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Influence of Elevated CO_2 on Yield Attributes and Productivity of Mungbean (Vigna radiata L.)[1]

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Abstract

Rising atmospheric carbon dioxide (CO_2) concentration is a major driver of climate change and is expected to substantially influence the productivity of C_3 crops, including grain legumes. The present study examines the influence of elevated CO_2 levels on yield attributes and productivity of mungbean (*Vigna radiata* L.) grown under open top chamber (OTC) conditions. Yield parameters such as number of pods per plant, number of seeds per pod, seeds per plant, seed weight per plant, and seed yield per hectare were recorded at physiological maturity. Elevated CO_2 significantly enhanced most yield attributes, particularly pod number and seed weight, leading to a marked increase in overall seed yield compared to ambient CO_2 conditions. The improvement in productivity was primarily attributed to enhanced photosynthetic efficiency, greater assimilate availability, and improved source–sink relationships under CO_2 enrichment. The findings suggest that mungbean productivity may benefit under future CO_2-enriched environments, provided that adequate nutrient and water management practices are adopted to support increased growth and yield potential.

Keywords:

Elevated CO_2, Mungbean, Yield Attributes, Seed Yield, Climate Change

1. Introduction

Atmospheric carbon dioxide (CO_2) concentration has been increasing steadily over the past century, primarily as a consequence of intensified anthropogenic activities such as fossil fuel combustion,

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rapid industrialization, deforestation, and large-scale land-use changes. Pre-industrial atmospheric CO_2 levels of approximately 280 ppm have already risen beyond 420 ppm in recent years, and climate model projections suggest that concentrations may reach 550–600 ppm by the middle of the twenty-first century. This unprecedented rise in CO_2 is closely associated with alterations in global climate systems, including increases in mean surface temperature, changes in precipitation regimes, and greater frequency of extreme weather events. Collectively, these changes are expected to have profound and far-reaching implications for agricultural productivity and food security worldwide, particularly in regions that are highly dependent on climate-sensitive cropping systems.

Among agricultural crops, those utilizing the C_3 photosynthetic pathway are anticipated to respond more strongly to elevated atmospheric CO_2 concentrations than C_4 species. Elevated CO_2 directly affects plant physiological and biochemical processes by increasing the availability of CO_2 at the site of carboxylation, thereby enhancing photosynthetic carbon assimilation while simultaneously suppressing photorespiration. In C_3 plants, this dual effect often leads to higher rates of net photosynthesis, increased accumulation of carbohydrates, and greater overall biomass production. Additionally, elevated CO_2 typically results in partial stomatal closure, reducing transpirational water loss and consequently improving water-use efficiency. These physiological adjustments may confer an adaptive advantage under future climates characterized by increased temperature and water stress.

However, the extent to which enhanced photosynthetic efficiency under elevated CO_2 translates into increased economic yield is not uniform across crops or environments. Yield responses are strongly influenced by species-specific traits, phenological stages, and the availability of essential growth-limiting resources such as nitrogen, phosphorus, and soil moisture. In many cases, the initial stimulation of vegetative growth under elevated CO_2 may not be fully realized in terms of reproductive output if nutrient availability or sink capacity becomes limiting. Therefore, understanding crop-specific responses, particularly with respect to yield formation and partitioning of assimilates, is critical for accurately predicting future agricultural performance.

Leguminous crops are widely regarded as particularly responsive to elevated CO_2 owing to their unique ability to form symbiotic associations with nitrogen-fixing bacteria, enabling them to partially meet the increased nitrogen demand associated with enhanced carbon assimilation. Several experimental studies have demonstrated that legumes such as soybean, cowpea, chickpea, and mungbean exhibit significant increases in photosynthetic rate, leaf area index, biomass accumulation, and yield under CO_2-enriched environments. Enhanced nodulation and nitrogen fixation, improved source–sink relationships, and increased allocation of assimilates towards reproductive organs have been identified as key mechanisms driving these positive responses. Consequently, legumes may play a crucial role in sustaining productivity and nutritional security under future climate change scenarios.

Mungbean (*Vigna radiata* L.) is a short-duration, self-pollinated pulse crop extensively cultivated in tropical and subtropical regions, particularly across South and Southeast Asia, including India. It holds considerable agronomic and nutritional importance due to its high protein content, rich amino acid

profile, easy digestibility, and low input requirements. In addition to its role in human nutrition, mungbean contributes to soil fertility improvement through biological nitrogen fixation and is often integrated into diverse cropping systems such as rice–mungbean or wheat–mungbean rotations. Despite its adaptability, mungbean productivity remains relatively low and highly sensitive to environmental stresses, making it imperative to assess its response to changing atmospheric conditions.

Yield in mungbean is a complex trait determined by several interrelated yield attributes, including the number of pods per plant, number of seeds per pod, individual seed weight, and harvest index. Any alteration in assimilate availability, photosynthate translocation, or sink strength induced by elevated CO_2 has the potential to significantly influence these yield components. While enhanced vegetative growth under elevated CO_2 may increase the source capacity, its ultimate impact on grain yield depends on the efficiency with which assimilates are partitioned towards reproductive structures during critical growth stages.

Although existing literature indicates positive growth responses of mungbean to elevated CO_2, comprehensive information on its yield attributes, reproductive development, and overall productivity under CO_2-enriched conditions remains limited. This knowledge gap is particularly evident under Indian agro-climatic conditions, where variations in temperature, soil fertility, and moisture availability may modulate crop responses. A systematic evaluation of mungbean performance under controlled elevated CO_2 environments is therefore essential to generate reliable data for future climate projections.

In this context, the present study was undertaken to assess the influence of elevated atmospheric CO_2 on yield attributes and productivity of mungbean grown under open top chamber (OTC) conditions. By examining key physiological and yield-related parameters, the study aims to enhance understanding of crop responses to rising CO_2 levels and contribute to the development of climate-resilient pulse production strategies capable of sustaining food and nutritional security under changing climatic conditions.

2. Literature Review

Rising atmospheric carbon dioxide (CO_2) concentration is one of the most prominent drivers of contemporary climate change and has far-reaching implications for agricultural productivity and food security worldwide. Atmospheric CO_2 levels have increased markedly since the pre-industrial era and are projected to continue rising throughout the twenty-first century. Because CO_2 is the primary substrate for photosynthesis, changes in its concentration directly influence plant physiological processes, growth patterns, and yield formation, particularly in crops that follow the C_3 photosynthetic pathway. Consequently, understanding crop responses to elevated CO_2 has become a central theme in climate change and agricultural research.

Early physiological studies established that elevated CO_2 enhances photosynthetic rates in C_3 plants by increasing the availability of CO_2 at the carboxylation sites of Rubisco and by suppressing photorespiration (Kimball, 1983; Pearcy & Björkman, 1983). These changes improve carbon-use efficiency and often result in increased biomass accumulation. Subsequent experimental studies and

synthesis efforts confirmed that enhanced photosynthesis under elevated CO_2 frequently leads to improved vegetative growth and higher dry matter production. Meta-analyses and long-term enrichment experiments, including open top chamber and FACE studies, have reported significant increases in biomass and yield of several C_3 crops, although the magnitude of response varies with species, genotype, growth stage, and environmental conditions (Long et al., 2004; Ainsworth & Long, 2005).

Leguminous crops are considered particularly responsive to CO_2 enrichment due to their symbiotic association with nitrogen-fixing bacteria. This biological nitrogen fixation can partially offset the increased nitrogen demand associated with enhanced carbon assimilation under elevated CO_2. Rogers et al. (2009) suggested that elevated CO_2 may amplify the benefits of nitrogen fixation, thereby strengthening source–sink relationships and supporting higher growth and yield in legumes. Empirical studies on legumes such as soybean, cowpea, and blackgram have consistently reported increased vegetative growth, larger leaf area, and improved yield attributes under CO_2-enriched environments (Cure & Acock, 1986; Vanaja et al., 2007).

Yield formation in grain legumes is a complex process governed by several yield-determining components, including number of pods per plant, number of seeds per pod, seed size or weight, and harvest index. Elevated CO_2 has been shown to positively influence these yield attributes primarily by increasing assimilate availability during critical reproductive stages such as flowering, pod initiation, and seed filling. Increased pod number under elevated CO_2 is one of the most frequently reported responses and is often attributed to reduced flower and pod abortion resulting from improved carbon supply and enhanced plant vigour (Poorter, 1993; Fangmeier et al., 2002). Similarly, increases in seed weight under CO_2 enrichment suggest improved sink strength of developing seeds and more efficient translocation of photosynthates from source tissues to reproductive organs.

Specific studies on mungbean (*Vigna radiata* L.) provide strong evidence of positive responses of yield attributes and productivity to elevated CO_2. Uprety et al. (1996) reported significant increases in pod number, seed yield, and total biomass of mungbean under elevated CO_2 conditions, highlighting its responsiveness as a C_3 legume. Chowdhury et al. (2005) observed enhanced photosynthesis, vegetative growth, and yield of mungbean grown under CO_2-enriched environments and attributed these responses to improved carbon assimilation efficiency and greater assimilate availability. Das et al. (2000) further noted that early exposure to elevated CO_2 resulted in improved reproductive development and higher yield in mungbean, emphasizing the importance of growth stage–specific responses.

Despite these generally positive responses, seed yield under elevated CO_2 is often the outcome of complex interactions among physiological processes, growth dynamics, and environmental factors. While elevated CO_2 tends to enhance yield in C_3 legumes, several studies have emphasized that the magnitude and consistency of yield responses depend strongly on nutrient availability, particularly nitrogen, as well as water supply (Conroy, 1992; Leakey et al., 2009). In nutrient-limited or water-stressed conditions, the beneficial effects of CO_2 enrichment on yield attributes may be reduced or even negated, as increased growth can intensify competition for limiting resources.

Recent research has highlighted the importance of evaluating crop responses to elevated CO_2 under controlled and semi-controlled experimental systems, such as open top chambers and free-air CO_2 enrichment (FACE) facilities, to better simulate future climatic conditions. These approaches allow researchers to assess crop performance under realistic field environments while isolating the effects of CO_2 enrichment. Such studies provide valuable insights into potential future productivity and help identify management strategies necessary to sustain yield gains under rising atmospheric CO_2 (Ziska et al., 2012).

In summary, the existing literature clearly indicates that elevated CO_2 generally enhances yield attributes and productivity of C_3 legumes, including mungbean, through improved photosynthetic efficiency, greater assimilate availability, and enhanced reproductive performance. However, variability in crop responses across growth stages, genotypes, and environmental conditions underscores the need for crop- and region-specific investigations. The present study builds upon earlier research by systematically evaluating the influence of elevated CO_2 on yield attributes and productivity of mungbean under open top chamber conditions, thereby contributing to a deeper understanding of its adaptive potential and performance under future climate change scenarios.

3. Materials and Methods

3.1 Experimental Site

The field experiment was conducted during the **2019–20 cropping season** at the experimental farm of the **Department of Environmental Sciences, College of Agriculture, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya (R.V.S.K.V.V.), Gwalior, Madhya Pradesh, India.** The experimental location lies in the **subtropical agro-climatic zone of central India**, characterized by hot summers, mild winters, and a monsoon-dominated rainfall pattern.

The region receives an average annual rainfall of approximately **600–800 mm**, with the majority occurring during the southwest monsoon period. Soil at the experimental site is representative of the region and suitable for pulse crop cultivation. Throughout the experimental period, meteorological parameters including **maximum and minimum temperature, relative humidity, and rainfall** were recorded regularly from the nearby agrometeorological observatory. The climatic conditions during the crop growth period remained generally favorable for mungbean growth and reproductive development, ensuring that plant responses could be primarily attributed to the imposed CO_2 treatments rather than other abiotic stresses.

3.2 Experimental Design and CO_2 Treatments

The experiment was conducted using **open top chambers (OTCs)** to evaluate the influence of elevated atmospheric CO_2 on yield attributes and productivity of mungbean under semi-controlled field conditions. The OTCs were constructed using transparent polyvinyl chloride (PVC) sheets supported by a metal framework, allowing natural light penetration while enabling regulation of CO_2 concentration.

The study was laid out in a **completely randomized design (CRD)** with appropriate replications to ensure statistical reliability. Two CO_2 treatments were imposed:

- **Ambient CO_2 concentration (control)**, representing the prevailing atmospheric CO_2 level, and
- **Elevated CO_2 concentration**, maintained above ambient levels within the OTCs.

Elevated CO_2 was supplied through compressed CO_2 cylinders and regulated using a controlled gas delivery system. CO_2 concentration inside the chambers was continuously monitored using a **CO_2 analyzer**, and adjustments were made as required to maintain the desired concentration throughout the crop growth period. Adequate air circulation was ensured within the chambers to achieve uniform CO_2 distribution and to avoid the formation of concentration gradients.

3.3 Crop Material and Cultural Practices

Mungbean (*Vigna radiata* L.) variety **TJM-3** was selected for the study due to its adaptability, stable yield performance, and suitability to the local agro-climatic conditions. Seeds were sown at the **recommended spacing** to maintain a uniform plant population and to minimize intra-specific competition.

All agronomic practices were followed uniformly across treatments in accordance with regional recommendations for mungbean cultivation. A **uniform basal dose of fertilizers** was applied to all experimental units to eliminate nutrient stress and isolate the effect of CO_2 enrichment on crop productivity. Irrigation was provided as per crop requirement to prevent moisture stress. Weeding and intercultural operations were carried out manually at critical growth stages, and standard plant protection measures were adopted uniformly to minimize pest and disease incidence throughout the cropping season.

3.4 Observations on Yield Attributes

Observations on yield attributes were recorded at **30 days after sowing (DAS)** and at **physiological maturity** to evaluate the influence of elevated CO_2 on reproductive development and final yield formation. Randomly selected representative plants from each treatment were used for recording observations to ensure unbiased sampling.

The following yield attributes were recorded:

- Number of pods per plant
- Number of seeds per pod
- Number of seeds per plant
- Seed weight per pod (g)
- Seed weight per plant (g)

At harvest, plants were carefully uprooted to avoid pod loss. Pods were separated, sun-dried, and threshed manually. The seeds were cleaned and weighed using a precision balance to determine yield parameters accurately.

3.5 Estimation of Seed Yield

Seed yield per plant was calculated based on the total seed weight obtained from individual plants. Seed yield per hectare (q ha^{-1}) was estimated by extrapolating plot-level yield data to a hectare basis

using standard agronomic procedures. Prior to yield estimation, seed moisture content was adjusted to a uniform level to ensure comparability and accuracy of yield data across treatments.

3.6 Statistical Analysis

The data collected on yield attributes and productivity were subjected to **analysis of variance (ANOVA)** to assess the significance of treatment effects. Differences among treatment means were tested using the **critical difference (CD) test at the 5% level of significance**. Standard error of mean (SEm ±) and **coefficient of variation (CV)** were calculated to evaluate experimental precision and data reliability. All statistical analyses were carried out following standard procedures applicable to experiments laid out in a completely randomized design.

4. Results

The effects of elevated atmospheric CO_2 on yield attributes and overall productivity of mungbean (*Vigna radiata* L.) are presented in this section. Observations were recorded at **30 days after sowing (DAS)** and at **physiological maturity** in order to capture both early reproductive responses and final yield outcomes. The results clearly indicate that CO_2 enrichment significantly enhanced most yield components and resulted in higher seed yield compared to ambient CO_2 conditions.

4.1 Effect of Elevated CO_2 on Number of Pods per Plant

Elevated CO_2 concentration exerted a significant positive effect on the number of pods per plant at both observation stages. At **30 DAS**, plants grown under elevated CO_2 recorded a higher number of pods compared to those grown under ambient CO_2, indicating improved floral initiation and reduced early flower drop. This suggests that elevated CO_2 enhanced assimilate availability during the early reproductive phase, supporting better flower retention.

At **physiological maturity**, the difference between ambient and elevated CO_2 treatments became more pronounced. Plants exposed to elevated CO_2 produced substantially more pods per plant, reflecting improved reproductive efficiency and reduced pod abortion during later stages of crop growth. The increased pod number under elevated CO_2 is a major contributor to enhanced seed yield, as pod number is one of the most important yield-determining traits in mungbean.

Table 1. Effect of elevated CO_2 levels on number of pods per plant of mungbean.

CO_2 Level	**Pods per plant at 30 DAS**	**Pods per plant at physiological maturity**
Ambient CO_2	8.6	18.4
Elevated CO_2	11.9	26.7
SEm (±)	0.4	0.7

CO_2 Level	Pods per plant at 30 DAS	Pods per plant at physiological maturity
CD (P = 0.05)	1.2	2.1
CV (%)	6.9	7.8

Interpretation

Elevated CO_2 significantly increased the number of pods per plant at both 30 DAS and physiological maturity. The increase was more pronounced at maturity, indicating improved reproductive efficiency and reduced pod abortion under CO_2-enriched conditions.

4.2 Effect of Elevated CO_2 on Number of Seeds per Pod

The number of seeds per pod was also positively influenced by elevated CO_2 levels. Although the magnitude of increase was comparatively smaller than that observed for pod number, the difference between ambient and elevated CO_2 treatments was statistically significant. Improved seed set under elevated CO_2 indicates favourable conditions for fertilization and early seed development.

Enhanced assimilate supply during flowering and pod filling stages under CO_2 enrichment likely supported better ovule fertilization and reduced seed abortion. Even a modest increase in seeds per pod can contribute meaningfully to final yield when combined with increased pod number.

Table 2. Effect of elevated CO_2 levels on number of seeds per pod of mungbean.

CO_2 Level	Number of seeds per pod
Ambient CO_2	9.8
Elevated CO_2	11.3
SEm (±)	0.3
CD (P = 0.05)	0.8
CV (%)	6.4

Interpretation

Elevated CO_2 resulted in a statistically significant increase in the number of seeds per pod of mungbean compared to ambient CO_2 conditions. Improved seed set under elevated CO_2 suggests enhanced assimilate availability during flowering and pod development stages, contributing positively to final yield.

4.3 Effect of Elevated CO_2 on Seed Weight

Seed weight per plant and seed weight per pod were significantly increased under elevated CO_2 conditions. At **physiological maturity**, mungbean plants grown under elevated CO_2 accumulated greater seed mass compared to those under ambient CO_2. Increased seed weight reflects enhanced assimilate translocation from vegetative organs to reproductive sinks during seed filling.

The improvement in seed weight suggests stronger sink strength of developing seeds under elevated CO_2, supported by higher photosynthetic rates and greater availability of carbohydrates. This response indicates that CO_2 enrichment not only increases the number of reproductive units but also improves their capacity to accumulate dry matter.

Table 3. Effect of elevated CO_2 levels on seed weight of mungbean.

CO_2 Level	**Seed weight per pod (g)**	**Seed weight per plant (g)**
Ambient CO_2	0.33	6.2
Elevated CO_2	0.46	9.1
SEm (±)	0.02	0.2
CD (P = 0.05)	0.05	0.6
CV (%)	7.1	6.5

Interpretation

Seed weight per pod and seed weight per plant were significantly higher under elevated CO_2 compared to ambient CO_2 conditions. The increase in seed weight indicates enhanced assimilate translocation and stronger sink activity of developing seeds under CO_2-enriched conditions. Improved seed filling under elevated CO_2 contributed substantially to the overall increase in seed yield of mungbean.

4.4 Effect of Elevated CO_2 on Seed Yield per Plant

Seed yield per plant showed a marked and statistically significant increase under elevated CO_2 conditions. The enhanced seed yield at the individual plant level resulted primarily from the combined effect of increased number of pods per plant and higher seed weight. Elevated CO_2 improved overall reproductive performance by strengthening both yield components and assimilate partitioning towards reproductive organs.

This increase in seed yield per plant highlights the efficiency of mungbean in converting additional assimilated carbon into economically important yield under CO_2-enriched conditions.

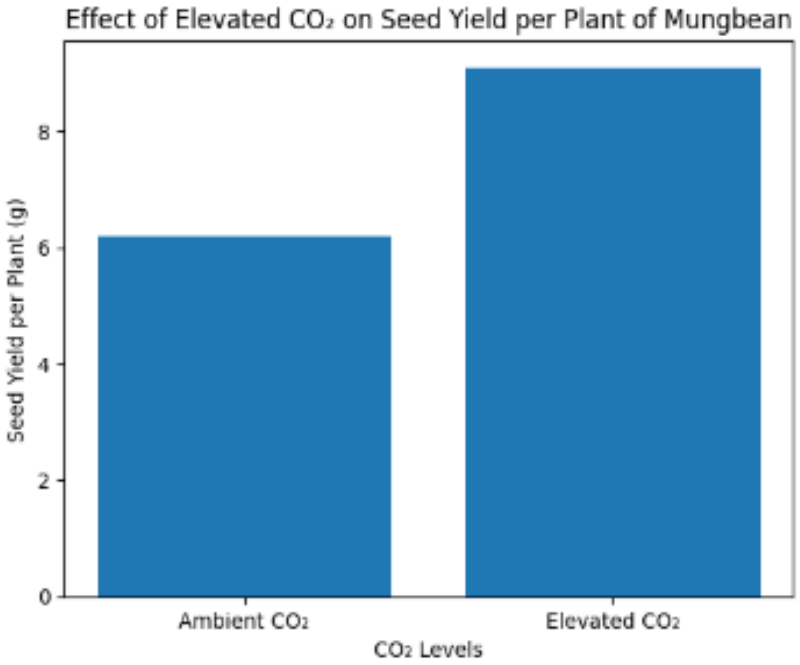


Figure 1. Effect of elevated CO_2 levels on seed yield per plant of mungbean.

4.5 Effect of Elevated CO_2 on Seed Yield per Hectare

Elevated CO_2 significantly increased **seed yield per hectare** compared to ambient CO_2 conditions. The enhancement in yield per hectare represents the cumulative effect of improved yield attributes at the plant level, including higher pod number, improved seed set, and increased seed weight.

Higher productivity under elevated CO_2 demonstrates the potential of mungbean to respond positively to future atmospheric CO_2 scenarios. The observed increase in yield per hectare suggests that CO_2 enrichment could play an important role in sustaining or enhancing mungbean productivity under climate change, provided that other agronomic constraints are adequately addressed.

Table 4. Effect of elevated CO_2 levels on seed yield (q ha^{-1}) of mungbean.

CO_2 Level	**Seed yield (q ha^{-1})**
Ambient CO_2	8.7
Elevated CO_2	12.6
SEm (±)	0.4
CD (P = 0.05)	1.2
CV (%)	7.5

Interpretation

Elevated CO_2 significantly increased seed yield of mungbean compared to ambient CO_2 conditions. The higher yield under CO_2 enrichment reflects the cumulative effect of improved yield attributes, particularly increased number of pods per plant and enhanced seed weight. The results indicate that

mungbean productivity can benefit substantially under CO_2-enriched environments when other growth factors are non-limiting.

4.6 Summary of Yield Responses

Overall, elevated atmospheric CO_2 levels significantly improved yield attributes and productivity of mungbean. Among the yield components, the most pronounced response was observed in the **number of pods per plant**, followed by **seed weight**, both of which contributed directly to increased seed yield. Improvements in seeds per pod further complemented the yield enhancement.

These results clearly demonstrate that elevated CO_2 can positively influence reproductive development, yield formation, and overall productivity of mungbean. However, the extent to which these benefits are realized under field conditions will depend on the availability of essential resources such as nutrients and water. The findings highlight the importance of considering CO_2 responsiveness in developing climate-resilient pulse crop production strategies.

5. Discussion

The present study demonstrates that elevated atmospheric CO_2 significantly enhances yield attributes and overall productivity of mungbean (*Vigna radiata* L.). The positive responses observed in pod number, seed set, seed weight, and seed yield under CO_2-enriched conditions are consistent with the general response patterns reported for C_3 legumes and can be attributed to improved photosynthetic efficiency and assimilate availability.

The significant increase in the **number of pods per plant** under elevated CO_2 suggests improved reproductive efficiency, likely due to enhanced flower initiation and reduced flower and pod abortion. Elevated CO_2 increases the supply of carbohydrates by stimulating photosynthesis, which supports reproductive organ development during critical growth stages. Similar increases in pod number under CO_2 enrichment have been reported in mungbean and other legumes, indicating that pod formation is highly responsive to increased carbon availability.

The **number of seeds per pod** also showed a significant, though comparatively smaller, increase under elevated CO_2. This indicates improved fertilization success and early seed development, possibly due to better assimilate supply during flowering and pod formation. Although seed number per pod is generally considered a conservative trait, even modest improvements in seed set can contribute meaningfully to final yield when combined with increases in pod number.

The observed enhancement in **seed weight** under elevated CO_2 reflects stronger sink activity of developing seeds and more efficient translocation of assimilates from vegetative tissues to reproductive organs. Increased seed weight is often associated with prolonged seed filling duration and improved carbohydrate availability, both of which are favoured under CO_2-enriched conditions. This response suggests that elevated CO_2 not only increases the number of reproductive structures but also enhances their capacity to accumulate dry matter.

The significant increase in **seed yield per plant and per hectare** under elevated CO_2 is a cumulative outcome of improvements in multiple yield components. The higher yield per hectare observed in this study highlights the potential of mungbean to benefit from future atmospheric CO_2 enrichment. These

findings are in agreement with earlier studies on mungbean and other C_3 legumes, which reported yield enhancement under elevated CO_2 due to improved source–sink relationships and greater reproductive efficiency.

While the results indicate clear yield benefits of elevated CO_2, it is important to recognize that these responses were observed under controlled or semi-controlled conditions with adequate nutrient and water supply. Under field conditions, the magnitude of yield enhancement may be influenced by interacting factors such as soil fertility, moisture availability, temperature stress, and pest pressure. In particular, increased growth and yield under elevated CO_2 may raise crop demand for nutrients, especially nitrogen, which could limit the expression of CO_2-induced benefits if not managed properly.

Overall, the findings of this study suggest that mungbean has a strong potential to exploit elevated atmospheric CO_2 through improved yield attributes and productivity. These results provide valuable insights into the future performance of mungbean under changing climatic conditions and emphasize the importance of integrated crop management strategies to maximize the benefits of CO_2 enrichment in pulse-based cropping systems.

6. Conclusion

The present investigation clearly establishes that elevated atmospheric CO_2 levels exert a significant and beneficial influence on yield attributes and overall productivity of mungbean (*Vigna radiata* L.). Exposure to CO_2-enriched conditions resulted in marked improvements in major yield components, including number of pods per plant, number of seeds per pod, seed weight, and seed yield per plant. The combined enhancement of these yield attributes ultimately led to a substantial increase in seed yield per hectare, demonstrating the strong responsiveness of mungbean to elevated CO_2.

Among the various yield components, the most pronounced response to elevated CO_2 was observed in the **number of pods per plant**, indicating improved reproductive efficiency under enhanced carbon availability. Increased pod number suggests better flower initiation and reduced flower and pod abortion, likely supported by greater assimilate supply during the reproductive phase. The significant increase in **seed weight** further indicates efficient translocation of photosynthates from vegetative tissues to developing seeds and stronger sink activity during the seed-filling stage. Together, these responses highlight the ability of mungbean to effectively utilize additional carbohydrates produced under elevated CO_2 for yield formation.

The observed enhancement in **seed yield per plant and per hectare** reflects improved source–sink relationships and sustained photosynthetic activity throughout the reproductive period. As a C_3 legume with the capacity for biological nitrogen fixation, mungbean appears well suited to benefit from rising atmospheric CO_2 concentrations projected under future climate change scenarios. These findings suggest that elevated CO_2 may partially offset some adverse impacts of climate change on crop productivity by enhancing reproductive performance and yield potential.

However, it is important to recognize that the magnitude of yield enhancement observed under CO_2-enriched conditions may vary under open-field environments. The full realization of CO_2-induced yield benefits will depend on the availability of essential resources such as nutrients, particularly nitrogen, and adequate water supply. Increased biomass production and yield under elevated CO_2 are likely to increase crop demand for nutrients, emphasizing the importance of balanced nutrient management.

In conclusion, elevated atmospheric CO_2 has considerable potential to improve mungbean productivity through enhanced yield attributes and reproductive performance. The results of this study provide valuable insights for the development of **climate-resilient pulse production systems** and highlight the need for integrated agronomic management practices to maximize the benefits of CO_2 enrichment in future agricultural systems.

References

1. Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytologist, 165*(2), 351–372. https://doi.org/10.1111/j.1469-8137.2004.01224.x
2. Bloom, A. J., Burger, M., Rubio Asensio, J. S., & Cousins, A. B. (2010). Carbon dioxide enrichment inhibits nitrate assimilation in wheat and Arabidopsis. *Science, 328*(5980), 899–903. https://doi.org/10.1126/science.1186440
3. Chowdhury, S. R., Bhattacharya, S., & Banerjee, S. (2005). Growth and yield responses of mungbean (*Vigna radiata* L.) to elevated carbon dioxide concentration. *Indian Journal of Plant Physiology, 10*(4), 353–357.
4. Chowdhury, S. R., Karim, M. A., Haque, M. M., & Hamid, A. (2005). Response of mungbean (*Vigna radiata* L.) to elevated carbon dioxide. *Photosynthetica, 43*(3), 389–394. https://doi.org/10.1007/s11099-005-0063-4
5. Conroy, J. P. (1992). Influence of elevated atmospheric CO_2 concentrations on plant nutrition. *Australian Journal of Botany, 40*(5), 445–456. https://doi.org/10.1071/BT9920445
6. Cure, J. D., & Acock, B. (1986). Crop responses to carbon dioxide doubling: A literature survey. *Agricultural and Forest Meteorology, 38*(1–3), 127–145. https://doi.org/10.1016/0168-1923(86)90054-7
7. Das, M., Uprety, D. C., & Dwivedi, N. (2000). Effects of elevated CO_2 on growth and yield of mungbean (*Vigna radiata* L.). *Indian Journal of Plant Physiology, 5*(1), 66–70.
8. Fangmeier, A., Chrost, B., Högy, P., & Krupinska, K. (2002). CO_2 enrichment enhances flag leaf senescence in barley due to greater grain nitrogen demand. *Environmental and Experimental Botany, 48*(2), 151–164. https://doi.org/10.1016/S0098-8472(02)00024-8
9. Fangmeier, A., De Temmerman, L., Black, C., Persson, K., & Vorne, V. (2002). Effects of elevated CO_2 and/or ozone on crops: A review. *Journal of Crop Improvement, 7*(1–2), 1–31. https://doi.org/10.1300/J411v07n01_01

10. Hamid, A., Haque, M. M., Karim, M. A., & Chowdhury, S. R. (2002). Photosynthesis, growth and yield of mungbean under elevated CO_2. *Bangladesh Journal of Agricultural Research, 27*(2), 227–234.
11. IPCC. (2014). *Climate change 2014: Impacts, adaptation, and vulnerability*. Cambridge University Press.
12. Kimball, B. A. (1983). Carbon dioxide and agricultural yield: An assemblage and analysis of 430 prior observations. *Agronomy Journal, 75*(5), 779–788. https://doi.org/10.2134/agronj1983.00021962007500050014x
13. Leakey, A. D. B., Ainsworth, E. A., Bernacchi, C. J., Rogers, A., Long, S. P., & Ort, D. R. (2009). Elevated CO_2 effects on plant carbon, nitrogen, and water relations. *Annual Review of Plant Biology, 60*, 207–236. https://doi.org/10.1146/annurev.arplant.59.032607.092033
14. Long, S. P., Ainsworth, E. A., Rogers, A., & Ort, D. R. (2004). Rising atmospheric carbon dioxide: Plants FACE the future. *Annual Review of Plant Biology, 55*, 591–628. https://doi.org/10.1146/annurev.arplant.55.031903.141610
15. Pal, M., Rao, L. S., Jain, V., & Srivastava, A. C. (2004). Impact of elevated CO_2 on growth and nitrogen metabolism in plants. *Plant Growth Regulation, 42*(2), 115–123. https://doi.org/10.1023/B:GROW.0000014891.39910.0c
16. Pearcy, R. W., & Björkman, O. (1983). Physiological effects of growth in high CO_2. In E. R. Lemon (Ed.), *CO_2 and plants: The response of plants to rising levels of atmospheric carbon dioxide* (pp. 65–105). Westview Press.
17. Poorter, H. (1993). Interspecific variation in the growth response of plants to an elevated ambient CO_2 concentration. *Vegetatio, 104*(1), 77–97. https://doi.org/10.1007/BF00048146
18. Reddy, K. R., Hodges, H. F., & McKinion, J. M. (1995). Carbon dioxide and temperature effects on cotton growth. *Agricultural and Forest Meteorology, 70*(1–4), 13–29. https://doi.org/10.1016/0168-1923(94)02104-X
19. Rogers, A., Ainsworth, E. A., & Leakey, A. D. B. (2009). Will elevated carbon dioxide concentration amplify the benefits of nitrogen fixation in legumes? *Plant Physiology, 151*(3), 1009–1016. https://doi.org/10.1104/pp.109.144113
20. Srivastava, A. C., Pal, M., Sengupta, U. K., & Jain, V. (2002). Growth, photosynthesis and nitrogen metabolism of mungbean under elevated CO_2. *Biologia Plantarum, 45*(3), 445–450. https://doi.org/10.1023/A:1022325713265
21. Uprety, D. C., Dwivedi, N., & Jain, V. (1996). Effect of elevated CO_2 on growth and yield of mungbean (*Vigna radiata* L.). *Indian Journal of Plant Physiology, 1*(1), 12–16.
22. Uprety, D. C., Dwivedi, N., Mohan, R., & Saxena, D. C. (1996). Effect of elevated CO_2 on growth and yield of mungbean. *Journal of Agronomy and Crop Science, 176*(2), 109–116. https://doi.org/10.1111/j.1439-037X.1996.tb00454.x
23. Vanaja, M., Raghuram Reddy, P., Maheswari, M., Jyothi Lakshmi, N., & Venkateswarlu, B. (2007). Response of yield and yield components of blackgram (*Vigna mungo* L.) to elevated CO_2. *Plant, Soil and Environment, 53*(2), 81–88.

24. Wheeler, T. R., & Reynolds, C. A. (2013). Predicting the risks from climate change to forage and crop production for animal feed. *Animal Frontiers, 3*(1), 36–41. https://doi.org/10.2527/af.2013-0006
25. Ziska, L. H., Bunce, J. A., Shimono, H., Gealy, D. R., Baker, J. T., Newton, P. C. D., Wilson, L. T. (2012). Food security and climate change: On the potential to adapt global crop production by active selection to rising atmospheric carbon dioxide. *Proceedings of the Royal Society B: Biological Sciences, 279*(1745), 4097–4105. https://doi.org/10.1098/rspb.2012.1005.