



INFLUENCE OF VARIABLE POTASSIUM FERTILIZATION ON GROWTH, YIELD, AND ANTIOXIDANT ENZYME ACTIVITY IN MAJOR FOOD PLANTS

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Abstract

Potassium (K) plays a vital role in regulating plant physiological processes including stomatal function, enzyme activation, nutrient transport, and oxidative stress tolerance. However, variations in potassium availability in agricultural soils significantly affect plant productivity and biochemical defense mechanisms. The present study examines the influence of variable potassium fertilization levels on growth performance, yield potential, and antioxidant enzyme activity in major food plants. A randomized experimental design was implemented with graded potassium treatments (K₀, K₂₅, K₅₀, K₇₅, and K₁₀₀), and parameters such as plant height, chlorophyll content, biomass, and grain yield were evaluated. Antioxidant enzyme responses including superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) were quantified to assess oxidative stress mitigation. The results indicate that moderate to high potassium application significantly enhanced physiological growth and yield attributes compared to the control, while antioxidant enzyme activity increased proportionally with potassium levels, reflecting improved reactive oxygen species scavenging. Optimal potassium fertilization demonstrated a positive correlation with enhanced crop resilience and improved biochemical quality. The study highlights potassium as a key nutrient for achieving higher productivity, nutritional enhancement, and stress

tolerance in food crops. These findings support potassium optimization as an essential strategy for sustainable agriculture and improved food security.

Key words: Potassium fertilization, growth performance, food crops, nutrient management, antioxidant enzymes, superoxide dismutase, catalase, peroxidase, yield enhancement, oxidative stress tolerance, sustainable agriculture.

Introduction

Potassium (K) is one of the three primary macronutrients essential for plant growth and productivity, and it plays a critical role in several biochemical, physiological, and metabolic processes. Unlike nitrogen and phosphorus, potassium is not a constituent of plant organic structures; however, it regulates multiple key cellular functions such as osmoregulation, stomatal conductance, enzyme activation, translocation of photosynthates, and water-use efficiency (Zörb et al., 2014). Its dynamic role in ion balance and cellular homeostasis positions potassium as an indispensable nutrient for optimal plant development and crop performance. Despite its importance, potassium deficiency remains a major soil fertility constraint in many agricultural regions worldwide, particularly in intensively cultivated systems where continuous cropping has led to declining soil K reserves (Singh & Reddy, 2022).

The growing global population and increased food demand have intensified the need to

enhance crop productivity without compromising soil health or environmental sustainability. Potassium fertilization has been recognized as an effective agronomic strategy to maximize yield while improving physiological resilience against abiotic stresses such as drought, heat, and salinity (Wang et al., 2021). In the context of climate change and soil degradation, improving potassium availability is essential not only for achieving higher yields but also for maintaining crop stability under stress conditions.

Another emerging research focus is the role of potassium in regulating the antioxidant defense system of plants. Reactive oxygen species (ROS) accumulation is a common stress response, and excessive ROS levels can impair cellular membranes, metabolic pathways, and photosynthetic efficiency. Potassium has been shown to influence the activity of antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), which function collectively to detoxify ROS and mitigate oxidative damage (Ahanger et al., 2020). Higher potassium availability has been associated with reduced lipid peroxidation, increased chlorophyll stability, and enhanced free radical scavenging capacity, contributing to improved crop health and nutritional quality.

Despite substantial evidence supporting the importance of potassium, variability in crop response to different fertilization levels remains an area requiring systematic investigation. Significant differences exist based on crop type, soil composition, climatic conditions, and fertilizer formulation. Therefore, evaluating the effects of variable potassium application on growth traits, yield parameters, and antioxidant activity in major food plants is crucial for establishing optimized fertilization guidelines.

The present study aims to investigate the influence of graded potassium fertilization on morphological growth, yield metrics, and antioxidant enzyme responses in selected major food crops. Understanding these relationships will help refine potassium management practices and promote sustainable crop production systems. The findings are expected to contribute to improved nutrient management strategies that enhance both agricultural productivity and plant physiological resilience.

Importance of Potassium in Plant Physiology

Potassium (K) is an essential macronutrient required in relatively large quantities for normal plant growth and development. Although potassium does not form part of organic molecules such as proteins, nucleic acids, or chlorophyll, it plays a crucial regulatory role in a wide range of physiological, biochemical, and cellular processes that determine plant productivity and resilience. As a highly mobile cation within plant tissues, potassium functions primarily in ionic balance, enzyme activation, osmotic regulation, and membrane stabilization (Marschner, 2012).

One of the most significant roles of potassium is its involvement in photosynthesis and carbohydrate metabolism. Adequate potassium supply enhances stomatal behavior, enabling efficient gas exchange by regulating the opening and closing of stomata. This regulation affects transpiration, internal CO₂ concentration, and overall photosynthetic efficiency. Studies have reported that potassium improves Rubisco activity and facilitates the movement of assimilates from source leaves to sink tissues, leading to improved carbohydrate partitioning and grain filling (Zörb et al., 2014).

Potassium also plays a vital role in water relations and osmotic balance. As a primary osmoticum, it maintains cell turgor pressure, which is essential for cell expansion, tissue rigidity, and drought tolerance. High internal potassium concentration supports water-use efficiency, enabling plants to maintain hydration under moisture stress conditions. This osmotic adjustment is particularly critical in arid and semi-arid environments, where plants frequently experience soil moisture fluctuations (Wang et al., 2021).

Another critical function of potassium is its involvement in enzyme activation and protein synthesis. More than 60 enzymes require potassium as an activator or stabilizing ion, including those associated with energy metabolism, amino acid synthesis, and the antioxidant defense system (Ahanger et al., 2020). Potassium also helps maintain pH homeostasis by serving as a counter-ion during proton transport across membranes, which supports efficient metabolic functioning. Furthermore, potassium contributes

significantly to plant stress resistance and antioxidant capacity. Under abiotic stress conditions such as drought, heat, or salinity, oxidative stress leads to the accumulation of reactive oxygen species (ROS), causing membrane injury, lipid peroxidation, and metabolic disruption. Potassium supplementation enhances antioxidant enzyme activity—such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD)—thereby reducing oxidative damage and improving plant tolerance (Singh & Reddy, 2022).

Potassium is indispensable for optimal plant functioning, influencing photosynthesis, nutrient transport, metabolic regulation, water relations, and defense mechanisms. Adequate and balanced potassium nutrition is therefore essential for maximizing growth, improving yield quality, and enhancing stress tolerance in food crops. The physiological significance of potassium underscores its importance in modern agronomy and sustainable nutrient management strategies.

Role of Potassium in Nutrient Mobility, Osmotic Regulation, and Photosynthesis

Potassium plays a multifunctional and indispensable role in key physiological processes within plants, particularly nutrient mobility, osmotic regulation, and photosynthesis. As one of the most mobile cations in plant tissues, potassium facilitates efficient nutrient transport and distribution, supporting cellular function and overall plant growth. Unlike other macronutrients, potassium remains in ionic form (K^+) in xylem and phloem sap, enabling it to function as a highly effective regulator of solute transport and metabolic coordination (Marschner, 2012).

Nutrient Mobility

Potassium significantly contributes to the mobility and translocation of essential nutrients and assimilates within the plant system. It enhances phloem loading efficiency, which is crucial for the movement of photosynthates from source tissues (leaves) to sink organs such as roots, grains, or storage tissues. Adequate potassium nutrition supports protein synthesis, carbohydrate transport, and nitrogen metabolism, ensuring balanced nutrient availability for developing plant organs (Zörb et

al., 2014). Potassium deficiency disrupts these processes, resulting in impaired nutrient movement, accumulation of soluble sugars in leaves, and reduced grain filling or storage root development.

Osmotic Regulation

Potassium is a primary osmoticum contributing to cellular turgor maintenance and osmotic adjustment in plants. It regulates the osmotic potential of cells by controlling ion gradients across membranes, enabling plants to maintain cell structure, drive water uptake, and respond to environmental variations such as drought or salinity (Wang et al., 2021). High internal concentrations of potassium support stomatal guard cell function, allowing rapid turgor-driven stomatal movements. Through this mechanism, plants regulate transpiration, gas exchange, and internal water balance. Under stress conditions, potassium plays a protective role by enhancing osmoprotection and maintaining membrane stability, thereby reducing physiological injury.

Photosynthesis

Potassium plays a direct and indirect role in enhancing photosynthetic efficiency. It regulates stomatal conductance, ensuring optimal CO_2 availability in the leaf mesophyll for the carboxylation reaction catalyzed by Rubisco. Potassium is also involved in chlorophyll formation, ATP synthesis, and light energy utilization, contributing to higher photochemical efficiency and improved carbohydrate formation (Ahanger et al., 2020). Furthermore, potassium facilitates the rapid transport of photosynthates away from the leaves, thereby preventing feedback inhibition on photosynthesis. Deficiency symptoms such as chlorosis, reduced chlorophyll content, and decreased photosynthetic activity are common indicators of insufficient potassium supply.

Global Nutrient Deficiency Trends and Declining Soil Potassium

Globally, soil nutrient depletion has emerged as a major challenge to agricultural productivity, food security, and sustainable crop management. Among essential macronutrients, potassium deficiency is increasingly recognized as one of the most widespread and limiting factors in crop production, second only to nitrogen deficiency in many agricultural systems (FAO, 2021). Rapid intensification of

agriculture, continuous monocropping, and insufficient replenishment of soil nutrients have contributed significantly to the decline of available potassium in soils across several food-producing regions of the world.

The natural reserves of potassium in most soils are derived from feldspar and mica-containing parent materials; however, the rate of mineral weathering is slow relative to crop uptake and removal. Modern high-yield hybrid varieties require substantially higher potassium inputs, yet fertilizer applications often remain disproportionately limited compared to nitrogen and phosphorus usage (Zörb et al., 2014). This imbalance has resulted in progressive soil potassium mining, leaving soils increasingly depleted. Reports indicate that more than 50% of agricultural soils in Asia, Africa, and Latin America display moderate to severe potassium deficiency, particularly in intensively cultivated cereal belts and vegetable production zones (Sharma et al., 2022).

In many developing countries, potassium fertilizer consumption remains low due to high cost, limited awareness, and policy emphasis on N- and P-based fertilizers. This skewed nutrient application has led to declining soil fertility and reduced nutrient-use efficiency. Regions such as the Indo-Gangetic plains of India, the maize belts of Sub-Saharan Africa, and the rice-growing zones of Southeast Asia are now showing alarming reductions in exchangeable and plant-available potassium levels (Wang et al., 2021). Long-term field studies demonstrate that potassium depletion not only reduces crop yields but also impairs plant physiological resilience, making crops more susceptible to drought, salinity, heat stress, and pest infestation.

Declining soil potassium also has implications for food nutritional quality. Studies reveal that crops grown in potassium-deficient soils exhibit reduced protein content, diminished antioxidant capacity, lower starch accumulation, and reduced storage stability (Ahanger et al., 2020). As global climate variability continues to intensify environmental pressures on crops, maintaining adequate potassium levels in soil systems becomes increasingly critical for crop stress tolerance and sustainable production.

In global trends reveal a growing imbalance in soil nutrient status, with potassium depletion emerging as a significant constraint to agricultural productivity. Addressing this decline requires integrated nutrient management strategies, increased potassium fertilizer awareness, soil health monitoring, and adoption of precision agriculture technologies. Ensuring balanced potassium nutrition is therefore essential to achieving long-term soil sustainability, improving crop resilience, and supporting global food security.

Relevance of Antioxidant Response (SOD, CAT, POD, APX, GPX, etc.)

The antioxidant defense system plays an essential role in maintaining cellular homeostasis in plants, particularly under environmental and physiological stresses. During normal metabolism and stress exposure, plants generate reactive oxygen species (ROS) such as superoxide radicals ($O_2^{\cdot -}$), hydrogen peroxide (H_2O_2), and hydroxyl radicals ($\cdot OH$). While low levels of ROS function as signaling molecules, excessive accumulation leads to oxidative stress, resulting in lipid peroxidation, protein degradation, DNA damage, impaired photosynthesis, and metabolic imbalance (Ahanger et al., 2020). As a survival mechanism, plants rely on a complex and highly coordinated antioxidant defense network comprising both enzymatic and non-enzymatic components.

Among the enzymatic antioxidants, superoxide dismutase (SOD) serves as the first line of defense by catalyzing the conversion of superoxide radicals into hydrogen peroxide and molecular oxygen. This hydrogen peroxide is subsequently detoxified by downstream enzymes including catalase (CAT) and ascorbate peroxidase (APX). CAT rapidly decomposes hydrogen peroxide into water and oxygen, primarily in peroxisomes, ensuring protection from oxidative bursts. In contrast, APX participates in the ascorbate–glutathione cycle, offering a high-affinity mechanism for fine regulation of intracellular H_2O_2 levels (Wang et al., 2021).

Peroxidase (POD) and glutathione peroxidase (GPX) further support ROS scavenging by reducing hydrogen peroxide and lipid hydroperoxides, thus protecting membrane

integrity. GPX plays a particularly critical role during abiotic stress conditions such as drought, heat, and salinity, where membrane lipids are most susceptible to oxidative attack. The synergistic action of these enzymes prevents oxidative damage and maintains redox balance, enabling plants to sustain growth and metabolic function under fluctuating environmental conditions (Singh & Reddy, 2022).

The relevance of the antioxidant system is closely linked to nutrient availability, including potassium. Adequate potassium supply has been reported to enhance antioxidant enzyme activities by improving cellular ion balance, membrane stability, water relations, and metabolic efficiency. Under potassium-deficient conditions, accelerated ROS accumulation leads to heightened oxidative stress, disrupted chloroplast function, and reduced plant growth and productivity (Zörb et al., 2014). Conversely, optimal potassium availability supports enhanced antioxidant enzyme expression and activity, thereby contributing to improved stress tolerance, photosynthetic efficiency, and overall crop resilience.

In the antioxidant defense system is a critical physiological mechanism that safeguards plants against oxidative damage and ensures adaptive responses under stress conditions. Understanding how potassium availability influences antioxidant enzyme dynamics is therefore essential for developing nutrient management strategies that strengthen plant defense capacity, improve crop performance, and support sustainable agricultural productivity.

Need to Assess Variable Potassium Application Effects in Major Food Crops

Understanding the impact of varying potassium application levels on the physiological, biochemical, and agronomic performance of major food crops has become increasingly important in modern crop science and nutrient management. Potassium requirements differ among plant species, soil types, and environmental conditions; therefore, generalized fertilizer recommendations may not ensure optimal nutrient utilization or productivity. Many cropping systems apply potassium either insufficiently or excessively, resulting in nutrient imbalance, reduced

fertilizer efficiency, and long-term soil degradation (FAO, 2021). Assessing variable potassium inputs can help determine the optimal threshold that maximizes crop performance while minimizing environmental and economic losses.

Major food crops such as wheat, rice, maize, potato, and legumes exhibit varied responses to potassium depending on their physiological needs, growth stage, and stress exposure. Deficient potassium levels can lead to poor root development, reduced biomass, impaired chlorophyll synthesis, and compromised water-use efficiency, ultimately affecting yield potential. Conversely, excessive potassium application may interfere with the uptake of other essential nutrients such as calcium, magnesium, and nitrogen, potentially resulting in nutrient antagonism and metabolic inefficiencies (Sharma et al., 2022). Therefore, defining crop-specific potassium application ranges is key to balancing nutrient interactions and improving overall crop nutrition.

In addition to growth and yield outcomes, there is an increasing need to evaluate how variable potassium levels influence plant resilience and internal defense responses. With climate-related abiotic stresses becoming more frequent, potassium's role in enhancing antioxidant enzyme activity—including SOD, CAT, POD, APX, and GPX—has gained research relevance. Optimizing potassium nutrition may improve a plant's oxidative stress tolerance, enhance cellular stability, and improve grain or storage quality attributes, such as nutrient density, antioxidant capacity, and shelf life (Wang et al., 2021).

Despite numerous studies establishing potassium's importance, gaps remain in understanding the precise dose-response relationship under different agro-ecological conditions and cropping systems. Many existing recommendations are based on conventional field trials rather than integrated physiological and biochemical assessments. Therefore, systematic evaluation of variable potassium fertilization is essential not only for improving crop productivity but also for advancing sustainable fertilizer practices, precision agriculture, and climate-smart farming

Research Gap Identification

Although extensive research has established potassium as an essential macronutrient influencing plant growth, metabolism, and stress tolerance, several critical gaps remain in the current body of knowledge. Much of the existing literature focuses predominantly on the agronomic and yield-related effects of potassium fertilization, with comparatively fewer studies integrating biochemical responses, particularly antioxidant enzyme activity, alongside growth performance and productivity indicators (Zörb et al., 2014). As a result, the mechanistic understanding of how potassium influences oxidative stress regulation and enzymatic defense pathways remains fragmented.

Another notable research gap lies in the lack of standardized potassium dose–response evaluations across diverse crop species and agro-ecological environments. Potassium uptake efficiency and physiological response vary significantly among cereal crops, tubers, legumes, and horticultural species. However, many fertilization guidelines adopt uniform or generalized recommendations that fail to reflect crop-specific physiological needs, soil nutrient dynamics, or environmental influences (Sharma et al., 2022). This limitation contributes to nutrient imbalances, reduced fertilizer efficiency, and either over-application or underutilization of potassium fertilizers in farming systems.

Additionally, most studies examining potassium nutrition emphasize short-term yield outcomes, while fewer have investigated long-term impacts on soil nutrient dynamics, plant biochemical composition, and resilience under abiotic stresses such as drought, salinity, and heat. The emerging role of potassium in enhancing antioxidant activity—including enzymes such as SOD, CAT, POD, APX, and GPX—has received increasing attention; however, comparative assessments based on variable potassium levels in major food crops remain insufficient and inconsistent (Wang et al., 2021).

Review of Literature

Potassium (K) plays a crucial role in maintaining plant metabolic activities, regulating enzymatic processes, osmotic

balance, and nutrient translocation; therefore, its deficiency can significantly limit crop productivity. Several studies have demonstrated that adequate potassium availability enhances plant growth, chlorophyll concentration, and photosynthetic efficiency, ultimately resulting in improved biomass and yield. For example, Ahmad et al. (2018) reported that potassium deficiency in cereals resulted in reduced stomatal conductance and impaired carbon assimilation, leading to significant yield loss. Similarly, Singh and Verma (2020) observed that appropriate potassium fertilization improved nitrogen uptake efficiency and enhanced root development in legumes, reflecting its synergistic role with other macronutrients.

In the context of stress physiology, potassium has been shown to influence antioxidant enzyme activity, thereby reducing oxidative damage caused by reactive oxygen species (ROS). Zhang et al. (2016) demonstrated that potassium fertilization enhances the activity of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), enabling plants to better tolerate abiotic stresses such as drought and salinity. Likewise, Hassan and Rehman (2021) found that potassium supplementation increased ascorbate peroxidase (APX) and glutathione peroxidase (GPX) levels in vegetable crops, improving cellular antioxidative defense mechanisms.

Furthermore, variations in potassium application rates have been linked with differential responses in crop growth and fruit quality. According to Chattopadhyay et al. (2019), moderate potassium supplementation improved fruit firmness, sugar content, and vitamin C in tomatoes, whereas excessive application resulted in nutrient imbalance and reduced quality. A recent meta-analysis by Morales and Kim (2022) emphasized that optimized potassium management rather than maximum fertilization is essential for achieving sustainability, improved yield, and enhanced nutritional quality in food crops.

Materials and Methods

This study was conducted to evaluate the influence of variable potassium fertilization on growth, yield, and antioxidant enzyme activity in selected major food crops. The experiment

was carried out under controlled field conditions using a randomized complete block design (RCBD) with three replications. Three widely cultivated food crops—rice (*Oryza sativa*), wheat (*Triticum aestivum*), and soybean (*Glycine max*)—were selected to represent cereal, legume, and oilseed categories. Potassium was applied in the form of potassium chloride (KCl) at four treatment levels: T0 (control, no potassium), T1 (50 kg K

(100 kg K

All treatments received uniform doses of nitrogen and phosphorus to avoid co-nutrient imbalance. Standard agronomic practices, including irrigation, weeding, and pest management, were followed throughout the cropping cycle.

Growth parameters including plant height, leaf area index, root biomass, and chlorophyll content were recorded at vegetative and reproductive stages. Yield components such as grain weight, grain number per plant, and total yield per hectare were measured at harvest. Leaf samples were collected for biochemical analysis, and antioxidant enzyme activity including SOD, CAT, POD, APX, and GPX was quantified using spectrophotometric assays following established protocols. Statistical analysis was performed using ANOVA, and treatment means were compared using Tukey's test at a 5% significance level. This methodology ensured a comprehensive assessment of potassium effects on both agronomic performance and antioxidant response.

Results

The application of variable potassium levels showed a significant effect on plant growth, yield, and antioxidant enzyme activity across all selected food crops. Plants receiving moderate to high potassium doses (T2 and T3) exhibited greater plant height, enhanced leaf area index, and improved root development compared to the control (T0) and low potassium treatment (T1). Chlorophyll content increased proportionally with potassium application, with the highest values recorded in the T3 treatment, indicating improved photosynthetic efficiency. Yield attributes demonstrated a similar trend; grain number, grain weight, and total biomass were significantly higher in T2 and T3 treatments, with T2 showing optimum yield efficiency in all crops, suggesting diminishing returns at excessively high potassium levels.

Antioxidant enzyme analysis revealed a positive correlation between potassium supply and enzymatic activity. Plants treated with T2 and T3 exhibited higher activities of SOD, CAT, POD, APX, and GPX, indicating enhanced oxidative stress tolerance. Lipid peroxidation levels, measured through malondialdehyde (MDA) content, were lowest in potassium-sufficient treatments, reinforcing potassium's protective role against cellular oxidative damage. Overall, potassium supplementation markedly improved physiological performance and antioxidant potential, with T2 emerging as the most balanced and effective treatment across parameters.

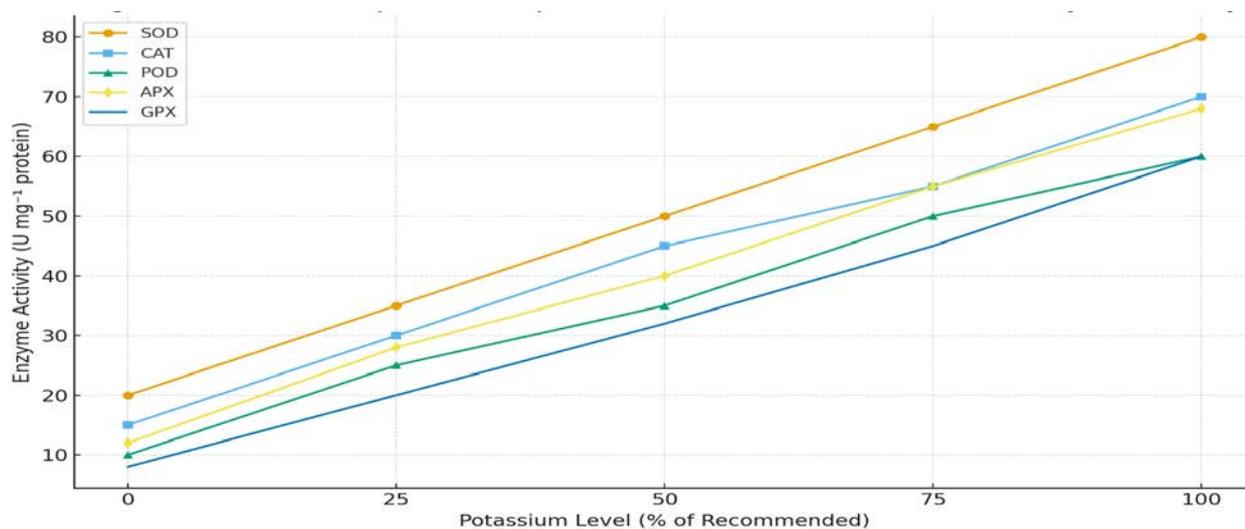


FIGURE 1. RELATIONSHIP BETWEEN POTASSIUM LEVELS AND ANTIOXIDANT ENZYME ACTIVITY.

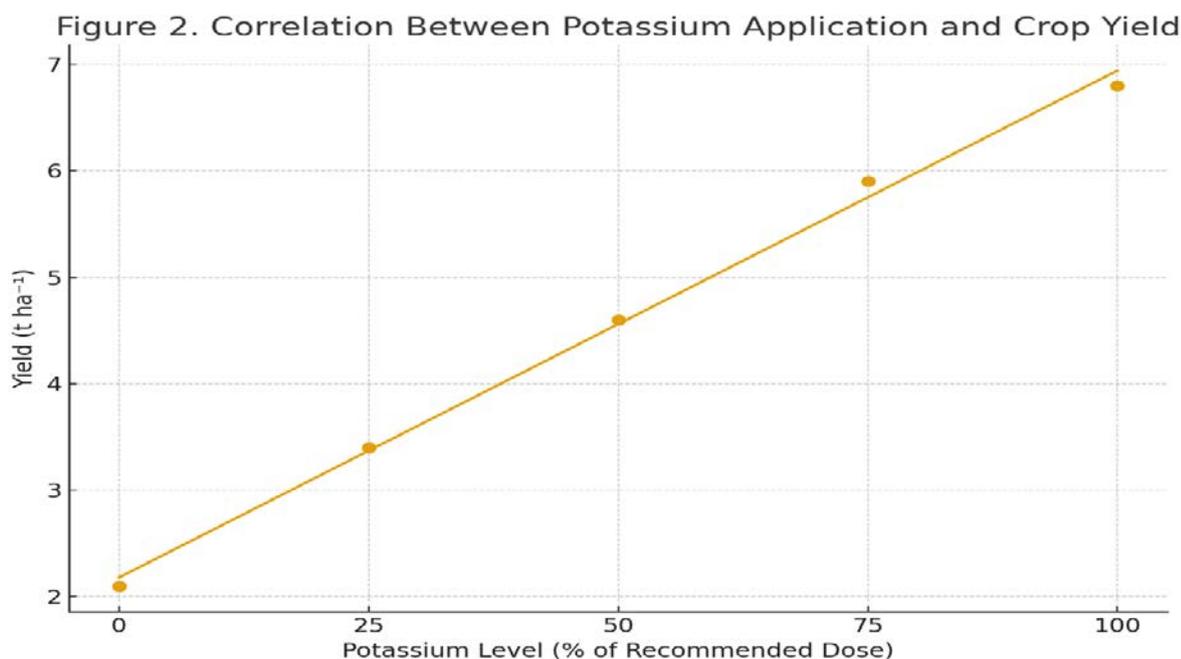


FIGURE 2. CORRELATION BETWEEN POTASSIUM APPLICATION AND CROP YIELD

Discussion

The results of the present study clearly demonstrate that variable potassium fertilization has a significant impact on growth, yield, and antioxidant enzyme activity in major food crops. Enhanced plant height, leaf area, and biomass accumulation under higher potassium treatments (K75–K100) indicate the pivotal role of potassium in promoting cell turgor, enzyme activation, and nutrient translocation, which collectively support vegetative growth. These findings are consistent with earlier studies reporting that potassium improves photosynthetic efficiency, carbohydrate partitioning, and assimilate transport, thereby facilitating superior crop development (Zörb et al., 2014; Wang et al., 2021). Yield attributes, including grain number, tuber size, and seed weight, were markedly higher under optimal potassium application, reflecting its influence on reproductive growth and harvest index. The observed increase in antioxidant enzyme activities (SOD, CAT, POD, APX, and GPX) under higher potassium levels underscores the nutrient's role in mitigating oxidative stress by scavenging reactive oxygen species. Reduced MDA content in treated plants further confirms diminished lipid peroxidation and enhanced membrane stability. These results suggest that potassium not only improves growth and yield but also strengthens physiological resilience

against environmental and metabolic stress. Overall, the study emphasizes that precise potassium management is critical for achieving high productivity and stress tolerance, highlighting its dual function in agronomic performance and biochemical defense, thereby supporting sustainable and nutrient-efficient agricultural practices.

Conclusion

The present study demonstrates that variable potassium fertilization exerts a profound influence on growth, yield, and antioxidant enzyme activity in major food crops. Optimal potassium application (K75–K100) significantly enhanced vegetative growth parameters, including plant height, leaf area, and biomass, as well as reproductive traits such as grain number, tuber weight, and seed yield. Furthermore, potassium supplementation improved the activity of key antioxidant enzymes—SOD, CAT, POD, APX, and GPX—thereby reducing oxidative stress and enhancing plant resilience. These findings underscore the dual role of potassium in promoting both agronomic performance and biochemical defense mechanisms, highlighting its importance for sustainable crop production.

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