes. If these treatments improve plant tolerance to stress, they can play a significant role in climate-resilient agriculture.

10.4 Industrial Application

The industrial application of physical seed treatment technologies is gaining increasing attention due to their efficiency, eco-friendly nature, and potential to replace chemical seed treatments. Technologies such as UV radiation and corona discharge are being explored for large-scale seed processing industries, seed production companies, and commercial agriculture.

In seed industries, maintaining seed quality is essential for improving crop productivity and ensuring uniform plant growth. Physical seed treatment technologies can be integrated into seed processing units where seeds pass through treatment chambers before packaging. UV radiation systems can be installed in conveyor-based seed treatment lines, allowing uniform exposure and high processing capacity. This makes UV radiation suitable for industrial-scale seed treatment operations. Corona discharge technology is also being adopted in industrial seed treatment systems. Industrial corona discharge equipment uses high-voltage electrodes and controlled chambers to treat large quantities of seeds efficiently. These systems improve seed surface characteristics, enhance water absorption, and promote uniform germination. Seed companies are exploring this technology to improve seed performance and increase market value.

Another important industrial application is in hybrid seed production. Hybrid seeds require high germination rate and uniform seedling growth. Physical seed treatment technologies help improve seed vigour and reduce microbial contamination, which is essential for hybrid seed production. These treatments also improve seed storage life, making them beneficial for commercial seed industries. Automation is playing a significant role in industrial applications. Modern seed treatment units are equipped with sensors and automated control systems that regulate treatment intensity, exposure time, and seed flow rate. These automated systems ensure consistent treatment quality and reduce human error. As a result, industries can process large volumes of seeds efficiently.

Figure 29. Industrial application of physical seed treatment technologies

In addition to seed companies, agricultural cooperatives and seed production centres can also benefit from industrial seed treatment technologies. Portable seed treatment units are being developed to support medium-scale agricultural operations. These systems allow farmers and cooperatives to treat seeds before sowing, improving crop establishment and productivity.

Industrial application of physical seed treatment also reduces dependence on chemical treatments. This helps industries meet environmental regulations and producesafer agricultural products. As consumer demand for sustainable agriculture increases, industries are adopting eco-friendly seed treatment technologies.

11. CONCLUSION

Seed quality plays a crucial role in determining crop establishment, plant growth, and final agricultural productivity. In recent years, the demand for sustainable and eco-friendly agricultural practices has increased significantly. Conventional chemical seed treatments, although effective, have raised concerns related to environmental pollution, health risks, and the development of resistant pathogens. logies that are safe, efficient, and environmentally friendly.

Physical seed treatment technologies such as ultraviolet (UV) radiation and corona discharge have emerged as promising solutions for improving seed performance. These treatments enhance seed germination, seedling vigour, plant growth, and crop yield without the use of harmful chemicals. UV radiation improves seed metabolism, reduces microbial contamination, and stimulates enzymatic activity, leading to better germination and uniform seedling growth. Similarly, corona discharge treatment modifies seed surface characteristics, improves water absorption, and enhances root development.

The application of these technologies across various crops including cereals, pulses, oilseeds, vegetables, and horticultural crops demonstrates their wide adaptability. Case studies on crops such as sunflower, wheat, rice, and vegetables further highlight the effectiveness of physical seed treatments in improving crop performance. Comparative analysis also shows that both UV radiation and corona discharge technologies offer complementary advantages in enhancing germination, growth, and yield. Despite their advantages, certain challenges remain, including optimization of treatment parameters, development of cost-effective equipment, and large-scale adoption. However, advancements in emerging technologies such as cold plasma, laser treatment, magnetic field exposure, and automation systems indicate strong future potential for physical seed treatment technologies. Industrial applications of these technologies are also expanding, with seed processing industries exploring large-scale implementation. Automated systems and modern treatment equipment are expected to improve efficiency and make these technologies accessible to farmers and seed companies. In conclusion, UV radiation and corona discharge represent innovative and sustainable seed treatment technologies with significant potential to improve crop productivity. Continued research, technological advancement, and industrial adoption will further strengthen their role in modern agriculture

REFERENCES

1. Abdullahi, U., & Ibrahim, H. (2018). Effect of UV radiation on seed germination and seedling growth of selected crops. *Journal of Agricultural Science*, 10(4), 112–120.

2. Bormashenko, E., Shapira, Y., Grynyov, R., Whyman, G., Bormashenko, Y., & Drori, E. (2015). Interaction of cold plasma with seeds of plants. *Plasma Chemistry and Plasma Processing*, 35(3), 563–576.

3. Ling, L., Jiafeng, J., Jiangang, L., Minchong, S., Xin, H., & Yuanhua, D. (2014). Effects of cold plasma treatment on seed germination and seedling growth. *Plasma Science and Technology*, 16(1), 54–58.

4. Sera, B., Spatenka, P., Sery, M., Vrchotova, N., & Hruskova, I. (2010). Influence of plasma treatment on wheat and oat germination. *Plasma Chemistry and Plasma Processing*, 30(4), 507–516.

5. Krapivina, S. A., & Gins, V. K. (2017). Effect of UV radiation on seed germination and plant growth. *Russian Agricultural Sciences*, 43(3), 191–194.

6. Dhayal, M., Lee, S. Y., & Park, S. U. (2006). Using low-pressure plasma for seed germination. *Current Applied Physics*, 6(3), 451–454.

7. Filatova, I., Azharonok, V., Lushkevich, V., Zhukovsky, A., Gadzhieva, G., & Spasiuk, L. (2013). The effect of plasma treatment on seeds of agricultural crops. *Journal of Physics D: Applied Physics*, 46(28), 285201.

8. Volin, J. C., Denes, F. S., Young, R. A., & Park, S. M. (2000). Modification of seed germination performance through cold plasma chemistry technology. *Crop Science*, 40(6), 1706–1718.

9. Selcuk, M., Oksuz, L., & Basaran, P. (2008). Decontamination of grains using cold plasma technology. *Bioresource Technology*, 99(11), 5104–5109.

10. Randeniya, L. K., & de Groot, G. J. J. B. (2015). Non-thermal plasma treatment of agricultural seeds for stimulation of germination. *Plasma Processes and Polymers*, 12(7), 608–623.

11. Gao, X., Li, H., & Li, J. (2018). Effects of plasma treatment on seed germination and seedling growth. *Scientific Reports*, 8(1), 1–9.

12. Zahoranová, A., Henselová, M., Hudecová, D., Kalinaková, B., & Machala, Z. (2016). Effect of plasma treatment on agricultural seeds. *Plasma Chemistry and Plasma Processing*, 36(2), 397–414.

13. Pawlat, J., Starek, A., Sujak, A., Terebun, P., & Kwiatkowski, M. (2018). Effects of plasma treatment on seed germination. *International Journal of Molecular Sciences*, 19(9), 2670.

14. Hayashi, N., Ono, R., & Oda, T. (2012). Plasma agriculture: Effects of plasma irradiation on seed germination. *Journal of Physics D: Applied Physics*, 45(20), 202001.

15. Mishra, P., & Pattanayak, S. (2019). UV radiation effects on plant growth and seed germination. *International Journal of Plant Sciences*, 14(2), 78–85.

16. Zhou, R., Zhou, R., Wang, P., Xian, Y., Mai-Prochnow, A., Lu, X., & Cullen, P. J. (2019). Plasma activated water and seed germination. *Scientific Reports*, 9(1), 1–9.

17. Thirumdas, R., Sarangapani, C., & Annapure, U. S. (2015). Cold plasma: A novel technology for food and agriculture. *Innovative Food Science and Emerging Technologies*, 32, 254–263.

18. Šerá, B., & Šerý, M. (2018). Non-thermal plasma treatment of seeds: A review. *Plasma Chemistry and Plasma Processing*, 38(5), 971–988.

19. Kumar, S., & Yadav, S. (2020). Corona discharge treatment in agriculture. *Agricultural Engineering Today*, 44(2), 45–52.

20. FAO (Food and Agriculture Organization). (2021). *Sustainable Seed Technologies for Improved Crop Productivity*. FAO Publications.

21. Afzal, I., Basra, S.M.A., Ahmad, N., & Farooq, M. (2006). Optimization of hormonal priming techniques for wheat seed germination. *International Journal of Agriculture and Biology*, 8(6), 785–788.

22. Aladjadjiyan, A. (2012). Physical factors for plant growth stimulation improve food quality. *Advances in Environmental Biology*, 6(3), 1018–1023.

23. Bilalis, D., Katsenios, N., Efthimiadou, A., & Karkanis, A. (2013). Pulsed electromagnetic field effects on seed germination and plant growth. *Agricultural Engineering International*, 15(3), 168–176.

24. Bradford, K. J. (2002). Applications of hydrothermal time to quantifying and modeling

seed germination and dormancy. *Weed Science*, 50(2), 248–260.

25. Dobrin, D., Magureanu, M., Mandache, N. B., & Ionita, M. D. (2015). The effect of non-thermal plasma treatment on wheat germination and early growth. *Innovative Food Science & Emerging Technologies*, 29, 255–260.

26. Farooq, M., Basra, S.M.A., Wahid, A., & Nawaz, A. (2009). Seed priming enhances the performance of late sown wheat. *Seed Science and Technology*, 37(3), 630–640.

27. Guo, Q., Meng, Y., Qu, G., & Zhang, H. (2012). Effects of plasma treatment on seed germination. *Applied Physics Letters*, 101(22), 224101.

28. Henselová, M., Slováková, L., Martinka, M., & Zahoranová, A. (2012). Growth, anatomy and enzyme activity changes in maize roots induced by plasma treatment. *Plant Growth Regulation*, 68(3), 459–466.

29. Iqbal, M., Haq, Z., & Jamil, Y. (2014). Effect of pre-sowing magnetic field treatment on seed germination. *International Agrophysics*, 28(3), 339–343.

30. Jamil, Y., Haq, Z., Iqbal, M., & Perveen, T. (2013). Enhancement in growth and yield of wheat by magnetic seed treatment. *International Agrophysics*, 27(2), 143–148.

31. Aladjadjiyan, A. (2012). Physical factors for plant growth stimulation improve food quality. *Advances in Environmental Biology*, 6(3), 1018–1023.

32. Bilalis, D., Katsenios, N., Efthimiadou, A., & Karkanis, A. (2013). Pulse electromagnetic field effects on seed germination and plant growth. *Agricultural Engineering International*, 15(3), 168–176.

33. Bradford, K.J. (2002). Applications of hydrothermal time to quantifying and modeling seed germination and dormancy. *Weed Science,* 50(2), 248–260.

34. Dobrin, D., Magureanu, M., Mandache, N.B., & Ionita, M.D. (2015). The effect of non-thermal plasma treatment on wheat germination and early growth. *Innovative Food Science & Emerging Technologies*, 29, 255–260.

35. Farooq, M., Basra, S.M.A., Wahid, A., & Nawaz, A. (2009). Seed priming enhances the performance of late sown wheat. *Seed Science and Technology*, 37(3), 630–640.

36. Guo, Q., Meng, Y., Qu, G., & Zhang, H. (2012). Effects of plasma treatment on seed germination. *Applied Physics Letters*, 101(22), 224101.

37. Henselová, M., Slováková, L., Martinka, M., & Zahoranová, A. (2012). Growth, anatomy and enzyme activity changes in maize roots induced by plasma treatment. *Plant Growth Regulation*, 68(3), 459–466.

38. Iqbal, M., Haq, Z., & Jamil, Y. (2014). Effect of pre-sowing magnetic field treatment on seed germination. *International Agrophysics*, 28(3), 339–343.

39. Jamil, Y., Haq, Z., Iqbal, M., & Perveen, T. (2013). Enhancement in growth and yield of wheat by magnetic seed treatment. *International Agrophysics*, 27(2), 143–148.

40. Ling, L., Jiafeng, J., Jiangang, L., Minchong, S., Xin, H., & Yuanhua, D. (2014). Effects of cold plasma treatment on seed germination. *Scientific Reports*, 4, 5859.

41. Mandal, A., & Basu, R.N. (1987). Seed treatment and its influence on crop yield. *Seed Science and Technology*, 15, 303–314.

42. Matthews, S., & Powell, A.A. (2011). Electrical conductivity test for seed vigor. *Seed Science and Technology*, 39(2), 249–268.

43. McDonald, M.B. (1999). Seed deterioration: Physiology, repair and assessment. *Seed Science and Technology*, 27, 177–237.

44. Mohan, M., & Kumar, R. (2016). Corona discharge treatment for seed surface modification. *Journal of Agricultural Engineering*, 53(3), 25–31.

45. Ohta, T. (2016). Plasma in agriculture: Cold plasma treatment for seed germination. *Plasma Processes and Polymers*, 13(1), 1–10.

46. Panwar, N.L., & Sharma, A. (2014). Seed treatment using physical methods. *Renewable and Sustainable Energy Reviews*, 34, 398–405.

47. Sera, B., Spatenka, P., Sery, M., Vrchotova, N., & Hruskova, I. (2010). Influence of plasma treatment on wheat germination. *Czech Journal of Food Sciences*, 28(4), 324–331.

48. Thirumdas, R., Sarangapani, C., & Annapure, U.S. (2015). Cold plasma: Emerging non-thermal technology for food and agriculture. *Innovative Food Science & Emerging Technologies*, 38, 1–11.

49. Zahoranová, A., Henselová, M., Hudecová, D., Kalinaková, B., Kovacik, D., Medvecká, V., & Machala, Z. (2016). Effect of cold plasma on seed germination and growth.*Plasma Chemistry and Plasma Processing*, 36(2), 397–414.

50. Afzal, I., Basra, S.M.A., Ahmad, N., & Farooq, M. (2006). Optimization of hormonal priming techniques for wheat seed germination. *International Journal of Agriculture and Biology*, 8(6), 785–788.

51. Finch -Savage, W.E., & Leubner-Metzger, G. (2006). Seed dormancy and the control of germination. *New Phytologist*, 171(3), 501–523.

52. Bewley, J.D. (1997). Seed germination and dormancy. *The Plant Cell*, 9(7), 1055–1066.

53. Bewley, J.D., Bradford, K.J., Hilhorst, H.W.M., & Nonogaki, H. (2013). *Seeds: Physiology of Development, Germination and Dormancy*. Springer.

54. Nonogaki, H. (2014). Seed dormancy and germination—emerging mechanisms and new hypotheses. *Frontiers in Plant Science,* 5, 233.

55. Copeland, L.O., & McDonald, M.B. (2001). *Principles of Seed Science and Technology*. Springer.

56. Baskin, C.C., & Baskin, J.M. (2014). *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*. Academic Press.

57. Taiz, L., Zeiger, E., Møller, I.M., & Murphy, A. (2015). *Plant Physiology and Development*. Sinauer Associates.

58. Khan, A.A. (1992). *Pre-Plant Physiological Seed Conditioning*. Horticultural Reviews.

59. Heydecker, W., Higgins, J., & Gulliver, R.L. (1973). Accelerated germination by osmotic seed treatment. *Nature*, 246, 42–44.

60. Farooq, M., Basra, S.M.A., & Wahid, A. (2006). Priming of field-sown rice seed. *Seed Science and Technology*, 34(2), 437–441.

61. Harris, D., Rashid, A., Miraj, G., Arif, M., & Shah, H. (2007). On-farm seed priming with zinc sulphate. *Field Crops Research*, 102(2), 119–127.

62. Ashraf, M., & Foolad, M.R. (2005). Pre-sowing seed treatment for stress tolerance. *Advances in Agronomy*, 88, 223–271.

63. Bradford, K.J. (1986). Manipulation of seed water relations via priming. *HortScience*, 21, 1105–1112.

64. McDonald, M.B. (2000). Seed priming. *Seed Technology and Biological Advances*, 287–325.

65. Basra, S.M.A., Farooq, M., & Khaliq, A. (2003). Comparative study of seed enhancement techniques. *International Journal of Agriculture and Biology*, 5(4), 575–577.

66. Paparella, S., Araújo, S.S., Rossi, G., et al. (2015). Seed priming: State of the art. *Plant Cell Reports*, 34, 1281–1293.

67. Kumar, V., & Sharma, A.K. (2018). Seed treatment technologies for sustainable agriculture. *Journal of Crop Improvement*, 32(6), 731–748.

68. Kader, M.A. (2005). A comparison of seed germination under different conditions. *Journal of Agronomy*, 4(1), 48–52.

69. Carvalho, N.M., & Nakagawa, J. (2012). *Seeds: Science, Technology and Production*. FUNEP.

70. Marcos -Filho, J. (2015). Seed vigor testing. *Seed Science and Technology*, 43, 1–15. ISTA (International Seed Testing Association). (2023). *International Rules for Seed Testing*. ISTA, Switzerland.

71. Hampton, J.G., & TeKrony, D.M. (1995). *Handbook of Vigour Test Methods*. ISTA. Delouche, J.C., & Baskin, C.C. (1973). Accelerated aging techniques. *Seed Science and Technology*, 1, 427–452.

72. Powell, A.A. (2006). Seed vigour and crop establishment. *Seed Testing International*, 131, 18–22.

73. Abdul -Baki, A.A., & Anderson, J.D. (1973). Vigor determination in soybean seed. *Crop Science*, 13, 630–633.

74. Bradford, K.J., Dahal, P., Van Asbrouck, J., et al. (2008). The Seed Biology Program. *Seed Science Research*, 18, 1–8.

75. Hilhorst, H.W.M. (2007). Definitions and hypotheses of seed dormancy. *Seed Science Research*, 17, 1–12.

76. Rajjou, L., & Debeaujon, I. (2008). Seed longevity and germination. *Plant Science*, 175(1–2), 1–6.

77. Finch-Savage, W.E., & Bassel, G.W. (2016). Seed vigour and crop establishment. *Plant Science*, 251, 180–191.

78. Nonogaki, H., Bassel, G.W., & Bewley, J.D. (2010). Germination—still a mystery. *Plant*

Science, 179, 574–581.

79. Sharma, P., & Singh, B. (2019). Emerging physical seed treatment technologies. *Agricultural Reviews*, 40(2), 95–103.

80. Yaldagard, M., Mortazavi, S.A., & Tabatabaie, F. (2008). Application of magnetic fields in agriculture. *African Journal of Biotechnology*, 7(21), 3757–3761.

81. Vashisth, A., & Nagarajan, S. (2010). Magnetic treatment and maize productivity. *Bioelectromagnetics*, 31, 405–412.

82. Radhakrishnan, R., & Kumari, B.D.R. (2012). Pulsed magnetic field effects on soybean. *Plant Physiology and Biochemistry*, 51, 139–144.

83. Pietruszewski, S., & Kania, K. (2010). Magnetic field treatment of seeds. *International Agrophysics*, 24, 297–302.

84. Bilalis, D., Katsenios, N., Efthimiadou, A., et al. (2012). Effects of magnetic field on seedling growth. *Agronomy Research*, 10(1), 57–64.

85. Aladjadjiyan, A. (2007). Laser irradiation effects on seeds. *Romanian Journal of Biophysics*, 17(2), 89–98.

86. Hernández, A.C., Carballo, C.A., & Michtchenko, A. (2010). Laser treatment and germination improvement. *International Agrophysics*, 24, 45–50.

87. Perveen, R., & Ahmad, M. (2017). UV radiation and crop productivity. *Journal of Plant Growth Regulation*, 36(3), 604–615.

88. Singh, H., & Kaur, J. (2020). Sustainable seed treatment technologies in agriculture. *Journal of Agricultural Engineering*, 57(1), 22–31.

89. FAO. (2018). *The Future of Food and Agriculture: Alternative Pathways to 2050*. FAO, Rome.

90. OECD. (2019). *Seed Schemes and Seed Certification Standards*. OECD Publishing.

91. ISTA. (2020). Seed Quality Assurance and Testing Procedures. International Seed Testing Association.

92. Kumar, R., & Verma, P. (2021). Eco-friendly seed treatment approaches. *Agricultural Science Digest*, 41(3), 201–209.

93. Sharma, N., Gupta, S., & Sharma, R. (2021). Advances in seed enhancement technologies. *Indian Journal of Agricultural Sciences*, 91(4), 512–519.

94. Patel, M., & Singh, D. (2022). Sustainable innovations in seed technology. *Journal of Crop Science*, 62(5), 1881–1892.

95. International Seed Federation (ISF). (2021). *Seed Technology and Global Food Security*. ISF Publications.

96. United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. United Nations.

97. World Bank. (2020). *Agricultural Innovation Systems: An Investment Sourcebook*. World Bank Publications.

98. OECD & FAO. (2021). *Agricultural Outlook 2021–2030*. OECD Publishing and Food and Agriculture Organization.

ABOUT THE AUTHORS

Mrs. V. Divyaprabha, B.E. (Agriculture Engineering), M.E. in Irrigation and Water Management .

Mrs. V. Divyaprabha is an Assistant Professor in the Department of Agricultural Engineering at SRM Valliammai Engineering College, Kattankulathur, Chengalpattu. She has published numerous articles, books, and guides students in Agricultural Engineering and Sciences.

Dr. N. Vairam, M.Sc. (Agriculture), Ph.D.

Dr. N. Vairam is an Assistant Professor in the Department of Agricultural Engineering at SRM Valliammai Engineering College, Kattankulathur, Chengalpattu. She holds a Ph.D. in Plant Breeding and Genetics from TNAU and qualified ASRB-NET. With extensive teaching and research experience, she has published numerous articles, books, and guides students in agricultural sciences.

Ms. B. Jananee, B.Tech (Agricultural Engineering)

Ms. B. Jananee is pursuing B.Tech in Agricultural Engineering at SRM Valliammai Engineering College, Kattankulathur, Chengalpattu. She aims to contribute to agricultural development through innovative engineering solutions.

Dr. N. Murugan, M.Sc. (Agriculture), Ph.D.

Dr. N. Murugan is an accomplished agricultural scientist and Assistant Professor-Senior Grade at SRM College of Agricultural Sciences, Baburayenpettai, Chengalpattu. He specializes in sericulture, pest management, and integrated farming systems. With extensive research publications, books, and patents, he actively contributes to teaching, research, and farmer-oriented extension activities in sustainable agriculture.

Email: skyfoxpublishing@gmail.com/
skyfox@skyfox.org.in

Website: www.skyfox.co

ISBN 978-93-90357-48-2