

## ARTICLE

# Effect of auxin and gibberellic acid on growth and yield components of linseed (*Linum usitatissimum* L.)

Anu Rastogi<sup>1</sup>, Ameena Siddiqui<sup>1</sup>, Brij K Mishra<sup>1</sup>, Mrinalini Srivastava<sup>1</sup>, Rawli Pandey<sup>1</sup>, Pratibha Misra<sup>1</sup>, Munna Singh<sup>2</sup> and Sudhir Shukla<sup>1\*</sup>

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**Abstract** – The commercial importance of linseed (*Linum usitatissimum* L.) has attracted breeders to increase its seed yield using various breeding approaches. Plant growth regulators (PGRs) have a significant role in enhancing yield and its related traits in linseed. In the present study, two plant growth hormones, auxin and gibberellic acid, were applied individually, as well as in combinations, in order to study their effect on yield and its components in “Neelam”, which is a high yielding variety of linseed. A comparative study was done under pot and field condition. A combined dose of auxin (1.0 mg L<sup>-1</sup>) and gibberellin (200 mg L<sup>-1</sup>) is recommended for the enhancement of seed yield, whereas a 0.5 mg L<sup>-1</sup> dose of auxin is recommended for the enhancement of vegetative growth. It was concluded that the plant growth regulators can be successfully employed to enhance the yield in this economically important oil seed crop.

**Key words:** Plant growth regulators, seed yield, indole acetic acid, vegetative yield, biomass.

## INTRODUCTION

Linseed (*Linum usitatissimum* L.), or flax, is a crop of interest from ancient times, as it is used both for fiber and oil. India is the fourth largest oilseed growing country in the world, and third largest producer of linseed. In India, approximately 2,009,100 tons of linseed is produced annually (Chauhan et al. 2009a). Linseed is largely a crop of temperate climate confined mainly to low elevations, but it can be grown successfully up to 770 meters. Linseed has long been used as a cash crop and is mainly grown for its oil, which is continuously being utilized for various industrial purposes and also as a food supplement (Chauhan et al. 2009a). A major alteration in demand of linseed oil and its other byproducts was observed in the last decade, which has elevated in recent times due to its increased demand as functional food and higher industrial uses. Its low productivity is ascribed to non-availability of superior cultivars to suit the diverse agroclimatic environment. Due to commercial importance of linseed, breeders have tried to increase its seed yield using various techniques. In recent years, growth hormones have attracted much attention to enhance yield and its related traits of linseed.

Growth regulators are organic substances besides nutrients, synthesized in plants, causing alteration in their cellular metabolism. Synthesis of some plant hormones is adversely affected by environmental factors, which causes restriction on physiological processes of the plant and ultimately, limits their growth potential (Copur et al. 2010). The application of these hormones in low concentration regulates growth, differentiation and development, either by promotion or inhibition (Naeem et al. 2004), and allows physiological processes to occur at their normal rate (Gulluoglu 2004). Major plant growth regulators (PGRs) significantly enhanced fiber yield in cotton (Copur et al. 2010), protein content in pea (Bora and Sarma 2006), chemical constituents in *Croton* (Soad et al. 2010), fruit size in *Molina* (Vwioko and Longe 2009), seed germination rate in black gram and horse gram (Chauhan et al. 2009b), floral buds in *Jojoba* (Prat et al. 2008) and other growth parameters in different plants. Thus, to overcome the production constraints, chemical manipulation could be done to improve yield and growth parameters.

Among PGRs, auxin and gibberellin play vital role in regulating developmental processes within plant bodies (Gou

<sup>1</sup> National Botanical Research Institute, Genetics and Plant Breeding Section, Rana Pratap Marg, Lucknow-226001, U.P., India. \*E-mail: s\_shukla31@rediffmail.com

<sup>2</sup> University of Lucknow, Department of Botany, Lucknow-226001, U.P., India

et al. 2010). Auxin promotes cell elongation, especially of shoots, and induces apical dominance and rooting, while gibberellin helps in cell growth of stem, leaves and other aerial parts by causing cell elongation, and increase in internodal length. A higher concentration of gibberellins increases plant growth (Bora and Sarma 2006) while higher concentration of auxin inhibits it (Hussain et al. 2010). Thus, only low doses of auxin are effective in growth promotion (Vwioko and Longe 2009). The different concentrations of GA had significant effect on growth in mustard (Akter et al. 2007). Baydar (2000) reported that oil synthesis increases with increasing dose of GA in safflower. Like gibberellins, auxins are effective in increasing oil yield. Farooqui et al. (2005) reported that indole acetic acid (IAA) application increases oil yield enormously in *Cymbopogon martinii* and *Cymbopogon winterianus*. Faizanullah et al. (2010) reported that judicious application of growth hormone increases seed yield in linseed. Besides yield, the fiber strength and fineness is also improved by the application of auxin and gibberellin (Ayala-Silva et al. 2005). Mckenzie and Deyholos (2011) reported that treatment of GA causes stem elongation, expansion and proliferation and cell wall thickening in bast fiber of linseed. Meager studies have been done so far in relation to the effect of growth hormones in linseed; however, seeing the potential effects of auxin and gibberellins on other oilseed crop and linseed itself shows that there are possibilities to investigate the influence of these PGRs on different growth parameters. The present study was planned with the objectives of i) evaluating the effect of auxin and gibberellin on yield and growth components of linseed and ii) comparing the effect of hormones in both pot and field conditions, respectively.

## MATERIAL AND METHODS

An experiment was designed by choosing “Neelam”, a high yielding variety of linseed (*Linum usitatissimum* L.). The experiment was conducted in the year 2009-10 at the experimental field of Genetics and Plant Breeding, National Botanical Research Institute, Lucknow, which is situated at lat 26°N, long 80.5°E and alt 120 m asl. The seeds were sown in three blocks of equal size, each block consisting of 48 rows, spaced 30 cm between rows and 20 cm between plants. Two growth hormones, IAA and GA, were used individually and in combinations. The hormones were dissolved in water in different concentrations. The treatment is set as 4 x 4 factorial combination of 0, 0.5, 1.0, 2.0 mg L<sup>-1</sup> IAA, and 0, 200, 400, 600 mg L<sup>-1</sup> GA. These doses (approx. 25 mL each) were sequentially applied on three rows of each dose in each block, and the last three rows of each block were taken as control. Initial dose of IAA was given to the first three rows of each block and subsequently, other doses were applied in each block in a randomized block design.

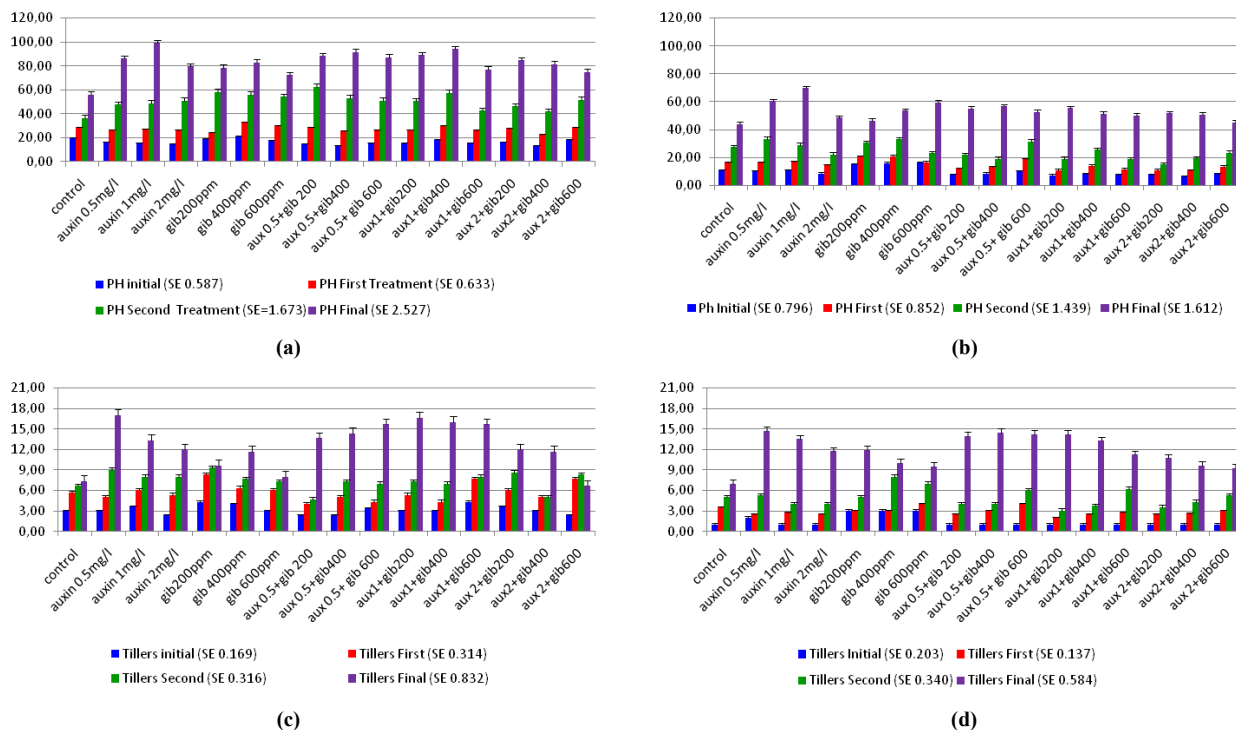
All the treatments were given through sprayer on the apical tip of stem. The first spray was applied after one month of sowing, followed by the second and the third, after an interval of 20 days, respectively. The initial data on plant height and tillers per plant were recorded prior to hormonal application. The first data was recorded after 20 days of first hormonal application, and the second, after next 20 days of second treatment. Final data on plant height, tillers plant<sup>-1</sup>, secondary branches plant<sup>-1</sup>, capsules plant<sup>-1</sup>, seeds capsule<sup>-1</sup>, dry weight plant<sup>-1</sup>, seed yield plant<sup>-1</sup> and vegetative (biomass) yield plant<sup>-1</sup> were recorded at the time of maturity.

A pot trial was also conducted in parallel with field trial in complete randomized block design. Each pot comprised of five plants treatments<sup>-1</sup> in three replications. Similar hormonal treatments at similar time intervals were also applied to potted plants. Finally, effect of different doses of IAA and GA on the above quantitative characters were recorded and compared with control, as well as among them. In order to observe the enhancement in plant height and number of tillers plant<sup>-1</sup> after each treatment, initial recorded data was subtracted with the data obtained after each treatment. Finally, the mean data was subjected to statistical analysis, in order to test the significant differences among treatments by calculating CD values at 0.5% probability level.

## RESULTS

### Plant height

The mean values for plant height ranged from 13.00 to 21.33 cm initially before any treatment; 22.16 to 33.00 cm after first treatment; 36.33 to 62.66 cm after second treatment; and 72.00 to 99.00 cm after third treatment, in field conditions. Likewise, it ranged from 6.33 to 16.50 cm initially before any treatment; 10.50 to 21.00 cm after first treatment; 15.00 to 33.37 cm after second treatment; and 44.00 to 69.75 cm after third treatment, in pot conditions. After each application of growth hormones, plant height increased considerably in relation to the control plants both under field and pot conditions (Figures 1a, b). General increase in plant height was maximized after third application of growth hormones. However, the doses which had the highest fold enhancement in the particular treatment were considered effective dose, and on this basis, the combined dose of 0.50 mg L<sup>-1</sup> IAA+200 mg L<sup>-1</sup> GA (28.66 cm) in field, and 0.50 mg L<sup>-1</sup> IAA + 600 mg L<sup>-1</sup> GA (18.87 cm) in pot were the most effective for enhancement in plant height after first treatment. Similarly, after second and third treatment, GA at 200 mg L<sup>-1</sup> (58.00 cm) and IAA at 1.0 mg L<sup>-1</sup> (99.00 cm) for field trial, and IAA at 0.50 mg L<sup>-1</sup> (33.37 cm) and 1.0 mg L<sup>-1</sup> (69.75 cm) for pot trial were found efficient, respectively.



**Figure 1.** Effect of plant growth hormones on (a) plant height in field (b) plant height in pot (c) tillers plant<sup>-1</sup> in field and (d) tillers plant<sup>-1</sup> in pot.

### Tillers plant<sup>-1</sup>

Tillers per plant ranged from 2.33 to 4.33 initially before any treatment; 4.00 to 8.33 after first treatment; 5.00 to 9.33 after second treatment; 6.66 to 17.00 after 3<sup>rd</sup> treatment, in field condition. Similarly, tillers per plant ranged from 1.00 to 3.00 initially before any treatment; 2.50 to 4.00 after first treatment; 3.50 to 8.00 after second treatment and 7.00 to 14.75 after the third treatment, in pot conditions. The effective doses were the combined dose of 2.0 mg L<sup>-1</sup> IAA + 600 mg L<sup>-1</sup> GA (7.66) in field condition and 0.50 mg L<sup>-1</sup> IAA + 600 mg L<sup>-1</sup> GA (4.00) in pot conditions (Figures 1c, d). After the second treatment, the dose of 0.50 mg L<sup>-1</sup> IAA (9.00) in field, and 400 mg L<sup>-1</sup> GA (8.00) in pot was the most effective. Meanwhile, after the last treatment, the combined dose of 1 mg L<sup>-1</sup> IAA + 200 mg L<sup>-1</sup> GA was significantly effective for field (16.66) and pot (14.25) experiments. Gibberellin alone at higher dose (600 mg L<sup>-1</sup>) showed some inhibitory effects, and resulted in a minimum number of tillers in field, as well as in pot experiments. Lower doses of auxin proved to be beneficial in comparison to its higher doses, as well as with GA.

### Secondary branches plant<sup>-1</sup>

Its mean ranged from 19.66 to 47.00 in field, and 20.50 to 44.66 in pot. The highest mean value for secondary branches

plant<sup>-1</sup> was observed for the dose of 2 mg L<sup>-1</sup> IAA (47.00), and for the combined dose of 2 mg L<sup>-1</sup> + 400 mg L<sup>-1</sup> of IAA and GA (42.00), while the lowest mean value was observed in the dose 200 mg L<sup>-1</sup> of GA (21.00), in field condition (Figure 2a). In the pot condition, mean value was higher in the combined dose of 2 mg L<sup>-1</sup> + 400 mg L<sup>-1</sup> of IAA and GA (44.66), while the lowest mean value was for the 600 mg L<sup>-1</sup> GA (24.00) dose (Figure 2b). It was noticed that any single dose of auxin was found more effective on formation of secondary branches as compared to GA. Combination of both the hormones did not create much difference on the number of secondary branches and it remained almost constant for all combinations.

### Capsules plant<sup>-1</sup>

Its mean ranged from 91.33 to 248.00 in field, and 85.00 to 164.5 in pot condition. Maximum number of capsules plant<sup>-1</sup> was noticed in the combined dose of 1 mg L<sup>-1</sup> + 400 mg L<sup>-1</sup> of IAA and GA (248.00), followed by 400 mg L<sup>-1</sup> GA (239.00), and in the combined dose of 1 mg L<sup>-1</sup> IAA + 200 mg L<sup>-1</sup> GA (233.00) over control. The lowest mean value was in auxin at the dose of 0.5mg L<sup>-1</sup>, which was not less than control in field (Figure 2a). On the other hand, in pot trial, the maximum number of capsule plant<sup>-1</sup> was obtained in the dose 400 mg L<sup>-1</sup> of GA (164.50), and minimum in the dose 1.0 mg L<sup>-1</sup> IAA + 200 mg L<sup>-1</sup> GA (125.75) (Figure 2b). Gibberellic

acid at its lower concentration proved to be more effective than IAA in the enhancement of capsules; however, higher concentration of GA (600 mg L<sup>-1</sup>) was not much effective.

### Seeds capsule<sup>-1</sup>

Its mean ranged from 6.00 to 9.73 seeds capsule<sup>-1</sup> in field, and 6.00 to 8.50 seed capsule<sup>-1</sup> in pot condition. The mean value showed that the dose 1.0 mg L<sup>-1</sup> of IAA (9.73) was the most effective, producing maximum number of seeds capsule<sup>-1</sup> in field, and the combined dose of 2.0 IAA + 600 mg L<sup>-1</sup> GA (6.46) was the least effective (Figure 2a). In relation to the pot condition, the maximum value was obtained when using the combined dose of 0.5 mg L<sup>-1</sup> IAA + 200 mg L<sup>-1</sup> GA (8.50), and the minimum value, when using the combined dose of 2 mg L<sup>-1</sup> IAA + GA 600 mg L<sup>-1</sup> (6.20) (Figure 2b). Individual doses of both of the growth hormones, as well as their combinations, had almost similar effect for this trait.

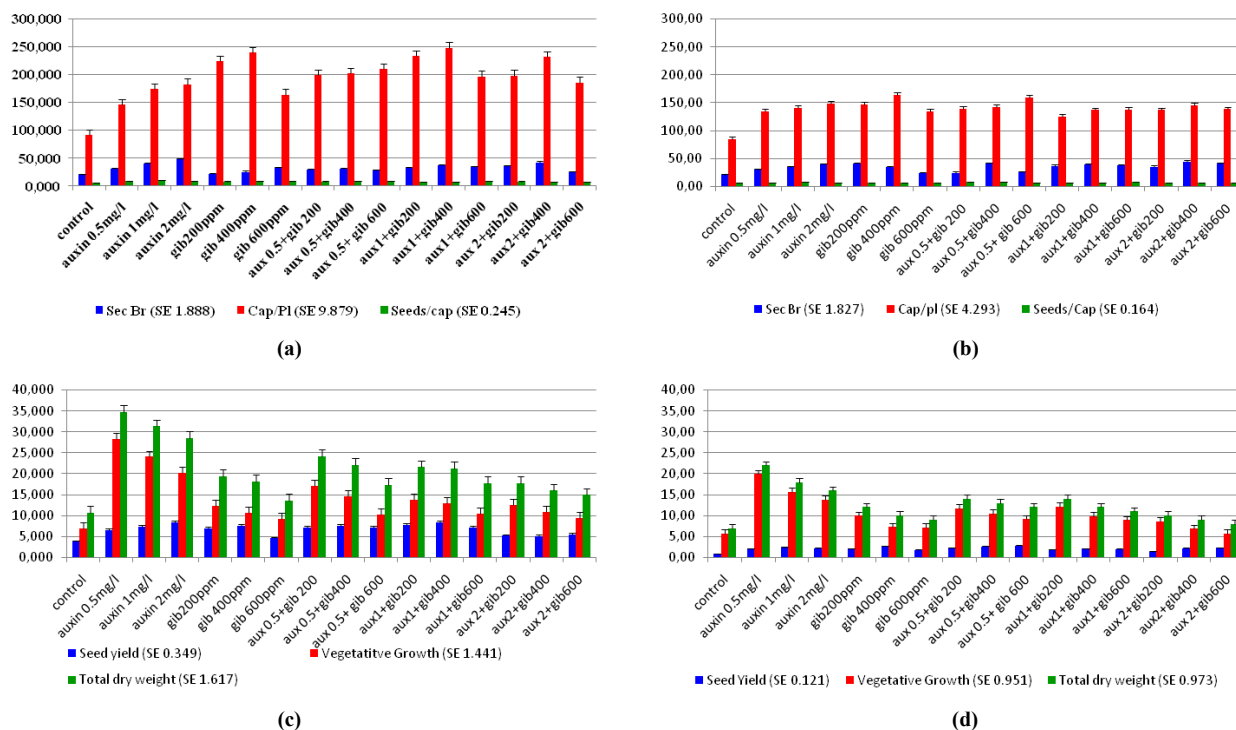
### Total dry weight plant<sup>-1</sup>

Its mean ranged from 10.66 to 34.66 g in field, and 7.00 to 22.00 g in pot condition. The mean values showed that IAA alone at all the concentrations increased dry weight effectively in both field and pot conditions (Figures 2c, d). Among three doses of IAA, dry weight was significantly

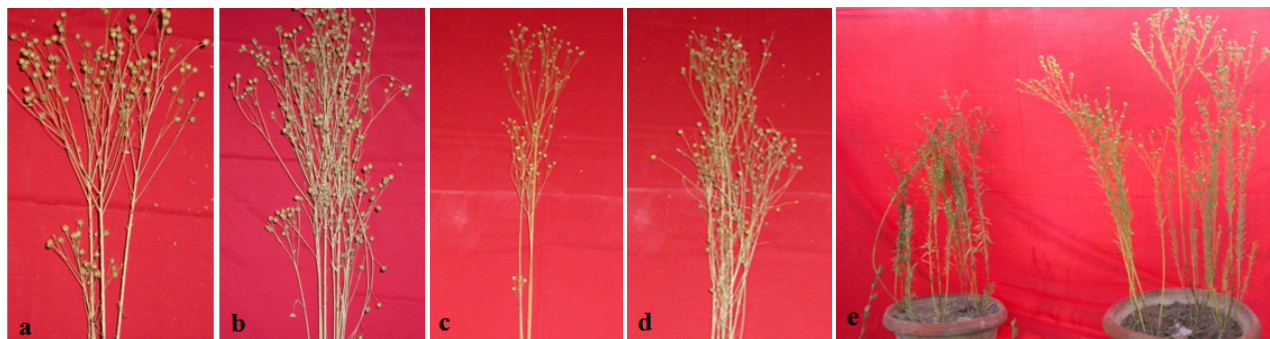
enhanced at the dose of 0.5 mg L<sup>-1</sup> (34.66 g), followed by 1.0 mg L<sup>-1</sup> (31.32 g) and 2.0 mg L<sup>-1</sup> (28.51 g). The lowest dry weight was noticed at the dose of 600 mg L<sup>-1</sup> GA, although it was higher than control. In pot trial, maximum dry weight was obtained at the dose of 0.5 mg L<sup>-1</sup> (22.00 g), followed by 1.0 mg L<sup>-1</sup> (18.00 g) and 2.0 mg L<sup>-1</sup> (16.00 g) of IAA. The lowest weight was registered in the combined dose of 2 mg L<sup>-1</sup> IAA + 600 mg GA L<sup>-1</sup> (8.00 g). It was interesting to notice that with the increase in the concentration of growth hormone, either IAA or gibberellins, dry weight plant<sup>-1</sup> declined, whereas in combination, not much differentiation was found.

### Seed yield plant<sup>-1</sup>

Its mean ranged from 3.70 g to 8.43 g in field, and 0.87 g to 2.85 g in pot condition. It was observed that application of growth hormones increased seed yield under both field and pot conditions (Figures 2c, d and 3c, e). However, this increase was higher in the field than in the pot experiment. The highest mean value (8.43 g) was obtained at the combined dose of 1 mg L<sup>-1</sup> + 400 mg L<sup>-1</sup> of IAA and GA, in field, while the highest yield (2.85 g) was obtained at the combined dose of 0.5 mg L<sup>-1</sup> + 600 mg L<sup>-1</sup> of IAA and GA in pot. All applied doses of growth hormones, either alone or in combination, were effective without much difference



**Figure 2.** Effect of plant growth hormones on (a) secondary branches, capsules plant<sup>-1</sup> and seeds capsule<sup>-1</sup> in field (b) secondary branches, capsules plant<sup>-1</sup> and seeds capsule<sup>-1</sup> in pot (c) seed yield, vegetative growth and total dry weight in field and (d) seed yield, vegetative growth and total dry weight in pot.



**Figure 3.** (a) Control Plant (b) Hormone Treated plant showing enhanced vegetative growth in field (c) Control Plant (d) Hormone treated plant showing enhanced seed yield in field and (e) Control and treated showing enhancement in seed yield and vegetative growth in pot.

between them, except for the dose of 600 mg L<sup>-1</sup> of GA, which was supra optimal for the enhancement of seed yield.

### Vegetative growth

Its mean ranged from 6.96 g to 28.19 g in field, and 5.66 g to 19.89 g in pot condition. Results showed that the highest vegetative yield (28.19 g) was obtained at the dose of 0.5 mg L<sup>-1</sup> of IAA, followed by 1.0 mg L<sup>-1</sup> (22.30 g) and 2 mg L<sup>-1</sup> (20.18 g), respectively. These mean values were significant in comparison to control (6.96 g), under field conditions (Figures 2c and 3a-b). The least growth (9.11 g) was observed in the dose of 600 mg L<sup>-1</sup> of GA (Figure 4). In pot condition, the highest vegetative yield (19.89 g) was obtained with auxin at 0.5 mg L<sup>-1</sup>, which was similar to field condition, while the lowest yield (5.66 g) was observed in combined dose of 2 mg L<sup>-1</sup> + 600 mg L<sup>-1</sup> of IAA and GA (Figure 2d). Higher concentrations of both the growth hormones were less effective as compared to lower concentrations, and showed enhanced vegetative growth in comparison to control (Figure 3e).

### DISCUSSION

In the present study, an apparent association seems to exist between growth hormones and growth parameters in linseed. Mean values for different traits showed that the cultivar “Neelam” responded positively to both the growth hormones (IAA and GA). The doses of growth hormone which enhanced the number of secondary branches plant<sup>-1</sup>, capsules plant<sup>-1</sup>, seeds capsule<sup>-1</sup> and the number of tillers plant<sup>-1</sup> ultimately enhanced seed yield. Among various doses of growth hormones, combined doses of IAA and GA were found to be the most effective in increasing seed yield in both field and pot experiments. The present study clearly indicated that growth hormones have the potentiality to increase seed yield, as also reported by Faizanullah et al. (2010). Rahimi et al. (2011) reported that seed yield was strongly influenced by various growth components, i.e.,

plant height, seeds capsule<sup>-1</sup>, capsules plant<sup>-1</sup> and branches plant<sup>-1</sup>. For vegetative growth and dry weight, each dose of IAA alone showed promotory effect in field, as well as in pot conditions. Quaderi et al. (2006) reported that IAA increases dry matter by increasing photosynthesis activity in mungbean. Ibrahim et al. (2007) reported that the application of bioregulators (GA<sub>3</sub>, IAA, benzyl adenine, ancymidol) significantly increased the total dry weight of shoot system in fababean. It was noticed that plant height was strongly associated with seed yield in linseed. Copur et al. (2010) reported that increase in plant height indirectly affects seed yield via number of nodes and sympodia in cotton. In the present study, it was observed that, for initial enhancement of plant height in field and pot conditions, a combined dose of both the growth hormones is required; however, for subsequent application, only one growth hormone, i.e., IAA, for both field, as well as for pot trials, proved to be beneficial. Plant height increases effectively by IAA application in other oilseed crops, like mungbean (Quaderi et al. 2006). In contrast, Ayala-Silva et al. (2005) showed that application of GA<sub>3</sub> increased plant height, while in the case of auxin, plant height decreased, probably due to the increase in stem diameter, which lowers down the shoot growth. In this field trial, combined doses of auxin and gibberellins were effective for the enhancement of tillers, secondary branches and capsules per plant, while auxin alone was effective for seeds per capsule. Similarly, in pot trial, combined doses of auxin and gibberellin were effective for tillering, secondary branching and in the enhancement of seeds capsule<sup>-1</sup>, while gibberellin alone enhanced capsules plant<sup>-1</sup>. Similar finding were also reported by Faizanullah et al. (2010). In the present study, higher dose of 600 mg L<sup>-1</sup> of GA was supra optimal for the formation of tillers plant<sup>-1</sup>. It was observed that IAA had more promotory effects than GA in the enhancement of vegetative growth, dry weight, secondary branches and seeds capsule<sup>-1</sup>; however, for capsules plant<sup>-1</sup>, GA was more effective. Higher concentration of GA

Effect of auxin and gibberellic acid on growth and yield components of linseed (*Linum usitatissimum* L.)

**Table 1.** Mean values for different traits in field (in bold) and pot conditions in linseed (*Linum usitatissimum* L.)

Treatments	Plant Height (cm)				Tillers Plant <sup>-1</sup>				Sec. Branches <sup>-1</sup>	Cap. Pt. <sup>-1</sup>	Seeds Cap. <sup>-1</sup>	Total dry Wt. <sup>-1</sup>	Seed Yield <sup>-1</sup>	Veg. growth
	Initial	First	Second	Final	Initial	First	Second	Final						
control	<b>19.67</b>	<b>28.17</b>	<b>46.33</b>	<b>77.00</b>	<b>3.00</b>	<b>5.67</b>	<b>6.67</b>	<b>8.33</b>	<b>19.67</b>	<b>91.33</b>	<b>6.00</b>	<b>10.66</b>	<b>3.70</b>	<b>7.28</b>
	10.33	16.17	25.50	44.33	1.00	3.33	5.00	6.67	20.33	87.33	6.98	6.73	0.81	6.16
auxin0.5mg L <sup>-1</sup>	<b>16.33</b>	<b>26.50</b>	<b>36.33</b>	<b>56.00</b>	<b>3.00</b>	<b>5.00</b>	<b>9.00</b>	<b>17.00</b>	<b>30.67</b>	<b>146.00</b>	<b>8.93</b>	<b>34.67</b>	<b>6.47</b>	<b>28.20</b>
	10.37	18.83	32.75	58.00	2.00	2.33	5.33	16.76	29.33	131.33	20.67	6.33	1.87	18.79
auxin1mg L <sup>-1</sup>	<b>15.33</b>	<b>26.83</b>	<b>48.83</b>	<b>99.33</b>	<b>3.67</b>	<b>6.00</b>	<b>8.00</b>	<b>13.33</b>	<b>40.00</b>	<b>174.00</b>	<b>9.73</b>	<b>31.33</b>	<b>7.30</b>	<b>24.03</b>
	10.83	17.33	29.67	68.08	1.00	3.00	4.33	13.33	32.33	138.33	18.33	9.13	2.31	16.01
auxin2mg L <sup>-1</sup>	<b>14.67</b>	<b>26.33</b>	<b>50.83</b>	<b>79.67</b>	<b>2.33</b>	<b>5.33</b>	<b>8.00</b>	<b>12.00</b>	<b>47.00</b>	<b>182.00</b>	<b>8.20</b>	<b>28.51</b>	<b>8.34</b>	<b>20.18</b>
	9.33	13.50	24.13	50.83	1.00	2.40	4.00	11.33	39.83	150.47	14.00	7.27	2.18	11.81
gib200ppm	<b>19.00</b>	<b>23.83</b>	<b>58.00</b>	<b>78.33</b>	<b>4.33</b>	<b>8.33</b>	<b>9.33</b>	<b>9.67</b>	<b>21.00</b>	<b>223.33</b>	<b>7.93</b>	<b>19.32</b>	<b>6.97</b>	<b>12.35</b>
	15.00	21.33	30.67	45.67	3.00	3.00	4.33	11.33	40.67	148.00	11.00	7.33	2.27	8.73
gib400ppm	<b>21.33</b>	<b>33.00</b>	<b>56.00</b>	<b>82.67</b>	<b>4.00</b>	<b>6.33</b>	<b>7.67</b>	<b>11.67</b>	<b>25.00</b>	<b>239.00</b>	<b>8.87</b>	<b>18.20</b>	<b>7.64</b>	<b>10.56</b>
	15.67	20.00	32.83	53.00	3.00	3.00	7.67	9.67	34.67	162.00	9.33	7.33	2.68	6.64
gib600ppm	<b>17.67</b>	<b>29.83</b>	<b>54.17</b>	<b>72.44</b>	<b>3.00</b>	<b>6.00</b>	<b>7.33</b>	<b>8.00</b>	<b>31.96</b>	<b>163.93</b>	<b>8.07</b>	<b>13.65</b>	<b>4.54</b>	<b>9.11</b>
	15.67	14.33	21.50	59.67	3.00	4.00	6.00	8.67	24.67	133.33	9.00	6.03	1.80	7.19
aux0.5+gib200	<b>14.33</b>	<b>28.67</b>	<b>62.67</b>	<b>88.33</b>	<b>2.33</b>	<b>4.00</b>	<b>4.67</b>	<b>13.67</b>	<b>28.67</b>	<b>199.00</b>	<b>7.80</b>	<b>24.15</b>	<b>7.10</b>	<b>17.05</b>
	8.33	13.08	23.41	48.67	1.00	2.67	3.67	15.33	24.33	139.00	14.67	8.47	2.31	12.35
aux0.5+gib400	<b>13.00</b>	<b>25.50</b>	<b>53.00</b>	<b>91.67</b>	<b>2.33</b>	<b>5.00</b>	<b>7.33</b>	<b>14.33</b>	<b>30.00</b>	<b>202.33</b>	<b>8.40</b>	<b>22.00</b>	<b>7.50</b>	<b>14.50</b>
	8.33	12.17	18.34	55.33	1.00	3.00	3.67	15.00	40.67	145.80	11.67	8.47	2.68	8.97
aux0.5+gib600	<b>15.00</b>	<b>26.00</b>	<b>51.00</b>	<b>87.33</b>	<b>3.33</b>	<b>4.33</b>	<b>7.00</b>	<b>15.67</b>	<b>27.00</b>	<b>210.00</b>	<b>8.73</b>	<b>17.32</b>	<b>7.11</b>	<b>10.21</b>
	9.67	17.86	29.00	54.67	1.00	5.00	6.33	12.40	25.00	156.00	12.67	7.10	2.92	9.75
aux1+gib200	<b>15.33</b>	<b>26.50</b>	<b>50.67</b>	<b>89.00</b>	<b>3.00</b>	<b>5.33</b>	<b>7.33</b>	<b>16.67</b>	<b>32.00</b>	<b>233.00</b>	<b>7.27</b>	<b>21.58</b>	<b>7.80</b>	<b>13.78</b>
	7.00	11.50	18.92	46.67	1.00	2.33	3.00	13.00	32.00	123.00	13.33	7.47	1.93	11.39
aux1+gib400	<b>18.00</b>	<b>29.83</b>	<b>57.50</b>	<b>94.00</b>	<b>3.00</b>	<b>4.33</b>	<b>7.00</b>	<b>16.00</b>	<b>37.00</b>	<b>248.00</b>	<b>7.67</b>	<b>21.33</b>	<b>8.43</b>	<b>12.90</b>
	6.67	13.00	23.00	44.33	1.00	2.50	3.33	13.00	41.00	133.00	11.33	7.53	2.17	9.15
aux1+gib600	<b>15.67</b>	<b>26.00</b>	<b>42.67</b>	<b>77.00</b>	<b>4.33</b>	<b>7.67</b>	<b>8.00</b>	<b>15.67</b>	<b>33.00</b>	<b>196.67</b>	<b>9.07</b>	<b>17.66</b>	<b>7.13</b>	<b>10.53</b>
	6.33	10.50	17.00	52.83	1.00	3.00	5.67	10.92	35.17	130.00	10.67	8.18	1.47	9.19
aux 2+gib200	<b>16.33</b>	<b>27.67</b>	<b>46.17</b>	<b>84.67</b>	<b>3.67</b>	<b>6.00</b>	<b>8.67</b>	<b>13.33</b>	<b>35.00</b>	<b>198.00</b>	<b>7.73</b>	<b>17.65</b>	<b>5.16</b>	<b>12.49</b>
	7.00	10.00	15.33	53.50	1.00	3.00	4.33	10.67	39.67	136.67	10.67	7.93	1.37	9.28
aux2+gib400	<b>13.33</b>	<b>22.17</b>	<b>41.83</b>	<b>81.33</b>	<b>3.00</b>	<b>5.00</b>	<b>5.00</b>	<b>11.67</b>	<b>42.00</b>	<b>231.33</b>	<b>7.07</b>	<b>15.96</b>	<b>5.07</b>	<b>10.89</b>
	7.00	12.50	23.17	47.00	1.00	2.67	5.00	10.00	44.67	144.67	8.33	7.33	2.19	6.14
aux2+gib600	<b>18.33</b>	<b>28.17</b>	<b>51.67</b>	<b>75.00</b>	<b>2.33</b>	<b>7.67</b>	<b>8.33</b>	<b>6.67</b>	<b>23.67</b>	<b>185.33</b>	<b>6.47</b>	<b>14.93</b>	<b>5.53</b>	<b>9.40</b>
	7.33	12.50	22.17	44.33	1.00	3.00	5.83	10.33	38.00	135.33	8.33	5.80	2.41	5.91

was less effective than its lower concentration for most of the growth parameters, i.e., seed yield, vegetative growth, dry weight, capsules plant<sup>-1</sup>, tillers plant<sup>-1</sup> and plant height.

The present study clearly showed that among various doses applied, combined dose of gibberellin and auxin had most pronounced stimulatory effect on growth components, which might be due to their effect on physiology of plant (Naeem et al. 2004). Auxin promotes cell elongation by causing acidification of cell walls, which increases their plasticity, and walls expand due to the force of cell internal turgor pressure. Gibberellin promotes growth by stimu-

lating cells for quick division, as well as elongation, by increasing mechanical extensibility and plasticity of cell wall, which is followed by hydrolysis of starch to sugar, resulting in reduced water potential and allowing water to enter inside the cell.

Various studies of hormonal treatments in different crops, viz. *Albizia lebeck*, *Senna siamea*, *Prosopis africana* and *Parkia biglobosa* (Ebofin et al. 2003) and in *Lagenaria siceraria* (Vwioko and Longe 2009) also supported the results of the present research. Khan et al. (1998) reported that foliar application of gibberellic acid at the pre-flowering

stage of mustard plants causes 35.5 % increase in leaf area, followed by increased trapping of sunlight, which apparently enhances dry matter. Gibberellin stimulate flowering and can cause fruit set by initiation of fruit growth, followed by pollination (Gupta and Gupta 2005). Jong et al. (2009) reported that auxin and gibberellin play major role in the development of fruit and expression of genes in tomato. However, influence of auxin and gibberellin on fruit setting was already proved in early 20<sup>th</sup> century by Gustafson (1937). Gibberellin is majorly involved in the regulation of cell division in meristematic tissues, which results in the formation of new cells (Emongor 2007), and auxin is involved in mitotic activity in sub-apical tissues, resulting in increased plant growth (Abel and Theologis 2010).

The present study clearly demonstrated that growth hormones, whether alone or in combination, have a major

impact in the stimulation of various growth parameters in linseed. It was concluded that plant growth hormones could be successfully employed for enhancement of seed yield, directly or indirectly, through its components. Based on the findings, it is recommended the use of a combined dose of auxin and gibberellins (1 mg L<sup>-1</sup> + 400 mg L<sup>-1</sup>) for seed yield, and auxin alone at 0.5 mg L<sup>-1</sup> dose for vegetative growth, in order to enhance yield in this important oil seed crop.

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## Efeito da auxina e do ácido giberélico no crescimento e nos componentes de produção de linhaça (*Linum usitatissimum* L.)

**Resumo** – A importância comercial da linhaça (*Linum usitatissimum* L.) tem atraído melhoristas para incrementar sua produção de grãos usando várias abordagens. Reguladores de crescimento de plantas (PGRs) jogam um importante papel no aumento da produção e caracteres relacionados em linhaça. Neste estudo, dois hormônios de crescimento, auxina e ácido giberélico, foram aplicados individualmente e em combinações, visando avaliar seus efeitos sobre a produção e seus componentes em “Neelam”, uma variedade de linhaça de alto desempenho. O estudo comparativo foi conduzido em vaso e em campo. A dose combinada de auxina (1,0 mg L<sup>-1</sup>) e giberelina (200 mg L<sup>-1</sup>) é recomendada para incremento da produção de grãos, enquanto a dose de auxina de 0,5 mg L<sup>-1</sup> é recomendada para incrementar o crescimento vegetativo. Em conclusão, reguladores de crescimento podem ser empregados com sucesso para incrementar a produção dessa importante oleaginosa.

**Palavras-chave:** Fitoreguladores de crescimento, produção de grãos, ácido indolacético, produção vegetativa, biomassa.

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