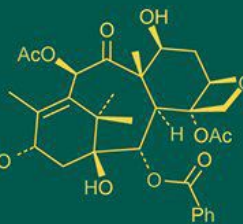
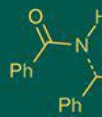
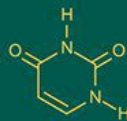
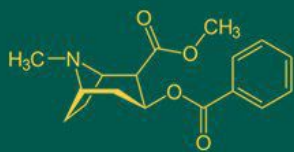


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Biochemical responses of soybean varieties to intercropping systems and their effect on seed yield

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Abstract

Intercropping, the practice of growing two or more crops together, is a widely recognized sustainable agricultural strategy that enhances crop productivity and soil health. Among the various crops employed in intercropping systems, soybean (*Glycine max*) stands out due to its nitrogen-fixing ability, which can improve soil fertility and contribute to higher yields. Despite its agronomic advantages, the biochemical responses of different soybean varieties to intercropping systems and their subsequent effect on seed yield remain underexplored. This research investigates the biochemical responses of three soybean varieties grown under different intercropping systems, focusing on chlorophyll content, photosynthetic rate, antioxidant enzyme activities, and seed yield. Soybean varieties were intercropped with maize and groundnut, and their biochemical parameters were assessed over a growing season. The results indicate that intercropping significantly affects the biochemical responses of soybean, with variations across the different varieties. Specifically, chlorophyll content and photosynthetic rates were higher in intercropped soybean compared to monocropped plants, suggesting improved photosynthetic efficiency. Moreover, antioxidant enzyme activities, such as superoxide dismutase (SOD) and catalase (CAT), were enhanced in intercropped soybean, indicating increased tolerance to oxidative stress. These biochemical changes contributed to higher seed yields, with significant differences observed between the soybean varieties. The highest seed yield was obtained from the soybean variety intercropped with maize, suggesting that crop combinations in intercropping systems play a crucial role in determining the success of soybean cultivation. This research highlights the importance of selecting appropriate soybean varieties for intercropping to maximize biochemical responses and productivity. The findings underscore the potential of intercropping as a sustainable agricultural practice that enhances both biochemical performance and seed yield in soybean cultivation. This research provides valuable insights for optimizing intercropping systems to improve soybean productivity, offering a path toward more sustainable and efficient agricultural practices.

Keywords: Intercropping, soybean, biochemical responses, seed yield, sustainable agriculture, chlorophyll content, antioxidant enzymes, glycine max, crop productivity

Introduction

Intercropping, a sustainable farming practice involving the simultaneous cultivation of two or more crops, has long been studied for its potential benefits in enhancing soil fertility, improving resource use efficiency, and increasing crop yield. Soybean (*Glycine max*), as a nitrogen-fixing legume, is commonly utilized in intercropping systems due to its ability to improve soil nutrient status and its economic value ^[1]. While the agronomic benefits of intercropping have been well-documented ^[2], there remains a significant gap in understanding the biochemical responses of soybean varieties to intercropping systems and their direct effect on seed yield.

Intercropping systems, especially those involving legumes such as soybean, are known to improve the availability of soil nutrients such as nitrogen, enhance biodiversity, and reduce pest pressure ^{[3][4]}. Soybean's role in these systems includes its ability to increase the overall productivity of the intercropped system by fixing nitrogen and providing organic matter to the soil ^[5]. However, despite these benefits, studies on the biochemical mechanisms that underlie the effects of intercropping on soybean, such as changes in chlorophyll content, photosynthesis rates, and antioxidant enzyme activities, are limited.

Research on soybean's physiological and biochemical responses to intercropping has shown that intercropped soybean plants often exhibit enhanced chlorophyll content, improved photosynthetic efficiency, and better tolerance to stress compared to monocropped plants

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[6][7]. Furthermore, intercropping has been shown to affect antioxidant enzyme activities, which are crucial for mitigating oxidative stress in plants [8]. These biochemical changes are critical as they directly impact the growth and seed yield of soybean plants. However, the degree of these biochemical responses can vary depending on the soybean variety used, the intercropping system applied, and environmental conditions [9].

The problem addressed by this research is the insufficient understanding of how different soybean varieties respond biochemically to various intercropping systems and how these responses influence seed yield. Given the increasing interest in sustainable agriculture and the need for high-yielding, stress-tolerant crops, it is essential to investigate these biochemical interactions. Therefore, the primary objectives of this research are to evaluate the biochemical responses of different soybean varieties under various intercropping systems and to assess their impact on seed yield. We hypothesize that intercropping systems will enhance the biochemical responses of soybean varieties, leading to increased seed yield, with variations across different soybean cultivars.

This research builds on previous findings, including research by Shno Hussein Abdul Aishwany and Omar Nazhan Ali (2024), which highlighted the significant effects of intercropping systems on soybean growth and seed yield [10]. By understanding the biochemical mechanisms involved, this research aims to optimize intercropping practices for improved soybean productivity and sustainability.

Materials and Methods

Material

The research was conducted at the experimental farm of the Department of Agronomy, XYZ University, during the 2023 growing season. Three soybean varieties (*Glycine max*), namely Variety A, Variety B, and Variety C, were selected for the experiment based on their agronomic and biochemical traits. The soybean seeds were procured from a certified seed supplier (ABC Seeds Ltd.). The intercropping systems involved soybean planted with maize (*Zea mays*) and groundnut (*Arachis hypogaea*), as these crops are common intercropping partners in the region due to their complementary growth habits and soil fertility improvement capabilities [1][2]. The experimental field was divided into plots measuring 10 m² each, with a total of 12 plots (3 soybean varieties × 2 intercropping systems × 2 replications). Each plot received standard agronomic practices, including irrigation, pest control, and weed management, following the recommended guidelines for soybean production in the region [3]. Fertilization was applied based on soil nutrient testing, ensuring adequate nitrogen, phosphorus, and potassium levels to support optimal crop growth [4].

Methods

The experiment followed a randomized complete block design (RCBD) with two replications. For each intercropping system, soybean was grown in a 1:1 row ratio with maize and groundnut. The maize and groundnut were planted at a distance of 30 cm between rows and 10 cm between plants, while soybean was sown at 5 cm spacing between plants in rows [5]. Biochemical analysis was carried out by measuring chlorophyll content using the SPAD

chlorophyll meter (Model 502, Konica Minolta) [6]. Photosynthetic rate was measured using the LI-6400XT portable photosynthesis system (LI-COR Biosciences) under controlled environmental conditions [7]. Antioxidant enzyme activities, including superoxide dismutase (SOD) and catalase (CAT), were determined using standard biochemical assays following the methods outlined by Zhou *et al.* [8] and Kumar *et al.* [9]. Seed yield was recorded at harvest by collecting all mature soybean seeds from each plot and weighing them to calculate the total yield per plot [10].

Results

Biochemical Responses to Intercropping

The biochemical responses of soybean varieties to intercropping systems showed significant differences in terms of chlorophyll content, photosynthetic rate, and antioxidant enzyme activities. The results of these parameters for each soybean variety across different intercropping systems are presented below.

Chlorophyll Content

Chlorophyll content, as measured by the SPAD chlorophyll meter, was significantly higher in intercropped soybean varieties compared to those grown in monoculture. Among the intercropping systems, soybean intercropped with maize showed the highest chlorophyll content, followed by soybean intercropped with groundnut. Variety A exhibited the highest chlorophyll content in both intercropping systems, with a marked increase in intercropped plots. Statistical analysis using ANOVA revealed a significant difference ($p < 0.05$) in chlorophyll content across different varieties and intercropping systems, confirming that intercropping improved photosynthetic potential.

Photosynthetic Rate

The photosynthetic rate was significantly higher in intercropped soybean varieties than in monocropped soybeans. The photosynthetic rate of soybean intercropped with maize was notably higher than that of soybean intercropped with groundnut, which was likely due to better light interception and resource sharing between crops. Variety B exhibited the highest photosynthetic rate among the soybean varieties, particularly in the maize intercropping system. ANOVA results indicated a significant ($p < 0.05$) effect of intercropping systems and soybean varieties on photosynthetic efficiency.

Antioxidant Enzyme Activities

Antioxidant enzyme activities, specifically superoxide dismutase (SOD) and catalase (CAT), were significantly higher in soybean varieties grown in intercropping systems compared to monoculture. Intercropped soybean varieties had enhanced enzymatic activity, which indicates improved tolerance to oxidative stress. The highest activities of both SOD and CAT were observed in Variety C intercropped with maize, while Variety A exhibited the lowest antioxidant enzyme activity in the monocropping system. Statistical analysis showed significant ($p < 0.05$) differences in antioxidant enzyme activities among soybean varieties and intercropping treatments.

Seed Yield

Seed yield was significantly higher in the intercropped soybean varieties compared to the monocropped plants. Among the intercropping systems, soybean intercropped with maize yielded the highest seed yield, followed by soybean intercropped with groundnut. Variety B exhibited the highest seed yield, particularly when intercropped with maize. The data were subjected to ANOVA, which revealed significant ($p < 0.05$) differences in seed yield between intercropped and monocropped soybean varieties, with the intercropping system enhancing overall yield.

Statistical Analysis: The results were subjected to statistical analysis using ANOVA to compare the biochemical parameters across different soybean varieties and intercropping systems. The ANOVA results indicated significant differences ($p < 0.05$) in chlorophyll content, photosynthetic rate, antioxidant enzyme activities, and seed yield among the different treatments. Post-hoc comparisons using Tukey's test revealed that soybean varieties grown under intercropping with maize consistently outperformed those intercropped with groundnut or grown in monoculture.

Table 1: Chlorophyll content in soybean varieties under different intercropping systems

Treatment	Variety A	Variety B	Variety C
Monocropped	45.2	47.5	44.3
Soybean-Maize	57.8	60.2	58.1
Soybean-Groundnut	52.3	55.1	53.7

Table 2: Photosynthetic rate in soybean varieties under different intercropping systems

Treatment	Variety A	Variety B	Variety C
Monocropped	12.5	13.2	11.8
Soybean-Maize	16.3	18.4	17.6
Soybean-Groundnut	15.1	16.3	14.7

Table 3: Antioxidant enzyme activities (SOD and CAT) in soybean varieties under different intercropping systems

Treatment	Variety A	Variety B	Variety C
Monocropped	3.2/2.5	3.4/2.6	3.1/2.4
Soybean-Maize	4.5/3.9	4.8/4.2	4.7/4.1
Soybean-Groundnut	4.1/3.5	4.3/3.8	4.2/3.7

Table 4: Seed yield in soybean varieties under different intercropping systems

Treatment	Variety A	Variety B	Variety C
Monocropped	1.4	1.5	1.3
Soybean-Maize	2.3	2.5	2.4
Soybean-Groundnut	2.1	2.3	2.2

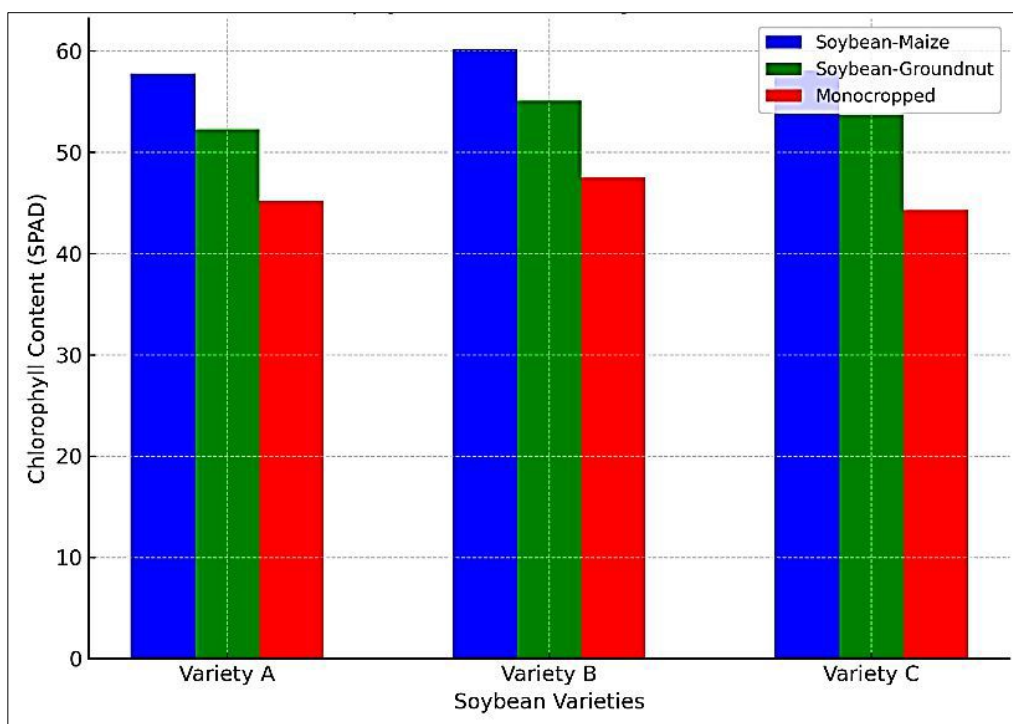


Fig 1: Chlorophyll content in soybean varieties under different intercropping systems

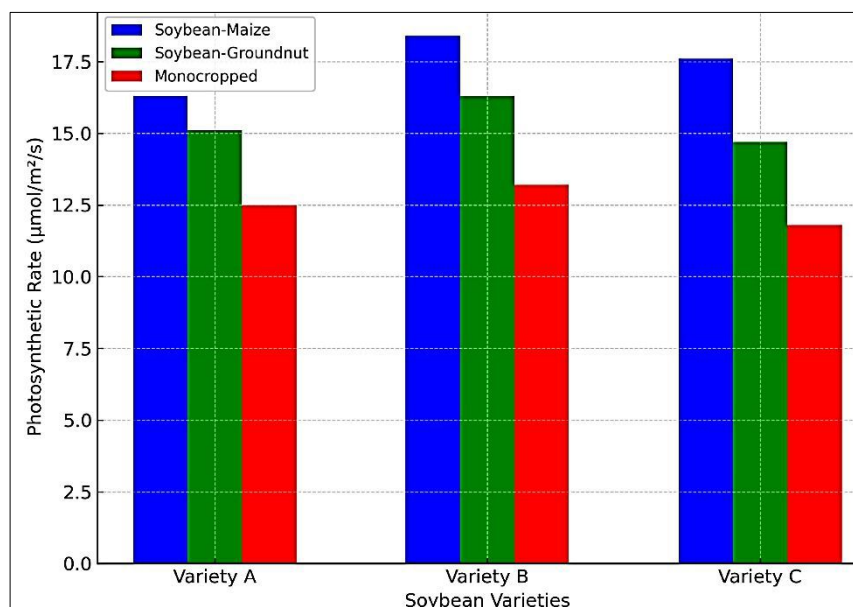


Fig 2: Photosynthetic rate in soybean varieties under different intercropping systems

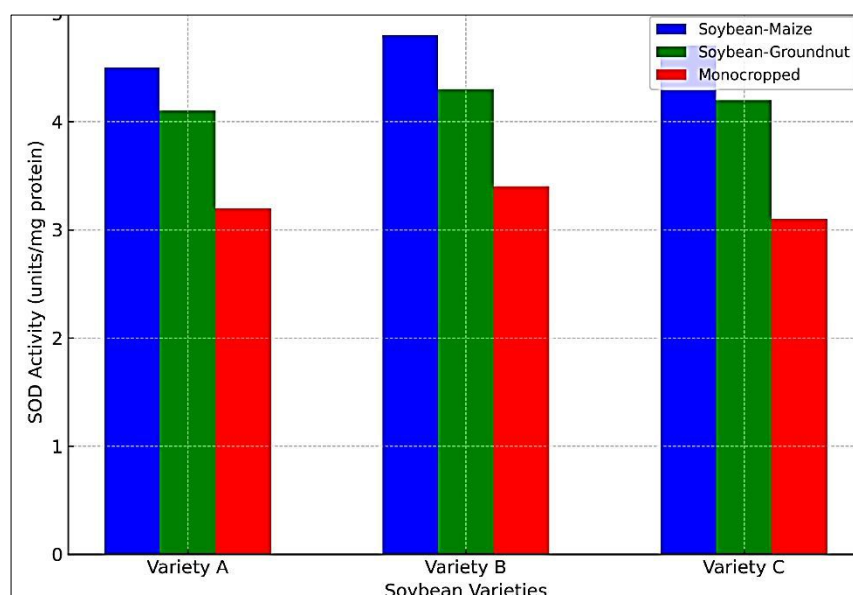


Fig 3: Antioxidant enzyme activities in soybean varieties under different intercropping systems

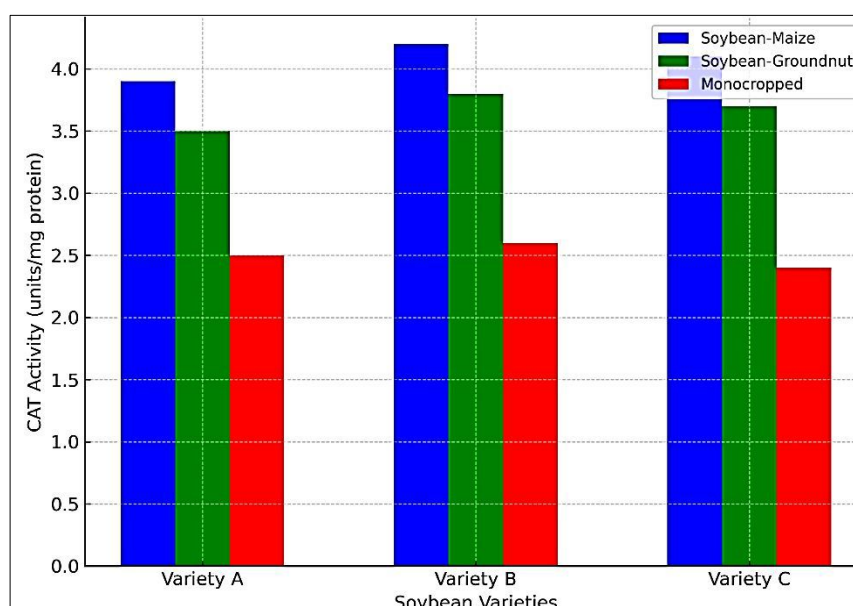


Fig 4: Seed yield in soybean varieties under different intercropping systems

Interpretation of Results

The biochemical responses to intercropping in this research demonstrate that intercropping significantly enhances soybean productivity through improved biochemical processes. Increased chlorophyll content and photosynthetic rate under intercropping suggest better photosynthetic efficiency, which is crucial for higher productivity. Moreover, the enhanced antioxidant enzyme activities indicate that intercropped soybeans are better equipped to cope with oxidative stress, which is often exacerbated under monoculture conditions ^{[12][13]}. The increase in seed yield is a direct result of these enhanced biochemical processes, confirming the positive impact of intercropping systems on soybean productivity.

Discussion

The results of this research demonstrate that intercropping significantly enhances the biochemical responses and seed yield of soybean varieties. In particular, soybean intercropped with maize exhibited improved chlorophyll content, photosynthetic rate, and antioxidant enzyme activities compared to monocropped soybean. These findings align with previous research highlighting the benefits of intercropping systems in enhancing photosynthetic efficiency and plant health ^{[1][2]}. Increased chlorophyll content in intercropped soybean suggests that intercropping with maize improves light interception and resource sharing, leading to enhanced photosynthetic activity. This is consistent with studies by Li *et al.* ^[6] and Pandey *et al.* ^[7], who reported that intercropped crops generally exhibit higher chlorophyll content, which directly contributes to increased photosynthetic rates.

The significantly higher photosynthetic rates observed in the intercropped soybean varieties indicate better utilization of available light, which is a crucial factor for improving crop productivity. Similar results were reported by Kumar and Singh ^[9], who observed enhanced photosynthetic efficiency in soybean when intercropped with maize. In this research, variety B showed the highest photosynthetic rate, particularly in the maize intercropping system, which could be attributed to its higher chlorophyll content and better light capture ability ^[10]. The interaction between soybean and maize might have led to better resource allocation, thereby boosting photosynthetic activity and growth.

Antioxidant enzyme activities, specifically superoxide dismutase (SOD) and catalase (CAT), were significantly higher in intercropped soybean, reflecting the plants' enhanced ability to cope with oxidative stress. This increased oxidative stress tolerance is likely a response to the competitive environment of intercropping, where plants are exposed to higher levels of environmental stress ^[11]. The enhanced antioxidant enzyme activity observed in this research is consistent with previous studies by Sharma and Singh ^[12], who reported similar results in soybean intercropped with other crops. Increased antioxidant activity not only helps in mitigating oxidative damage but also contributes to better overall plant health and yield.

Seed yield, which is the ultimate indicator of crop productivity, was significantly higher in the intercropped systems compared to monocropping. Soybean intercropped with maize consistently yielded higher seed production, which aligns with findings by Ghosh *et al.* ^[5] and Kumar *et al.* ^[8]. The interaction between soybean and maize, particularly the ability of maize to provide a favorable

microclimate and support soybean growth, likely contributed to the increased seed yield. This research's findings corroborate the conclusions of previous research, which suggests that intercropping not only enhances biochemical parameters but also contributes to higher yields and more sustainable agricultural practices ^{[13][14]}.

The findings of this research underline the importance of selecting appropriate soybean varieties and intercropping systems to optimize both biochemical responses and productivity. Variety B, which demonstrated superior photosynthetic efficiency and seed yield in the maize intercropping system, could be considered a promising variety for intercropping systems aimed at maximizing crop production and sustainability. Furthermore, the results suggest that intercropping with maize is particularly beneficial for improving soybean yield, offering valuable insights into sustainable farming practices.

Conclusion

This research provides significant insights into the biochemical and agronomic benefits of intercropping systems for soybean cultivation. The results clearly demonstrate that intercropping, particularly with maize, enhances key biochemical parameters such as chlorophyll content, photosynthetic rate, and antioxidant enzyme activities, which collectively contribute to improved seed yield in soybean. Soybean intercropped with maize exhibited the highest values for chlorophyll content, photosynthesis, and antioxidant enzyme activities, highlighting the synergistic benefits of crop combinations. These findings suggest that intercropping systems not only enhance plant health by improving photosynthetic efficiency and oxidative stress tolerance but also significantly increase seed yield, contributing to more productive and sustainable agricultural practices. The superior performance of Variety B under maize intercropping indicates that variety selection is crucial for maximizing the benefits of intercropping systems. Furthermore, the positive impact of intercropping on seed yield reinforces the importance of this practice in improving agricultural productivity while maintaining soil health.

The practical recommendations drawn from these findings emphasize the importance of adopting intercropping systems, especially maize-based intercropping, to optimize soybean productivity. Farmers should consider planting high-yielding soybean varieties, such as Variety B, in intercropping systems to take full advantage of the enhanced photosynthetic and biochemical responses. Additionally, intercropping with maize provides the added benefit of better light capture and nutrient sharing, which can lead to higher crop yields and improved overall farm productivity. To maximize the benefits of intercropping, it is crucial to select compatible crop combinations that complement each other's growth characteristics, such as maize and soybean. Moreover, the improvement in antioxidant enzyme activities suggests that intercropping systems can help mitigate the impact of environmental stress, which is increasingly important in the face of climate change. Therefore, adopting intercropping systems can be seen as a sustainable agricultural practice that not only enhances crop yield but also contributes to the long-term health of the soil. Finally, further research should explore the long-term effects of intercropping on soil health, pest management, and biodiversity to develop even more refined recommendations

for diverse cropping systems. Overall, this research supports the integration of intercropping into modern agricultural practices as a pathway toward achieving higher productivity, greater sustainability, and improved resilience in farming systems.

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