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Harnessing Agro-chemicals for Resilient Green Gram: Strategies to Alleviate Moisture Stress in Rainfed Ecosystems

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Abstract

A field experiment was conducted during the 2021 *Kharif* season to assess the effectiveness of agro-chemicals in mitigating moisture stress in green gram (*Vigna radiata* L.) under rainfed conditions. The study was executed in a Randomized Block Design with ten treatments, including a control, soil application of the herbal hydrogel *Tragacanth katira*, foliar sprays of salicylic acid (SA), potassium nitrate (KNO_3) and their various combinations. The primary objective was to evaluate the impact of these treatments on physiological traits, yield parameters, nutrient uptake and water use efficiency of green gram under rainfed conditions. Results consistently showed that the combined application of *Tragacanth katira* @ 5.0 kg ha^{-1} along with a 1% foliar spray of KNO_3 at flowering and pod initiation (T10) stages proved to be the most effective treatment. While the treatments showed non-significant effects on root-shoot ratio and harvest index, T10 significantly enhanced the number of grains pod^{-1} (11.3, representing a 61.4% increase compared with the control) and extended the duration to physiological maturity (64.7 days, corresponding to a 8.19% increase over the control). This led to a substantial increase in grain yield (1178 kg ha^{-1}) and straw yield (2551 kg ha^{-1}), representing a 26.1 and 16.6% increase, respectively, over the control. Furthermore, T10 maximized N, P and K uptake and significantly improved both water use efficiency and water productivity. The findings underscore the synergistic benefits of integrating soil moisture conservation with foliar nutrient supply, demonstrating a viable and profitable strategy for enhancing green gram productivity in water-scarce environments.

Keywords: Nutrient uptake, Potassium nitrate, Salicylic acid, *Tragacanth katira*, *Vigna radiata*, Water use efficiency

Introduction

India has achieved significant advancements in pulse production over the past two decades. Between 2005–06 and 2020–21, the country's total pulse production increased from 13.38 to 25.58 million metric tonnes. Among the various pulse crops, green gram recorded the highest increase in production at 178%, followed by chickpea (125%), black gram (90%), pigeon pea (51%) and lentil (34%) (Gurusamy *et al*., 2022). Green gram (*Vigna radiata L.*), commonly known as mungbean, is a self-pollinating legume native to India, cultivated during both the *Kharif* and summer seasons in the arid and semi-arid regions. It is a rich source of high-quality protein (25%) and essential amino acids such as lysine and tryptophan, making it easily digestible and suitable for patients. Besides its nutritional value, green gram contributes to soil health by fixing atmospheric nitrogen (Jat *et al*., 2020).

Water scarcity is a major agricultural concern in India, with over 60% of cultivated land relying on rainfed systems and more than 30% of areas experiencing inadequate rainfall (Kalhapure *et al*., 2016; Waghmare *et al*., 2019). In this context, agro-chemicals like herbal hydrogel (*Tragacanth katira*), salicylic acid (SA) and potassium nitrate (KNO_3) are crucial in mitigating drought stress and promoting crop growth. Salicylic acid, a phenolic phytohormone, enhances photosynthesis and regulates stomatal function (Abrol *et al*., 2020; Shemi *et al*., 2021). Potassium, an essential macronutrient, plays a key role in plant water regulation by maintaining osmotic balance and supporting physiological functions such as turgor pressure, root and shoot growth and transpiration (Noreen *et al.*, 2018; Lather, 2019). Foliar application of potassium has been shown to improve both crop yield and water use efficiency (Mesbah, 2009). Given its role in water uptake and plant hydration, potassium nitrate stands out as a promising treatment for enhancing water economy and growth in crops like green gram, especially under rainfed conditions (Krishna and Kaleeswari, 2018). Considering these benefits, the current study was designed to evaluate the water use efficiency of green gram under various agro-chemical treatments in field conditions.

Materials and Methods

A field experiment was conducted during the *Kharif* season of 2021 at the Regional Research Station, Bawal (Rewari) of CCS Haryana Agricultural University, Hisar, located in the south-western zone of Haryana. The average weekly weather data recorded during the cropping period is depicted in Fig. 1. The experimental field was characterised by loamy sand soil with a pH of 8.16, electrical conductivity [$EC_{(1:2)}$] of 0.15 dS m^{-1} and organic carbon content of 0.17%. The nutrient status of the soil indicated low available nitrogen (N) (102.35 kg ha^{-1}), medium phosphorus (P) (11.17 kg ha^{-1}) and medium potassium (K) (170.11 kg ha^{-1}) levels. The study involved ten treatments; each replicated three times and arranged in a Randomized Block Design (RBD). The treatments included: T1 – Control; T2 – Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1}; T3 – Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1}; T4 – Foliar spray of salicylic acid (SA) @ 100 mg l^{-1}; T5 – Foliar spray of SA @ 200 mg l^{-1}; T6 – Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}; T7 – Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}; T8 – Foliar spray of KNO_3 @ 1%; T9 – Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of KNO_3 @ 1%; and T10 – Soil application of

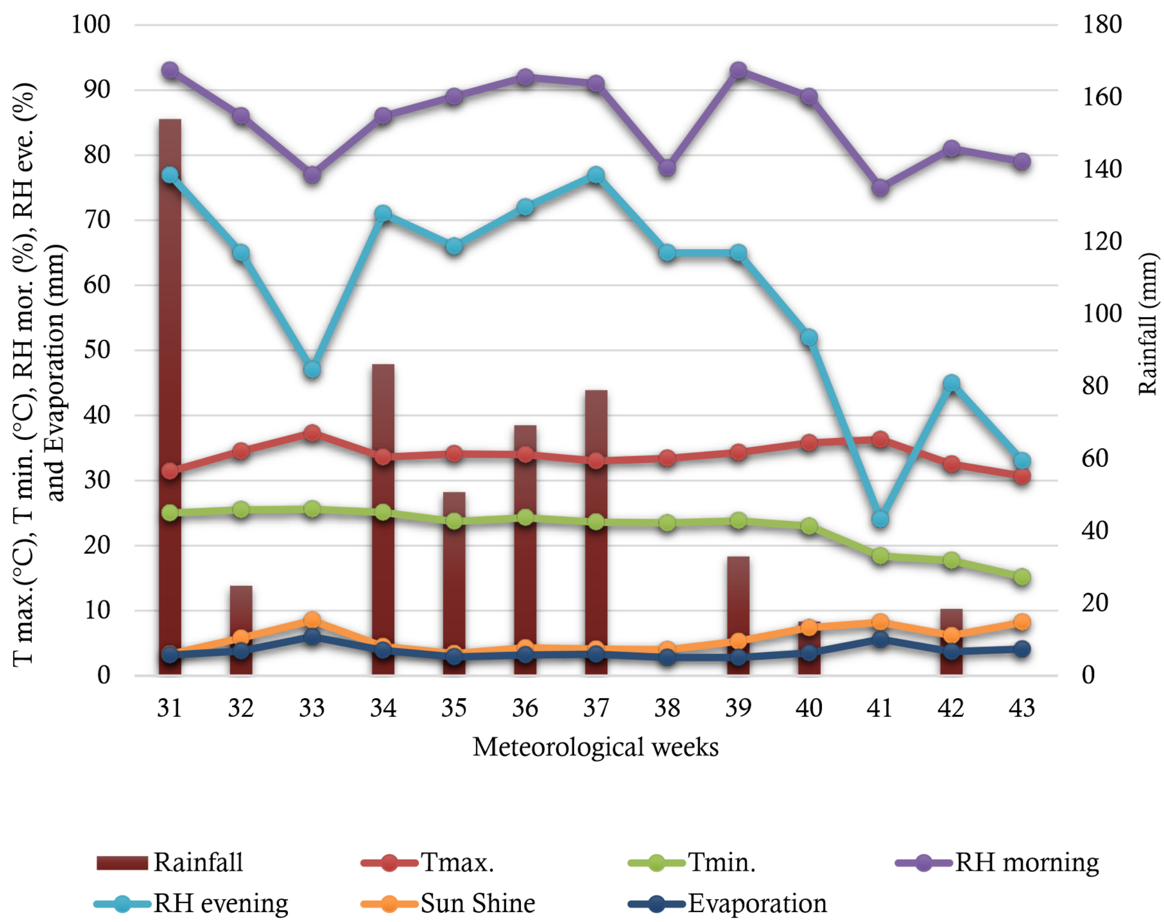

Fig. 1. Mean weekly meteorological data of crop season

Tragacanth katira @ 5.0 kg ha^{-1} + foliar spray of KNO_3 @ 1%. *Tragacanth katira* was applied to the soil at time of sowing through drilling, whereas foliar sprays of salicylic acid and KNO_3 were applied at the flowering and pod initiation stages. The green gram variety MH-421 was sown on August 11, 2021, at a seed rate of 20 kg ha^{-1}. All recommended agronomic practices provided by the state agricultural university were followed throughout the season.

Root-to-shoot ratio was determined at 30, 45 days after sowing (DAS) by separating and oven-drying roots and shoots and calculated as the dry weight of roots divided by that of shoots. Dry matter partitioning (g) at harvest was determined by uprooting five plants, separating roots, shoots, pods and grains after cleaning, drying them and recording the dry weight of each component. Days to 50% flowering, 50% pod formation and physiological maturity were recorded by daily monitoring each plot from the first appearance of flowers or pods until 50% of the plants reached the respective stage and from pod greening to browning for maturity, with the duration expressed in days from sowing. The number of grains pod^{-1} was determined by collecting ten pods from tagged plants in each plot, threshing and cleaning them, counting the total grains and calculating the average per pod. Biological yield (kg ha^{-1}) was determined by harvesting, bundling, sun-drying and weighing the total crop from each plot, then converting to a per-hectare basis. Grain yield (kg ha^{-1}) was obtained by threshing, cleaning and drying the produce, while straw yield (kg ha^{-1}) was calculated by subtracting grain yield from biological yield, with both expressed kg ha^{-1}. Harvest Index (%) was used to assess the efficiency of a crop in allocating assimilates to the economic part and was calculated as the ratio of economic yield to biological yield multiplied by 100, while Attraction Index (%) was calculated as the ratio of grain yield to straw yield multiplied by 100.

Nitrogen, phosphorus and potassium uptake by grains and straw (kg ha^{-1}) were calculated by multiplying the respective nutrient content (%) in grains or straw with their yield (kg ha^{-1}) and dividing by 100. Protein content (%) in grains was estimated by multiplying the grain nitrogen content by 6.25 and protein yield (kg ha^{-1}) was calculated by multiplying the grain yield with the protein content and dividing by 100. Water use efficiency (kg ha^{-1} mm^{-1}) was calculated as the grain yield per unit of water used, while water productivity (Rs ha^{-1} mm^{-1}) was calculated as the gross returns per unit of water consumed or evaporated. The cost of cultivation (Rs ha^{-1}) for each treatment was calculated based on prevailing market prices of inputs and labour, while gross returns (Rs ha^{-1}) were computed by multiplying the yield with the minimum support price for the economic product and market price for by-products. Net returns (Rs ha^{-1}) were obtained by subtracting the cost of cultivation from gross returns and the benefit–cost ratio (B:C) was calculated by dividing gross returns by the cost of cultivation to assess economic feasibility. Data were statistically analyzed using analysis of variance (ANOVA) and the significance of treatment effects was determined through the F-test at a 5% level of significance.

Results and Discussion

Root-shoot ratio on weight basis

Analysis of data presented in Table 1 indicated that various agro-chemical treatments did not significantly affect root-shoot ratio on weight basis at any stage of crop growth. Among different treatments, the value for root-shoot ratio on weight basis at 45 DAS and at harvest varied from 0.19-0.23 and 0.23-0.27, respectively. At 45 DAS and at harvest, the highest root-to-shoot ratio on a weight basis (0.23 and 0.27, respectively) was recorded in treatment T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%), corresponding to an increase of 21.05% and 17.39% over the control. The lowest values (0.19 and 0.23, respectively) were observed in T1 (control). This increase in root to shoot ratio might be due to the significant role played by potassium in cell division as a necessary component of cell wall and a direct effect on cell membrane to promote auxin transport and to improve the root development (Sustr *et al.*, 2019). Similar observations were recorded by Rangaswamy *et al.* (1993) in groundnut, Ghassemi-Golezani *et al.* (2008) in lentil and Shehzad *et al.* (2012) in sorghum.

Table 1. Effect of agro-chemicals on root-shoot ratio, dry matter partitioning at harvest (g) and phenological attributes of green gram

Treatment	Root:Shoot		Dry matter partitioning (g)				Days after sowing		
	45 DAS	At Harvest	Shoot	Root	Husk	Seed	50% flowering	50% pod formation	Physiological maturity
T1	0.19	0.23	7.3	3.3	2.8	4.3	35.9	50.2	59.8
T2	0.20	0.25	7.5	3.6	2.7	4.5	36.3	50.9	60.6
T3	0.20	0.25	7.5	3.8	2.8	4.6	36.3	51.0	60.9
T4	0.21	0.24	8.3	3.7	2.7	4.8	36.5	52.1	62.4
T5	0.21	0.25	8.5	4.1	2.9	4.9	37.7	52.5	62.5
T6	0.21	0.25	8.7	4.1	2.8	5.0	37.8	52.6	62.7
T7	0.21	0.25	8.9	4.2	3.0	5.2	37.8	52.7	63.0
T8	0.22	0.26	10.8	5.2	3.1	6.2	36.8	53.9	64.0
T9	0.23	0.27	10.7	5.5	3.2	6.4	37.4	54.1	64.0
T10	0.23	0.27	10.8	5.6	3.4	6.5	38.5	54.7	64.7
C.D. (p=0.05)	NS	NS	1.0	1.1	NS	1.0	NS	1.3	1.3

DAS-Days after sowing, T1-Control, T2-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1}, T3-Foliar spray of KNO_3 @ 1%, T4-Foliar spray of salicylic acid (SA) @ 200 mg l^{-1}, T5-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T6-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1}, T7-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of KNO_3 @ 1%, T8-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T9-Foliar spray of SA @ 100 mg l^{-1} and T10-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of KNO_3 @ 1%.

Effect of different agro-chemicals on dry matter partitioning

Dry matter partitioning is the end result of the flow of assimilates to the sink organs from source organs via a transport path. Among different agro-chemical treatments, significantly higher dry matter accumulation in different plant parts was observed in T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%) (Table 1, Fig. 2). Treatment T10 resulted in the highest dry matter allocation to the shoot (10.8 g; 47.94% increase over control), followed

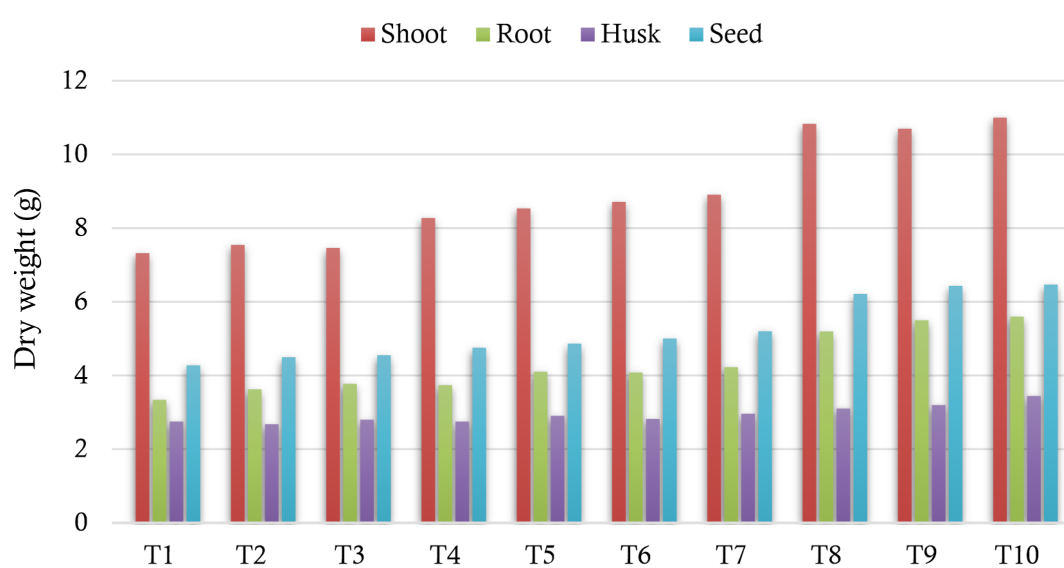

Fig. 2. Dry matter partitioning in different plant parts at harvest

T1-Control, T2-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1}, T3-Foliar spray of KNO_3 @ 1%, T4-Foliar spray of salicylic acid (SA) @ 200 mg l^{-1}, T5-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T6-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1}, T7-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of KNO_3 @ 1%, T8-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T9-Foliar spray of SA @ 100 mg l^{-1} and T10-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of KNO_3 @ 1%.

by the seed (6.5 g; 51.16% increase), root (5.6 g; 69.69% increase) and husk (3.4 g; 21.43% increase).

Days to 50% flowering and pod formation

Data in Table 1 revealed that days taken to 50% flowering in different agro-chemical treatments was not significantly affected and ranged from 35.9-38.5 days. Minimum days (35.9) to 50% flowering was found in T1 (control) and maximum days (38.5, 7.24% increase over the control) to 50% flowering was observed in T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%). Days taken to 50% pod formation observed in various treatments ranged from 50.2-54.7 days. Maximum number of days (54.7, 8.96% increase over the control) to 50% pod formation was observed under T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%), which was statistically at par with T8 (foliar application of KNO_3 @ 1%) and T9 (soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar application of KNO_3 @ 1%). Minimum number of days (50.2) to 50% pod formation was observed in T1 (control). Significantly more days were required by crop to achieve 50% pod formation under treatments with application of SA *viz*. T4, T5, T6 and T7 as compared to control. The effect of different agro-chemicals on days to 50% flowering was non-significant, whereas a significant effect was recorded on days to 50% pod formation. The maximum number of days to 50% pod formation under T10 may be attributed to the synergistic effect of nitrogen and potassium, which extended the pod-filling period by enhancing photosynthetic activity and water uptake, thereby sustaining crop growth.

Days to physiological maturity

Data pertaining to days taken to physiological maturity is presented in Table 1. Minimum days (59.8) required to achieve physiological maturity was documented in T1 (control). Maximum days (64.7, 8.19% increase over the control) taken to physiological maturity was witnessed in T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%) that was statistically at par with T8 (foliar application of KNO_3 @ 1%) and T9 (soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar application of KNO_3 @ 1%). It may also be due to proper availability of soil moisture in whole crop season which resulted in better growth of plants and N availability at later stage also helped plant to photosynthesize for longer time. Similar results were also observed by Balaji (1990) in soybean, green gram and red gram; and by Rehman and Khalil (2018) in canola. Treatments including foliar application of SA *viz*. T4, T5, T6 and T7 followed the same trend as in days to 50% pod formation. Soil application of *Tragacanth katira* alone either @ 2.5 or 5.0 kg ha^{-1} had no significant influence on phenological parameters viz. days to pod formation and physiological maturity.

Number of grains pod^{-1}

It is evident from data presented in Table 2 that different treatments significantly affected the number of grains pod^{-1}. The data revealed that maximum grains pod^{-1} (11.3, 61.43% increase over the control) was found in T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%), followed by T9 (soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar application of KNO_3 @ 1%) and T8 (foliar application of KNO_3 @ 1%), which were at par with respect to each other and were significantly higher over the remaining treatments. This could be due to soil application of *Tragacanth katira* prior to sowing which resulted in availability of more water in the rhizosphere. Foliar application of nutrients supplied through KNO_3, also boosts growth and yield attributes such as pod filling of green gram, while delaying senescence. Similar findings were reported by Venkatesh and Basu (2012) and Waghmare *et al*. (2019). Similarly, T4, T5, T6 and T7 produced statistically similar grains pod^{-1} except that T7 resulted in significantly higher grains pod^{-1} than T4.

Effect of agro-chemicals on grain yield

Data given in Table 2 revealed that grain yield of green gram was significantly affected by different treatments. Treatments T2, T3 and T4 were statistically similar to each other with respect to

Table 2. Effect of agro-chemicals on no. of grains pod^{-1}, yield, harvest index and attraction index of green gram

Treatment	No. of grains pod^{-1}	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	Attraction index (%)
T1	7.0	934	2187	3121	29.9	42.8
T2	7.3	998	2258	3256	30.6	44.2
T3	7.4	1002	2270	3272	30.6	44.1
T4	8.6	1024	2348	3372	30.4	43.7
T5	8.6	1041	2375	3416	30.5	43.8
T6	9.4	1058	2432	3490	30.3	43.5
T7	9.6	1065	2447	3512	30.3	43.5
T8	11.1	1113	2509	3622	30.7	44.4
T9	11.2	1140	2533	3673	31.0	45.0
T10	11.3	1178	2551	3729	31.6	46.2
LSD (p=0.05)	0.8	91	134	174	NS	NS

T1-Control, T2-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1}, T3-Foliar spray of KNO_3 @ 1%, T4-Foliar spray of salicylic acid (SA) @ 200 mg l^{-1}, T5-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T6-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1}, T7-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of KNO_3 @ 1%, T8-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T9-Foliar spray of SA @ 100 mg l^{-1} and T10-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of KNO_3 @ 1%.

grain yield. Among various treatments, minimum grain yield was noticed in control (T1) and maximum grain yield was recorded in T10. Grain yield recorded under T8 (1113 kg ha^{-1}), T9 (1140 kg ha^{-1}) and T10 (1178 kg ha^{-1}) was statistically at par among themselves but significantly higher than the T1 (934 kg ha^{-1}). Likewise, T6, T7, T8 and T9 gave statistically at par grain yield. Grain yield was higher by 13.27, 14.02, 19.17, 22.06 and 26.12% under treatment T6, T7, T8, T9 and T10 respectively, over T1. The spray of salicylic acid @ 200 mg l^{-1} alone or in combination with *Tragacanth katira* @ 2.5 and 5.0 kg ha^{-1}, also produced significantly higher grain yield than T1, T2 and T3. *Tragacanth katira* applied at the time of sowing had little effect on grain yield. The data clearly showed that grain yield of green gram is significantly enhanced by treatments that included foliar applications of KNO_3 or salicylic acid, particularly when combined with *Tragacanth katira*. The highest grain yield was recorded in T10, which involved the combined use of *Tragacanth katira* @ 5.0 kg ha^{-1} and foliar spray of KNO_3 @ 1%, followed closely by T9 and T8; these treatments were statistically at par and significantly superior to the control (T1). The observed increase in grain yield up to 26.1% over T1 can be attributed to improved water retention by *Tragacanth katira* and the physiological benefits of potassium, which enhances water uptake, reduces transpiration and promotes better dry matter partitioning into grains. While treatments T2 and T3 (*Tragacanth katira* alone) and T4 (SA alone) showed some improvement, they were statistically similar and did not significantly surpass the effects of foliar nutrient applications. This highlights that moisture conservation alone is not sufficient to boost grain yield and that supplemental foliar nutrition with KNO_3 or SA is essential to maximize yield through better dry matter accumulation and translocation to harvestable parts. Amarjeet *et al*. (2018), Kavita *et al*. (2022) and Phogat *et al.* (2025) also reported improvement in yield with foliar spray of KNO_3.

Effect of agro-chemicals on straw yield

Data given in Table 2 revealed that straw yield of green gram was significantly affected by different treatments and ranged from 2187 to 2551 kg ha^{-1}. Maximum straw yield (2551 kg ha^{-1}, 16.64% increase over the control) was recorded with T10 and lowest with T1 (2187 kg ha^{-1}). Treatment T10 was significantly superior to T1 and statistically at par with T6 (2432 kg ha^{-1}), T7 (2447 kg ha^{-1}), T8 (2509 kg ha^{-1}) and T9 (2533 kg ha^{-1}). The significantly higher straw yield of green gram observed under treatment T10, as compared to the lowest yield in the control T1, can be attributed to the combined application of *Tragacanth katira* @ 5.0 kg ha^{-1} and KNO_3 @ 1% foliar spray, which improved both soil moisture availability and nutrient uptake efficiency. *Tragacanth katira*, acting as a hydrogel, retained more moisture in the root zone during early growth, enhancing vegetative biomass development, while KNO_3 supplied essential potassium and nitrogen, promoting robust plant growth and physiological activity. Treatments T6, T7, T8 and T9 also recorded statistically similar straw yields, indicating that even lower doses of *Tragacanth katira* or its combination with SA or KNO_3 were effective in improving plant biomass. These treatments collectively enhanced plant water status and nutrient availability, leading to increased vegetative growth and hence higher straw yield. Deotale *et al*. (2015) and Jagdish and Srivastava (2015) also reported similar results for KNO_3.

Effect of agro-chemicals on biological yield

Data given in Table 2 revealed that biological yield of green gram was significantly affected by different treatments and ranged from minimum (3121 kg ha^{-1}) under control and maximum (3729 kg ha^{-1}, 19.48% increase over the control) under T10. Treatment T10 was significantly superior to T1 and statistically at par with T8 (3622 kg ha^{-1}) and T9 (3673 kg ha^{-1}). Foliar spray of salicylic acid alone or in combination with *Tragacanth katira* @ 2.5 and 5.0 kg ha^{-1}, produced significantly higher biological yield than T1 (control), T2 (soil application of *Tragacanth katira* @ 2.5 kg ha^{-1}) and T3 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1}). On the other hand, application of *Tragacanth katira* alone @ 2.5 or 5.0 kg ha^{-1} did not show significant improvement on biological yield. The significantly higher biological yield of green gram under treatment T10, compared to the minimum yield under control T1, highlights the synergistic benefits of combining *Tragacanth katira* @ 5.0 kg ha^{-1} with foliar spray of KNO_3 @ 1%, which enhanced both moisture retention and nutrient availability, leading to increased overall plant productivity. Treatments T9 and T8 were statistically at par with T10, showing that KNO*f* foliar application, whether alone or combined with *Tragacanth katira*, played a major role in boosting biological yield. While foliar application of salicylic acid (SA), either alone or combined with *Tragacanth katira*, also resulted in significantly higher biological yield than T1, T2 and T3, the application of *Tragacanth katira* alone (T2 and T3) did not significantly improve yield. This suggests that moisture conservation by *Tragacanth katira* alone was not sufficient to enhance biological yield unless complemented with growth-promoting agents like SA or KNO_3, which improved physiological processes and biomass accumulation. Sarma *et al*. (2015), Rao *et al*. (2016) and Bangar *et al*. (2019) also reported similar results for KNO_3.

Harvest index and attraction index

Harvest index signifies the ability of a crop to in translocating total biomass into parts of economic importance. Data in Table 2 unveiled that different agro-chemical treatments did not significantly influence the harvest index. The data conveyed that minimum harvest index (29.9%) was recorded under control (T1), while maximum harvest index (31.6%, 5.69% increase over the control) was found in treatment T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%). The data presented in Table 2 indicated that different agro-chemical treatments did not significantly influence the attraction index and followed trend similar to harvest index. Minimum attraction index (42.8%) was computed in T1 (control), while, maximum attraction index (46.2%, 7.94% increase over the control) was found in treatment T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%).

N, P and K uptake in grains and straw

N uptake in green gram ranged from 32.3-43.1 and 21.7-26.8 kg ha^{-1} in grains and straw, respectively (Table 3). Maximum N uptake in grains (43.1 kg ha^{-1}, 33.43% increase over the control) and straw (26.8 kg ha^{-1}, 23.50% increase over the control) was observed in T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%) and which was statistically at par with T8 (foliar application of KNO_3 @ 1%) and T9 (soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar application of KNO_3 @ 1%). Minimum N uptake in grains

Table 3. Effect of agro-chemicals on NPK uptake (kg ha^{-1}) in grains and straw of green gram

Treatment	Grain			Straw		
	N	P	K	N	P	K
T1	32.3	3.9	12.5	21.7	2.8	44.4
T2	34.9	4.2	13.5	22.8	3.4	46.1
T3	34.9	4.2	13.4	23.4	3.4	46.3
T4	36.2	4.4	13.9	24.0	3.3	47.9
T5	37.0	4.5	14.0	24.7	3.6	48.4
T6	37.9	4.6	14.3	25.1	3.7	49.9
T7	38.1	4.7	14.6	25.0	3.7	49.9
T8	40.3	5.0	15.6	26.1	3.5	51.4
T9	41.5	4.9	15.5	26.1	3.6	51.7
T10	43.1	5.2	15.7	26.8	3.7	52.3
LSD (p=0.05)	4.1	NS	1.5	1.8	NS	4.0

T1-Control, T2-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1}, T3-Foliar spray of KNO_3 @ 1%, T4-Foliar spray of salicylic acid (SA) @ 200 mg l^{-1}, T5-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T6-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1}, T7-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of KNO_3 @ 1%, T8-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T9-Foliar spray of SA @ 100 mg l^{-1} and T10-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of KNO_3 @ 1%.

(32.3 kg ha^{-1}) and straw (21.7 kg ha^{-1}) was observed in control, where no agro-chemical was applied. Table 3 shows that phosphorus uptake in grains and straw did not differ significantly among the various treatments. However, P uptake in grains of green gram ranged from 3.9 kg ha^{-1} (under control) to 5.2 kg ha^{-1} (33.33% increase over the control) under T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%). It is evident from data presented in Table 3 that various treatments significantly affected the K uptake in grains and straw. The data conveyed that K uptake ranged from 12.5-15.7 and 44.4-52.3 kg ha^{-1} in grains and straw, respectively. Maximum K uptake in grains (15.7 kg ha^{-1}, 25.60% increase over the control) and straw (52.3 kg ha^{-1}, 17.79% increase over the control) was observed in T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%) which was statistically at par with T8 (foliar application of KNO_3 @ 1%) and T9 (soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar application of KNO_3 @ 1%). Minimum K uptake in grains (12.5 kg ha^{-1}) and straw (44.4 kg ha^{-1}) was observed in control, where no agro-chemical was applied. Uptake of nutrients by crop is function of its content in grains and grains yield produced under that particular treatment. This might be due to the reason that foliar spray of KNO_3 directly supplies the N and K to the leaves at later stage of crop, which was highly effective and also enhanced the protein synthesis in cell. Similar results of increased nutrient uptake were also reported by Rahman and Venkatrama (2006), Thakare *et al*. (2006) and Dixit and Elamathi (2007).

Protein content and protein yield

The protein content and protein yield as affected by agro-chemicals is shown in Table 4. Application of agro-chemicals did not show any impact on protein content in green gram. Maximum protein content (22.8%, 5.55% increase over the control) was reported with T9 and T10 and minimum (21.6%) was observed under control (T1). On the other hand, different agro-chemicals exerted significant impact on protein yield and significantly higher protein yield was recorded with T10 (soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar application of KNO_3 @ 1%), followed by T9 (soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar application of KNO_3 @ 1%) and T8 (foliar application of KNO_3 @ 1%) and lowest with T1 (control) having protein yield [269.2 (33.27% increase over the control), 259.4 (28.42% increase), 251.9 (24.70% increase) and 202.0 kg ha^{-1}], respectively. Foliar application of SA alone or in combination with *Tragacanth katira*

Table 4. Effect of agro-chemicals on protein content, protein yield, water use efficiency, water productivity and economics of green gram

Treatment	Protein content (%)	Protein yield (kg ha^{-1})	Water use efficiency (kg ha^{-1} mm^{-1})	Water productivity (Rs ha^{-1} mm^{-1})	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	B:C
T1	21.6	202.0	2.7	193.1	46,263	67,949	1.47
T2	21.8	217.8	2.8	206.4	47,013	72,605	1.54
T3	21.7	218.0	2.8	207.2	47,763	72,896	1.71
T4	22.1	226.0	2.9	211.8	46,463	74,496	1.62
T5	22.2	231.2	3.0	215.3	46,663	75,733	1.62
T6	22.4	236.8	3.0	218.8	47,413	76,970	1.53
T7	22.4	238.3	3.0	220.2	48,163	77,479	1.72
T8	22.6	251.9	3.2	230.2	47,463	80,971	1.61
T9	22.8	259.4	3.2	235.7	48,213	82,935	1.60
T10	22.8	269.2	3.3	243.6	48,963	85,700	1.75
LSD (p=0.05)	NS	25.3	0.2	18.8	-	-	-

T1-Control, T2-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1}, T3-Foliar spray of KNO_3 @ 1%, T4-Foliar spray of salicylic acid (SA) @ 200 mg l^{-1}, T5-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T6-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1}, T7-Soil application of *Tragacanth katira* @ 2.5 kg ha^{-1} + foliar spray of KNO_3 @ 1%, T8-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of SA @ 200 mg l^{-1}, T9-Foliar spray of SA @ 100 mg l^{-1} and T10-Soil application of *Tragacanth katira* @ 5.0 kg ha^{-1} + foliar spray of KNO_3 @ 1%.

@ 2.5 or 5.0 kg ha^{-1} had statistically similar results with soil application of *Tragacanth katira* @ 2.5 or 5.0 kg ha^{-1}. The higher protein content and protein yield are the reflection of N content and grains yield, respectively. Results were supported by the findings of Mondal *et al*. (2011).

Effect of different agro-chemicals on water use efficiency and water productivity of green gram

Water use efficiency is defined as the carbon assimilated or grains produced per unit amount of water used by the crop and water productivity is the monetary returns gained per unit of water used by the crop in the whole growth season. Data presented in Table 4 illustrated that use of agro-chemicals significantly influenced the water use efficiency and water productivity of green gram. Water use efficiency and water productivity were significantly higher under treatment T10 (3.3 kg ha^{-1} mm^{-1}), followed by T9 (3.2 kg ha^{-1} mm^{-1}) and T8 (3.2 kg ha^{-1} mm^{-1}) and lowest in T1 (2.7 kg ha^{-1} mm^{-1}, control). Water use efficiency increased by 18.51, 18.51 and 22.22% under T8, T9 and T10 respectively, as compared to control. Whereas, water productivity witnessed 19.21, 22.06 and 26.15% increase over control (193.1 Rs ha^{-1} mm^{-1}) under the treatments T8 (230.2 Rs ha^{-1} mm^{-1}), T9 (235.7 Rs ha^{-1} mm^{-1}) and T10 (243.6 Rs ha^{-1} mm^{-1}), respectively. This might be primarily due to the synergistic effect of *Tragacanth katira* and potassium nitrate (KNO_3). T10, which combined a higher dose of *Tragacanth katira* (5.0 kg ha^{-1}) with foliar application of KNO_3 (1%), improved soil moisture retention through the hydrogel properties of *Tragacanth katira* and enhanced physiological efficiency via KNO_3, which supports osmotic regulation, stomatal function and nutrient uptake. This dual action allowed plants to maintain better hydration and metabolic activity, translating into higher yield per unit of water used. T9, with a lower dose of *Tragacanth katira*, showed slightly reduced but still superior WUE and productivity compared to T8, which involved only KNO_3 and lacked the soil moisture-conserving benefits of the hydrogel. In contrast, control (T1) had no such interventions, resulting in poor soil moisture conservation, reduced nutrient uptake efficiency and thus the lowest WUE and water productivity. Placement of *Tragacanth katira* at the time of sowing had insignificant effect on water use efficiency and water productivity. Similar findings were also reported by Vekaria *et al*. (2013), Majeed *et al*. (2016), Shahi *et al*. (2019), Vora *et al*. (2019) and Kataria and Singh (2021).

Effect of agro-chemicals on economics of green gram

Data related to cost of cultivation of green gram (Table 4) depicted that among various treatments, highest cost of cultivation was incurred on T10 (Rs 48963 ha^{-1}, 5.84% increase over the control) followed by T9, T7, T3, T8, T6, T2, T5, T4 and T1 (control: Rs 46263 ha^{-1}), respectively. Table 4 showed that different treatments significantly influenced gross returns. Among different treatments, highest gross returns were observed with T10 (Rs 85700 ha^{-1}, 26.12% increase over the control) followed by T9 (Rs 82935 ha^{-1}, 22.05% increase) and T8 (Rs 80971 ha^{-1}, 19.16% increase) and lowest with control (Rs 67949 ha^{-1}). This might be due to improvement in growth and yield attributes of green gram which finally leads to increase in grains yield. Vekaria *et al*. (2013), Bangar *et al*. (2019) and Vora *et al*. (2019) also reported KNO_3 as a beneficial economic option. Economics is the most important criterion for success or failure of a technology. Higher economic returns are an important determinant any technology for specific agro-climatic conditions because stakeholders are more focused towards net returns over investment. Maximum net returns (gross return – cost of cultivation) i.e., Rs 36737 ha^{-1} were recorded with T10 (69.40% increase over the control) followed by T9 (Rs 34723 ha^{-1}, 60.11% increase over the control) and T8 (Rs 33508 ha^{-1}, 54.51% increase over the control). Minimum net returns i.e., Rs 21686 ha^{-1} were earned under T1. B:C for different treatments under study was computed and was found highest under T10 (1.75, 19.04% increase over the control) and minimum under T1 (1.47). The highest net returns and benefit-cost (B:C) under treatment T10 clearly demonstrate the financial viability of combining *Tragacanth katira* @ 5.0 kg ha^{-1} with foliar spray of KNO_3 @ 1%. This combination not only enhanced yield components like biological and straw yields but also maximized the economic output relative to the input costs. Treatments T9 and T8 also showed high net returns and B:C, reflecting the profitability of KNO_3-based foliar nutrition, with or without the hydrogel. In contrast, the control treatment T1 yielded the lowest net returns (Rs 21,686 ha^{-1}) and the least B:C (1.47), highlighting the economic inefficiency of relying solely on conventional practices without moisture-retention or nutrient-enhancing inputs. These findings underscore that integrating cost-effective inputs that improve resource use efficiency translates directly into higher economic returns, which is critical for technology adoption by farmer. Similar findings were reported by Kumar *et al*. (2019) and Nibhoria *et al*. (2021).

Conclusions

The present study demonstrates that the application of specific agro-chemicals can significantly enhance the physiological and economic performance of green gram under rainfed conditions. The findings confirm that the combined treatment of soil application of *Tragacanth katira* at 5.0 kg ha^{-1} and a foliar spray of 1% potassium nitrate (KNO_3) at the flowering and pod initiation stages (T10) is the most effective strategy for mitigating moisture stress and boosting crop yield. This treatment led to significant improvements in yield attributes, including an increased number of grains pod^{-1} and an extended physiological maturity period, ultimately resulting in the highest grain, straw and biological yields and net returns. The findings underscore the synergistic benefits of integrating soil moisture conservation with foliar nutrient supply, demonstrating a viable and profitable strategy for enhancing green gram productivity in water-scarce environments.

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