This study aimed to determine the fate of zinc oxide nanoparticles (ZnO-NPs) in soil and to investigate their behavior under different environmental conditions by analyzing the influence of various ecological factors. It also sought to evaluate the toxic effects and physiological changes resulting from the exposure of *wheat* plants (*Triticum aestivum* L.) to different concentrations of ZnO-NPs, as well as to assess the response of soil fungi such as *A. niger*, *A. fumigatus*, and *R. stolonifer* to these nanoparticles. The overall objective was to understand the environmental behavior and biokinetic dynamics of ZnO-NPs within the Iraqi agricultural ecosystem and to evaluate their effects on both biotic and abiotic components of the environment.

The study was conducted in Abada village, located in Al-Fuhud district, Thi-Qar Governorate, southern Iraq, characterized by sandy-clay soil and favorable climatic conditions for winter cultivation. Planting began on November 5, 2024, and ended at the grain-filling stage on March 5, 2025. The soil at the study site was found to have a high sand content (86.4%), low organic matter (0.72%), an alkaline reaction (pH = 8.12), and relatively low electrical conductivity (1.25 dS/cm). The experiment included four treatments: one control and three treatments with added ZnO-NPs at concentrations of 100, 200, and 300 mg/kg in 5 kg pots of soil. The results indicated that ZnO-NP accumulation in soil and plant tissues increased with the applied concentrations, reaching the highest accumulation of 217.39 mg/kg in soil and 192.55 mg/kg in the whole plant at 300 mg/kg, while the grains showed the highest accumulation of 211.47 mg/kg.

The results revealed that the lowest concentration (100 mg/kg) of ZnO-NPs produced the most favorable response in wheat growth and yield, showing the highest number of spikes (52 spikes/plant), the highest dry weight of leaves (0.0295 g), and the greatest total plant dry weight (0.2994 g), in addition to the highest chlorophyll content (1.23) compared with the control. Environmental parameters such as temperature, humidity, and rainfall were found to significantly influence the interactions between ZnO-NPs and soil microorganisms. During the study period, temperatures ranged from 20 °C to 26 °C, relative humidity reached a maximum of 65% in spring and a minimum of 45% in winter, and rainfall was minimal, reflecting the semi-arid nature of the region. These climatic conditions increased the soil's susceptibility to nanoparticle effects, especially due to the low organic matter and limited water retention capacity.

Isolation and identification of soil fungi indicated that *Ascomycota* were the most prevalent (79.9%), surpassing *Zygomycota* and *Basidiomycota*, which appeared at lower frequencies. Among the most common species were *Aspergillus fumigatus*, *Aspergillus niger*, and *Rhizopus stolonifer*. The results demonstrated that higher concentrations of ZnO-NPs altered the balance of the fungal community, as sensitive species such as *Alternaria alternata* and *Fusarium solani* declined, while resistant species became dominant. The differences between treatments were significant, suggesting that prolonged soil exposure to such nanoparticles may lead to a decline in microbial biodiversity.

Measurements of fungal colony diameters after seven days of incubation on solid Potato Dextrose Agar (PDA) medium supplemented with various ZnO-NP concentrations (Control, 100, 200, 300 mg) showed that all three fungal isolates (*A. niger*, *A. fumigatus*, *R. stolonifer*) were able to grow under all treatments, though their growth varied with concentration. In the control treatment, colony diameters reached 8.1 cm for *A. niger*, 8.0 cm for *A. fumigatus*, and 8.5 cm for *R. stolonifer*, indicating no inhibitory effect in untreated media. At 100 mg, growth remained similar, with diameters of 7.5, 8.7, and 8.4 cm respectively, showing no significant differences compared to the control. At 200 mg, slight differences appeared, with 7.8 cm for *A. niger* and *R. stolonifer*, and 8.2 cm for *A. fumigatus*. At the highest concentration (300 mg), colony diameters decreased noticeably to 6.8 cm for *A. niger*, 7.8 cm for *A. fumigatus*, and 8.5 cm for *R. stolonifer*, showing significant differences compared with the control. This indicates that higher concentrations had a partially inhibitory effect, with *R. stolonifer* showing greater tolerance than the other fungi.

Overall, all three fungi (*A. niger*, *A. fumigatus*, *R. stolonifer*) demonstrated the ability to grow under different conditions, though their responses varied with ZnO-NP concentration. The highest colony diameter was recorded in the control treatment (8.5 cm) for *R. stolonifer*, followed by *A. niger* (8.1 cm) and *A. fumigatus* (8.0 cm), indicating no inhibition in untreated media. Fungal growth continued well at 100 mg/L without significant differences compared to the control, but decreased gradually with higher concentrations. The smallest colony diameter was observed at 300 mg/L for *A. niger* (6.8 cm). These results suggest that *R. stolonifer* exhibited the highest tolerance to ZnO-NPs, maintaining superior growth even at high concentrations. This indicates that the type of available carbon and nitrogen sources plays a crucial role in determining fungal response to ZnO-NPs, as adequate nutrient availability may enhance fungal adaptability and enable utilization of nanoparticles for growth processes.

Using Fourier-transform infrared spectroscopy (FTIR), it was observed that soil fungi isolated from ZnO-NP-treated soils caused clear spectral changes across different concentrations (100, 200, 300 mg). The FTIR spectra showed variations in intensity and position of absorption peaks depending on the concentration and medium used. The findings also revealed that the fungi influenced ZnO-NPs by altering the pH values in the mineral salt medium supplemented with different carbon and nitrogen sources.