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Enhancing yield, quality, and nutrient content of green gram (*Vigna radiata* L.) through phosphorus fertilization and thiourea application

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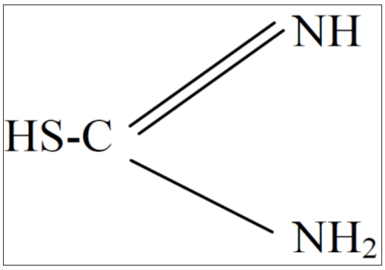
Abstract
A study conducted in the summer of 2021 evaluated the effects of various phosphorus levels and thiourea applications on the growth and nutrient dynamics of green gram in loamy sand soil. The experiment comprised four phosphorus levels (0, 20, 40, and 60 kg/ha) and five thiourea treatments (control, 500 ppm at branching, 500 ppm at branching and flowering, 1000 ppm at branching, and 1000 ppm at branching and flowering), resulting in fifteen treatment combinations. Results showed that applying up to 60 kg/ha of phosphorus significantly increased seed and straw yield, net returns, seed protein content, and nitrogen, phosphorus, and potassium concentrations and uptake. Notably, similar outcomes were observed at 40 kg/ha. The most substantial efficiency gains in phosphorus utilization were observed when increasing levels from 0 to 60 kg/ha. Additionally, the application of 500 ppm thiourea at both branching and flowering stages notably enhanced nitrogen and phosphorus concentrations, total nutrient uptake, and seed protein content. This study underscores the efficacy of tailored phosphorus and thiourea treatments in optimizing green gram cultivation in specific soil types.

Keywords: Enhancing, fertilization, nutrient, green, *Vigna radiata* L.

Introduction
Pulses, particularly vital for vegetarians, are a significant source of dietary protein, contributing approximately 14% to the average Indian diet's total protein content. The green gram, scientifically known as Vigna radiata, is a member of the legume family. Commonly referred to as mung bean or moong in India, it ranks as the third most important pulse crop in the country, following chickpea and pigeon pea. It is cultivated on about 16% of India's total pulse-growing area. During the 2019-20 period, India's total green gram production was 17.83 lakh tonnes over an area of 34.37 lakh hectares (Anon., 2019) [1]. This self-pollinated legume boasts a protein content of 24%. Its short growth duration makes it an excellent fit for various multiple and intercropping systems. Once harvested, the plant can be repurposed as high-quality green or dry fodder, or as green manure. As a legume, it enhances soil fertility by fixing atmospheric nitrogen.

In regions like Gujarat, phosphorus is often a deficient nutrient, especially in light-textured soils. The application of phosphorus to pulse crops significantly boosts yield and is hence considered a master key element. Phosphorus plays a crucial role in the growth and development of roots and is essential for the proliferation of Rhizobium bacteria, which are instrumental in the biological fixation of nitrogen. This not only improves the soil's quality but also increases the yield of both the main and subsequent crops. An adequate supply of phosphorus is known to enhance growth, yield, quality, and nodule formation in legumes (Sammauria *et al*., 2009) [10]. As a component, it contributes to the structural integrity of cell membranes, chloroplasts, and mitochondria. It is also found in energy phosphates like ADP and ATP, nucleic acids (DNA and RNA), nucleo proteins, purines, pyrimidines, nucleotides, and several coenzymes. However, 93-99% of the total phosphorus is insoluble and thus not directly available to plants. Thiourea is a sulphydryl compound with a structural formula that includes an –SH group (42.1% S) and nitrogen (36.8%) in the form of NH2.



Recognized as a plant growth regulator (Sahu and Solanki, 1991) [9], thiourea might be beneficial in enhancing the availability of phosphorus to plants. The external application of growth regulators can modify plant growth through hormonal control, differentiation, morphogenesis, and key physiological processes such as carbon and nutrient assimilation, partitioning of photosynthates, and utilization efficiency. Studies, such as those by Arora (2004), have shown that both soaking seeds and foliar spraying with thiourea not only improve plant growth and development but also enhance dry matter partitioning, leading to increased seed yield.

Materials and Methods

A field experiment was conducted in 2021 at the Instructional Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Gujarat. The soil in the experimental plot was clayey with alkaline pH (7.98) and moderate levels of available nitrogen (252.20 kg/ha), available phosphorus (36.57 kg/ha), and sulphur (11.88 kg/ha). The experiment employed a randomized block design with fifteen treatment combinations, varying phosphorus levels (20, 40, and 60 kg/ha) and thiourea treatments (control, 500 ppm spray at branching, 500 ppm spray at branching and flowering, 1000 ppm spray at branching, and 1000 ppm spray at branching and flowering). The mungbean variety GM-4 was sown at a rate of 20 kg/ha with a row spacing of 45 cm. Uniform nitrogen (20 kg/ha) was applied to all plots using urea at sowing, while phosphorus was applied through SSP based on treatment specifications. Thiourea foliar spray (500 ppm and 1000 ppm) occurred at branching and flowering stages, incorporating teepol (0.05 ml/L.), a spreading agent, in the spray solution. Nutrient concentrations and uptake were assessed using established methodologies.

Results and Discussion

Impact of Phosphorus Levels: Incremental increases in phosphorus levels significantly enhanced crucial yield parameters such as number of pods per plant, pod length, seeds per pod, test weight, seed yield, and straw yield up to 60 kg/ha, comparable to results obtained with 40 kg/ha application. The increase in seed yield at 60 kg/ha (12.60%) and 40 kg/ha (10.08%) over control was attributed to improved root development, enhanced nutrient availability and uptake, energy transformation, and enhanced metabolic processes. Phosphorus positively influenced fruiting, facilitating better metabolite translocation, contributing to increased seed yield and improved straw yield due to improved growth and nutritional status. These findings align with prior research in related leguminous crops, emphasizing phosphorus's role in enhancing growth, yield, and nutrient uptake. Application of 40 kg/ha phosphorus resulted in higher net returns (Rs. 43205/ha) compared to other levels.

Increased phosphorus levels significantly improved protein content in seeds and nitrogen, phosphorus, and potassium concentrations in both seeds and straw. Improved rhizospheric and plant nutritional environments led to increased nutrient uptake and translocation, contributing to heightened nutrient concentrations. The rise in nutrient concentration directly correlated with higher seed and straw yields, resulting in increased total nutrient uptake. Protein content elevation was attributed to increased nitrogen concentration in seeds, consistent with previous studies. Notably, increasing phosphorus from 20 to 60 kg/ha registered the highest efficiency in agronomic, apparent recovery, and physiological phosphorus efficiency.

Effect of Thiourea

Foliar application of thiourea (500 ppm at branching and flowering, 1000 ppm at branching and flowering) significantly enhanced yield attributes, including pods per plant, pod length, and seeds per pod compared to the control. Thiourea application, even at higher concentrations (1000 ppm at branching and flowering), notably increased seed yield (1251 kg/ha) over single-stage application, yielding results akin to lower concentration dual-stage application. Similar yield improvements due to foliar spray of 500 ppm thiourea were noted in earlier studies. Thiourea's role in enhancing photosynthate transport and dry matter partitioning has been established in maize productivity studies, indicating improved growth and yield. Thiourea's effect on enhancing photosynthate transport efficiency from stem to pod was substantiated in mustard plant studies, resulting in increased biological and seed yield. The study conducted at BARC, Mumbai, has demonstrated that the application of thiourea, a sulphydryl compound, plays a significant role in enhancing the translocation of photosynthates, which in turn contributes to yield formation in mustard plants. Foliar treatments with thiourea increased the efficiency of labelled sucrose (14-C) transport from the stem to the pod by 35.1-44.1% compared to untreated controls. This increase in transport efficiency resulted in a notable improvement in both biological and seed yields, attributed to enhanced growth parameters due to the foliar spray treatments.

Interestingly, the study found that a thiourea concentration of 500 ppm applied at branching and flowering stages was as effective as a 1000 ppm treatment at the same stages. The yield improvements with thiourea application were likely due to enhanced crop photosynthesis, which benefited from both improved photosynthetic efficiency and a better source-to-sink relationship. Additionally, the yield increase could be attributed to a concomitant rise in several plant growth characteristics, such as the number of pods per plant, number of seeds per pod, plant height, dry matter accumulation, and the number of nodules per plant. These findings align with the research conducted by Meena and Sharma (2005) [7] on mothbean and Bamaniya (2009) [3] on mungbean. The economic impact of thiourea application was also significant. The treatment of 1000 ppm thiourea at the branching and flowering stages yielded the highest net returns, amounting to Rs 47,752 per hectare, outperforming all other treatments. Moreover, the study revealed that foliar application of thiourea (1000 ppm at branching and 500 ppm at branching and flowering) notably increased the protein content, and nitrogen (N) and phosphorus (P) concentrations in both seed and straw, as shown in Table 2. This increase in nutrient uptake can be attributed to the enhanced yields and the increased nutrient concentration at the cellular level. The application of thiourea likely facilitated improvements in the plants' metabolic processes, leading to better growth and development through more efficient absorption of nutrients from the rhizosphere. This effect might also be linked to the metabolic role of the SH-group in root physiology and biochemistry. Additionally, thiourea may enhance soil microbial populations responsible for mobilizing essential nutrients, a finding consistent with the research of Meena and Sharma (2005) [7] and Singh (2007) [11].

Table 1: Effect of phosphorus fertilization and thiourea on yield and yield attributing characters of green gram

Treatments	Number of pods per plant	Length of pod (cm)	Number of seeds per pod	Seed yield (kg/ha)	Stover yield (kg/ha)	Test weight (g)	Harvest index (%)
[A] Phosphorus (kg/ha)							
P_1: 20	21.86	7.20	7.03	1111	1900	38.74	36.90
P_2: 40	23.19	7.78	7.16	1231	2135	40.48	36.57
P_3: 60	23.30	8.09	7.52	1251	2177	41.04	36.49
S.Em ±	0.42	0.18	0.13	27.7	60.7	0.72	0.17
C.D. at 5%	1.21	0.53	0.37	80.3	175.8	NS	NS
[B] Thiourea							
TU_0: Water spray at branching and flowering	21.40	7.16	6.96	1012	1703	38.57	37.27
TU_1: Thiourea 500 ppm spray at branching	22.34	7.18	7.01	1170	2017	38.59	36.71
TU_2: Thiourea 500 ppm spray at branching and flowering	23.58	8.19	7.37	1305	2283	41.45	36.37
TU_3: Thiourea 1000 ppm spray at branching	22.41	7.59	7.18	1177	2030	40.04	36.70
TU_4: Thiourea 1000 ppm spray at branching and flowering	24.17	8.31	7.67	1324	2321	41.80	36.32
S.Em ±	0.54	0.23	0.17	35.8	78.34	0.93	0.21
C.D. at 5%	1.57	0.68	0.48	103.6	226.94	NS	NS
Interaction (P × TU)	NS	NS	NS	NS	NS	NS	NS
C.V. %	7.12	9.16	6.91	8.96	11.35	6.95	1.74

Table 2: Effect of phosphorus fertilization and thiourea on protein, nitrogen, phosphorus and sulphur content of green gram

Treatments	Protein content in seed (%)	Protein yield (kg/ha)	Nitrogen content (%)		Phosphorus content (%)		Sulphur content (%)	
			Seed	Stover	Seed	Stover	Seed	Stover
[A] Phosphorus (kg/ha)								
P_1: 20	20.36	227.77	3.26	1.38	0.384	0.184	0.176	0.094
P_2: 40	22.04	271.98	3.53	1.51	0.425	0.208	0.197	0.102
P_3: 60	22.21	279.87	3.55	1.54	0.432	0.216	0.200	0.106
S.Em ±	0.39	6.64	0.06	0.03	0.007	0.004	0.003	0.002
C.D. at 5%	1.14	19.25	0.18	0.08	0.022	0.011	0.010	0.005
[B] Thiourea								
TU_0: Water spray at branching and flowering	19.25	195.69	3.08	1.28	0.359	0.171	0.160	0.089
TU_1: Thiourea 500 ppm spray at branching	21.10	246.59	3.38	1.43	0.397	0.193	0.178	0.097
TU_2: Thiourea 500 ppm spray at branching and flowering	22.82	298.73	3.65	1.60	0.453	0.221	0.212	0.105
TU_3: Thiourea 1000 ppm spray at branching	21.46	252.98	3.43	1.48	0.401	0.198	0.191	0.101
TU_4: Thiourea 1000 ppm spray at branching and flowering	23.05	305.38	3.69	1.62	0.459	0.231	0.214	0.111
S.Em ±	0.51	8.58	0.08	0.04	0.010	0.005	0.004	0.002
C.D. at 5%	1.48	24.85	0.24	0.10	0.028	0.014	0.012	0.006
Interaction (P × TU)	NS	NS	NS	NS	NS	NS	NS	NS
C.V. %	7.10	9.90	7.10	7.27	6.97	7.12	6.69	6.63

Table 3: Effect of different levels of phosphorus and thiourea spray on economics of green gram

Treatments	Yield (kg/ha)		Gross realization (₹/ha)	Cost of cultivation (₹/ha)	Net realization (₹/ha)	BCR
	Seed	Stover				
[A] Phosphorus						
P_1: 20	1111	1900	69050	32339	36710	2.14
P_2: 40	1231	2135	76584	33480	43104	2.29
P_3: 60	1251	2177	77826	34621	43205	2.25
[B] Thiourea						
TU_0: Water spray at branching and flowering	1012	1703	62831	32991	29840	1.90
TU_1: Thiourea 500 ppm spray at branching	1170	2017	72760	32738	40022	2.22
TU_2: Thiourea 500 ppm spray at branching and flowering	1305	2283	81215	33834	47381	2.40
TU_3: Thiourea 1000 ppm spray at branching	1177	2030	73197	33159	40038	2.21
TU_4: Thiourea 1000 ppm spray at branching and flowering	1324	2321	82430	34678	47752	2.38

Conclusion

In conclusion, this study illustrates that the combined application of phosphorus and thiourea significantly boosts the yield and nutrient content of green gram. Phosphorus application up to 60 kg/ha enhances root development, nutrient uptake, and plant metabolism, leading to increased yields in seeds and straw, a higher number of pods, and improved nutrient content in seeds. Concurrently, the use of thiourea as a foliar spray increases the number of pods, pod length, and seed numbers, thereby contributing to higher yields and better seed quality. These combined treatments present effective strategies for optimizing green gram cultivation in similar soil conditions, underscoring their potential to elevate productivity and nutritional value in this vital crop.

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