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EVALUATION OF PRECISION NUTRIENT MANAGEMENT PRACTICES IN GREEN GRAM

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ABSTRACT

A field experiment was conducted during summer season of 2024 and 2025 at Instructional Farm, Department of Agronomy, College of Agriculture, Dapoli; Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra (India). The experiment was laid out in Split Plot Design (SPD) with twenty-one treatment combinations and replicated thrice. The main plot treatment comprised of fertilizer levels viz., F_1: Absolute control, F_2: 100 % RDF through straight fertilizer, F_3: 80 % RDF through straight fertilizer. The sub plot treatment comprised of Nano fertilizer levels viz., N_1: Absolute control, N_2: Nano N @ 50 ppm + Nano P @ 100 ppm, N_3: Nano N @ 50 ppm + Nano P @ 200 ppm, N_4: Nano N @ 50 ppm + Nano P @ 300 ppm, N_5: Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm, N_6: Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm, N_7: Nano N conjugate @ 50ppm + Nano P conjugate @ 300 ppm. Two foliar sprays are given at 20 DAS and 40 DAS. The results revealed that, 100% RDF (F_2) significantly increased seed protein content (pooled: 23.32%) and leaf total soluble sugar (3.35 mg g^{-1} FW) and total reducing sugar (2.86 mg g^{-1} FW) compared to the absolute control. Among sub-plot treatments, the combination of nano N conjugate @ 50 ppm with nano P conjugate @ 300 ppm (N_7) consistently recorded the highest values for seed protein (23.01%), leaf total soluble sugar (3.39 mg g^{-1} FW), and total reducing sugar (2.90 mg g^{-1} FW). Significant interaction effects between main plot and sub-plot treatments indicated that integrating conventional fertilizers with nano-fertilizers synergistically improves the nutritional and metabolic quality of green gram. The overall means of seed protein (22.14%), total soluble sugar (3.12 mg g^{-1} FW), and total reducing sugar (2.63 mg g^{-1} FW) highlight the potential of nano-fertilizer-based nutrient management for enhancing green gram seed quality.

***Keywords* :** Fertilizer levels, Nano Fertilizers, Nitrogen, Phosphorous, Green gram.

Introduction

Green gram (*Vigna radiata* L. Wilczec) commonly known as moong, mug, or mung, is one of India's oldest and most widely cultivated leguminous crops. Belonging to the family Leguminosae, it ranks third in area and production among pulses, after pigeon pea and chickpea. Green gram is grown across almost all regions of the country under a variety of agro-climatic conditions. It is highly valued for its protein-rich seeds, making it an important dietary source to help combat protein malnutrition in humans. It occupies prime position among pulses by virtue of its short growth period, high biomass and outstanding nutrient value as food, feed and forage. It is an ideal source of protein and amino acids and its seed contain, 24.7% protein, 3.7% ash, 0.9% fiber and 0.6% fat as well as sufficient quantity of calcium, phosphorus and important vitamins (Ghule et. al., 2020). Sprouted seeds of green gram synthesize vitamin C and are commonly consumed as salads or after roasting. Considering that the majority of the Indian population follows a vegetarian diet, green gram plays a crucial role in fulfilling dietary protein requirements. It is widely utilized in various forms, including dal, halwa, namkeen, snacks, and other culinary preparations. Green gram also offers significant potential for expanding pulse production and cultivation area. Its cultivation during the summer season has gained broad acceptance among farmers due to several agronomic advantages, including additional income generation, improvement of soil fertility, efficient land utilization, low incidence of pests and diseases, and contribution to long-term agricultural sustainability without negatively affecting main crops. (Idnani and Gautam, 2008). It also provides nutritious and laxative green and dry fodder for livestock. As a short-duration crop with wide adaptability, it can be cultivated in both the summer and *kharif* seasons. In particular, it is an important summer crop, locally referred to as 'Vaishakhi Mug'. During the summer season, green gram achieves high yields with bold, lustrous seeds, which can be attributed to favorable climatic conditions and the low incidence of insect pests and diseases during this period. Based on average data from 2018–19 to 2022–23, mung bean (*Vigna radiata* L.) is a significant pulse crop in India. Nationally, it is cultivated on 51.13 lakh hectares, producing 29.78 lakh tonnes, with an average productivity of approximately 583 kg per hectare. In Maharashtra, mung bean is grown on 3.89 lakh hectares, representing 8% of the country's total cultivation area, and contributes 1.83 lakh tonnes, accounting for 6% of national production. The state's average productivity is around 471 kg per hectare, which is below the national average (Anonymous, 2024). The major green gram-producing states are Rajasthan, Madhya Pradesh, Maharashtra, Karnataka, and Uttar Pradesh, collectively contributing the majority of the country's output.

The increasing global population, rapid urbanization, climate change, and environmental degradation collectively present significant challenges to food security, which remains a cornerstone of sustainable development in the 21st century (FAO, 2017). According to FAO projections, global food demand is expected to rise substantially in the coming decades, placing pressure on agricultural systems to produce more from limited land and resources. Low productivity in pulse crops is attributed to multiple factors, including cultivation by smallholder and resource-poor farmers on marginal lands. However, the lack of adoption of scientific cultivation practices is also a major constraint, highlighting the need for the implementation of improved agronomic methods to enhance pulse yields. Fertilizers have played a crucial role in enhancing crop yields and supporting global food security. However, the increasing dependence on chemical fertilizers to meet rising crop demands has exerted significant pressure on soil and water ecosystems. While conventional fertilizers have contributed to substantial yield improvements, their indiscriminate and excessive use has resulted in numerous adverse effects, including soil degradation, contamination of surface and groundwater, greenhouse gas emissions (e.g., nitrous oxide), and disruption of soil microbial communities. These impacts collectively lead to the depletion of soil organic matter, accelerated acidification, and long-term deterioration of soil fertility. Therefore, developing strategies to minimize fertilizer input while maintaining or improving crop productivity is a critical challenge for achieving sustainable agricultural systems. To overcome the limitations of conventional agricultural inputs, nanotechnology has emerged as a promising innovation in modern agriculture (Zulfiqar *et al*., 2019). Nanofertilizers, in particular, represent a significant advancement in enhancing nutrient-use efficiency in crop production. They can be formulated as nano-sized particles, nano-encapsulated nutrients, or nutrients incorporated within nanoporous carriers, enabling controlled and targeted nutrient release that aligns with crop demand at different growth stages. The unique physicochemical properties of these nanomaterials facilitate improved penetration into plant tissues, efficient internalization, and enhanced nutrient mobility. For instance, nitrogen-based nanofertilizers improve nitrogen-use efficiency by reducing nitrate leaching and mitigating nitrous oxide emissions, while phosphorus-based nanofertilizers address soil fixation issues and increase phosphorus bioavailability. Encapsulation of urea and phosphorus within chitosan matrices has enabled the development of slow-release nanofertilizers, which minimize nitrogen losses and enhance crop productivity. Additionally, foliar application of nanoparticle-based fertilizers allows direct nutrient uptake, reduces soil-mediated nutrient interactions, lowers disease incidence, and improves overall crop performance.

Materials and Methods

The experiment was conducted at the Instructional Farm, Department of Agronomy, College of Agriculture, Dapoli, located in the subtropical zone at 17°45′57″ N latitude and 73°10′29″ E longitude, with an elevation of approximately 157.8 meters above mean sea level. The region experiences a warm and humid subtropical climate. The experimental soil was sandy clay loam in texture.

The study was laid out in a split-plot design with three main treatments and seven sub-plot treatments, each replicated thrice. The planting spacing was maintained at 30 cm × 15 cm. The gross plot area was 3.60 m × 3.75 m, and the net plot area was 3.00 m × 3.45 m. The main plot treatments consisted of conventional fertilizer levels: F_1 - Absolute control, F_2 - 100% RDF through straight fertilizer F_3 - 80% RDF through straight fertilizer. The sub plot treatment for green gram are N_1 - Absolute control, N_2 - Nano N @ 50 ppm + Nano P @ 100 ppm, N_3 - Nano N @ 50 ppm + Nano P @ 200 ppm, N_4 - Nano N @ 50 ppm + Nano P @ 300 ppm, N_5 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm, N_6 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm, N_7 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm.

Protein content in grains was estimated by multiplying the nitrogen content (%) by 6.25. For biochemical analyses, fresh mature leaves were collected at 45 days after sowing (DAS), immediately preserved in liquid nitrogen, and stored under deep refrigeration. Total soluble sugars and total reducing sugars in the leaves were determined following the method described by Dubois *et al*. (1956).

Results and Discussion

Effect of fertilizer levels on seed protein content:

The protein content in seeds was significantly influenced by the main plot treatments over both years (2024 and 2025) and in the pooled analysis as showed in Table 1. The highest protein content was observed under F_2 (100% RDF through straight fertilizer), recording 23.15% in 2024, 23.48% in 2025, and a pooled mean of 23.32%, which was significantly higher than the absolute control (F_1), which recorded 20.48%, 20.65%, and 20.57%, respectively. The 80% RDF treatment (F_3) also increased protein content compared to the control, with a pooled value of 22.53%. Statistical analysis revealed that the differences among the main plot treatments were significant. The observed increase in protein content can be attributed to the sufficient availability of nitrogen, which is essential for amino acid synthesis, the fundamental building blocks of proteins. Additionally, phosphorus promotes root nodulation in leguminous crops, thereby enhancing biological nitrogen fixation and improving nitrogen availability to the plant. Phosphorus also serves as an energy source in metabolic processes involved in protein synthesis. These findings are consistent with previous reports by Singh *et al*. (2007), Singh and Pandey (2017), Muwal and Dhaked (2022), and Pareek *et al*. (2022), who emphasized the role of nitrogen as a protein precursor and the contribution of phosphorus-induced nodulation in increasing nitrogen content and protein synthesis in plants.

Table 1 : Effect of different treatments on protein content (%) in seed of green gram during 2023-2024, 2024-2025 and in the pooled mean

Treatment	Protein content in seed (%)		
	2024	**2025**	**Pooled data**
A) Main plot			
F_1 -Absolute Control	20.48	20.65	20.57
F_2 -100 % RDF through straight fertilizer	23.15	23.48	23.32
F_3 - 80 % RDF through straight fertilizer	22.41	22.65	22.53
S.E.(m)±	0.03	0.05	0.04
C.D. at 5%	0.13	0.20	0.14
B) Sub plot			
N_1 -Absolute Control	20.21	20.54	20.38
N_2 - Nano N @ 50 ppm + Nano P @ 100 ppm	21.82	21.90	21.86
N_3 - Nano N @ 50 ppm + Nano P @ 200 ppm	22.02	22.17	22.09
N_4 - Nano N @ 50 ppm + Nano P @ 300 ppm	22.20	22.43	22.32
N_5 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm	22.43	22.68	22.55
N_6 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm	22.62	22.91	22.76
N_7 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm	22.82	23.20	23.01
S.E.(m)±	0.07	0.08	0.09
C.D. at 5%	0.19	0.23	0.27
Interaction effects			
S.E.(m)±	0.11	0.14	0.16
C.D. at 5%	0.32	0.39	0.46
General mean	22.02	22.26	22.14

Effect of nano fertilizers on seed protein content

Nano-fertilizer applications significantly enhanced seed protein content compared to the N_1 (absolute control). Among the sub-plot treatments, N_7 (Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm) resulted in the highest protein content, with values of 22.82% (2024), 23.20% (2025), and a pooled mean of 23.01%. Protein content generally increased with increasing doses of nano P and its conjugates. The differences among subplot treatments were statistically significant. These results are in agreement with the findings of Yacoub *et al*. (2020), Prakash *et al*. (2023), and Khemshetty *et al*. (2024), who demonstrated that enhanced nitrogen uptake promotes protein biosynthesis by increasing amino acid formation, while phosphorus supports protein synthesis through the regulation of nucleic acid (RNA and DNA) metabolism.

Table 2 : Effect of fertilizer levels and nano fertilizers on total soluble sugars (mg g^{-1} FW) in leaves of green gram during 2024, 2025 and in the pooled data

Treatment	**Total soluble sugar in leaves (mg g^{-1} FW)**		
	2024	**2025**	**Pooled data**
A) Main plot			
F_1 -Absolute Control	2.75	2.86	2.81
F_2 -100 % RDF through straight fertilizer	3.30	3.41	3.35
F_3 - 80 % RDF through straight fertilizer	3.18	3.24	3.21
S.E.(m)±	0.01	0.01	0.01
C.D. at 5%	0.02	0.06	0.04
B) Sub plot			
N_1 -Absolute Control	2.74	2.84	2.79
N_2 - Nano N @ 50 ppm + Nano P @ 100 ppm	2.92	2.99	2.95
N_3 - Nano N @ 50 ppm + Nano P @ 200 ppm	3.00	3.08	3.04
N_4 - Nano N @ 50 ppm + Nano P @ 300 ppm	3.09	3.18	3.13
N_5 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm	3.18	3.28	3.23
N_6 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm	3.26	3.37	3.32
N_7 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm	3.34	3.44	3.39
S.E.(m)±	0.02	0.02	0.03
C.D. at 5%	0.06	0.07	0.09
Interaction effects			
S.E.(m)±	0.04	0.04	0.05
C.D. at 5%	0.11	0.12	0.15
General mean	3.08	3.17	3.12

Effect of fertilizer levels on total soluble sugars (mg g^{-1} FW) in leaves:

Total soluble sugar content in leaves was significantly influenced by the fertilizer levels during both years and in the pooled analysis (Table 2). The highest sugar accumulation was observed under F_2 (100% RDF through straight fertilizer), recording 3.30 mg g^{-1} FW in 2024, 3.41 mg g^{-1} FW in 2025, and a pooled mean of 3.35 mg g^{-1} FW. This was significantly higher than the absolute control (F_1), which showed 2.75, 2.86, and 2.81 mg g^{-1} FW, respectively. The 80% RDF treatment (F_3) also increased sugar content over the control, with a pooled value of 3.21 mg g^{-1} FW. These results indicate that appropriate fertilizer application enhances the photosynthetic activity and carbohydrate accumulation in leaves.

Effect of nano fertilizers on total soluble sugars (mg g^{-1} FW) in leaves:

Nano-fertilizer applications significantly improved leaf total soluble sugar compared to the absolute control (N_1). Among the treatments, N_7 (Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm) exhibited the highest sugar content, with 3.34 mg g^{-1} FW in 2024, 3.44 mg g^{-1} FW in 2025, and a pooled mean of 3.39 mg g^{-1} FW. A clear trend was observed where sugar content increased with higher doses of nano P and its conjugates. The enhancement of soluble sugar under nano-fertilizer treatments can be attributed to improved nutrient uptake, better photosynthetic efficiency, and enhanced metabolic activity in the leaves. The increase in total soluble sugar can be mechanistically linked to enhanced activity of α-amylases and invertase, leading to greater hydrolysis of starch into soluble sugars such as glucose, sucrose, and fructose. These sugars act as compatible solutes, help in cell turgor maintenance, and serve as immediate carbon sources for energy metabolism (Bilge *et al*., 2026).

Table 3 : Effect of fertilizer levels and nano fertilizers on total reducing sugars (mg g^{-1} FW) in leaves of green gram during 2024, 2025 and in the pooled data

Treatment	Total reducing sugars in leaves (mg g^{-1} FW)		
	2024	2025	Pooled data
A) Main plot			
F_1 -Absolute Control	2.32	2.35	2.33
F_2 -100 % RDF through straight fertilizer	2.87	2.86	2.86
F_3 - 80 % RDF through straight fertilizer	2.70	2.70	2.70
S.E.(m)±	0.01	0.02	0.01
C.D. at 5%	0.03	0.09	0.06
B) Sub plot			
N_1 -Absolute Control	2.33	2.33	2.33
N_2 - Nano N @ 50 ppm + Nano P @ 100 ppm	2.47	2.48	2.48
N_3 - Nano N @ 50 ppm + Nano P @ 200 ppm	2.54	2.56	2.55
N_4 - Nano N @ 50 ppm + Nano P @ 300 ppm	2.63	2.63	2.63
N_5 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 100 ppm	2.73	2.73	2.73
N_6 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 200 ppm	2.81	2.80	2.81
N_7 - Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm	2.89	2.91	2.90
S.E.(m)±	0.02	0.02	0.02
C.D. at 5%	0.05	0.06	0.07
Interaction effects			
S.E.(m)±	0.03	0.04	0.04
C.D. at 5%	0.08	0.11	0.12
General mean	2.63	2.63	2.63

Effect of fertilizer levels on total reducing sugars (mg g^{-1} FW) in leaves

Total reducing sugar content in leaves was significantly influenced by the main plot treatments over both years and in the pooled analysis (Table 3). The highest reducing sugar content was observed under F_2 (100% RDF through straight fertilizer), recording 2.87 mg g^{-1} FW in 2024, 2.86 mg g^{-1} FW in 2025, and a pooled mean of 2.86 mg g^{-1} FW. This was significantly higher than the absolute control (F_1), which recorded 2.32, 2.35, and 2.33 mg g^{-1} FW, respectively. The 80% RDF treatment (F_3) also showed a moderate increase in reducing sugar content over the control, with a pooled value of 2.70 mg g^{-1} FW. The results indicate that optimal nutrient supply through RDF enhances carbohydrate metabolism and accumulation of reducing sugars in leaves.

Effect of nano fertilizers on total reducing sugars (mg g^{-1} FW) in leaves

Nano-fertilizer applications significantly enhanced leaf reducing sugar content compared to the N_1 (absolute control). Among the sub-plot treatments, N_7 (Nano N conjugate @ 50 ppm + Nano P conjugate @ 300 ppm) resulted in the highest reducing sugar content, with 2.89 mg g^{-1} FW in 2024, 2.91 mg g^{-1} FW in 2025, and a pooled mean of 2.90 mg g^{-1} FW. A consistent trend of increasing reducing sugar content was observed with higher doses of nano P and its conjugates, reflecting improved nutrient uptake and metabolic efficiency under nano-fertilizer application. Francis *et al*. (2022) reported that the nanoparticles such as nanoparticles improved total reducing sugar in amaranthus, indicating that the potential of nanomaterials in enhancing crop productivity

Conclusion

Application of 100% of the recommended dose of conventional fertilizers resulted in significantly higher seed protein content, total soluble sugars, and reducing sugars, both in individual years of experimentation and in pooled analysis. Among the nano-fertilizer treatments, the combined application of Nano N conjugate (50 ppm) and Nano P conjugate (300 ppm) significantly improved seed protein content, total soluble sugars, and reducing sugars compared to the absolute control. These findings indicate that both conventional and nano-fertilizer strategies can effectively enhance the nutritional quality of seeds, with nano-fertilizers offering a promising alternative for sustainable nutrient management.

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