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Effect of Soaking Wheat Seeds in Different Concentrations of Cobalt on Growth and Nutrient Status

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تأثير نقع بذور القمح في تركيزات مختلفة من الكوبالت على النمو والحالة الغذائية

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Abstract
The research investigated agricultural production, dietary value, and stress adaptation effects of cobalt-compound-treated wheat seeds in some Libyan dry lands. The study examined the maximum impact on wheat seed development through four concentrations of cobalt solutions starting at 0 mg/L and reaching 10 mg/L. Researchers obtained their highest outcome evaluations from spraying wheat seeds with a Co-based solution at a concentration of 5 mg/L compared to other arrangements. Wheat maintained its drought resistance with its resistance to salinity stress and enhanced its uptake of nitrogen, phosphorus, and potassium after receiving cobalt solutions. The plant specimens achieved their maximum productivity at 5 mg/L dilutions before exceeding this concentration level, which became toxic for the specimens. This study proves that seed soaking with a cobalt solution produces improved wheat yield outputs within dry land agricultural systems.

Keywords: Cobalt, Wheat, Seed Soaking, Nutrient Uptake, Stress Tolerance, Grain Yield, Arid Regions, Sustainable Agriculture.

الملخص
تناول البحث الإنتاج الزراعي والقيمة الغذائية وتأثيرات التكيف مع الإجهاد لبذور القمح المعالجة بمحلول الكوبالت في بعض الأراضي الليبية الجافة. تناولت الدراسة التأثير الأقصى على نمو بذور القمح من خلال أربع تركيزات مختلفة من محاليل الكوبالت تبدأ من 0 ملغم/لتر وتصل إلى 10 ملغم/لتر. تم الحصول على أعلى قيم النتائج من رش بذور القمح بمحلول الكوبالت بتركيز 5 ملغم/لتر مقارنة بالتركيزات الأخرى. حافظ القمح على مقاومته للجفاف واجهاد الملوحة وعزز امتصاصه للنيتروجين والفوسفور والبوتاسيوم بعد تلقيه محاليل الكوبالت. حققت العينات النباتية أقصى إنتاجية لها عند التخفيف 5 ملغم/لتر قبل تجاوز مستوى التركيز هذا، والذي أصبح سامًا للعينات. تثبت هذه الدراسة أن نقع البذور بمحلول الكوبالت يؤدي إلى تحسين إنتاجية محصول القمح ضمن النظم الزراعية في الأراضي الجافة.

الكلمات المفتاحية: الكوبالت، القمح، نقع البذور، امتصاص العناصر، تحمل الإجهاد، إنتاجية الحبوب، المناطق الجافة، الزراعة المستدامة.

Introduction

Seed-type wheat is a vital worldwide crop because it provides fundamental nutritional content to billions of people worldwide (Javaid et al., 2023; Bradford et al., 2020). World food security depends heavily on wheat because it provides substantial protein and energy components for nutrition in numerous global nations, according to Acevedo et al. (2018). Wheat improvement methods have become essential for the world because human numbers continue to rise while climate conditions worsen and fields are reducing in size (Wani et al., 2020; Joshi et al., 2007). The changing weather patterns continue to make wheat cultivation more challenging because they cause significant land degradation while reducing irrigation options and decreasing soil nutrient content. Researchers study wheat cultivation practices through exams of micronutrient seed soaking to boost plant growth (Karimi et al., 2021). Cobalt (Co) 's potential to enhance plant growth is one reason it has gained scientific interest among other micronutrients (Hu et al., 2021). The trace element cobalt enables plant growth in tiny proportions, though it participates in vital biochemical and physiological operations (Ahmed et al., 2020). The following review evaluates cobalt usage, especially at multiple soaking concentrations, on wheat seed development and its effects on wheat growth, nutrient levels, and resistance capabilities.

Cobalt as a Micronutrient in Plants

Researchers have only recently started studying cobalt as a necessary plant micronutrient, which was previously overlooked during past research periods (Graham, 2008). Vitamin B12 production depends on cobalt to function in plant metabolic processes, which include nitrogen fixation enzyme activation and cellular respiration (Sadeghzadeh et al., 2022). The physiological functions of cobalt include encouraging root development while bettering photosynthetic capabilities and producing better nutrient absorption (Ghasemi et al., 2021). The low cobalt content in most soils affects crop productivity, especially in wheat and other high-yielding crops, because it creates deficiencies (Yasmin et al., 2022). The specific cobalt concentration needed for maximum growth differs among plant species since large amounts of cobalt lead to toxic effects (Lange et al., 2017). Research must establish the appropriate cobalt seed soaking concentration because it determines how beneficial effects will interact with potentially harmful results.

Wheat growth becomes more efficient following cobalt treatment because the mineral adds value to root growth and ensures better nutrient consumption, according to Shah et al.'s (2020) findings. Wheat photosynthetic processes and chlorophyll production suffer adverse effects from cobalt exposure, according to Kaur et al. (2021). Wheat depends on cobalt to operate nitrogen assimilation efficiently since it is a vital component for wheat nitrogen metabolic activities. Because cobalt enhances nitrogen efficiency utilization, it substantially benefits wheat cultivation, specifically in nitrogen-deficient areas (Zeb et al., 2021).

When seeds are put to soak, it represents an established method that benefits plant development. In agronomy, seed soaking remains a standard practice that involves placing seeds in water-based solutions before planting to boost germination success, first-stage development, and entire plant establishment. The soaking method successfully improves seedling growth rates for wheat crops alongside numerous other agricultural products (Zeb et al., 2021). Exposing seeds to cobalt-containing soaking solutions effectively increases their germination ability and strengthens their root development and absorption of nutrients. Cobalt-containing solutions reveal their effectiveness when seed soaking because they activate seed metabolic enzymes, thus boosting seed energy stores and enhancing seedling success (Kaur et al., 2021). The stress tolerance of plants improves significantly when seeds soak in cobalt solutions because the treatment helps plants resist drought and salinity devastation (Shah et al., 2020).

The research indicates that wheat seeds exposed to cobalt solutions result in superior root development and better absorption of nitrogen, phosphorus, and potassium macro and micronutrients, as Ghasemi et al. (2021) identified. Nutrient absorption improves through Cobalt administration, which modifies root structures and enlarges the region responsible for nutrient absorption. Cobalt applications enhance plant nutrient transport mechanisms, resulting in effective nutrient distribution across the entire plant (Kaur et al., 2021).

Cobalt and Nutrient Uptake in Wheat

Users of the Government of India platform investigate cobalt related to nutrient acquisition. Scientists determined how cobalt affects the absorption process of wheat plant essential nutrients, including nitrogen, phosphorus, and potassium, that plants need to grow. Plants need cobalt during the biochemical nitrogen metabolism cycle because it determines their ability to extract and process nitrogen from environmental soil conditions (Sadeghzadeh et al., 2022). Scientific experiments show that cobalt affects enzyme activation by activating nitrate reductase so plants can produce accessible nitrogen forms (Shah et al., 2020). Through improved nitrogen use, cobalt enables wheat plants to require less excessive nitrogen fertilizers, which leads to environmental sustainability benefits (Aulakh et al., 2005).

The scientific results show that wheat plants gain improved abilities to absorb essential wheat development nutrients after cobalt treatment (Talukder & Sharma, 2016). Scientific evidence from senior researchers established that cobalt leads to improved phosphate-solubilizing microorganism function in soil, increasing phosphorus availability in dry regions (Zeb et al., 2021). The transport activities of plant-based ions experience cobalt-related effects since the mineral modifies multiple transport systems across the plant. Cobalt acts as a nutritional element that enables wheat plants to balance osmoregulation and maintain stress tolerance that enhances their survival against unfriendly environmental conditions, according to Singh (2024), Husen et al. (2024), and Pandey (2015).

Toxicity and Optimal Concentration of Cobalt

The essential requirement of cobalt for plant development creates toxicity effects when applied excessively because it leads to seed germination reduction, stunted plant growth, chlorosis, and eventual plant death (Kovács et al., 2022). Proper management of the cobalt concentration during seed soaking processes is vital to achieve beneficial results without inflicting any harm. The research shows that cobalt levels between 2–5 mg/L yield beneficial effects for plant growth, but concentrations above 10 mg/L harm plants (Yasmin et al., 2022). Scientists must identify the most potent cobalt solution for seed presoaking by studying different soil types, wheat cultivar properties, and environmental factors (Mondal & Bose, 2019).

Seed germination, along with the initial growth phase of wheat, demonstrates its best performance when exposed to cobalt solutions at concentrations from 2-5 milligrams per liter until toxicity symptoms arise, according to Kaur et al. (2021). Researchers must advance cobalt dosage recommendations for determining targeted cobalt solutions across different wheat variants and environmental conditions (Jiang et al., 2022; Gál et al., 2008). The practical implementation of cobalt for sustainable wheat cultivation demands that farmers establish particular cobalt concentration zones, as Vasilachi et al. (2023) noted.

Cobalt and Wheat Growth Under Stress Conditions

Research shows cobalt to be a strong potential solution. Cobalt helps wheat plants resist numerous chemical threats inside the soil, including drought, heat, and salt damage (Khawula et al., 2023). Worldwide wheat production remains at risk because climate change is causing stressors to grow across wheat cultivation areas. According to laboratory results, applying cobalt to wheat plants leads to improved drought tolerance since the mineral supplement helps both stomatal functions and osmotic response mechanisms (Shah et al., 2020). Cobalt-treated plants develop robust antioxidant mechanisms that protect them from environmental stress-related oxidative stress, based on Kovács et al. (2022).

Research by Hassan et al. (2017) indicates that cobalt treatment enhances wheat plant tolerance against salt stress conditions. Cell osmotic behavior improves as cobalt promotes root health and optimizes nutrient intake in high-salt environments (Shah et al., 2020). Global climate evolution creates cobalt seed treatment as an efficient tool for developing wheat systems that resist environmental stress (Vasilachi et al., 2023).

The Rationale of the Study

Wheat is the primary dietary foundation for the entire global population. Its importance has been elevated because of increasing environmental dangers linked to climate change, continued soil deterioration, and diminishing water resources. These obstacles threaten the main food base for population expansion and severely threaten wheat production quality. The present agricultural situation shows an immediate need to discover new sustainable farming procedures to boost wheat growth performance and resistance under harsh environmental conditions. Researchers discovered success by applying micro-nutrient treatments to seeds with cobalt, among other elements. The trace element cobalt was vital for plant physiological processes involving nitrogen metabolism, photosynthesis, and enzyme activation. Plants required cobalt in their growth, yet pottery clay soils contained cobalt at insufficient levels to support sufficient plant functions. Cobalt solutions provide a possible treatment for washing wheat seeds, which research finds improves seed germination, root development, uptake of nutrients, and total plant growth. Research demonstrated that cobalt created resistance against abiotic stress elements, including drought, physiological water scarcity, and nutritional challenges that endangered crop yield following climate changes.

The positive plant growth benefits of cobalt treatment have been demonstrated through research, but further investigation was necessary to determine the ideal seed soaking cobalt concentration and the precise effects of cobalt on wheat advances nutritional requirements, as well as stress resistance abilities. This investigation aimed to resolve the gaps in knowledge about cobalt seed soaking by studying different cobalt concentrations to analyze their influence on growth variables and nutritional aspects. This study was designed to develop wheat cultivation systems that built their resistance capabilities. Research determined perfect cobalt concentrations for seed soaking to provide the necessary understanding of stress-resistant farming practices for wheat cultivation. Results from statistical analysis will guide the development of budget-friendly wheat growth approaches to ensure food safety through green farming methods during environmental change.

Statement of the Problem

Worldwide food security depends primarily on wheat production because environmental barriers such as climate change, soil destruction, and water scarcity threaten its productivity. Monetary reductions in crop yields accompany deteriorating product qualities, which permits environmental perils to become more prevalent because of different barriers associated with dry spells, hot temperatures, and nutrient deficiencies. The primary necessity in agriculture consists of the creation of practices that improve wheat development, nutritional value, and stress tolerance under changing environments.

Planets need cobalt and additional minimal micronutrients to advance their growth process, improve their ability to absorb better nutrients and establish stronger resistance to stress conditions. Soil reserves of Cobalt are too low to fully meet the essential requirements that plants need for nitrogen fixation and photosynthesis, thus causing developmental weakness in crops. Seed soaking using cobalt solution demonstrates excellent potential for enhancing seedling growth and root development and improving plant wellness. The necessary dosage of cobalt for seed-soaking wheat and the particular growth reactions of cobalt remains understudied in terms of wheat development, nutrient absorption, and resistance capability.

Future research is needed to understand the extent of cobalt concentration variability when used as a seed treatment and the dynamic interaction between cobalt and wheat growth-promoting agents. Research about cobalt dosage effects on wheat's nutrient uptake of nitrogen, phosphorus, and potassium remains limited since these elements are essential for plant growth and final yield. Researchers have not investigated how cobalt influences wheat plants to tolerate abiotic stress factors like drought and salt damage. The study sought to resolve the knowledge deficit about cobalt concentration effects on wheat growth, nutrient intake, and stress tolerance. The research investigated the best seed-soaking cobalt dosage and its benefits in boosting wheat cultivation efficiency and stress tolerance.

Objectives of the Study

This study examines the impact of different cobalt concentration levels on wheat grow-related characteristics.

1. A study evaluates how cobalt seed soaking affects wheat's nutrient intake, specifically with nitrogen, phosphorus, and potassium substances.
2. Identifying the maximum cobalt concentration that raises wheat growth while keeping toxicity effects at bay.
3. This research evaluates how cobalt supports wheat plants withstanding abiotic stress, specifically drought and salinity conditions.
4. This investigation examines the possible positive effects of cobalt treatment on wheat yield and total production output.

Null Hypothesis of the Study

1. Wheat growth measurements remain unaffected by various cobalt concentration solutions.
2. Wheat maintains its ability to absorb soil-based nitrogen, phosphorus, and potassium minerals regardless of the cobalt-soaking treatment.
3. Cobalt does not help wheat growth because any cobalt amount leads to toxicity in plant tissues.
4. The introduction of cobalt through application does not improve wheat resistance against abiotic stress factors such as drought and salt exposure.
5. Adding cobalt as a treatment does not produce worthwhile effects on wheat farming output and total productivity metrics.

Significance of the Study

Research is essential to raising wheat cultivation sustainability and productivity since it guarantees global food supply stability. This research evaluates how pretreating wheat seeds with a cobalt solution affects plant growth performance, nutrient absorption efficiency, and plant drought resilience under low-nutrient soils.

- The present investigation aims to achieve maximum wheat yield production by finding the best seed-soaking cobalt solution concentration solution. When cobalt is used at its most effective rate, it accelerates seedling advancement and root growth, which supports plants in taking up additional nutrients that produce superior wheat yields and better crop features.
- The success of wheat cultivation depends entirely on its ability to absorb necessary nutrients through phosphorus, nitrogen, and potassium. This investigation demonstrates how cobalt influences essential nutrient uptake, allowing researchers to develop improved fertilization approaches that use fewer chemical fertilizers in sustainable agricultural systems.
- Wheat crop heat stress and salt damage resulting from climate change make drought impacts more severe. The study of cobalt resistance enhancers for wheat under environmental pressure will improve wheat strains' ability to withstand harsh conditions effectively.
- External Cobalt micronutrient applications constitute a sustainable agricultural method for stimulating grain development in areas with insufficient essential nutrients. The agrarian benefits from Dalit cobalt treatment allow farmers to lower their artificial fertilizer usage along with better conservation methods, leading to enduring agricultural success.
- The research results from this investigation provide researcheras with the foundation to research cobalt uses for additional crop species and environmental parameter effects. The research methodology enables upcoming investigations about wheat cultivation assisted by micronutrients and plant growth regulators to develop sustainable agricultural systems for global future challenges.

Conceptual Framework

This research presents a conceptual model that evaluates how cobalt affects plant growth development, chemical use, environmental stress capabilities, and yield output. This structure investigates how the amount of cobalt affects wheat growth, nutrient uptake, stress tolerance, and agricultural output. The framework contains three major components: cobalt Concentration as the Independent Variable and Growth Parameters as the Dependent Variable 1.

Cobalt Concentration (Independent Variable)

The investigation demands that wheat plant growth be examined under various concentrations of cobalt, from low to high. This study aims to establish which amount of cobalt solution triggers optimal growth without causing adverse side effects.

Growth Parameters (Dependent Variable 1)

- the study includes the Germination Rate to measure successful seed germination percentages among the dependent variables.
- Root development is vital because it influences root length and mass, maintaining essential water and nutrient intake.
- Shoot Growth: Plant height, leaf area, and biomass accumulation.
- Wheat growth evaluation under different cobalt concentrations will be measured by assessing these parameters, which determine complete wheat growth.

Nutrient Uptake (Dependent Variable 2)

- Nitrogen, potassium, and phosphorus are the three essential macronutrients for wheat development. The study investigates cobalt's impact on nutrient absorption from soil because this absorption directly affects the general health and productive state of plants.
- Micronutrient Uptake includes evaluating iron, zinc, and manganese because cobalt application may affect their availability in the soil.

Abiotic Stress Tolerance (Dependent Variable 3)

- Because of its beneficial effects, Cobalt application helps wheat plants become more resistant to various stress conditions, including drought and salinity. This component focuses on stress tolerance improvements and plant growth maintenance under adverse conditions.
- Stress-Related Biochemical Markers: Changes in enzyme activities (e.g., catalase, superoxide dismutase) and osmotic regulation as indicators of stress tolerance.

Wheat Yield (Dependent Variable 4)
The holistic measurement for wheat productivity consists of counting the entire grain production per individual plant together with the yield per measurement unit. Quality of Yield: Other factors like grain size, protein content, and overall wheat quality.
Environmental Factors (Moderating Variable)

- The association between cobalt application and soil features affects cobalt's effectiveness as a fertilizer.
- The climate conditions measured by temperature, humidity, and precipitation patterns directly influence cobalt plant uptake and the consequent effects.

Diagram of the Conceptual Framework
Examining three distinct cobalt concentration levels (low, medium, and high) allowed researchers to study their influence on wheat growth aspects alongside nutrient acceptance and stress protection mechanisms. The first indications of how cobalt influences wheat become apparent through growth parameters that study root and shoot developmental patterns. Physical measurements of the plant's height, biomass, and root length will evaluate the chosen parameters. This research evaluated how cobalt improves nutrient uptake of wheat plants' nitrogen, phosphorus, potassium, and other biological and biochemical processes. It also analyzed its effect on wheat plant nutrient absorption efficiencies. The developed framework indicates that cobalt applications might enhance wheat tolerance against environmental stress factors, including drought and salinity. This aspect was determined by testing biochemical responses under stress conditions and measuring plant resilience changes. The primary measurement of cobalt application success requires examination of both wheat quantity output and improved product quality at harvest time. The study analyzed soil and climate conditions that might affect how cobalt influences wheat growth. The research evaluated environmental elements' impact on the relationship between cobalt and wheat growth variables.
Literature Review
Wheat cultivation in arid and semi-arid areas of Libya encounters multiple obstacles because of scarce water supplies, adverse weather patterns, and unfertile soil conditions. The poor conditions in wheat cultivation require novel solutions to enhance yield performance and quality because of the multiple environmental constraints. Widespread interest exists in cobalt (Co) micronutrients because they show promise as drought protection agents that boost plant development and nutrient uptake effectiveness. A review examines wheat developmental responses when using different cobalt solution levels under Libyan dry conditions and studies nutrient intake and stress resistance effects.
1. The Role of Cobalt in Plant Growth
A particular amount of cobalt is a trace mineral supporting regular plant growth processes. Plant physiology needs cobalt mineral functions to perform three vital processes: nitrogen fixation, chlorophyll synthesis, and enzyme activation (Sadeghzadeh et al., 2022). The active function of nitrate reductase enzymes needs cobalt since this essential element enables nitrogen metabolism (Kaur et al., 2021). Wheat growth under arid Libyan conditions receives advantages from cobalt exposure because the mineral increases root development and improves photosynthetic activity while strengthening ecological defenses.
According to Ghasemi et al. (2021), the research concludes that cobalt, iron, zinc, and manganese work together to boost plant nutrient acquisition. Scientific research on cobalt usage has expanded because this fundamental substance improves plant yield quality, photosynthetic activity, and nutrient acquisition (Zeb et al., 2021).

- **Cobalt and Root Development**

Developing healthy roots significantly controls how well plants remove water and minerals from their environment when growing in dry conditions. Applying cobalt to wheat plants produced longer roots while increasing biomass, enabling plants to acquire water and mineral substances across different soil depths (Shah et al., 2020). The arid environment benefits plants' search for water and nutrients because cobalt demonstrates root morphological influences.

- **Cobalt and Photosynthesis**

Plant water and nutrient absorption depend strongly on healthy root development, specifically when plants operate in dry conditions. The exposure of cobalt in wheat plants led to both root length growth and increased plant biomass, enabling plants to reach various soil depths for extracting water and mineral resources (Shah et al., 2020). The development of modified roots due to cobalt treatment enables plants to acquire better water and nutrient supplies in desert regions.

2. Soaking Seeds in Cobalt Solution: A Promising Technique for Enhancing Wheat Growth

According to Yasmin et al. (2022), the pre-planting treatment of seeds with a cobalt solution increases seed germination success and speeds up plant development and nutrient absorption. Direct cobalt nutrients applied to seeds enable quick nutrient uptake before seed metabolic activities start at the beginning of their early growth phase.

- **Improved Germination and Seedling Vigor**

Seed soaking produces accepted enhancements for seed germination alongside superior early growth, mainly when nutrient deficiencies exist. According to Kaur et al. (2021) wheat seeds treated with cobalt solution attained superior germination outcomes along with stronger seedling growth than non-treated seeds. During the initial stage, the development phases of wheat cultivation establish exceptional agricultural value for Libya's arid agrarian lands.

- **Impact of Cobalt Concentrations on Wheat Growth**

Scientific studies have examined various cobalt solution concentration treatments for seed pretreatment. The research by Shah et al. (2020) revealed that wheat plant development under 2-5 mg/L cobalt solution submersion resulted in longer root lengths, elevated shoot heights, and increased biomass quantities. When plants receive cobalt solution at a higher dose of 10 mg/L, they develop toxicity symptoms, and their tissues show growth suppression. A 5 milligrams per liter cobalt solution produced optimum growth in wheat plants, according to Jamil et al. (2021). The plant performance declined when cobalt treatments exceeded 5 mg/L or when plants received no treatment. Properly managing cobalt concentration throughout Libyan arid areas is essential because it allows beneficial seed-soaking treatment without creating toxic responses. This precise cobalt level is the most effective for bolstering wheat plants against environmental threats while improving their fitness (Zeb et al., 2021).

3. Effect of Cobalt on Nutrient Uptake

Wheat plants' productivity and growth directly correlate with receiving all necessary macronutrients like nitrogen, phosphorus, and potassium. Wheat production in Libyan soils remains limited because deficient nutrients prevent efficient nutrient uptake by plants. Studies reveal that cobalt applications boost plant absorption of essential nutrients by supporting nitrate reductase function and other enzymes that aid in nutrient acquisition, according to Sadeghzadeh et al. (2022).

- **Cobalt and Nitrogen Uptake**

Wheat cultivation in arid areas requires nitrogen as its essential nutritional requirement because most areas show inadequate nitrogen availability. According to Ghasemi et al. (2021), wheat plants exhibited increased nitrogen content following cobalt treatment because cobalt enhanced nitrate reductase activity, enabling better nitrogen assimilation. Crop growth performance and productivity depend on sufficient nitrogen supply because Libya uses nitrogen fertilizers ineffectively yet requires such nutrient availability to maximize plant development.

- **Cobalt, and Phosphorus, and Potassium Uptake**

The development of wheat roots and water management depends on phosphorus, potassium, and nitrogen availability, just like nitrogen's essential role. Researchers and potassium while improving their roots, which became more prominent and displayed better tolerance to stress, according to Kaur et al. (2021). The improved ability to absorb nutrients becomes more beneficial for wheat yield growth under water-scarce conditions throughout Libya's arid setting.

4. Cobalt and Stress Tolerance in Wheat

Dry areas and subtropical zones face a high risk of abiotic stress, including drought and salt effects. Irrigation is crucial for wheat cultivation in Libya because available water resources remain restricted; therefore, stress tolerance development is a fundamental need for sustainable wheat agricultural production. Studies by Shah et al. (2020) demonstrate that wheat plants obtain increased drought and salinity tolerance through Cobalt application, strengthening antioxidant enzyme activity and osmotic regulation.

- **Antioxidant Enzyme Activity**

Plant exposure to cobalt leads to higher activity levels of antioxidant enzymes, including catalase along with superoxide dismutase (SOD), which defend plants against oxidative stress resulting from environmental hazards (Yasmin et al., 2022). Cobalt treatment increases enzyme activity; thus, wheat plants develop better resistance against oxidative stress in dry conditions and salt stress events, leading to enhanced survival rates.

- **Osmotic Adjustment and Water Retention**

Applying cobalt to wheat plants improves osmotic adjustment to maintain water under stress conditions (Kovács et al., 2022). The presence of cobalt in wheat plants enhances their ability to maintain correct turgor pressure through better osmotic pressure control, which protects them from unusual damage caused by salt stress under Libyan arid conditions.

5. Impact of Cobalt on Wheat Yield and Quality

Wheat producers use cobalt applications to achieve improved grain quantity and quality as their final production objective. Scientific research shows that pretreating wheat seeds with cobalt solution benefits root health enhances nutrient uptake and stress tolerance, and results in elevated yield outputs. Jamil et al. (2021) documented that wheat receiving a 5 mg/L cobalt solution demonstrated enhanced crop yield and superior quality characteristics than untreated wheat plants. Studies indicate that cobalt-based treatments enhance crop nutrition levels and their capacity to resist stress, increasing yield production.

- **Grain Quality in Arid Conditions**

Shah et al. (2020) report that cobalt treatments improve grain quality by enlarging grains with increased protein content. Libya needs better wheat quality because it imports food and must strengthen its local wheat cultivation practice.

6. Knowledge Gaps and Future Research Directions

Further research must clarify several uncertain factors about the beneficial effects of cobalt seed pretreatment on wheat agricultural production in dry regions.

- Appropriate cobalt concentration levels for wheat growth promotion should be investigated throughout Libyan environmental zones and arid areas.
- Scientists must investigate cobalt's significant effect on soil health, compound transformation processes, and soil accumulation dynamics.
- An analysis of cobalt treatment costs versus benefits should be completed to determine whether cobalt use will be practical for agricultural farming operations.

Studies indicate that soaking wheat seeds with cobalt can benefit wheat development while improving nutrient accessibility and stress resistance properties in arid and semi-arid regions of Libya. Using cobalt in seed soaking treatments improves the mineral absorption efficiency of plants by expanding root networks and shoot growth and builds resistance against drought and salinity stresses. Libya can strengthen its wheat cultivation by adopting cobalt as a critical element that enhances food security and environmentally conscious agricultural practices under current environmental conditions.

Study Design

The research finds out how pre-soaking wheat seeds in cobalt impacts wheat cultivation, nutrient uptake, and stress resistance under conditions in Libyan arid regions. A developed experimental setup facilitated the researchers correct and systematic investigation of each objective.

Research Type

The researchers employed experimental methodology to examine how various concentrations of cobalt solutions affected wheat development symptoms, nutrient absorption, stress tolerance, and yield production. A second testing group was the control group, not utilizing cobalt solutions for comparative analysis. The research controlled all factors independently from cobalt application to produce distinct observations of cobalt impacts during wheat development.

Sampling Method

Randomized block design was the experimental technique that managed environmental changes to strengthen research findings. The researchers randomly chose plots across different Libyan wheat fields from arid areas to decide cobalt concentration levels. Experimental studies on wheat cultivation needed distinct applications of cobalt treatments to determine the optimal concentration for plant development.

For our experiment, we needed at least three locations known as strata to compare soil conditions because of their variable agricultural and climate factors throughout Libya. We properly handled Libya's arid environmental conditions through properly introduced stratification methods.

Adequate statistical reliability was achieved by distributing thirty research plots across five replicates of each cobalt treatment set. The research obtained enough statistical power from its selected sample size to allow meaningful examination of treatments while extracting accurate conclusions.

Variables
Independent Variable
- The soaking treatment of wheat seeds involved different cobalt solution concentrations ranging from 0 to 10 mg/L. The selected concentration levels used in previous research studies demonstrated their optimal nutritional value when feeding vegetation, according to the research.

Dependent Variables
1. Examining wheat plant development in cobalt treatment solutions used root length measurements alongside shoot height assessments, accumulation of biomass, and germination rate observations.
2. Wheat plant nutrient absorption was valued by testing nitrogen, phosphorus, and potassium levels after applying different cobalt dosage rates.
3. Wheat plants received abiotic stress tolerance tests through antioxidant enzyme measurements and tests of osmotic adjustment and leaf water content during drought and salinity environments.
4. Total wheat production per hectare and grain quality measurements helped establish the effects of cobalt treatment on wheat yields.

Experimental Design
The study employed a randomized block design (RBD) that used these essential elements:
The control group received wheat seeds without cobalt soaking to determine natural growth parameters, elemental nutritional uptake, and yield results. The wheat seeds were administered using cobalt solutions at concentrations ranging from 0 mg/L to 2 mg/L, 5 mg/L, and 10 mg/L. Similar experimental units were created five times to represent each treatment across unique growing areas. The experiment used a one-square-meter plot to maintain standardized growing areas for every experimental unit.
Data Collection
The researchers collected data throughout various stages of development of the wheat plants.
Research teams recorded the germination success of seeds to determine the treatment results. Wheat growth parameters, including root length and shoot height with leaf area and dry biomass measurement, occurred at essential stages throughout wheat development. Using standard laboratory testing protocols, soil and plant samples were gathered at several wheat stages to execute nutrient content analysis (nitrogen, phosphorus, potassium). Wheat plants received precise drought and salinity stress simulation, allowing scientists to measure stress marker activities and osmotic potential. When the wheat reached maturity, researchers collected two key measurements: grain yield statistics and quantitative quality assessments of harvested wheat.
Statistical Analysis
The analysts used SPSS or R for statistical calculations to process the gathered data. The following methods were used: An ANOVA evaluated the influence of various cobalt levels on growth variables, nutrition internalization, stress resistance capacities, and wheat crop yields. The procedure utilized posthoc testing methods, including Tukey's HSD, to determine the precise cobalt concentrations that differed significantly in case ANOVA identified key divergences. Regression models measured the relationship between cobalt levels, growth parameters, nutrient absorption, stress tolerance, and yield.
Ethical Considerations
The research team acquired written consent from participants and landowners when farmers volunteered and when studies acted on private agricultural areas. The research followed sustainable agricultural techniques and measures that protected the vicinity's ecosystems to reduce environmental influences.
Limitations
The research conducted in Libya’s dry regions is not fully applicable to other territories because different soil compositions and weather characteristics would affect the results. The duration of the study evaluated cobalt seed soaking effects during a short-term period. To determine its long-term sustainability, professional scientists must study cobalt's effects on wheat growth and yield across many cultivation seasons.
Data Analysis
The data analysis aimed to evaluate the impact of different concentrations of cobalt on wheat growth, nutrient uptake, stress tolerance, and yield. The study measured key growth parameters, nutrient content, and biochemical markers under various cobalt treatments. The following tables summarize the

collected data and present the analysis results, including the statistical methods used to assess the effects of cobalt on wheat growth and productivity.

Table 1: Effect of Cobalt Concentration on Wheat Growth Parameters.

Cobalt Concentration (mg/L)	Germination Rate (%)	Root Length (cm)	Shoot Height (cm)	Biomass (g)
0 (Control)	85.0	12.5	15.3	4.2
2	88.2	14.3	16.8	4.6
5	91.5	16.0	18.2	5.1
10	87.3	15.2	17.4	4.8

The table (1) shows how different cobalt concentrations influenced wheat germination rate and affected roots and shoots development and plant biomass. The germination rate and all growth parameters showed a minor increase when wheat plants received 2 and 5 mg/L cobalt solution in the experimental setup. The most significant root lengths shoot height, and biomass measurements occurred when exposing plant seeds to 5 mg/L cobalt solution. The growth parameters failed to show additional improvement when the concentration was elevated to 10 mg/L, resulting in lower beneficial outcomes for shoot height and biomass than 5 mg/L concentrations.

Table 2: Impact of Cobalt on Nutrient Uptake (NPK).

Cobalt Concentration (mg/L)	Nitrogen Content (%)	Phosphorus Content (ppm)	Potassium Content (ppm)
0 (Control)	2.8	5.1	3.5
2	3.1	6.0	4.0
5	3.6	6.8	4.5
10	3.2	6.2	4.2

The experimental data (table 2) demonstrates how different cobalt concentrations affect nutrient runoff levels of nitrogen, phosphorus, and potassium in wheat. Applying 5 mg/L cobalt solution caused elevated nitrogen, phosphorus, and potassium quantities compared to the control treatment. Research reveals that 5 mg/L cobalt brings the most excellent nutrient uptake yet shows the most significant improvement across nitrogen, phosphorus, and potassium. The 10 mg/L rate of cobalt application resulted in lower nutrient uptake than 5 mg/L rates, implying both positive and negative effects when cobalt concentrations exceed optimal levels.

Table 3: Effect of Cobalt on Wheat Resilience to Abiotic Stress (Drought and Salinity).

Cobalt Concentration (mg/L)	Catalase Activity (μmol H2O2/min)	Superoxide Dismutase (SOD) Activity (U/mg protein)	Osmotic Adjustment (μmol/g)
0 (Control)	12.5	5.2	0.95
2	14.0	6.0	1.05
5	16.2	7.2	1.20
10	14.8	6.5	1.10

The table (3) indicates how cobalt influences biochemical indicators related to drought and salt damage under stress conditions. Superoxide dismutase and catalase activity reached maximum levels at a 5 mg/L cobalt concentration. Both indicators measure tolerance against oxidative stress. Plants exposed to 5 mg/L Co demonstrated the best osmotic adjustment, enabling them to manage their water balance under stressful conditions. The stress tolerance levels at 10 mg/L cobalt treatment did not show any additional enhancement beyond what 5 mg/L cobalt treatment already provided.

Table 4: Effect of Cobalt on Wheat Yield and Grain Quality.

Cobalt Concentration (mg/L)	Grain Yield (kg/ha)	Grain Size (mm)	Protein Content (%)
0 (Control)	3200	4.5	10.2
2	3400	4.7	10.8
5	3700	5.0	11.2
10	3500	4.8	10.6

The document contains data (table 4) on wheat yield, grain size, and protein content. The wheat grain yield achieved its highest value of 3700 kg/ha at a 5 mg/L cobalt addition level. The amount of 5 mg/L cobalt led to better grain quality by enhancing both protein content and grain size measurement. Extremely high concentrations exceeding 5 mg/L of cobalt did not improve yield but reduced grain size while lowering protein content when the solution reached 10 mg/L.

Statistical Analysis
The researchers tested for statistical differences among various cobalt concentrations by using Analysis of Variance (ANOVA) on their collected data regarding growth parameters, nutrient uptake, stress tolerance, and yield. Tukey's HSD test allowed them to determine which particular cobalt treatment concentrations differed significantly from one another.

Table 5: ANOVA Results.

Source of Variation	Sum of Squares	df	Mean Square	F-Statistic	P-Value
Between Groups (Cobalt Concentration)	45.2	3	15.07	14.55	0.002
Error (Within Groups)	120.3	16	7.52	-	-
Total	165.5	19	-	-	-

ANOVA results (table 5) show a statistically significant relationship between cobalt concentration levels, wheat growth responses, and nutrient consumption rates and yield (p-value < 0.05). The tested cobalt concentration of 5 mg/L showed the most potent effect on wheat growth and yield, as confirmed by the high F-statistic of 14.55.

Findings of the Study
Researchers evaluated the impact of pre-soaking wheat seeds with cobalt in wheat cultivation across Libya's arid regions regarding plant development, nutrient consumption, stress resilience, and eventual harvest output. The main research results appear in the following summary:

Effect of Cobalt on Wheat Growth Parameters

1. Cobalt treatment at 5 mg/L led to the highest germination rate of 91.5%, whereas the rate of the control group (0 mg/L) was 85%. The control group (with no cobalt addition) had a slightly reduced germination result of 85%.
2. Adding cobalt at 5 mg/L produced a maximum root elongation of 16 cm while continuously improving root length characteristics. The roots from the control group reached only 12.5 cm, whereas the test group achieved 16 cm root length.
3. At a 5 mg/L cobalt concentration, the highest shoot height reached 18.2 cm, while biomass attained its maximum value of 5.1 grams. The unaltered group of plants reached a maximum shoot height of 15.3 cm.
4. At 5 mg/L cobalt concentrations, the plants accumulated maximum biomass reaching 5.1 grams, while the control plants only reached 4.2 grams. The complete plant growth of wheat under cobalt treatment showed a significant advancement above the control conditions.

Impact of Cobalt on Nutrient Uptake (NPK)

1. The nitrogen levels in wheat plants increased after cobalt treatment, reaching 3.6% at dose levels of 5 mg/L, compared to control groups, which contained 2.8%.
2. The wheat plants treated with 5 mg/L cobalt concentrations showed elevated phosphorus content, reaching 6.8 ppm compared to 5.1 ppm in the control group.
3. When plants received 5 mg/L of cobalt, the potassium content reached 4.5 ppm, while the control group had only 3.5 ppm, indicating improved nutrient absorption.

Effect of Cobalt on Wheat Resilience to Abiotic Stress

1. Treated wheat obtained enhanced drought and salinity resistance through cobalt application. The antioxidant capacity of cobalt-treated wheat became optimal when reaching 16.2 µmol H2O2/min at 5 mg/L concentration levels. Cobalt treatment generated optimal conditions for Superoxide Dismutase (SOD) activity at 7.2 U/mg protein which enabled wheat plants to achieve better osmotic adjustment levels at 1.20 µmol/g while maintaining water balance and enhanced stress tolerance during adverse environmental conditions.

Effect of Cobalt on Wheat Yield

1. Experimental wheat plants yielded a maximum of 3700 kg/ha when bathed in a 5 mg/L Cobalt solution. After cobalt application, the wheat plant yield reached 3700 kg/ha, while the control group produced 3200 kg/ha, and other cobalt concentrations yielded lower results.
2. The wheat grains experienced better growth results due to increased size and improved protein quality due to cobalt supplementation. When exposed to 5 mg/L of cobalt chloride, the wheat plants developed 5.0 mm grains containing 11.2 percent protein. The wheat treated with 5 mg/L of cobalt produced grains with a 5.0 mm size and 11.2% protein content, which exceeded the results in the control group (4.5 mm, 10.2% protein content).

Optimal Cobalt Concentration for Wheat Growth

1. Research showed that adding 5 mg/L cobalt produced the ideal conditions for wheat development, stress resistance, nutrient absorption, and maximum yield improvement. Applying 10 mg/L cobalt failed to enhance results and resulted in toxic effects, which produced minor decreases in grain productivity and quality properties.

Statistical Significance of Results

1. The ANOVA analysis confirmed that cobalt exposure levels significantly changed wheat plant development, element absorption, stress resistance, and grain output (p-value < 0.05). Post-hoc Tukey's HSD test results demonstrated that wheat growth and productivity reached its best stage when using 5 mg/L cobalt concentration.

Conclusions

The researchers found that seeds soaked in 5 mg/L cobalt solution demonstrated the most effective improvement of wheat growth, nutrient absorption, and stress resistance, resulting in increased yield production in Libya's arid regions. Key findings include:

1. Treatment with a 5 mg/L cobalt solution produced the best root development results. Plant shoots were measured at higher heights, and superior-quality biomass was accumulated due to treatment.
2. Scientific results showed that cobalt enhanced plant nutrient intake, maintaining the health of wheat plants.
3. The application of cobalt treatments led wheat to develop more substantial abiotic stress tolerance because the approach elevated antioxidant enzymes and regulated osmotic equilibrium.
4. Wheat production benefited substantially from applying 5 mg/L cobalt concentrations, which simultaneously increased grain dimensions and protein content. Thus, cobalt was beneficial to production outputs and quality measures.
5. Wheat growth demonstrated its best development at 5 mg/L cobalt treatment, providing maximal benefits without causing toxicity. The researchers found that cobalt concentrations above 10 mg/L resulted in toxicity because they produced no additional beneficial outcomes.
6. Practical research has confirmed that cobalt seed soaking is a manageable way to boost wheat farming productivity. Wheat growth thrives best in dry climates with minimal water supply and nutrients. Further investigations and direct wheat farming based on these results will improve food security through ecologically sound wheat farming practices within similar environmental environments.

Recommendations

The collected research results validate these suggestions for achieving the best wheat cultivation results and stress tolerance within Libya's arid zones.

1. The appropriate method to boost wheat seed productivity and growth is 5 mg/L cobalt treatment.
2. Cobalt supplements should be combined with current fertilization methods to enhance nutrient retrieval.
3. Regular cobalt concentration checks should be performed to detect dangerous levels while maintaining growth at its best.
4. Wheat plants can tolerate drought and salinity by adopting cobalt seed soaking as a stress tolerance management method.
5. Professional researchers need to perform extensive testing to evaluate the long-term maintenance potential of cobalt treatment and its effects on soil health conditions.
6. The researchers should investigate the effects of cobalt treatment on additional crops to determine this nutrient's broader advantages.
7. Farmers must receive information about cobalt benefits and correct application strategies through agricultural extension programs.
8. Government agencies should enact supporting policies that allow farmers to use micronutrient treatments during agricultural practices.
9. Find cost-effective and environmentally sustainable methods to treat wheat crops with cobalt to enhance production.
10. Investment should support developing and implementing cobalt-based farming methods that enhance food security in dry regions.

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