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Effect of Different Concentrations of Cadmium Sulfate $CdSO_4$ on Germination, Growth, and Development of Common Barley *Hordeum vulgare* L;

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ABSTRACT

This study was carried out to investigate the effect of cadmium sulfate $CdSO_4$ on germination, growth, and development of common barley Hordeum vulgare L. at several concentrations (0, 100, 200, and 300 µmol). The experiment lasted for an entire month and was designed based on four treatments for each plant, and each treatment was replicated four times (16 pots). Results revealed that the highest germination rate of the seeds was scored for the concentration of 0% µmol (the control) at 98%, whilst the 300-µmol concentration recorded the lowest germination rate at 27%. It was observed that the highest average length of the plant was recorded at the 0% concentration while the lowest was at the concentration of 300 µmol, which reached (13.1 ± 2.1 and 6.7 ± 0.9 cm), respectively. Results have also shown an inverse relationship between cadmium sulfate concentrations and the wet and dry weight of the plant, where the higher the concentration, the lower the wet and dry weights of the shoot and root systems of the plant. Furthermore, many morphological and anatomical changes were detected, such as a decrease in turgor pressure, which led to a shrinkage of the leaf surface area as well as a shortening of the internodes due to the small size and number of cells that resulted in stunted plants.

Keywords: Cadmium Sulfate; Germination; Growth; Development; *Hordeum vulgare* L; Heavy Metals; Pollution.

Introduction

Barley, a cereal plant belongs to the herbaceous family of Poaceae grown in a variety of environments. Worldwide, barley is the fourth most widely grown edible grain crop right after wheat, rice, and corn. It is commonly used in animal feed, bread, soups, stews, health goods, and different food industries such as beer. Barley is a small, alternate-leaved annual grass with erect stems (Rajasekharan & Kumar, 2023). More than any other cereal, barley is climate-adaptable and suitable for temperate, subarctic, or subtropical regions. It can grow and mature faster than any other grain, even though it thrives in growing seasons that last at least 90 days. In the almost desert regions of North Africa, where it is mostly cultivated in the fall, barley flourishes as it is more resistant to dry heat than other minor grains. Western Europe and North America's milder, more humid regions are ideal for spring-sown crops. Barley has a nutty flavor, rich in carbohydrates, and contains small amounts of vitamin B, as well as moderate amounts of protein, calcium, and phosphorus.

Common barley, *Hordeum vulgare* L. (Figure 1) has embryonic roots of up to eight roots, and one or more of them may vertically deepen and reach a depth of two meters, while the rest of the embryonic roots grow horizontally to a distance of 40 cm. The adventitious roots arise from the stem nodes at the level of the soil surface during the branch formation stage (tillering). Adventitious roots may also arise from the branchings and go deep into the soil, forming a mass of fibrous roots. The stem in barley, especially in spring varieties, is erect and hollowed out consists of solid nodes and internodes, increases in length from the bottom to the top, and may reach a height ranging from (120-150) cm. The stem arises from several branchings ranging from (3-5). The barley leaf is simple, arising from the nodes in an alternating and opposite manner on the stem. The leaf consists of a blade, a sheath, and auricles that are large, clear, and devoid of villi compared to the auricles of wheat, and the tongue is short compared to the auricles of wheat. The inflorescence in barley is a spike consisting of the central axis, which is divided into nodes and internodes. Three spikelets grow at each node of the axis. Other than that, the flower in barley consists of the outer gall (Lemma), the inner gall (Palea), the stamens, and the anthers. In most varieties of barley, the outer and inner stalks stick to the grain at maturity, except for one type known as (naked) barley (Reid, 1985).

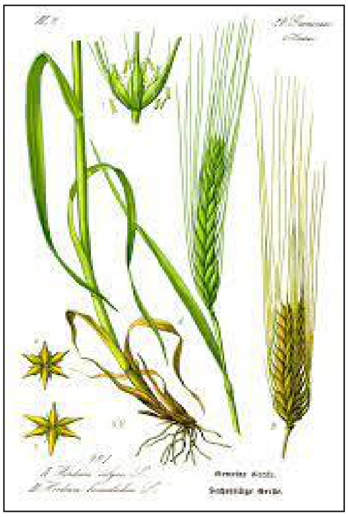

Figure 1: Common barley, Hordeum vulgare L.

Environmental pollution has become a serious growing trouble that threatens the existence of the human race and even threatens the lives of all other living creatures, including animals, plants, and other forms of life. This emerging problem is a predictable result of the technological, industrial, and cultural progress of humankind, which includes land, water, and the air layers above them. Heavy metals, or what is known as heavy elements, are defined as those whose density is more than five times that of water, 5 g/cm^3, and they have adverse effects on human, animal, and plant health (Ali & Khan, 2018). Heavy metal pollution is one of the most spread forms of environmental issues resulting from anthropogenic activities. In recent years, scientists have always been interested in studying heavy metals regarding their presence in the environment, their biological effects, and their relationship to human health. Food is the main source of human exposure to these elements through its movement through food chains; so many studies have focused on developing appropriate methods to determine the extent of food contamination with these elements (Rehman *et al.,* 2018).

According to Tucker (2008), cadmium has been widely spread into the environment through the air due to mining and smelting activities as well as other manufacturing methods including the use of phosphate fertilizers, inclusion in sewage sludge, and different industrial uses like NiCd batteries, plating, pigments, and plastics. Cadmium is one of the most dangerous and toxic heavy elements in the environment due to its high ability to move through the food chain and its toxicity at low concentrations (Peralta-Videa *et al.,* 2009; Jaishankar *et al.,* 2014) although it is not an essential element for living organisms. The presence of cadmium in the soil causes harm to plant cells as it changes the plant's nutritional method and damages the chloroplasts and mitochondria inside the cells. It also causes oxidative damage to fats and proteins and interferes with the absorption and transportation of essential elements, such as iron, which is important for plants, affecting the process of photosynthesis. A leading study conducted by Ruiz *et al.,* (2010) stated that cadmium is considered a cancer-causing agent and when eaten, large amounts of cadmium may severely irritate the stomach and cause stomachache, vomiting, and diarrhea. However, breathing high amounts of cadmium damages the respiratory tract and may lead to death. Exposure to low levels of cadmium in air, food, water, and particularly in tobacco smoke over time may accumulate in the kidneys and cause kidney failure.

Methodology

This study was conducted at the laboratory of the Botany Division, Faculty of Science, El-Mergib University, Al-Khums, Libya to determine the effects of different concentrations of cadmium on germination, growth, and development of common barley *Hordeum vulgare* L. Four different concentrations of cadmium sulfate $CdSO_4$ were applied at (0, 100, 200, and 300 µmol) based on a full-month experiment. The purpose of the study was to determine the extent of the barley plant's tolerance to increasing concentrations of this element and the extent of its effect on germination, growth, and development. The experiment was designed and randomly distributed based on four treatments for each plant, and each treatment was repeated 4 times (16 pots) as shown in Figure 2.

After identification with the help of a taxonomist, barley seeds were brought from the local market and stored in the laboratory at room temperature until the experiment began. The soil used in agriculture was collected from the area of Al-Jahawat located in the southern part of Al-Khums city, transferred to the laboratory, air-dried, and sieved by a 2 mm sieve to remove impurities. Pots were labeled with the date, treatment number, and replicate number then ten seeds were planted in each pot at the beginning of March 2023 at (2-3 cm) depth.

Two days after planting, planting pots were treated with cadmium sulfate $CdSO_4$ at (0, 100, 200, and 300 µmol). Seed germination was monitored daily, the first seedling emergence occurred 3 days after planting for the different treatments. However, the germination rate (%) was estimated ten days after planting by calculating the average number of germinated seeds in each replicate according to the following equation:

$$Germination\ rate\ (\%) = \frac{number\ of\ germinated\ seeds}{total\ number\ of\ planted\ seeds} * 100$$

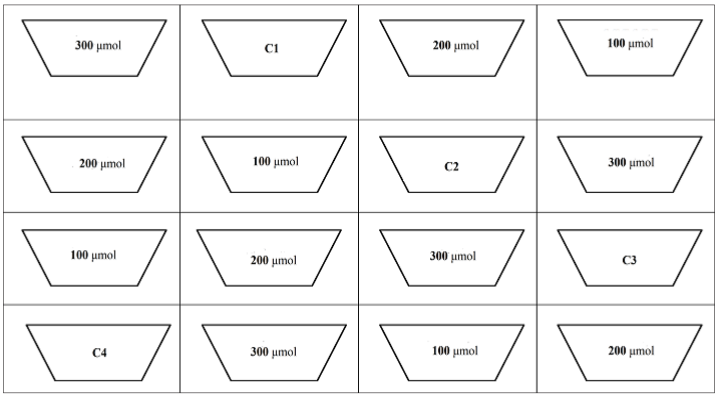

Figure 2: Experimental Design.

Plants were harvested at the age of 30 days from the day of germination and prepared for further measurements such as height and wet and dry weight for both shoot and root systems. Size was measured using a regular ruler, while fresh and dry weights were measured using a 1-decimal precision electronic scale. The obtained data were recorded in tables that we will discuss in the coming section.

Results & Discussion

Based on findings reported in Table 1, it is noted that there is an inverse proportion between germination rate and treatment concentration as the highest germination percentage scored in the control treatment, reaching 98%, while the germination percentage decreased to 27% at the 300-µmol concentration. The low germination rates of barley at high concentrations of cadmium sulfate might be due to the toxic effects of cadmium ions on the germination process that interrupt the enzymatic system, which affects the various metabolic processes required to complete germination (Haider *et al.,* 2021).

Table 1: Effect of Different Concentrations of Cadmium Sulfate CdSO4 on the Germination Rates of Barley.

Treatment	Germination rate (%)
Control	98%
100 µmol	86%
200 µmol	67%
300 µmol	27%

Similar findings were obtained by Huybrechts *et al.,* (2019) as the inhibitory effect of cadmium on the germination of *Vigna unguiculata* seeds was proposed to be due to an impairment of water uptake, thereby limiting the water availability for the developing of seed embryo.

Growth in shoot length was almost identical to the results of the previous part as the highest shoot length was at 13.1 ± 2.1 cm for the control treatment (0 µmol); whilst the lowest shoot length taken was for the concentration of 300 µmol at 6.7 ± 0.9 cm (Table 2). The reason behind the decrease in the height of the main stem is a logical consequence of cadmium toxicity as it led to morphological and anatomical changes including the shortening of the internodes because of the small size and number of cells (Genchi *et al.,* 2020). Based on findings revealed by Waheed *et al.,* (2022) on *Eruca sativa*, length reduction of the shoot system as plant photosynthetic organs and structures were damaged by cadmium stress as it reduces the amount of critical minerals that plants can absorb, which inhibits plant development. The detrimental effects of cadmium stress are often more severe on plant aboveground organs than underground organs. Moreover, Cadmium stress can diminish or stop the process of photosynthesis, which in turn inhibits the formation of photo-assimilates and eventually decreases their development.

Table 2: The Mean Shoot Length of Barley at Different Concentrations of Cadmium Sulfate

Treatment	Shoot length (cm)
Control	13.1 ± 2.1
100 µmol	11.4 ± 1.9
200 µmol	8.2 ± 1.3
300 µmol	6.7 ± 0.9

The results in Table (3) showed that there is a negative effect of cadmium on the average wet and dry weight of the shoot system of barley, especially at high concentrations. However, such a decrease in weight may be because heavy metals inhibit the absorption and accumulation of calcium in plant tissues, which inhibits the functional ability to regulate the entry and exit of essential elements to the plant. Piršelová & Ondrušková, (2021) came up with a similar conclusion as the reductions in fresh weight, dry weight, and water content of *Vicia Faba* were proportionate to the applied dosage of cadmium when compared to the control treatment. The decline in fresh weight and dry weight was inversely correlated with the decline in cell viability. The reason behind the decline in fresh and dry weight is due to a decrease in the relative water content, which results in a decrease in turgor pressure, then leaf shrinkage, and a smaller leaf area, which leads to a reduction in the process of building carbohydrates.

Table 3 also indicates the average wet and dry weight of the root system of barley. It is unignorable that increasing the concentration of cadmium is associated with a decrease in the wet and dry weight of the plant, especially the concentration of 300 µmol. The presence of excessive amounts of cadmium in the soil usually causes many symptoms of stress in plants, such as growth limitation, especially root growth, and disturbances in mineral nutrition and carbohydrate metabolism, thus significantly reducing biomass production.

Table 3: The Average Wet and Dry Weight of Both Shoot and Root systems of Barley

Treatment	Shoot system		Root system	
	Wet weight (gm)	Dry weight (gm)	Wet weight (gm)	Dry weight (gm)
Control	0.6 ± 0.1	0.4 ± 0.1	1.3 ± 0.4	0.3 ± 0.1
100 µmol	0.4 ± 0.1	0.2 ± 0.0	0.9 ± 0.2	0.2 ± 0.0
200 µmol	0.3 ± 0.0	0.1 ± 0.0	0.7 ± 0.2	0.1 ± 0.0
300 µmol	0.3 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0

Conclusion

This study concluded that the higher the cadmium concentrations, the lower the germination rate, plant size, and wet and dry weight of barley plants in all applied treatments. The toxicity of this element affects the physiological processes of photosynthesis, water uptake, and nutrient absorption. This negative impact extends to the morphological and anatomical characteristics of the plant causing plants to be stunted. The danger of this element to living organisms lies in its extreme toxicity, even at low concentrations, if this element is transmitted to living organisms through food, or what is known as the transfer of energy through food chains. Exposure to cadmium leads to the emergence of many serious illnesses, such as kidney failure, liver cirrhosis, and respiratory diseases, as well as cancer.

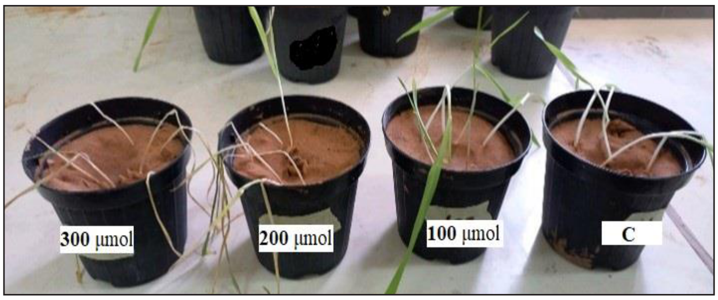

Figure 1: Effect of Different Concentrations of $CdSO_4$ on Size of Barley

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Recommendations

Simply because human life and maintaining one's health are among the most significant sacred things, the researcher endorses the necessity of spreading environmental awareness in the field of nutrition and adopting similar studies from the competent authorities as barley is considered an essential crop in the nutrition of many people around the world.

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