International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating: 5.29
IJABR 2025; 9(3): 649-652
www.biochemjournal.com
Received: 16-01-2025
Accepted: 19-02-2025

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Impact of plant growth regulators and micronutrients on the economic aspects of fenugreek (*Trigonella foenum-graecum* L.)

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i3h.4014

Abstract
An experiment was conducted during *Rabi* 2019-20 at the College of Agriculture, Indore (Madhya Pradesh), to evaluate the profitability and cost-effectiveness of integrating Plant Growth Regulators (PGRs) and micronutrient applications in fenugreek (*Trigonella foenum-graecum* L.) cultivation. The experiment comprised nine treatments, including varying levels of GA3, NAA, and Mixol (a micronutrient mix containing zinc, iron, manganese, copper, boron, and molybdenum) compared to a control. Economic parameters such as cost of cultivation, gross returns, net returns, and benefit-cost ratio (BCR) were analyzed. The data revealed that the highest seed yield of 15.24 q/ha, along with a maximum net income of Rs. 132080 per ha, Gross income of Rs. 182880 per ha and benefit-cost ratio of 3.60, was recorded under treatment T_4 (GA3 @ 100 ppm as foliar spray + 1.0% Mixol) followed by net income of Rs. 123513 per ha, Gross income of Rs. 180960 per ha and benefit-cost ratio of 3.15 were observed in treatment T_8 (NAA @50 ppm as foliar spray + 1.0% Mixol). The control treatment (T_9) resulted in a seed yield of 12.32 q/ha, with the minimum net income of Rs. 69202 per ha of Rs. 180960 per ha, Gross income of Rs. 147840 and lowest benefit-cost ratio (1.88). Among the treatments, the of T_4 (GA3 @ 100 ppm as foliar spray + Mixol 1.0%) demonstrated the highest economic viability, with significantly increased net returns and benefit-cost ratio due to improved seed yield. This study highlights the financial benefits of adopting optimized PGR and micronutrient applications in fenugreek cultivation, providing a practical framework for enhancing farmers' income and resource-use efficiency.

Keywords: Benefit-cost ratio, cost of cultivation, micro-nutrient (Mixol), PGRs, GA_3, NAA, foliar spray, fenugreek

Introduction

Fenugreek (*Trigonella foenum-graecum* L.) is an important spice and one of the oldest medicinal crop widely cultivated for its seeds and leaves, which have culinary, pharmaceutical, and industrial applications (Srinivasan, 2006) [14, 15]. It is a tropical crop and generally sown in the winter season for seed production. Seeds of fenugreek spice have medicinal properties such as hypocholesterolemic, lactation aid, antibacterial, gastric stimulant, for anorexia, antidiabetic agent, galactogogue, hepatoprotective effect and anticancer. Its seeds contain 45.4% dietary fiber (32% insoluble and 13.3% soluble), and the gum is composed of galactoseand mannose (Wani and Kumar, 2018) [17]. In recent years, enhancing the economic viability of fenugreek cultivation has gained attention due to its potential role in sustainable agriculture and the increasing demand for its bioactive compounds (He *et al*., 2015) [3].

Plant growth regulators (PGRs) play a crucial role in modulating physiological processes, improving growth, and increasing seed yield, ultimately affecting economic returns (Patel *et al*., 2018) [12]. Studies have demonstrated that foliar application of gibberellic acid (GA_3) and NAA significantly enhances seed yield and biomass accumulation in fenugreek, leading to higher net profits (Parmar *et al*. 2018) [11]. Gibberellic acid, a key growth-stimulating substance, aids in increasing stalk length, enhancing vegetative growth, initiating flowering, improving fruit size, hastening maturity, and improving fruit quality in various crops (Swamy, 2012; Haq *et al*., 2013) [16, 2]. Similarly, synthetic auxin, such as Naphthalene Acetic Acid (NAA), is important in processes like cell elongation, cell division, vascular tissue differentiation, root inhibition, apical dominance, leaf senescence, leaf and fruit abscission, fruit setting, and flowering. Foliar application of PGRs has proven to be highly effective in increasing vegetative growth, early fruiting, total yield, and overall productivity, which directly influence economic feasibility. (Mandal *et al*. 2012) [5]. Micronutrients elements like Mixol, particularly zinc, iron, manganese, copper, boron and molybdenum, are essential for enzymatic activities, chlorophyll synthesis, reproductive stages and overall plant growth. Zinc (Zn) and iron (Fe) are some of the most important micronutrient essential for plant growth. Muthukumararaja *et al*. 2012 [8]. Iron is most important for the respiration and photosynthesis processes. Iron is play responsibility in many plant functions. These functions include chlorophyll development, energy transfer, an ingredient of sure enzymes and proteins, and involved in nitrogen fixation. Co is required by bacteria that fix nitrogen in legumes. Boron is a micronutrient required for all plant nutrition. Research indicates that seed treatment and foliar supplementation of PGRs and micronutrients not only improves seed quality but also enhances marketable yield, contributing to better cost-benefit ratios (Meena *et al*. 2017; Mandal *et al*. 2012) [7, 5]. The synergistic effects of micronutrients with PGRs have shown promising results in improving nutrient uptake efficiency and maximizing economic returns for farmers (Sivran *et al*. 2016) [13].

Despite these benefits, limited studies have comprehensively evaluated the combined impact of PGRs and micronutrients on fenugreek's economic aspects. Therefore, this study aims to assess how integrating plant growth regulators and micronutrients influences growth, yield, and profitability in fenugreek cultivation. Understanding these interactions will provide insights into cost-effective and sustainable agronomic practices that can enhance farmers' incomes and ensure better resource utilization (Gour *et al*. 2009) [1].

2. Materials and Methods

The field experiments were carried out using fenugreek plants grown under natural condition of field. The experiments were performed during the Rabi seasons 2019-20 at the Experimental Unit of the College of Agriculture, Indore Madhya Pradesh. Geographically, the study site is located at 22°43' N latitude and 75°66' E longitude, with an elevation of 556 meters above sea level. This region falls under Agro-Climatic Zone-I (Malwa Plateau) in Western Madhya Pradesh. The climate is sub-tropical, characterized by moderately cold winters and occasional winter rainfall. Summer temperatures range from 21 °C to 44 °C, while winter temperatures vary between 6 °C and 32 °C. Precipitation was 965 mm during the growing season. The experimental field comprises medium black clay soil (Vertisols), known for its high fertility and good moisture retention capacity. The soil surface remains stable and has effective drainage, making it well-suited for fenugreek cultivation. The experiment was carried out in a randomized block design (RBD) with a plot size of 3 x 2.5 m, with three replications and nine treatments. Spraying of PGRs and micronutrients was carried out at 30 and 35 days after sowing. The treatments included GA_3 (50 and 100 ppm) and NAA (50 and 100 ppm), applied as both seed treatment and foliar spray. Additionally, a foliar application of Mixol (1.0%) was tested, along with a control treatment without plant growth regulators (PGRs) and micronutrients.

Table 1: Treatment combinations

Symbols	Treatments details
T_1	GA_3 at 50 ppm + seed treatment + Mixol 1.0%
T_2	GA_3 at 100 ppm + seed treatment + Mixol 1.0%
T_3	GA_3 at 50 ppm + foliar spray + Mixol 1.0%
T_4	GA_3 at 100 ppm + foliar spray + Mixol 1.0%
T_5	NAA at 25 ppm + seed treatment + Mixol 1.0%
T_6	NAA at 50 ppm + seed treatment + Mixol 1.0%
T_7	NAA at 25 ppm + foliar spray + Mixol 1.0%
T_8	NAA at 50 ppm + foliar spray + Mixol 1.0%
T_9	Control (No use of PGRs and micro-nutrients)

Economics from different treatments

Cost of Cultivation

The cost of cultivation for every treatment was calculated with the aid of thinking about the market expenses of all inputs applied for cultivating fenugreek on a per-hectare basis. This concerned isolating the costs into common inputs/practices, which were consistent across all treatments, and variable inputs, which differed based at the particular treatments. The entire cost of cultivation changed into derived by summing the common costs with the variable prices relevant to every treatment. This furnished an correct illustration of the investment required for each treatment.

Gross Monetary Return

The gross economic return for every treatment turned into determined by calculating the cost of the overall produce based at the prevailing market expenses. This calculation was carried out on a per-hectare basis, reflecting the gross income generated from the fenugreek crop for every particular treatment.

Net Monetary Return

The net monetary return, representing the profitability of each treatment, was calculated using the formula:

Net Monetary Return (₹/ha) = Gross Monetary Return (₹/ha)-Cost of Cultivation (₹/ha)

This formula facilitated a straightforward comparison of the economic viability of each treatment, helping to identify the most cost-effective and profitable approach.

Benefit and cost ratio (Profitability)

The benefit and cost ratio for each treatment was calculated by using the following formula:

B:C Ratio = Gross monetary return per hectare for a treatment/Cost of cultivation per hectare for the same treatment.

Results and Discussion

The economic analysis of different treatment combinations revealed a significant variation in net return and benefit-cost ratio (BCR) in fenugreek production (Table 2).

Net return from each treatment combination:

Among all treatments, T_4 (GA_3 @ 100 ppm as foliar spray + 1.0% Mixol) exhibited the highest seed yield of 15.24 q/ha, leading to a maximum net income of Rs. 132080 per ha. The superior yield and profitability in T_4 can be attributed to the synergistic effect of gibberellic acid (GA_3) and micronutrient supplementation, which enhanced plant growth, phenology, and seed development. These findings are in agreement with Nehara *et al*. (2006) [10] who also reported improved yield attributes in fenugreek with the application of plant growth regulators (PGRs). Conversely, the lowest economic response was recorded in T_9, which did not receive any PGRs or micronutrients, resulting in the minimum seed yield of 12.32 q/ha and significantly lower net returns. The reduced productivity in T_9 suggests that the absence of growth stimulants and micronutrients restricted plant development and yield potential, corroborating the observations of Manickam *et al*. (2021) [6]. The comparative analysis clearly indicates that integrating GA_3 and micronutrients plays a crucial role in enhancing fenugreek yield and economic viability, making T_4 the most effective treatment for maximizing productivity and profitability. Similar views have been expressed by Meena *et al*. (2017) [7], Nair *et al*., (1992) [9] in Japanese mint, Gour *et al*. (2009) [1] and Kumawat (2015) [4] in fennel.

B: C ratio

The benefit-cost ratio (B:C) analysis revealed significant variation among different treatment combinations, indicating the economic effectiveness of plant growth regulators (PGRs) and micronutrient applications in fenugreek production (Table 2). The highest B:C ratio (3.60) was observed in T_4 (100 ppm GA_3 foliar spray with Mixol 1.0%), highlighting its superior cost-effectiveness due to increased seed yield and net returns. This improvement can be attributed to the role of GA_3 in enhancing cell elongation, photosynthetic efficiency, and nutrient uptake, leading to better growth and yield formation. Additionally, the presence of micronutrients in Mixol further contributed to enhanced enzymatic activities and physiological functions, ultimately maximizing economic returns. These findings align with previous studies by Nehara *et al*. (2006) [10] and Meena *et al*. (2017) [7], which demonstrated the positive impact of PGRs on fenugreek yield and profitability. On the other hand, the lowest B:C ratio (1.88) was recorded in T_9, where no PGRs or micronutrients were applied. The lack of external growth stimulation resulted in restricted plant development and lower seed yield, leading to reduced net returns and cost-effectiveness. Similar observations were reported by Manickam *et al*. (2021) [6], emphasizing that untreated fenugreek plots exhibited lower economic benefits compared to those treated with growth-enhancing substances. The substantial difference between T_4 and T_9 underscores the economic advantage of integrating GA_3 and micronutrients, proving that their application significantly improves both productivity and profitability in fenugreek cultivation.

Gross income: The prevailing market price for fenugreek seed was considered @ Rs. 80/-per kg.

Table 2: Effect of plant growth regulators (PGRs) and Micro-nutrient on economics

Sym.	Seed yield (q/ha)	Gross income (Rs/ha)	Expenditure (Rs/ha)	Net income (Rs/ha)	B:C Ratio
T_1	12.56	150720	62539	88181	2.41
T_2	14.12	169440	59244	110196	2.86
T_3	14.88	178560	58352	120208	3.06
T_4	15.24	182880	50800	132080	3.60
T_5	13.42	161040	63152	97888	2.55
T_6	13.84	166080	61970	104110	2.68
T_7	14.44	173280	58540	114740	2.96
T_8	15.08	180960	57447	123513	3.15
T_9	12.32	147840	78638	69202	1.88

Conclusion

The study clearly demonstrates the significant influence of integrating plant growth regulators and micronutrients on the economic viability of fenugreek production. Among all treatments, T_4 (GA_3 @ 100 ppm as foliar spray + 1.0% Mixol) emerged as the most effective, yielding the highest seed production (15.24 q/ha), net income (Rs. 132080/ha), and benefit-cost ratio (3.60). The enhanced productivity in T_4 is attributed to the synergistic effects of GA_3 and micronutrients, which improved plant growth, phenology, and seed development. Conversely, the lowest economic response was recorded in T_9, highlighting the importance of external growth stimulants in maximizing yield potential. The findings reaffirm the crucial role of plant growth regulators and micronutrients in improving both productivity and profitability, making T_4 a promising strategy for optimizing fenugreek cultivation.

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