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Effect of IAA, GA_3, Salicylic Acid and Tebuconazole on Growth, Productivity and Economics of Linseed (*Linum usitatissimum* L.) Cultivation under Rainfed Conditions

Noyingthung Kikon[1], L. Tongpang Longkumer[1], Imlilemla Amlari[1], Lanunola Tzudir[1], Debika Nongmaithem[1], Rekha Yadav[1], Sridhar Rathod[1]

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ABSTRACT

Background: The use of plant growth regulators (PGRs) to manipulate and enhance the physiological and biochemical processes in plants is a potential area in crop production, to mitigate the many barriers imposed by genetics and environment especially for oilseed crop like linseed which is generally grown in high-risk environments under input starved conditions resulting in very low yields.

Methods: Field investigations were conducted during the *rabi* seasons of 2019 and 2020 to study the response of linseed crop (*Linum usitatissimum* L.) to foliar applications of PGRs (plant growth regulators) under rainfed conditions. The trials were laid out in randomized block design with seven (7) treatments *viz*., control (water spray), Indole-3-Acetic Acid (IAA) @ 1 mg/l, IAA @ 2 mg/l, Gibberellic Acid (GA_3) @ 200 mg/l, GA_3 @ 400 mg/l, Salicylic Acid @ 75 mg/l and Tebuconazole @ 0.1%.

Result: Results showed that the treatments IAA @ 1.0 and 2.0 mg/l and GA_3 @ 200 and 400 mg/l were at par with each other and recorded significant higher seed yields ranging from 1270.72 kgs/ha to 1180.17 kgs/ha during 2019 and 1244.23 kgs/ha to 1135.10 kgs/ha during 2020. Application of IAA @ 2.0 mg/l was found to record the highest benefit cost ratio (BCR) [2.72 and 2.66 during 2019 and 2020 respectively] as well as economic efficiency (210.12 and 208.70 Rs./ha/day during 2019 and 2020 respectively).

Key words: GA_3, IAA, Linseed, Plant growth regulators, Salicylic acid, Tebuconazole.

INTRODUCTION

Linseed (*Linum usitatissimum* L.) a dual-purpose rabi oilseed crop, is grown for its fibre and seed oil and occupies great importance among oilseed crops owing to its various uses and special qualities. Globally, India with a total area, production and productivity of 1.7 lakh ha, 1.1 lakh tonnes and 604 kg/ha respectively holds 5th position in terms of area and production and 4th position in terms of productivity (FAO, 2023). The significantly low productivity of the crop in our country is mainly due to cultivation of the crop in high-risk environments under input starved conditions. In India 63% and 25% of linseed crop is grown under rainfed and utera conditions respectively (Dash *et al.,* 2017), where the crops are subjected to a number of biotic and abiotic stresses which results in low productvity and unstable yield of the crop. A potential area in crop production, to mitigate the many barriers imposed by genetics and environment, is the application of PGRs to manipulate and enhance the physiological and biochemical processes in plants so as to enable balanced response of plants to developmental and environmental cues and successfully survive and perform under biotic and abiotic stress conditions. PGRs are regarded as a new class of agrochemicals which, when applied in low concentrations, can influence plant growth by stimulating or adjusting certain aspects of the natural growth regulation system (Desh and Kumar, 2016) either by promotional or inhibitory action (Naeem *et al*., 2004), by allowing physiological processes to occur at normal rates (Gulluoglu, 2004) and by acting as traffic controllers and facilitating the efficient transfer of photosynthetic products from source tissues to sink tissues (Wavhale and Salve, 2024). Different PGRs are known to affect different facets of plant life from growth and development aspects through to reproduction development. Auxin promotes cell elongation of shoots, initiates rooting and induces apical dominance while gibberellin promotes the growth of stem, leaves and aerial parts through cell expansion by stimulating the destruction of growth-repressing proteins (Achard *et al.,* 2009). Triazole

[1]Department of Agronomy, School of Agricultural Sciences, Nagaland University, Chumoukedima-797 106, Nagaland, India.

Corresponding Author: Noyingthung Kikon, Department of Agronomy, School of Agricultural Sciences, Nagaland University, Chumoukedima-797 106, Nagaland, India.
Email: noyingkikon@gmail.com
ORCID: 0009-0000-3909-740X

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fungicides have dual effects on plants *i.e.* inhibition of the biosynthesis of gibberellins in the plant (retardant properties) and inhibition of the biosynthesis of sterols (fungicide properties) (Matysiak and Kaczmarek, 2013). Salicylic acid is a plant defense activator and growth regulator, which not only regulates plant tolerance against adverse biotic and abiotic stresses but also regulates other responses such as plant growth, flower induction, nutrient uptake and photosynthesis (Hayat and Ahmed, 2007). So far studies on effect of PGRs on linseed is limited however, given the documented potential effects of PGRs on other crops such as mustard (Khan *et al*., 2023), soybean (Wavhale and Salve, 2024), garden pea (Choudhary *et al*., 2023), green gram (Bhadane *et al*., 2022), *etc*., there is scope of investigation in this area with respect to linseed. As in case of cereals and oilseed rape, PGRs are substances, which to a large extent permit full use of the plant potential (Matysiak and Kaczmarek, 2013). Keeping in view the above facts, the present investigtion was conducted to assess the potential effect of foliar applications of PGRs on growth and yield performance and profitability of linseed cultivation under rainfed conditions.

MATERIALS AND METHODS

Field investigations were conducted during successive *rabi* seasons of 2019 and 2020 in the experimental farm of School of Agricultural Sciences, Nagaland University, Medziphema Campus, Nagaland, India located at an altitude of 310 m above mean sea level with the geographical location at 25°45′45″N latitude and 95°53′ 04″ E longitude. The trials were laid out in randomized block design with 7 PGR treatments replicated thrice. A total of seven (7) treatments *viz*., control (water spray), IAA @ 1.0 mg/l, IAA @ 2.0 mg/l, GA_3 @ 200 mg/l, GA_3 @ 400 mg/l, Salicylic Acid @ 75 mg/l and Tebuconazole @ 0.1% were tested to study the response of the crop to foliar applications of selected PGRs. Two sprays were given for each treatment *viz*., first spray at vegetative stage and second spray at reproductive stage. To avoid any form of dilution of concentrations, separate hand sprayers were used for each treatment. Linseed variety 'Shekhar' was sown during the 2nd week of November and standard agronomic practices were maintained uniform for all the experimental plots. Data on plant growth and yield attributes *viz*., leaf chlorophyll content, days to 50% flowering, plant height, primary and secondary branches, plant dry weight, capsules/plant, seeds/capsule, test weight and seed yield were recorded to study the response of the crop. Standard field observation methods were employed for recording plant growth and yield observations. Total chlorophyll content of leaves samples in mg/g was estimated by following acetone extract method as given by Arnon (1949). Data recorded during the course of investigation were analysed statistically by applying the technique of analysis of variance as described by Gomez and Gomez (2010). Economic parameters *viz*., of cost of cultivation, gross monetary return (GMR), net monetary return (NMR), additional net returns over control, benefit cost ratio (BCR) and economic efficiency were calculated on the basis of prevailing rates of inputs and outputs.

RESULTS AND DISCUSSION

Growth attributes

Foliar sprays of PGRs, in particular IAA an GA_3, were found to have significant effect on growth attributes of linseed. During both years, leaf chlorophyll content at vegetative and reproductive stages was found to be statistically comparable among all PGR treatmets and significantly higher compared to control (Table 1). While, among the different PGR treatments, numerically highest values at both stages were recorded with GA_3 @ 200 mg/l followed by IAA @ 2.0 mg/l. Days to 50% flowering was also found to be significantly earlier during both years with respect to PGR treatments as compared to control except for application of Tebuconazole @ 0.1% however, no significant variations werer recorded among the different PGR treatments (Table 1).

Plant height was found to be significantly higher in case of IAA and GA_3 treatments, which were at par and recorded significantly taller plants compared to control as well as twice spray of Salicylic Acid @ 75 mg/l and Tebuconazole @ 0.1% (Table 1). All PGR treatments tested were also found to record significantly higher number of primary and secondary branches/plant compared to control. While IAA @ 2.0 mg/l was found to record numerically highest number of branches (Table 1), GA_3 @ 200 and 400 mg/l and IAA @ 2.0 mg/l were at par and recorded significantly higher number of primary and secondary branches compared to Salicylic acid @ 75 mg/l and Tebuconazole @ 0.1%. Plant dry weight at capsule development and harvest was also found to be significantly higher in case of all PGR treatments compared to control, except for Tebuconazole @ 0.1% at capsule development stage during the year 2019 (Table 2). While, IAA @ 2.0 mg/l recorded numerically highest values of plant dry weight at both stages during both years, all treatments with IAA and GA_3 were found to be at par with each other and recorded significantly higher plant dry weight compared to Tebuconazole @ 0.1%.

Yield attributes and seed yield

During both years, all the PGR treatments tested were found to record significantly higher number of capsules/ plant and seeds/capsule compared to control (Table 2). The treatments GA_3 @ 200 and 400 mg/l and IAA @ 2.0 mg/l were also found to record significantly higher number of capsules/plant compared to both Salicylic acid @ 75 mg/l and Tebuconazole @ 0.1%. Seed yield of linseed was also found to be significantly influenced by application of different PGR treatments. All PGR treatments tested were found to record significantly higher seed yield compared to untreated

control (Table 2). Among the PGR treatments, IAA @ 1.0 mg/l, IAA @ 2.0 mg/l, GA_3 @ 200 mg/l and GA_3 @ 400 mg/l were found to be at par and recorded significantly higher seed yield compared to both Salicylic acid @ 75 mg/l and Tebuconazole @ 0.1% whereas, numerically highest seed yield of 1270.72 kg/ha during 2019 and 1244.23 kg/ha during 2020 was recorded with application of IAA @ 2.0 mg/l.

Cultivation economics

During both years, the highest cost of cultivation was incurred with the treatment GA_3 @ 400 mg/l followed by GA_3 @ 200 mg/l. The highest GMR during both years was recorded with application of IAA @ 2.0 mg/l whereas, the highest NMR, BCR, additional net returns over control and economic efficiency was recorded with application of IAA @ 2.0 mg/l (Table 3).

Growth attributes

Enhanced chlorophyll content of leaves as observed with PGR treatments could be due to effect of applied PGRs in chlorophyll biosynthesis. Supplementation of PGRs invariably influences chlorophyll content in plants (Shah *et al*., 2023). It may also be attributed to involvement of PGRs in improving leaf mineral nutrient content leading to enhanced chlorophyll content in plants (Shah *et al.,* 2022), decreasing chlorophyll breakdown and enhancing synthesis of chlorophyll (Hiremath *et al*., 2021). PGR mediated enhancement in chlorophyll content may also have resulted in higher photosynthetic efficiency (Shah *et al*., 2023) and accumulation of more photosynthates that were diverted to the sink (flower) (Ehsanullah *et al*., 2022) resulting in earlier flowering. In the present investigation it was observed that application of GA_3 @ 400 mg/l was found to record significantly earlier days to 50% flowering compared to rest of the PGR treatments, which could be due to higher cell division and cell elongation under GA_3 treatments resulting in reduced juvenile period and early maturity of the crop (Selvarasu *et al*., 2022).

Significantly taller plants recorded with PGRs GA_3 and IAA could be due to its positive role of these PGRs in regulation of a wide range of morphological and physiological functions in the crop. Enhanced plant height under GA_3 treatments could be attributed to its positive affects on growth through influence on stem and internode elongation (Hussain *et al*., 2018) cell division, cell enlargement, differentiation and elongation of young tissues (Selvarasu *et al*., 2022) and destruction of growth-repressing proteins (Achard *et al.,* 2009). Whereas, enhanced plant height recorded with application of IAA could be due to its role in stimulation of cell elongation, apical dominance, organogenesis, root initiation (Li *et al*., 2016) and cell division and differentiation (Pérez-Llorca *et al*., 2019).

In the present investgation application of PGRs particularly IAA and GA_3 was found to enhance number of primary and secondary branching in linseed this could be

Table 1: Effect of growth regulators on leaf chlorophyll content, phenology and growth attributes of linseed.

Treatments	Leaf chlorophyll content at 10 days after spray (mg/g)				Days to 50% flowering		Plant height (cm)		Number of branches/plant			
	Vegetative stage		Reproductive stage						Primary branches		Secondary branches	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Control (water spray)	1.06	0.98	2.53	1.96	87.00	88.67	56.10	54.84	2.44	2.63	13.07	13.27
Twice spray of IAA @ 1mg/l	1.30	1.23	3.28	3.24	85.00	86.00	80.27	76.53	3.45	3.37	19.48	19.77
Twice spray of IAA @ 2 mg/l	1.32	1.28	3.36	3.27	85.00	85.67	82.20	79.50	3.54	3.50	21.62	22.00
Twice spray of GA_3 @ 200 mg/l	1.33	1.36	3.49	3.40	83.67	84.67	88.21	83.37	3.53	3.50	20.54	20.17
Twice spray of GA_3 @ 400 mg/l	1.30	1.22	3.25	3.16	83.00	83.33	87.39	84.31	3.50	3.47	19.87	20.83
Twice spray of Salicylic acid @ 75 mg/l	1.27	1.19	3.15	2.99	85.00	86.00	68.24	66.19	3.00	3.04	17.34	16.83
Twice spray of Tebuconazole @ 0.1%	1.23	1.14	3.08	2.75	86.00	87.33	62.17	63.48	2.96	3.00	16.08	16.67
SEm ±	0.06	0.07	0.21	0.28	0.87	1.02	5.43	4.63	0.22	0.17	1.02	1.50
CD ($P \leq 0.05$)	0.12	0.15	0.45	0.60	1.73	2.18	11.65	9.93	0.48	0.36	2.18	3.22

Table 2: Effect of growth regulators on growth and yield attributes and seed yield of linseed.

Treatments	Plant dry weight (g)				Seeds/capsule		Capsules/plant		Test wt. (g)		Seed yield (kg/ha)	
	Capsule development		At harvest									
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Control (water spray)	124.72	119.19	401.16	443.99	7.56	7.01	33.59	29.33	8.01	7.78	752.00	814.09
Twice spray of IAA @ 1 mg/l	241.43	248.44	586.96	598.56	8.93	8.80	52.81	48.27	8.34	8.43	1195.52	1135.10
Twice spray of IAA @ 2 mg/l	252.37	257.14	612.31	626.27	9.13	8.87	57.11	52.93	8.53	8.45	1270.72	1244.23
Twice spray of GA_3 @ 200 mg/l	245.79	233.47	596.48	608.73	8.88	8.69	59.67	53.10	8.32	8.32	1232.35	1160.07
Twice spray of GA_3 @ 400 mg/l	223.04	226.83	581.51	590.10	9.10	8.77	56.08	54.87	8.28	8.38	1180.17	1161.66
Twice spray of Salicylic acid @ 75 mg/l	189.14	193.11	486.58	505.33	8.86	8.53	45.80	42.67	8.20	8.06	986.80	1018.67
Twice spray of Tebuconazole @ 0.1%	159.93	164.89	472.01	498.82	8.83	8.47	42.91	40.00	8.24	8.05	953.04	1013.28
SEm ±	27.42	17.83	30.71	23.48	0.42	0.50	4.00	3.72	0.28	0.29	49.59	54.19
CD (P≤0.05)	58.82	38.25	65.87	50.37	0.90	1.08	8.57	7.99	NS	NS	106.38	116.24

Table 3: Effect of growth regulators on cultivation economics of linseed.

Treatments	Cost of cultivation (Rs./ha)		GMR* (Rs./ha)		NMR* (Rs./ha)		Additional net returns over control (Rs./ha)		BCR*		Economic efficiency (Rs./ha/ Day)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Control (water spray)	18181	18181	30080	32579	11899	14398	-	-	1.65	1.79	77.77	96.63
Twice spray of IAA @ 1mg/l	18650	18650	47821	45404	29171	26754	17272	12356	2.56	2.43	190.66	179.56
Twice spray of IAA @ 2 mg/l	18679	18679	50829	49777	32149	31097	20250	16699	2.72	2.66	210.12	208.70
Twice spray of GA_3 @ 200 mg/l	23826	23826	49294	46405	25468	22579	13569	8181	2.07	1.95	166.46	151.54
Twice spray of GA_3 @ 400 mg/l	29031	29031	47207	46467	18176	17436	6277	3038	1.63	1.60	118.80	117.02
Twice spray of Salicylic acid @ 75 mg/l	18648	18648	39472	40754	20824	22106	8925	7708	2.12	2.19	136.10	148.36
Twice spray of Tebuconazole @ 0.1%	18861	18861	38122	40539	19261	21678	7362	7280	2.02	2.15	125.89	145.49

*GMR- Gross monetary returns, NMR- Net monetary returns, BCR- Benefit cost ratio.

attributed to the role of these PGRs in cell elongation and differentiation, stem and internode elongation and elongation of young tissues. Yang *et al*. (2022) also reported that plant branching development is controlled by environment factors, genetic elements and plant hormones such as Auxin and Gibberellin. Additionally, the role of PGRs in breaking the dormancy of lateral buds and promoting the growth of branches (Assuero and Tognetti, 2010) as well as the dynamic balance of plant hormone thereby stimulating the expression of plant branching genes (Yang *et al*., 2022) could also be attributed for the increased branching.

Significant variations in plant dry weight recorded among the different PGR treatments could be attributed to the enhanced plant growth attributes recorded under the influence of those PGRs particularly IAA, GA_3 and salicylic acid. Previous workers have also attributed increased shoot dry matter accumulation due to PGR-mediated enhancement in photosynthesis, enhanced utilization of available soil nutrients, development of larger LAI (Khan *et al*., 2009), enlargement of carbohydrate sink capacity and carbohydrate production (El-Hariri *et al*., 1996) and stem elongation (Ayal-Silva *et al*., 2005).

Yield attributes and seed yield

Significantly better expression of yield attributes as recorded with IAA and GA_3 treatments may be due to enhanced photosynthesis, which may have resulted in increased leaf sugar content (Galeriani *et al*., 2022) which reduced the abortion of reproductive structures and grain filling (Liu *et al*., 2004) and thereby the efficient redistribution of leaf sugar content to the developing organs, resulting in greater numbers of pods and grains/plant (Galeriani *et al*., 2022). Significantly higher number of branches as recorded with application of IAA and GA_3 could also be attributed for the enhanced yield attributes under those treatments as similarly reported by Dwivedi *et al*. (2021). Yang *et al*. (2022) also reported that the number of branches is an important agronomic character, which ultimately determine the number of panicles or pods. Ultimately the PGR-mediated improvements in growth and yield attributes as observed under IAA and GA_3 treatments may have resulted in higher seed yields of linseed. Earlier findings also indicate the positive correlation between seed yield with plant height, plant biomass, branches/plant, capsules/plant and seeds/capsule (Yang *et al*., 2022 and Shah *et al*., 2023). Significantly higher accumuation of leaf chlorophyll under IAA and GA_3 treatments is also another factor, which could be attributed for higher seed yields observed under those treatments since chlorophyll content is an indicator which directly determines the photosynthetic rate and yield potential of plants (Chaudhary *et al*., 2023).

Cultivation economics

In the present investigation it observed that, during both years, higher cost of cultivation was recorded with treatments involving applications of GA_3, which could be attributed to its market price as well as higher doses used as compared to rest of the treatments. Similar findings were reported by Yagum *et al*. (2023). Application of IAA @ 2.0 mg/l was also found to record the highest GMR, NMR, BCR, additional net returns over control treatment as well as economic efficiency during both years, which could be attributed to significantly higher seed yields, gross returns and lower cultivation cost associated with the treatment. Similar findings were aslo reported by Singh *et al*. (2018) and Yagum *et al*. (2023).

CONCLUSION

In line with the findings of this investigation, twice spray of PGR IAA @ 2.0 mg/l *viz*., first spray at vegetative stage and second spray at reproductive stage may be adopted as a low cost and economically viable production technology to enhance the growth and yield response of linseed crop under resource-constrained rainfed conditions. Future studies could investigate the effects of different concentrations and combinations of PGRs, along with their interactions with varying residual soil moisture and nutrient levels, to optimize PGR applications for enhancing the growth and yield performance of linseed under rainfed conditions.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal Care and Handling Techniques were approved by the University of Animal Care Committee.

Conflict of interest

The research is conducted ethically and in compliance with relevant guidelines and regulations. All authors declare that they have no conflict of interest.

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