Barley Diseases: Introduction, Etiology, Epidemiology, and Their Management

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Abstract

Barley is regarded as the globe's fourth major cereal crop. A variety of airborne, seedborne, and soilborne infective agents attack barley, causing a variety of barley diseases and substantial losses in agricultural output. Brown and yellow rusts, smut, net blotches, spot blotches, barley yellow dwarf, and molya disease are among the most serious diseases. In general, employing integrated disease management approaches is the best way to handle barley diseases. Growing resistant or tolerant varieties with the fewest foliar fungicides is the most effective approach for barley disease treatments. However, managing soilborne pathogens in barley plants is problematic due to a deficiency in distinguishing symptoms for diagnosis and the absence of fungicides or nematicides that are effective for these pathogens. Recently, nanotechnology has driven the advancement of creative concepts and agricultural productivity with a broad scope for managing plant infections and pests. The antimicrobial properties of metallic and metal oxide nanoparticulates such as silver, selenium, titanium dioxide, zinc oxide, and iron oxide have been extensively researched. In this chapter, we go over barley disease and the role of nanomaterials in reducing the incidence of disease and diagnosis, as well as barley seed germination, physiology, and nutritional quality of barley grain.

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6.1 Introduction

Nanotechnology causes the progress of innovative concepts and agricultural yield with a vast perspective to manage plant pathogens and pests. Nanotechnology has considerably developed in the field of pharmacological medicine, but has gained moderately less awareness for agronomic purposes (Balaure et al. 2017; Sinha et al. 2017). The application of agricultural nanobiotechnology is presently being discovered in the germination of seeds and the delivery of phytohormones, water managing, target genes transference, nano-barcoding, agro-nanosensors, and restricted discharge of agrichemicals.

Nowadays, researchers have designed nanoparticles (NPs) with desired features, to offer new pesticides and other actives for controlling plant disease and protect plants through two diverse approaches: (a) nanoparticles for plant protection, or (b) nanocarriers for the offered pesticides or other actives, including ds- RNA, and can be practiced by spray purposes or onto waterlogged seeds, leaves, or roots. Nanocarriers can offer some advantages, similar to (1) a better shelf life, (2) transferred the weakly water-soluble pesticides into soluble substances, (3) decreased toxicity, and enhanced the uptake, efficiency, and constancy of the nano-pesticides under unfavorable circumstances (Hayles et al. 2017; Khandelwal et al. 2016).

Metallic and metallic oxide nanoparticulates including silver, copper, iron oxide, zinc oxide, and titanium dioxide have been widely investigated for their antimicrobial properties (Gogos et al. 2012; Kah and Hofmann 2014; Kim et al. 2018). Recently, silver nanoparticulates have revealed inhibition of the fungal growth, such as *Alternaria alternata, Macrophomina phaseolina, Sclerotinia sclerotiorum, Curvularia lunata, Botrytis cinerea,* and *Rhizoctonia solani* (Krishnaraj et al. 2012a, b). Also, low concentrations of copper nanoparticulates increase the resistance of seedlings to the harmful fungi, which cause root decaying in sprouts (Maslobrod et al. 2014). Furthermore, NPs have a main effect on the plant's morphology and genome. A trivial number of nanoparticles can enhance crop productions, but a large amount of nanoparticulates' exposure can cause disorder in plants' physiology and oxidative damage. Furthermore, NPs can decrease the efficiency of the oxidative enzymes that cause genotoxicity and toxicity (Ali et al. 2016; Rizwan et al. 2017).

One of the most crucial cereal plants is barley (*Hordeum vulgare* L.), which is commonly used not only in agriculture but also in food manufacturing. Barley is affected by different diseases, frequently caused by pathogens (Aubert et al. 2018; Giraldo et al. 2019; Gozukirmizi and Karlik 2017; Kumar et al. 2012). The demand for barley grains is rising because of their different uses and high nutritive significance. Therefore, extensive production will be required over the next few years.

Several biotic and abiotic factors should be controlled to enhance the yield of barley. Barley diseases significantly affect net blotch, rusts, spot blotch, stripe disease, molya, powdery mildew, and barley yellow dwarf disease which are the main biotic factors in improving the barley grain yield. Other diseases are vital for manufacturing because they spoil the value of malt and beer.

Understanding the pathogens associated with the disease and modulating the reacted variables are the most effective ways to manage it. Resistant variants are the simplest and most efficient way to treat serious diseases. It is critical to employ integrated disease management strategies that focus on variables for successful disease management. Adoption of resistant barley cultivars provides the most long-term pathogen control (for instance, cultivars with diverse MLO genes). Using resistant cultivars for pathogens enhances output in their cultivated areas automatically (Gangwar et al. 2018). Moreover, fungicide seed dressings or fungicides sprayed in-furrow with fertilizer can protect barley from diseases or reduce early seedling infection. The target diseases should guide the choice of fungicide. Foliar fungicide treatment in the crop is intended to prevent disease growth and keep the greening of leaves. It lessens the effect of diseases on productivity and grain quality. The economic effectiveness of foliar fungicide treatments is determined by disease severity, variety susceptibility, crop production potential, grain quality prognosis, and the environment. For example, triazole fungicides have been effective at a rate of 0.1% against barley rust diseases (Bhardwaj et al. 2017).

Moreover, the disease still faces a critical challenge. Therefore, there is an urgent need to achieve progress in the growing and productivity of barley crops as well as develop an alternative control approach against barley diseases. However, the absence of nanomaterials in the early stage of the plant indicates their unharmful effects and the safety of their use. For example, manganese ferrite NPs, magnetite NPs, and Fe/SiO2 enhance the growing factors of barley and can be planned for future barley breeding applications (Disfani et al. 2017; Tombuloglu et al. 2018). Also, iron oxide or magnetite nanoparticulates endorsed gene expression and proficient photosynthetic activity of barley (Tombuloglu et al. 2019a) and stabilized selenium NPs enhanced barley seed germination (Siddiqui et al. 2021). Barley diseases and the impact of nanomaterials on controlling such diseases, germination of seeds, physiology, and nutritional quality of barley grains were all explored in depth in this chapter.

6.2 Barley Diseases and Their Managements

Barley is a major cereal crop that has been farmed for thousands of years, dating back to early times, and is used in animal feed, malt products, and food production. With around 150 million tons of grain production, it ranks fourth in the world (Arabi and Jawhar 2004). In all places where barley is grown, barley leaf diseases produce major output reductions while also lowering quality. Barley, like other cereals, is susceptible to a variety of plant infections and illnesses, resulting in a considerable drop in output and poor grain quality. In his "Compendium of Barley Diseases," Mathre (1997) listed around 80 diseases caused by pathogens, including net blotch, yellow and brown rusts, powdery mildew, smut, spot blotch, speckled leaf blotch, barley stripe, barley yellow dwarf, and molya disease, which are cautiously significant in several countries. The routine of fungicides or disease-resistant varieties is efficient in disease control, although pathogens have the potential to overcome plant resistance genes and neutralize fungicide treatments (Ellwood et al. 2019; Hawkins et al. 2014; Mohd-Assaad et al. 2016). The ability of diseases to evolve is useful in the development of control approaches (Palumbi 2001; McDonald and Linde 2002a, b).

6.2.1 Leaf Rust Disease

Leaf rust is the most common rust disease in the *Hordeum vulgare* crop, and it may be found almost everywhere the crop is planted. It doesn't happen very often, but it can be very important in some places where barley is grown.

It has been stated as potentially harmful in North America (Reinhold and Sharp 1982; Mathre 1982) and Kenya (Reinhold and Sharp 1982; Mathre 1982). Actual losses in field crops are hard to come by. However, in New Zealand (Arnst et al. 1979) and England, losses of 10–20% have been reported, at least in part due to leaf rust (Jenkins et al. 1972). Infections caused by *Puccinia hordei* uredial grow on the barley as little (up to 0.5 mm) orange-brownish pustules that blacken with time. The pustules spread mostly on the superior and inferior leaf surfaces and sheaths and are generally accompanied by chlorotic halos. Some stem, glume, and awn infections can happen late in the season with severe infections, and there is often broad tissue chlorosis and final necrosis accompanied by this severe pathogen. Blackish-brown telia appear late in the season. They usually appear as stripes, especially on leaf sheaths, and they can also be seen on stems, heads, and leaf edges. The host's consequences vary depending on the length and strictness of the infection, but biotrophy generally has an unfavorable influence on photosynthesis, respiration, nutrient passage, and water interactions, resulting in overall debilitation. Spring barley is predominantly vulnerable, particularly if planted late, since it is susceptible when the infection is vigorously growing. Primary, severe infections can cause restricted growth and a lessening in the number of fertile tillers and grains per year (Lim and Gaunt 1981; Udeogalanya and Clifford 1982). A lot of people have problems with grain size and quality because epidemics don't start for a long time (Lim and Gaunt 1981; Udeogalanya and Clifford 1982).

Up until roughly 1970, leaf rust was thought to be not nearly as serious as other Hordeum vulgare diseases. However, the disease's recent spread, mainly in northern and western Europe and portions of the US, has prompted an increase in both basic investigation and the progress of disease management strategies that depend on both plant resistance and fungicides. Despite the success of these efforts, more study is needed to uncover new bases of resistance and novel fungicides to control any damage to the outputs of current trials due to variations in the pathogen population.

To that end, research into pathogen evolution and the relationship between type II plant resistance and current systemic fungicides should be pursued. There seems to be a requirement for extra data on the resistant plant in order to make predictions about its long-term viability (Clifford 1985). Until 2015, 21 seedling resistance genes were known. It is expected that achieving long-term resistance to leaf rust in *Hordeum vulgare* will necessitate the introduction of both seedling resistance genes and adult-resistant plant (APR) genes (Park et al. 2015).

6.2.2 Net Blotch Disease

The ascomycete *Pyrenophora teres* causes net blotch, which has become one of the most serious diseases of *Hordeum vulgare*. Net blotch is easily identified by brown reticular bands on the susceptible barley leaf. It reduces production by up to 40% and lowers seed quality. The pathogen's life cycle, mechanism of spread, and expansion allow for rapid infection of the host. Agricultural wastes, seeds, and grasses are the pathogen's origins. The relationship between the Hordeum vulgare plant and the fungi is complicated, involving physiological fluctuations such as the appearance of signs on the barley plant as well as genetic alterations such as the modification of many genes involved in defensive pathways.

Net blotch resistance genes have been found, and their locations on 7 barley chromosomes have been determined. Because of the disease's importance, numerous management measures have been used to combat net blotch. For instance, the use of plant growth promoting rhizobacteria, which are helpful bacteria that colonize the rhizosphere. The preventive role of these bacteria and their bioactive compounds against possible pathogens has been described in several investigations. (Backes et al. 2021). Small bacteriocins and fungal defensins are among the antimicrobial peptides produced by bacteria (Waghu and Idicula-Thomas 2020). Microbes can synthesize secondary products via non-ribosomal pathways (Montesinos et al. 2012). Useful bacteria also create antifungals known as cyclic lipopeptides, which permit them to function as antagonists against pathogenic fungi. These compounds are harmful to the progress of further species and have a low molecular weight (Beneduzi et al. 2012). Due to their amphiphilic properties, lipopeptides, which are synthesized non-ribosomally, have antibacterial and surfactant capabilities that have piqued the interest of researchers (Cazorla et al. 2007). For instance, *Bacillus* sp. and *Burkholderia* yield the majority of these antibiotics (Ongena et al. 2007; Pérez-García et al. 2011; Esmaeel et al. 2016, 2018).

6.2.3 Powdery Mildew

Powdery mildew (caused by the fungus *Erysiphe graminis* D.C.) is the most serious disease afflicting barley around the globe. On the leaves, it is simply recognized by its conidial phase, which usually appears in distinct lesions. However, it will occasionally cover the entire leaf in a weft of spore-bearing mycelium. The fungi demonstrate a high level of physiological specialization (Marchal 1902). It's been fascinating to see how the discovery of a successful systemic fungicide has affected the amount of mildew research being done around the globe. Researchers now have an active tool for estimating disease-related costs, and results from 25 nations show that mildew is causing larger losses than previously thought. Because mildew stagnates mostly in the winter season, the harvest is regarded as extremely risky in places where spring barley is also cultivated. To avoid the initial formation of reproductive structures in the spring barley, it is critical to evaluate the efficiency of pesticides in reducing mildew over the winter. In the autumn of 1968, trials were put up in the UK to investigate this issue. Due to the extremely rainy autumn, mildew did not quickly expand into the developing crop. Ethirimol provided almost perfect treatment of mildew attacks in the autumn. The next spring, there was no disease in the treated plants, whereas the untreated plants showed a modest but unchanging infection. Moreover, some control was maintained in the treated plants until June, resulting in a significant reduction in crop spore production (Brooks 1970). Breeding the broad-based *mlo* gene in barley is a good source of long-lasting resistance. It's possible to stack a lot of different types of resistance genes on top of each other or use introgressions from bulbous barley (Dreiseitl 2020).

6.2.4 Barley Yellow Dwarf

The most common viral disease of cereals is barley yellow dwarf (BYD), which is caused by the barley yellow dwarf virus (BYDV). The virus is delivered to phloem cells by aphids feeding on the leaf phloem. When viruses enter the plants, they proceed to multiply and build new virions. This mechanism, which causes the symptoms of this disease, necessitates a considerable metabolic input from the plant. Symptoms begin about 14 days after the viral infection. Susceptible plants exhibit yellowish or reddish leaves, an erect posture with thicker, stiffer leaves, decreased root growth, and a reduced harvest. Because of saprotrophic fungus colonization, the heads of infected plants persist erect and turn black and discolored throughout maturation. Young plants are especially vulnerable. When the aphid feeds, the viruses are propagated via the phloem. When an aphid eats, the virus's coat protein is detected by the epithelium of the aphid's hindgut, and the virus particle is permitted to enter the hemolymph of the insect and persist forever. However, the virus is unable to multiply within this insect. The virus is energetically carried into the attachment salivary gland, where it is discharged into the salivary canals. In the aphid's next feeding, the virus is expelled in its saliva (Gray and Gildow 2003). Insecticide management of the aphid insect is one method of preventing BYDV contamination. However, the use of insecticides is aggressively discouraged because of environmental conditions and the potential for resistance to progress. As a result, developing virus-resistant varieties is the most effective way to mitigate the harmful effects of viral infection on farming. Exposure to viruses indicates that they can proliferate and propagate within the plant, resulting in severe disease signs. Because viral management is not achievable, resistant barley genes are regarded as the best strategy to avoid the loss of products. Though multiple genes and numerical trait loci for viral tolerance are recognized and employed in barley breeding, little is known about the molecular and physiological basis of this characteristic (Paulmann Maria et al. 2018). The higher productivity of the resistant variety, which harbors the Ryd2 gene, was shown to be related to small degrees of hormone signaling, offering innovative indicators for resistance and a novel framework for researching the origin of viral resistance in barley (Ordon et al. 2009).

6.2.5 Barley Smut

Smut of barley is caused by the fungus *Ustilago hordei*. The disease is present all over the world and is more widely transmitted than loose smut. Infected kernels are substituted by masses of dark brown smut spores. Smutted heads are compact and hard. Plants that have been infected may become stunted. Smut sori can also emerge as lengthy streaks on leaf edges on rare occasions. To control covered smut disease, resistant cultivars and seed treatments are applied (Mathre 1997). On the other hand, *Ustilago nuda* generates loose barley smut. It is a disease that has the potential to wipe out a large section of barley yield. Loose smut substitutes grain heads with spores that invade open blossoms on plants and produce seed without causing visible signs. The seeds seem to be in good health, and it is only after they mature the next time of year that it is obvious that they were diseased.

The real-time PCR results showed that loose smut infection occurs at the secondary leaf phase and that it is therefore appropriate for practice in different barley cultivars (Wunderle et al. 2012). Systemic fungicides are the primary technique of controlling loose smut disease (Thomas 1984a, b). For covered smult, five barley cultivars, including HBL 391, HBL 316, HBL 113, DWRUB 123, and DWRUB 92, were extremely resistant, although BL 1656 and BL 1562 germplasm lines displayed a resistant response to *Ustilago horde* (Singh et al. 2020).

6.2.6 Spot Blotch

The causal agent of the spot blotch disease is *Cochliobolus sativus*. The disease can be found anywhere barley is planted, but it only causes major output losses in warm, humid areas (Mathre 1997; Martens et al. 1984). Infections manifest in the form of dark, chocolate-colored spots. The spots meld together, leaving uneven necrotic areas on the leaves. A zone of yellow leaf tissue of varied width may edge leaf spots. During kernel filling, infections on the standard leaf are the most dangerous, with heavily diseased leaves entirely drying up. Resistant cultivars, rotation by non-cereal crops, seed treatments, and foliar fungicides are used to fight the disease. (Martens et al. 1984). An eco-friendly foliar spray for control of this disease, *Trichoderma harzianum*, neem, and tulsi extracts as biological control agents, and SAR chemical (SA) can be applied (Kaur et al. 2021).

6.2.7 Molya Disease

The *Heterodera avenae* nematode is responsible for “Molya disease” in wheat and barley. The second juvenile (J2) swells and becomes a lemon-shaped, creamish-white adult female as she grows. When this white female reaches maturity, she will transform into a brown female known as a “Cyst” (dead female), with 400 eggs inside her body acting as a protective cover against the harsh environment. When the second stage, J2, detects humidity and a host plant, it raptures the cyst and emerges from the birth hole to attack the crop the following season. Dissimilar to other pathogens, nematode signs are not diagnostic since they are similar to water or nutritional deprivation or any other physiological problem. There are two types of nematode symptoms, and normally, above ground signs are not distinguishable and can be readily confused with any other infection. However, in blown ground signs, roots frequently become bushy, with mild swelling at the site of infection. The brown cyst matures, it detaches from the roots and remains in the mud until the following crop is grown, behaving as a source of infection for future years, and J2 hatches out upon identifying the host crop, precise temperature, and humidity conditions. There are no other options for managing the nematode in standing crops. To avoid additional output losses, it is recommended that certain agronomic treatments (seed treatments, resistant cultivars, etc.) be implemented to regulate the nematode population (Priyanka 2018).

6.2.8 Barley Diseases Control Using Fungicides

Fungicides are commonly employed to shield crops because they can offer extremely high rates of disease avoidance. Foliar fungicides are applied to the majority of *Hordeum vulgare* diseases in Europe. Nevertheless, unselective fungicide usage, combined with disease adaptation, can significantly impair fungicide efficiency. If administered before severe symptoms progress, metrafenone, proquinazid, and cyflufenamid fungicides can provide excellent defense against powdery mildew. It is very hard to control the disease when it has established itself in the plant. Morpholines can eliminate powdery mildew and give effective short-term elimination and protectant action. However, disease resistance renders strobilurin fungicides ineffective against powdery mildew (HGCA 2011).

In net blotch disease, seed should be examined to determine if the treatment is mandatory or not. In susceptible plants, SDHI fungicides and prothioconazole can provide good protection. Furthermore, in order to eradicate brown rust disease, SDHIs, as well as the majority of triazoles and strobilurins, are good controls. However, the disease can be treated by combining morpholine with one or more other fungicides. The optimum control for leaf spot disease is obtained by combining a triazole with, for instance, boscalid or chlorothalonil.

Suitable fungicide choice is thus required to reduce yield losses. Before applying fungicides, the counsellor or planter should assess the grade of fungicide resistance. The Fungicide Resistance Action Group (FRAG) is the primary foundation of these data in the United Kingdom. The majority of fungicides have extremely exacting approaches to their target fungus. This uniqueness can frequently lead to fast fungal development. The fungicide's target place is a critical factor driving pathogen progress because fungicides with only one target site frequently generate quick resistance against fungicides, as seen with methyl benzimidazole carbamate fungicides. As a result, to reduce the losses of active fungicides, an integrated management system for the control of barley diseases must be adopted. The most effective ways now being used are: delivering the suitable dose at the suitable time and combining multiple compounds with distinct mechanisms of activity in conjunction with the adoption of resistant varieties (Walters et al. 2012).

6.3 Nano Diagnostics for Barley Infections

Rapid detection solutions for plant pathogens with elevated sensitivity and selectivity are required to avoid disease propagation and limit losses to ensure maximum production and food security. Microscopy and culturing are time-consuming, labor-intensive methods that require complicated sample management. Immunological and molecular approaches have evolved, although there are still significant challenges with speed, signal strength, and equipment. The combination of molecular and immunologic diagnosis with nano-approaches yields a solution in which all detection processes can be housed on a portable tiny instrument for quick and precise diagnosis of plant infections (Kashyap et al. 2017).

Nanotechnology, nanoparticles, and quantum dots (QDs) have developed as critical instruments for the rapid and precise detection of a specific biological signature. Using biosensors, QDs, nano platforms, nanopore DNA sequencing technologies, and nanoimaging can help improve disease diagnosis and crop protection. These technologies can also help with high-throughput analysis and crop protection.

6.3.1 Nano Diagnostic Kits for Barley Mycotoxins

The term "nano diagnostic kit," also known as "lab in a packet," refers to the practice of packing a laboratory's instruments, reagents, power supply, and other components into a package no larger or heavier than a briefcase (Khiyami et al. 2014). This allows for the simple and rapid identification of plant diseases in fields, permitting specialists to assist agronomists in disease epidemic inhibition (Pimentel 2009; Nezhad 2014). A mycosensor is a dipstick-based antibody-based test for the real-time diagnosis of Zearalenone, Trichothecene, Deoxynivalenol, and Fumonisin B1/Fumonisin B2 mycotoxins in barley samples (Lattanzio et al. 2012).

Nano diagnostics using immunoassay kits and nucleic acid-based tests are quick, inexpensive, and simple to use, making them ideal for on-site testing. However, there are several hurdles, such as the detection and choice of efficient antigens, antibodies, nucleotide targets, nanomaterials, and their manufacture as kits, which need more research work to make them practicable at the ground level on a wide scale (Lattanzio et al. 2012). Furthermore, the transportable diagnostic device, nanoparticle-based, bio-barcoded DNA sensor, and QD might all be used to identify plant diseases and toxogenic fungus. Transportable diagnostic tests have been established to identify plant diseases quickly and may be applied to avert outbreaks. These nano-based kits are rapid for pathogen identification and also improve diagnostic precision. Furthermore, the grouping of nanotechnology and microfluidic devices has been successfully used in molecular studies of plant pathology and may be customized to identify definite infections and poisons. For instance, the micro-PCR, which can execute 40 cycles of PCR in a short time. In the near future, nano-instruments with unique features might be employed to create smart agricultural systems in the near future. These nanodevices, for example, may be applied to detect plant health concerns before they become observable to the planter. Such devices may be able to respond to unusual events, identifying the problem and initiating disease management intervention. Nano-smart instruments will therefore serve as both a defensive and an initial alarm system. Nanodevices that can do thousands of measurements quickly and affordably will become available during the next few years. The downsizing of biochip technology to the nanoscale level will continue to improve future possibilities in plant disease diagnostics. Nano-phytopathology can be used to better understand plant-pathogen interactions, perhaps leading to novel crop protection measures. Specific nano-instruments and DNA nano-instruments might provide precise tracking, diagnosis, and monitoring of the pathogens in the first stage of plant infection (Khiyami et al. 2014).

6.4 Effect of Metallic Oxide Nanoparticulates on the Barley Varieties

Plants require iron as an essential micronutrient for their growth, whereas copper is a microelement that aids in plant metabolism. Fertilizers containing iron oxide and copper oxide nanoparticulates are applied in trace amounts to improve the necessary metal content of the soil, thus enhancing crop development. These NPs are employed in large dosages as antifungals to protect plants from diseases caused by fungal pathogens (Anderson et al. 2018; Devi et al. 2019; Elmer et al. 2018). Also, zinc oxide nanoparticles are found in a variety of commercial items, including sunscreens, cosmetics, and paints (Hussain et al. 2018; Vance et al. 2015). Furthermore, ZnO NPs have been recommended as a fertilizer to provide Zn to plants.

Metal oxide nanoparticulates have a significant effect on the morphology of the plant. Wheat, tomato, and lettuce roots can be lengthened with Fe_3O_4 nanoparticles. Different concentrations of CuO nanoparticulates can lower the length of roots and shoots in chickpea plants. CuO NPs stress decreased the germination of cucumber, lettuce, rice, and radish seeds (Konate et al. 2018; Kumar et al. 2019). Also, the levels of microRNA expression in plants can be influenced by metal oxide nanoparticles. It is known that microRNAs can defend plants against biotic stress, such as infections that cause powdery mildew.

6.4.1 Barley Morphology and Seedlings Germination

Petrova et al. (2021) investigated the morphology, genotoxicity, and miRNA156a of *Hordeum vulgare* L. cultivars Marthe and KWS Olof when they were grown in different concentrations of iron oxide and copper oxide nanoparticles. The impact of diverse doses of iron oxide and copper oxide nanoparticulates on shoot length on Marthe and KWS Olof barley cultivars was compared; the 17 mg/L dose of iron oxide nanoparticulates generated a substantial increase in the Marthe and KWS Olof varieties. Only the Marthe variety's shoot length was greatly boosted by treatment with 35 mg/L of iron oxide nanoparticulates. Copper oxide nanoparticulates at 35 mg/L enhanced shoot length exclusively in the KWS Olof cultivar. The shoot length of the Marthe cultivar control group was 16.15 cm, whereas the shoot length of the groups treated with 17, 35, and 70 mg/L iron oxide nanoparticulates was 16.04, 18.96, and 17.23 cm, respectively (Fig. 6.1). However, when they were treated with copper oxide nanoparticulates, the shoot length of the groups was 16.08, 15.58, and 15.18 cm at 17, 35, and 70 mg/L, respectively. On the KWS Olof cultivar, the shoot length of the control group was 15.78 cm, whereas the shoot length of the groups treated with iron oxide nanoparticulates at 17, 35, and 70 mg/L was 18.53, 18.13, and 17.35 cm, respectively. The shoot length of copper oxide nanoparticulates-treated KWS Olof variety attained 15.06, 17.36, 16.95 cm at

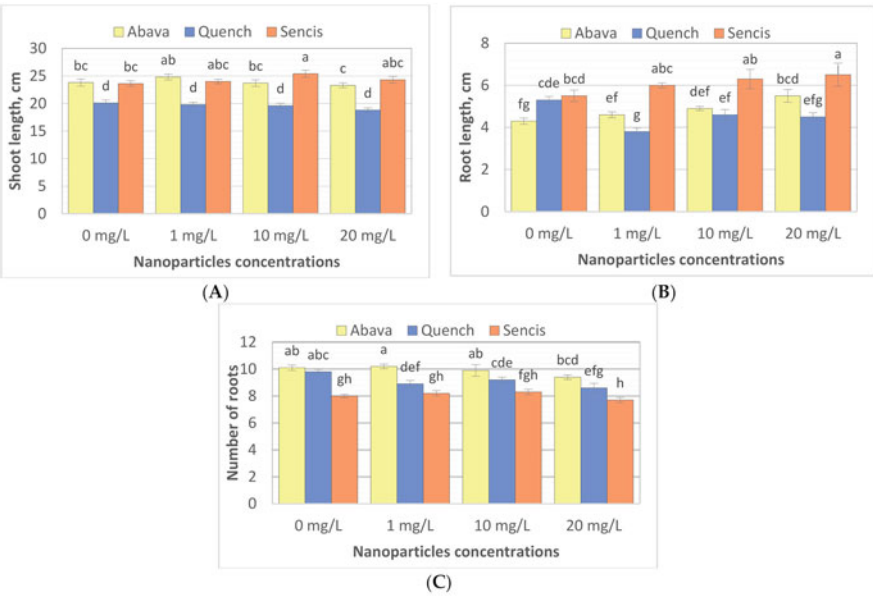

Fig. 6.1 Growth parameters expressed as the % of control; in barley cultivars, seedlings have grown 8 days with different doses of iron oxide nanoparticulate. Diverse letters show significant differences at $p < 0.05$. However, the similar letters show no significant difference (Kokina et al. 2021)

17, 35, and 70 mg/L, respectively. All other iron oxide nanoparticulates treatments improved the shoot length of both cultivars of barley.

Copper oxide nanoparticulates at all treatments reduce the shoot length of Marthe cultivar, but in the KWS Olof cultivar, all doses of CuO NPs in this cultivar enlarged shoot length except in case of using 17 mg/L concentration of copper oxide nanoparticulates (Petrova et al. 2021).

The root length of the Marthe and KWS Olof cultivars was unaffected by different treatments of iron oxide nanoparticulates. All treatments of copper oxide nanoparticulates lowered Marthe and KWS Olof roots lengths substantially. The root length for the control group of Marthe cultivar was 7.58 cm, whereas the root length of the group with iron oxide nanoparticulates at 17 and 35 mg/L concentrations was 7.17 and 6.33 cm, respectively. However, at the 70 mg/L concentration, the root measured 9.86 cm long. The Marthe set with copper oxide nanoparticulates at 17, 35, 70 mg/L concentrations had a height of 3.08, 5.31, 5.76 cm, respectively. All Fe_3O_4 NPs concentrations had a beneficial effect on the fresh biomass of the Marthe and KWS Olof cultivars, with biomass increasing. However, iron oxide and copper oxide NPs at 17, 70, and 35 mg/L did not influence the fresh biomasses of seedlings.

On the contrary, recent research by Kokina et al. (2021) showed the increase in root length and shoot length in both Sencis and Abava varieties when they were treated with iron oxide nanoparticulate. Abava seedlings grew to 1 cm in shoot length and 0.1 cm in root number when given a 1 mg/L dose. However, insignificant root development of Abava was observed when given a 20 mg/L dose. Moreover, the reduction of growth parameters was observed only in the Quench variety (Fig. 6.1).

Also, Petrova et al. (2021) showed that ZnO NPs improve barley seed growing, shoot/root extension, and stress level of hydrogen peroxide and reduce the viability of root cell, the stability of genomic template, and up/downregulated miRNAs in the seeds. The seeds grown with the supplements 4 mg/L of ZnO NPs had the highest germination rate (66%), while the control seedlings had a much lesser germination percentage (42%). Germination rates at 2 mg/L and 1 mg/L were 57 and 63%, respectively. ZnO NPs had a substantial influence on the regular length of shoots. There was no noteworthy statistical variation between the length of the seedling root and the number of seminal roots. The maximum dose (4 mg/L) of ZnO NPs had the greatest impact on barley germination and shoot and root length. In another study, Tombulogu et al. (2019b), cultivated Barley for 3 weeks in a hydroponic solution enriched with different concentrations of NiFe2O4 NPs and the results in rising in iron and nickel levels of leaves that were 5.5 and 8 times larger than the control, respectively. Furthermore, the NPs treatment boosted the leaf's calcium, potassium, manganese, sodium, and magnesium constituent (Tombuloglu et al. 2019b).

Also, Rico et al. (2015) proved that cerium oxide NPs ($nCeO_2$) improved biomasses, plant height, and chlorophyll composition while decreasing spike formation in *Hordeum vulgare L.* Ce buildup by 294%, which was associated with increased nutrient storage including phosphorous, potassium, magnesium, calcium, iron, copper, sulfur, and zinc in grains. Similarly, $nCeO_2$-amended soil (250 μg/kg DW) improved the levels of amino acids including methionine, aspartic acid,

Table 6.1 Amino acid and fatty acid compositions in barley grains harvested from $nCeO_2$-amended soil (Rico et al. 2015)

N CeO_2 Concentrations (mg kg^{-1})			
0		125	250
Amino acids (μg g^{-1} dry wt)			
Alanine	61.10 + 539	67.62 + 1 24	88.72 + 25 M
Amide-NH_3	78.37 + 5_12	84.36 + 236	99.52 + 24.45
Arginine	13.08 + 232c	3 7.19 + 3 25b	62.53 + 2.10a
Aspartic *acid*	126.56 + 83,713	123.05 + 292b	160.84 + 18.95a
Cysteine	6.57 + 1 36	832 + 0.70	6.25 + 0.77
Glutamic acid	500.49 + 52.65	47,327 + 14.55	573.74 + 189.40
Glycine	75.02 + 5.91	77.02 + O31	82.79 + 32.99
Isoleucine	41.30 + 5.48	5030 + 230	47.51 + 24.69
Leucine	67.48 + 830	7626 + 737	130.75 + 56.94
Lysine	42.16 + 3.19	4430+ 1.78	7 1.24 + 22.36
Methionine	4.36 + 0.433	5.80+ 1.98b	3 1.24 + 0.58a
Phenylalanine	35.56 + 2.78	3829 + 3.61	61.42 + 20.57
Proline	373.96 + 31.15	345.97+ 10.78	395.94 + 25.49
Serine	26.70 + 239	3 1.97 + 2.41	45.86 + 16.55
Threonine	65.86 + 5.5 8b	74.82 + 2.65ab	103.79 + 18.44a
Tyrosine	36.64 + 4.3 lb	6048 + 5.1 5ab	8 &35 + 25.95a
Valine	82.62 + 899	101.92 + 1 26	125.94 + 36.55
Total	1637.84 + 12,138	1702.14 + 36.82	1816.96 + 448.64
Fatty acids (relative % abundance)			
Linoleic acid	55.17 + 0.1 2b	54.76 + 04913	56.11 + 0.28a
Linolenic acid	6.62 + 0.11	6.8 1 + 0.1 1	7.10 + 0.29
Oleic acid	15.11 + 031	14.99 + 030	14.86 + 0.20
Palmitic acid	2 1.72 + 0.12a	2130 + 0.13b	21.54 + 0 1 2ab
Stearic acid	0.84 + 0.0313	1.00 + 0.05a	0.89 + 0.07ab

tyrosine, threonine, linolenic acid, and arginine in grains by up to 617, 31, 141, 58, 2.47, and 378%, respectively (Table 6.1) (Rico et al. 2015).

In that concern, $nCeO_2$ and $nTiO_2$ exhibited differential effects on the content and nutritional value of *H. vulgare* kernels. Both MNPs did not affect β-glucans, but lowered amylose concentration by around 21%. The majority of amino acids and crude protein levels rose. Lysine, followed by proline, showed the greatest growth among amino acids (51% and 37%, respectively) (Poščić et al. 2016).

The oxidative stress in the leaves was not always caused by the $nCeO_2$ treatment; nonetheless, yield was reduced at the maximum $nCeO_2$ concentration (500 mg/kg). Further, the plant couldn't form grain at this high concentration (Rico et al. 2015).

6.4.2 Barley Genotoxicity

CuO NPs had a greater impact on the barley genome than Fe_3O_4 NPs which decreased genome constancy to 72% in the Marthe cultivar and 76.34% in the KWS Olof cultivar, whereas CuO NPs raised genome stability from 53.33 to 78.66%, in the Marthe cultivar and reduced genome constancy to 68.81% in the KWS Olof cultivar. After Fe_3O_4 NPs treatments, levels of miRNA expression were not altered in the Marthe cultivar, but rose in the KWS Olof cultivar. The treatment by CuO NPs raised the expression levels of miRNA in the Marthe cultivar, but it decreased in the KWS Olof cultivar. The results imply that the examined NPs may be useful because they may alter the expression of miRNA, which affects plant resistance (Petrova et al. 2021). Forthcoming research is required to examine the impact of NPs stress on expressions of miR156 and other miRNA in mlo and non-mlo barley seedlings, as well as the prospect of using NPs to boost the disease resistance.

6.5 Effect of Metallic Nanoparticles on the Barley Diseases, Seed Germination, Root, and Shoot System

Seed nanoparticles are beneficial to seed growth and sowing quality. Plants grow more resistant to harsh situations such as diseases and pests as a result of their effects. In studies, nanoparticles have been shown to dramatically enhance seedling germination during the early phases of growth (Barabanov et al. 2018; El-Ramady et al. 2014; Krishnaraj et al. 2012a, b). The impact of nanoparticulates on plant development can vary depending on the dose. It has been demonstrated, for example, that increasing the absorption of silver nanoparticulates can delay seedling growth compared to the control (Gubbins et al. 2011; Lee et al. 2012; Mirzajani et al. 2013). Furthermore, the toxicity of nanoparticles may be affected by their size (Jiang et al. 2014). For instance, small silver nanoparticles with a diameter of 6 nm, for example, have been shown experimentally to be more hazardous than the big ones (20–1000 nm) (Musante and White 2012).

6.5.1 Selenium Nanoparticles (SeNPs)

The impacts of critical trace elements such as selenium are being studied in depth. This component is required for the plant organism to function properly. The influence of SeNPs on diverse plant species differs substantially depending on the development of plant growth, the extent of SeNPs exposure, as well as the nanoparticle's morphology, chemical structure, absorption, surface construction, solubility, and aggregation (Romero et al. 2019). The effect of SeNPs on the germination features of *Hordeum vulgare* L. seeds was examined by Siddiqui et al. (2021). SeNPs were found to have a favorable influence on the shoot and root length and the percentage of germination. The treated sample with the

Fig. 6.2 Photos of Barley seeds: (**a**) barley seeds were treated with Selenium nanoparticulate in a Petri dish; (**b**) only one germinated *Hordeum* seed (Siddiqui et al. 2021)

formulation of SeNPs at a dose of 4.65 g/mL had the highest percentage of seed germination (Siddiqui et al. 2021) (Fig. 6.2).

6.5.2 Silver Nanoparticles (AgNPs)

The dispersion of AgNPs in the shoot and root tissues and seedlings of *Hordeum vulgare* was examined by Linares et al. (2020). The strong, linear responses of barley seedlings to soil AgNP doses over a 14-day exposure time validate barley's usefulness as a detective examination for silver bioavailability in AgNP biosolid-amended soils. The growth of root and shoot was reduced linearly by the increased concentration of AgNPs. Furthermore, Elamawi and Al-Harbi (2014) reported that the lower doses of AgNPs enhanced the percentage of barley seed germination and lessened the prevalence of barley seed rot disease produced by *Fusarium oxysporum*. However, the higher doses of AgNPs reduced the germination of barley grain and showed a robust lessening in the length of roots. The chlorosis of leaves was caused by a loss in chlorophyll pigments and disorganization of chloroplast thylakoids in positive silver ions and the treated barley groups with AgNPs. As a result, increased monoaldehyde content in response to the influence of positive silver ions and AgNPs gave an indication of oxidative stress intensification. Silver toxicity caused the death of mitochondria, chloroplasts, and the nucleus, which showed that these were the main goals of silver poisoning (Fayez et al. 2017).

6.5.3 Gold Nanoparticles (AuNPs)

Feichtmeier et al. (2015) investigated the influence of 2–19 nm spherical AuNPs on barley seedling germination. There was no noteworthy influence on germination, but there was wilting of leaves, blackening of roots, and reduced biomass, which worsened as the concentration of AuNPs increased. However, a relatively modest concentration of AuNPs in the nutritional media (1 g/mL) stimulated growth. It is supposed that low concentrations trigger hormone roles (Barrena et al. 2009), whereas higher concentrations and larger AuNPs have a negative outcome on barley growth and biomass yield. Adsorption of AuNPs onto the primary root may have reduced pore size, hindering water passage capacity and thus lessening barley growth and related features. Previously, researchers explained this as well (Feichtmeier et al. 2015; Asli and Neumann 2009).

6.6 Conclusion

One of the most vital cereal plants is barley (Hordeum vulgare L.), which is widely employed not only in agronomy but also in nutrient production. Barley is susceptible to a variety of diseases, the majority of which are caused by plant pathogens. Fast diagnosis methods for crop pathogens are needed to avoid disease spread and limit losses in order to maximize output and food security. For instance, a mycosensor is a dipstick-based antibody-based test that detects mycotoxins in barley samples in real time. Barley diseases: nanotechnology propels a broad range of options for managing barley diseases. Silver, selenium, copper, iron oxide, zinc oxide, and titanium dioxide nanoparticles have received a lot of attention. These nanomaterials have a role in reducing disease incidence, as well as barley seed germination, physiology, and nutritional quality of barley grain. Future studies are needed to investigate the role of miR156 and other miRNA expressions in NP-stressed barley seedlings, as well as to evaluate the feasibility of applying NPs to boost barley resistance to diseases.

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