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Effect of spraying NAA on soybean (*Glycine max* (L.) Merrill.) var. MAUS 71 growth, yield, and seed quality

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Abstract
Soybean, a prominent leguminous crop, is predominantly cultivated in Maharashtra, contributing to a substantial 89% of the overall production. This study delves into the impact of foliar spray of NAA (Naphthalene Acetic Acid) on the growth, yield, and seed quality of soybeans at the Agricultural Technical School, VNMKV, Parbhani, during the Kharif season of 2021-2022. The research incorporates an examination of physiological growth analysis parameters, specifically AGR (Absolute Growth Rate), RGR (Relative Growth Rate), and NAR (Net Assimilation Rate). Notably, treatment T_9 (90 ppm NAA) demonstrated superior results compared to other treatments at 40-61 DAS (Days After Sowing). In terms of yield components, such as seed yield per plot, biological yield per plot, seed yield per hectare, number of pods, and length of pod, treatment T_9 exhibited the highest outcomes. Additionally, maximum harvest index was observed in T_6 (NAA 60 ppm). The study also delves into protein and oil content in seeds. Notably, a positive and significant correlation was identified between seed yield and various yield-contributing traits, including plant height, number of branches per plant, leaf area, total dry weight, number of pods per plant, length of pod (whether one, two, or three-seeded), Net Assimilation Rate (NAR), biological yield, and harvest index. However, Absolute Growth Rate (AGR) displayed a negative correlation. In summary, the foliar application of NAA showcased a profound influence on the growth, yield, and seed quality of soybeans, with treatment T_9 standing out in several key parameters during the specified Kharif season. Further exploration of these findings can contribute to optimizing soybean cultivation practices and enhancing overall crop productivity.

Keywords: Growth regulator, seed quality, soyabean, correlation

1. Introduction

Glycine max (L.) Merrill, a leguminous crop, is a member of the sub-family papillionaceae of the Leguminosae family. Soybeans are said to have originated in China or Eastern Asia. Although it is widely believed that soybeans are the most adaptable crop for temperate climates, they are also grown in many tropical regions of South East Asia, India, and Africa. Soybean was first imported to India in the tenth century AD via the Himalayan routes from China. Indonesian traders also carried soybeans to India through Burma (now Myanmar). Additionally, it has been reported that, after China, the Indian continent serves as the crop's secondary domestication hub. Compared to other pulses, soybeans are more nutrient-dense. It has high-quality oil (18–20%) and protein (40–42%) (Koushal *et al.*, 2011) [25]. Isoflavones and other nutrients including calcium, iron, and glycine may comprise found in soybeans. As the most abundant, affordable, and convenient source of high-quality protein and fat in the 20th century, soybeans are referred to as the "Golden bean" or the "Miracle crop."

The main producers of soybeans are Brazil, Argentina, and the United States. With three countries producing 80 percent of the world's soybeans, they control the majority of global output. Since 1960, soybean production has increased globally. Pulse crops like soybeans have grown in significance as oil seed crops. In India, there were 11.34 million hectares of soybeans grown, yielding 11.22 million tonnes of product and 12 qt/ha of productivity. Production of soybean in India is dominated by Maharashtra and Madhya Pradesh which contribute 89 per cent of the total production. Rajasthan, Andhra Pradesh, Karnataka, Chhattisgarh and Gujrat contribute the remaining 11 per cent production (Anonymous II, 2022) [3]. The state of Maharashtra produced 6264 million tonnes of soybeans, with an average area of 28820.05 hectares in the state and 10021.72 hectares in the Marathwada region (Pathrikar *et al*., 2022) [33].

India features the world's fifth-largest vegetable oil economy. Oilseeds, with 14% of the nation's gross cropped area, are the second-largest agricultural commodity after cereals.

In India's edible oil scenario, soybeans came in third place out of all oilseed crops. One major contributor to the edible oil pool in India is soybean. Soybeans currently make up 43% of all oilseeds and 25% of all oil produced in the nation. It raises higher profits to the growers owing to the massive export market for soybean oilcake (Anonymous, 2015) [2].

To improve the crop, a thorough grasp of the relationship between yield and yield components is essential. It is only via employing correlation to understand the interrelationships between different features that a genotype can acquire the optimal combination of traits that contribute to yield. Because seed production depends on a number of characteristics and, to some extent, environmental factors, it is always misleading to choose for it. The main issue with soybeans is germination, which can be successfully addressed with the application of growth regulators. Applying a tiny amount of growth chemicals to seeds and leaves can modify and often regulate the growth behavior of many crop plants. Growth hormone has been shown to have an impact on cell elongation. The precise action depending on the concentration of the substance used and sensitivity of the organ concerned Auxin are organic substances which promote growth along the longitudinal axis when applied in low concentrations to shoot of plant. IAA is naturally occurring in the plant but NAA is synthetic chemical which is similar to IAA in its biological activity. all these chemical activities are same as auxins and also have common structural features in their molecules If foliar feeding is done, it decreases the cost of cultivation which subsequently reduces the quantity of fertilizer thereby decreasing the loss and also maximizing the crop production. Hence, other than the circumstances where only soil application is feasible, foliar feeding can be done wherever possible. With above considerations keeping in view the research work was planned on Effect of foliar spray of NAA on growth, yield and seed quality of soybean (*Glycine max* (L.) *Merrill.*) *var.* MAUS 71.

2. Material and Methods

2.1 Experimental site

A field trial was conducted during *Kharif* 2021-2022 at farm of Agricultural Technical School, VNMKV, Parbhani.

2.2 Experimental detail

Soybean seed of variety MAUS - 71 was used for the experiment. seed was obtained from Seed Processing Plant, Seed Technology Research Unit (STRU), VNMKV, Parbhani. Standard solution of NAA (Naphthalene acetic acid) was prepared at Department of Agricultural Botany, VNMKV Parbhani. The experimental soybean planted in a Gross plot measuring 2.7 × 3.0 meters. As per the experimental Design RBD, net 1.80 x 2.90 m using dabbling sowing method with three replicates and nine treatments. 70 kg of seed per hectare is needed for sowing. The N:P:K were applied at the rate of 25:50:50 kg/ha and full dose of nitrogen, phosphorus and potash was given at the time of sowing. Foliar application of NAA was done after 35 days of sowing for preparation of T_1 (NAA 10ppm) 10 mg of NAA powder was dissolved in small quantity of acetone. When complete granular dissolved in acetone the volume was made to 1 lit by adding double distilled water to obtain 10 ppm, For T_2 (NAA 20ppm) 20 mg of NAA powder dissolved in small quantity of acetone. When complete granular dissolved in acetone the volume was made to 1 lit by adding double distilled water to obtain 20 ppm. Likewise, in the same way preparation was done till T_9 (NAA 90 ppm). Foliar application was done with power sprayer.

2.3 Treatment Details: (NAA concentration): T_1-10 ppm, T_2 -20 ppm, T_3- 30 ppm, T_4 - 40 ppm, T_5 - 50 ppm, T_6 - 60 ppm, T_7 -70 ppm, T_8 - 80 ppm, T_9 -90 ppm, T_0 - control.

3. Observations recorded

For the purpose of taking all observations at 15-day intervals during the growth and development of the soybean crop as impacted by the various treatments, five plants per treatment were randomly chosen.

3.1 Growth characters

From the base of the shoot to the last leaf that opened, the plant's height was measured in centimeters. Number of branches per plant counted and noted. Using the method described by Pawar (1978) [35], leaf area was calculated as follows. LA = length of leaf in cm x breadth of leaf in cm x leaf area constant (0.6886 by Pawar,1978) [35] x number of leaves. Weight of each plant's leaf, stem, and pods was included in the total dry matter and expressed in g/plant.

3.2 Growth analysis

3.2.1 Absolute growth rate (AGR) (g/plant/day)

Absolute growth rate was computed using Richards' recommended formula (1969) [40].

$$\text{AGR} = \frac{\text{W2} - \text{W1}}{\text{T2} - \text{T1}}$$

3.2.2 Relative growth rate (RGR) (g/g/day)

It was computed using Fisher's (1921) formula and reported in g/g/day.

$$\text{RGR} = \frac{\text{loge W2} - \text{loge W1}}{\text{T2} - \text{T1}}$$

3.2.3 Net assimilation rate (NAR) (g/dm^2/day)

Net assimilation rate is expressed as increase in dry matter per unit leaf area per unit time. It is expressed in g/dm^2/day. The concept of NAR on the basis of leaf area was introduced by Gregory (1957) [13].

$$\text{NAR} = \frac{\text{W2} - \text{W1}}{\text{T2} - \text{T1}} \times \frac{\text{loge W2} - \text{loge W1}}{\text{T2} - \text{T1}}$$

Where,
W_1 = total dry weight of plant at time T_1
W_2 = total dry weight of plant at time T_2
T_1 = initial time of observation
T_2 = final time of observation.

3.3 Yield components

Following crop harvesting, the total seed yield for five randomly chosen and tagged plants from each plot was determined. The biological yield per plot was calculated by multiplying the number of plants in each plot by the biological yield per plant. The seed yield per plot was then multiplied by the hectare factor to get the seed yield per hectare. Calculation of harvest index was done by using the following formula of Donald (1962) [8] and expressed in percentage (%). Number of pods was counted from five highly vigorous tagged plants at the time of harvest from each plot. Using a scale, the length of pods with varying seed numbers from one to three seeds was measured from tip to base and expressed in centimeters.

3.4 Chemical analysis
Protein content in seed was estimated by using micro-kjeldahl digestion and distillation method and as per the procedure given by Jackson (1967) [17]. A representative seed sample was obtained, and the Nuclear Magnetic Resonance (NMR) Spectrometer method (Jambhunathan *et al.*, 1985) [19] was used to ascertain the percentage of oil in the seed.

3.5 Seed quality traits
The root length was measured using a metric scale, ranging from the tip of the primary root to the base of the hypocotyl. An average was then computed and expressed in centimeters (cm). Using a metric scale shoot length was measured from tip of primary root to the base of hypocotyls and average was calculated and expressed in centimeter (cm). The between-paper method was used in the laboratory to estimate the germination percentage. Estimation of seedling vigour index was done using formula given by ISTA (1976) [16].

3.6 Correlation
According to the instructions provided by the Pearson method, the correlation coefficient (r) value between yield-contributing characteristics and seed quality was determined. The degree to which character is linked to yield and to each other is measured by correlation. The table of correlation coefficients at the 5% and 1% levels of significance will be used to determine the significance of simple correlation.

3.7 Statistical analysis
Statistical analysis of the field data was conducted using the randomized block design (RBD). To determine the importance of treatments, analysis of variance was applied to all investigational data entries (Panse and Sukhatme, 1985) [31].

4 Results and Discussion
4.1 Growth parameters
4.1.1 Plant height (cm)
The results of this experiment showed that all NAA treatments significantly affected plant height in comparison to the control group, and that these effects increased gradually as the plants grew until they reached maturity. Up until 60 days of growth, the pace of height increase was rapid; after that, it slowed down until maturity. At all growth stages, there were significant treatment differences in the mean plant height of the plant; however, no significant treatment differences among concentrations were seen at 30 DAS (Table 1).

When compared to the other treatments and the control, treatment T_9 (NAA 90 ppm) had the significant and largest plant height at 90 DAS, measuring 85.39 cm. This was determined to be on par with treatments T_8 (NAA 80 ppm), T_7 (NAA 70 ppm), T_6 (NAA 60 ppm), and T_5 (NAA 50 ppm). T0 (control) had the lowest plant height, measuring 79.92 cm. Ghuge (1999) [11] reported similar outcomes working with soybeans, and Hivare *et al*. (2019) [15] reported similar results working with safflower.

Table 1: Effect of foliar spray of NAA on plant height (cm)

Treatments	Days after sowing				
	30	45	60	75	90
T_1 (NAA 10 ppm)	24.17	41.02	62.74	72.18	80.38
T_2 (NAA 20 ppm)	24.60	41.97	63.06	73.05	81.12
T_3 (NAA 30 ppm)	24.19	42.02	63.23	73.14	81.62
T_4 (NAA 40 ppm)	25.77	41.69	63.56	73.67	82.10
T_5 (NAA 50 ppm)	26.13	41.95	64.36	73.82	82.68
T_6 (NAA 60 ppm)	27.41	42.75	65.39	74.62	83.17
T_7 (NAA 70 ppm)	27.25	42.89	65.60	74.94	83.70
T_8 (NAA 80 ppm)	25.58	43.26	66.58	75.47	84.71
T_9 (NAA 90 ppm)	27.53	42.77	67.49	75.79	85.39
T_0 (Control)	26.56	40.10	62.12	71.15	79.92
SE(m)±	0.85	0.60	1.12	0.92	0.98
C.D.@ 5%	N/A	1.80	3.34	2.75	2.92

4.1.2 Number of branches per plant
The quantity of branches on a plant is a crucial factor that influences yield. Data on the number of branches per plant at different growth stages are shown in Table 2. The current study found that, in comparison to the control, every NAA treatment significantly affected the number of branches per plant. is discovered to have gradually increased during the plant's development cycle till maturity. With the exception of the 30 DAS growth stage, every treatment produced more branches than the control. because 35 days after seeding, NAA was applied topically. When compared to all of the other treatments and the control, treatment T_9 (90 ppm NAA) had the highest and significant number of branches per plant at 90 DAS, 18.42 over the control. Treatments T_8 (NAA 80 ppm), T_7 (NAA 70 ppm), T_6 (NAA 60 ppm), T_5 (NAA 50 ppm), and T_4 (NAA 40 ppm) were also found to be on par. T0 (control) had the smallest number of branches per plant, at 15.02. The result mentioned above confirms that foliar NAA application can enhance growth characteristics, which are crucial for plant growth and development. Similar findings were observed for broad beans by Sharief *et al*. (2017) [42], chickpea by Gyandev *et al*. (2019) [12], and green gram by Rai *et al*. (2019) [37].

Table 2: Effect of foliar spray of NAA on number of branches per plant

Treatments	Days after sowing				
	30	45	60	75	90
T_1 (NAA 10 ppm)	5.45	9.40	10.77	15.09	15.32
T_2 (NAA 20 ppm)	5.92	9.42	11.66	15.11	15.46
T_3 (NAA 30 ppm)	5.60	9.72	11.86	15.13	16.04
T_4 (NAA 40 ppm)	6.28	9.82	12.12	15.76	16.69
T_5 (NAA 50 ppm)	6.38	10.01	12.43	15.63	17.03
T_6 (NAA 60 ppm)	5.97	10.09	12.80	16.70	17.37
T_7 (NAA 70 ppm)	6.57	10.35	13.08	16.77	17.39
T_8 (NAA 80 ppm)	6.83	10.72	13.38	17.03	17.80
T_9 (NAA 90 ppm)	6.76	10.89	13.39	17.07	18.42
T_0 (Control)	6.13	8.74	10.66	14.61	15.02
SE(m)±	0.40	0.41	0.54	0.57	0.68
C.D. @ 5%	N/A	1.23	1.60	1.70	2.02

4.1.3 Leaf area (cm2)
Table 3 presents data on the average leaf area per plant recorded at different stages of crop growth. The data reveals a rapid increase in leaf area up to 60 days after sowing (DAS),

followed by a slower increase up to 75 DAS, and subsequently, a decrease. Differences in the mean leaf area among treatments were significant at all growth stages, except at 30 DAS, where the difference was not significant. At 75 DAS, the treatment T_9 (90 ppm NAA) exhibited the highest and statistically significant leaf area of 1112.49 cm2, surpassing all other treatments. This result was comparable to treatments T_8 (80 ppm NAA) and T_7 (70 ppm NAA). The lowest leaf area per plant was recorded in the control group (T0) at 1098.55 cm^2. The observed increase in leaf area and the presence of functional leaves likely contributed to an enhanced photosynthetic capacity in the plant. These findings align with previous studies by Selvanathan (1989) [52] on green gram and Kothule *et al*. (2003) [24] on soybean.

Table 3: Effect of foliar spray of NAA on leaf area per plant (cm^2)

Treatments	Days after sowing				
	30	45	60	75	90
T_1 (NAA 10 ppm)	426.35	738.49	1056.42	1099.35	983.14
T_2 (NAA 20 ppm)	424.98	740.01	1056.70	1102.60	984.98
T_3 (NAA 30 ppm)	427.45	741.04	1057.55	1103.96	985.78
T_4 (NAA 40 ppm)	427.25	742.39	1059.55	1105.15	986.83
T_5 (NAA 50 ppm)	428.08	742.47	1061.19	1105.84	988.39
T_6 (NAA 60 ppm)	428.58	742.55	1062.70	1107.54	989.05
T_7 (NAA 70 ppm)	427.91	743.33	1063.71	1109.29	990.05
T_8 (NAA 80 ppm)	425.75	743.72	1064.80	1110.65	991.30
T_9 (NAA 90 ppm)	429.41	744.11	1065.93	1112.49	992.86
T_0 (Control)	428.23	737.09	1055.86	1098.55	981.66
SE(m)±	0.99	1.34	1.02	1.07	1.63
C.D.@5%	N/A	4.00	3.04	3.21	4.87

4.1.4 Dry weight per plant (g)

The data indicated a continuous increase in the dry weight of the stem per plant throughout all growth stages until maturity. The rate of this increase was rapid up to 60 days after sowing (DAS), after which it slowed until reaching maturity. Differences in the mean dry weight of the stem with pods were significant among treatments at all growth stages, except at 30 DAS. At 90 DAS, treatment T_9 (90 ppm NAA) exhibited the highest and statistically significant dry weight per plant, recording 29.53 g. This was notably higher compared to the other treatments and comparable to the values of T_8 (NAA 80 ppm), T_7 (NAA 70 ppm), T_6 (NAA 60 ppm), T_5 (NAA 50 ppm), and T_4 (NAA 40 ppm) (Table 4). In contrast, the lowest dry weight per plant was observed in the control group (T0) at 28.26 g. The enhanced accumulation of dry matter, along with a higher partitioning ratio towards reproductive parts, contributed to a higher grain yield. Similar findings were reported by Lamade (1995) [27], Ullah *et al*. (2007) [50], and Kothule *et al*. (2003) [24] in soybean.

Table 4: Effect of foliar spray of NAA on Dry weight per plant (g)

Treatments	Days after sowing				
	30	45	60	75	90
T_1 (NAA 10 ppm)	9.71	13.21	20.55	25.52	28.37
T_2 (NAA 20 ppm)	9.89	13.34	20.61	25.65	28.76
T_3 (NAA 30 ppm)	9.78	13.37	20.69	25.71	28.86
T_4 (NAA 40 ppm)	10.02	13.42	20.74	25.76	28.93
T_5 (NAA 50 ppm)	9.91	13.55	20.81	25.82	28.99
T_6 (NAA 60 ppm)	10.06	13.63	20.92	25.96	29.21
T_7 (NAA 70 ppm)	10.04	13.71	20.99	25.95	29.33
T_8 (NAA 80 ppm)	10.20	13.87	21.18	26.21	29.45
T_9 (NAA 90 ppm)	10.14	14.06	21.28	26.59	29.53
T_0 (Control)	10.22	12.95	20.41	25.35	28.26
SE(m)±	0.12	0.11	0.17	0.22	0.27
C.D.@5%	N/A	0.34	0.51	0.67	0.81

4.2 Growth analysis parameters

4.2.1 Absolute growth rate (AGR) (g/plant/day)

According to the data, the absolute growth rate increased at its fastest during the 46 and 60 DAS periods before declining afterwards (Table 5). At every development stage, with the exception of 31–45 DAS, all concentrations of NAA were found to be effective in increasing AGR over control. Treatment T_9 (NAA 90 ppm) 0.4883 at 46–60 DAS showed the highest AGR at all concentrations compared to other treatments at all growth stages. Bhagel and Yadav (1992) [6] have discovered similar outcomes in black gram.

Table 5: Effect of foliar spray of NAA on Absolute growth rate (AGR) (g/plant/day)

Treatments	Days after sowing			
	31-45	46-60	61-75	76-90
T_1 (NAA 10 ppm)	0.2329	0.4868	0.3309	0.1791
T_2 (NAA 20 ppm)	0.2304	0.4842	0.3362	0.2107
T_3 (NAA 30 ppm)	0.2398	0.4878	0.3347	0.2071
T_4 (NAA 40 ppm)	0.2262	0.4880	0.3349	0.2131
T_5 (NAA 50 ppm)	0.2422	0.4840	0.3340	0.2296
T_6 (NAA 60 ppm)	0.2384	0.4858	0.3362	0.1987
T_7 (NAA 70 ppm)	0.2449	0.4851	0.3309	0.2458
T_8 (NAA 80 ppm)	0.2447	0.4873	0.3356	0.1836
T_9 (NAA 90 ppm)	0.2611	0.4883	0.3440	0.1964
T_0 (Control)	0.1816	0.4863	0.3298	0.1729

4.2.2 Relative growth rate (RGR) (g/g/day)

Within all concentrations at 46-90 DAS T_9 (NAA 90 ppm) 0.0296 was found to be more effective in increasing RGR over all other treatments and more or less similar to T_8 (NAA 80 ppm) 0.0295 (Table 6). Similar finding was reported by the Bhagel and yadav (1992) [6] in black gram.

Table 6: Effect of foliar spray of NAA on Relative growth rate (RGR) (g/g/day)

Treatments	Days after sowing			
	31-45	46-60	61-75	76-90
T_1 (NAA 10 ppm)	0.0205	0.0291	0.0189	0.0074
T_2 (NAA 20 ppm)	0.0200	0.0290	0.0189	0.0076
T_3 (NAA 30 ppm)	0.0209	0.0291	0.0184	0.0077
T_4 (NAA 40 ppm)	0.0194	0.0290	0.0182	0.0077
T_5 (NAA 50 ppm)	0.0208	0.0286	0.0187	0.0077
T_6 (NAA 60 ppm)	0.0203	0.0285	0.0188	0.0079
T_7 (NAA 70 ppm)	0.0208	0.0292	0.0192	0.0082
T_8 (NAA 80 ppm)	0.0205	0.0295	0.0192	0.0083
T_9 (NAA 90 ppm)	0.0218	0.0296	0.0193	0.0083
T_0 (Control)	0.0158	0.0284	0.0181	0.0073

Net assimilation rate (NAR) (g/dm^2/day)

Table 7 presents data regarding the mean net assimilation rate calculated at different growth stages of a crop. The data reveals a consistent decline in NAR up to 76–90 days after sowing (DAS) across all experimental treatments and control groups. Notably, in treatment T_9 (NAA 90 ppm), the highest NAR was observed at 46–60 DAS (0.0574), surpassing all other treatments and the control. Subsequently, NAR gradually decreased, reaching its minimum level at maturity. This decline could be attributed to factors such as significant mutual shading and the senescence of older leaves as they age or as the crop progresses in growth. Similar observations were reported by Abraham *et al*. (1987) [1] in green gram and Maske *et al*. (1998) [28] in soybean.

Table 7: Effect of foliar spray of NAA on Net assimilation rate (NAR) (g/dm^2/day)

Treatments	Days after sowing			
	31-45	46-60	61-75	76-90
T_1 (NAA 10 ppm)	0.0410	0.0548	0.0479	0.0183
T_2 (NAA 20 ppm)	0.0406	0.0548	0.0477	0.0189
T_3 (NAA 30 ppm)	0.0421	0.0555	0.0488	0.0193
T_4 (NAA 40 ppm)	0.0427	0.0555	0.0491	0.0197
T_5 (NAA 50 ppm)	0.0424	0.0558	0.0491	0.0202
T_6 (NAA 60 ppm)	0.0417	0.0562	0.0490	0.0206
T_7 (NAA 70 ppm)	0.0429	0.0565	0.0497	0.0212
T_8 (NAA 80 ppm)	0.0436	0.0570	0.0503	0.0215
T_9 (NAA 90 ppm)	0.0456	0.0574	0.0515	0.0219
T_0 (Control)	0.0363	0.0537	0.0450	0.0178

4.3 Yield components

4.3.1 Seed yield per plot (kg)

The economic yield, or seed yield, is the product of a plant's physiological processes. According to statistics, the largest and most significant seed yield per plot was reported in T_9 (90 ppm NAA) at 2.23 kg, whereas T0 (control) had the lowest yield per plot at 1.76 kg. Improved yield characteristics, the formation of lager sink size, and effective photosynthetic translocation all contribute to the increased grain output (Table 8). Results obtained in the present investigation are confirmed with findings of several workers. i.e., by Tagade *et al*. (1999) [48] in soybean, Ramesh *et al.* (2015) [38] in black gram, Sarkar *et al*. (2017) [41] reported that there was highest seed yield/ha with use of NAA 100 ppm in mungbean.

Biological yield per plot (kg)

Treatment T_9 (90 ppm NAA) had the greatest and most significant biological yield per plot (4.78 kg), and when compared to the other treatments and the control, it was determined to be on par with T_8 (NAA 80 ppm), T_7 (NAA 70 ppm), T_6 (NAA 60 ppm), T_5 (NAA 50 ppm), and T_4 (NAA 40 ppm). T0 (control) had the lowest biological yield, 3.91 kg (Table 8). Similar results were seen by Aslam *et al*. (2010) [5] in chickpea and Sarkar *et al*. (2017) [41] in mungbean, where the application of NAA 100 ppm produced the maximum biological yield per hectare.

Seed yield per hectare (qt)

Significant and highest seed yield per hectare was recorded in treatment T_9 (90 ppm NAA) 27.56 kg, and also found at par with T_8 (NAA 80 ppm), T_7 (NAA 70 ppm), T_6 (NAA 60 ppm) and T_5 (NAA 50 ppm) when compared with rest of the treatments and control. Lowest seed yield per hectare was recorded in T_0 (control) 21.68 kg (Table 8). Similar results were reported by Sharma *et al*. (1989) [43] in mungbean, Maske *et al*. (1998) [28] and Tagade *et al*. (1998) [48] in soybean.

Harvest index

The harvest index is the ratio of economic yield to biological yield. It is also known as the migration coefficient or the coefficient of efficacy. Data on the harvested index were statistically examined and determined to be non-significant (Table 8). When compared to the other treatments and the control, the maximum harvest index was found in treatment T_6 (NAA 60 ppm) at 47.39%, followed by treatment T_5 (NAA 50 ppm) at 47.29% and treatment T_8 (NAA 80 ppm) at 47.10%. T0 (control) had the lowest harvest index, at 45.21%. When using pigeon pea in their experiments, Jadhav *et al*. (2018) [18] and Prasad (2001) [36] observed similar results. All the NAA treatments have significant and positive effect on number of pods per plant when compared to control. Thus, it can be concluded that foliar application of NAA likely to contribute for increasing seed yield. Similar findings were reported by Kapase *et al*. (2014) [21] in chickpea. Data regarding length of pod (1 seeded, 2 seeded, 3 seeded) is presented in the Table 8 was found to be significant. The present study revealed that all the NAA treatments had significant and positive effect on length of pod over control. The results are in accordance with those reported by Sarkar *et al*. (2017) [41] while working with mungbean, and Siddik *et al*. (2014) [44] in sesame.

Table 8: Effect of foliar spray of NAA on Yield components

Treatments	Seed yield per plot (kg)	Biological yield per plot (kg)	Yield per hectare (qt)	Harvest index
T_1 (NAA 10 ppm)	1.88	4.12	23.16	45.49
T_2 (NAA 20 ppm)	1.95	4.22	24.06	46.31
T_3 (NAA 30 ppm)	1.95	4.28	24.10	45.30
T_4 (NAA 40 ppm)	1.99	4.39	24.56	45.28
T_5 (NAA 50 ppm)	2.04	4.34	25.22	47.29
T_6 (NAA 60 ppm)	2.08	4.40	25.71	47.39
T_7 (NAA 70 ppm)	2.14	4.62	26.41	46.59
T_8 (NAA 80 ppm)	2.19	4.67	27.02	47.46
T_9 (NAA 90 ppm)	2.23	4.78	27.56	47.43
T_0 (Control)	1.76	3.91	21.68	45.21
SE(m)±	0.07	0.17	0.81	2.27
C.D.@5%	0.20	0.52	2.43	N/A

Treatments	Number of pods per plant	Length of pod (1 seeded, 2 seeded, 3 seeded)		
		1 Seeded	2 Seeded	3 Seeded
T_1 (NAA 10 ppm)	40.91	1.84	3.46	6.68
T_2 (NAA 20 ppm)	41.83	1.87	3.52	6.72
T_3 (NAA 30 ppm)	42.20	1.91	3.69	6.86
T_4 (NAA 40 ppm)	43.02	1.94	3.76	6.92
T_5 (NAA 50 ppm)	43.64	1.95	3.80	6.98
T_6 (NAA 60 ppm)	44.31	1.97	3.91	7.17
T_7 (NAA 70 ppm)	45.94	2.01	3.99	7.29
T_8 (NAA 80 ppm)	47.07	2.08	4.20	7.40
T_9 (NAA 90 ppm)	40.45	2.21	4.37	7.68
T_0 (Control)	43.00	1.82	3.39	6.42
SE(m)±	1.43	0.06	0.11	0.21
C.D.@ 5%	4.29	0.17	0.33	0.62

4.4 Chemical analysis

Data revealed that the total protein content in seed was found maximum in treatment T_9 (NAA 90 ppm) 40.85% followed by T_8 (NAA 80 ppm) 40.68% and treatment T_7 (70 ppm NAA) 40.42% when compared with rest of the treatments and control (Table 9). Lowest protein content was observed in T_0 (control) 38.14%. The results are in line with the Sumabai *et al*. (1987) [47] in green gram, Ravikumar and Kulkarni (1988) in soybean and Patel and Saxena (1995) [32] in mungbean. Lowest oil content in seed was observed in T_0 (control) 38.14%. Increase oil content is consequence of more synthesis of amino acid and increased conversion of carbohydrates to oil. Foliar application of NAA increases the uptake and availability of nutrients and its further assimilation for biosynthesis of oil. These might be the reason for increased oil content in seed in the present investigation. These results are comparable with Pain and Sarkar (1980) [30] and Vasudevan *et al*. (1996) [51] observed in sunflower and Kene *et al*. (1992) [22] in safflower.

Table 9: Effect of foliar spray of NAA on Chemical analysis

Treatments	Protein (%)	Oil (%)
T_1 (NAA 10 ppm)	38.66	18.84
T_2 (NAA 20 ppm)	38.81	18.98
T_3 (NAA 30 ppm)	39.18	19.29
T_4 (NAA 40 ppm)	39.26	19.41
T_5 (NAA 50 ppm)	39.56	20.03
T_6 (NAA 60 ppm)	39.82	20.14
T_7 (NAA 70 ppm)	40.42	20.20
T_8 (NAA 80 ppm)	40.68	20.62
T_9 (NAA 90 ppm)	40.85	20.38
T_0 (Control)	38.14	18.36
SE(m)±	0.58	0.46
C.D.@5%	1.72	1.38

4.5 Seed quality parameters

4.5.1 Root length (cm)

Significant and maximum root length was recorded in treatment T_9 (90 ppm NAA) 11.88 cm which is followed by treatment T_8 (80 ppm NAA) 11.72 cm when compared with rest of the treatments and control. Minimum value for this character was measured in T_0 (control) 9.54 cm (Table 10). Root length is good indicator for seed vigour measurement which may contribute toward better establishment of seedling. The results are in accordance with those reported by Kumbari (2002) [26] in tomato. Singh *et al*. (2017) [46] in coriander.

4.5.2 Seedling Shoot length (cm)

The result for shoot length for different treatments for soybean of NAA varied from 13.31 to 15.13 cm (Table 10). Similar findings were observed by Kumbari (2002) [26] and revealed that NAA 100 ppm recorded maximum shoot length in tomato and Singh *et al*. (2017) [46] reported that NAA @ 50 ppm resulted in increase in seedling length.

4.5.3 Germination (%)

Germination percentage among various treatments of soybean ranged from 82.04 to 85.12%. Significantly highest germination% was recorded in treatment T_9 (90 ppm NAA) 85.12%, followed by treatment T_8 (80 ppm NAA) 84.61% when compared with rest of the treatments and control. Lowest germination percentage observed in T_0 (control) 82.04% (Table 10). The germination percentage is one of the most important characteristics of seed to be used for estimation of planting value. Germination is the biological process that depend upon various factors including the differential behavior of harmones. The results are in accordance with those reported by Borkar *et al*. (1991) [7] while working with soybean, Hilli *et al*. (2008) [14] in ridge gourd, Khan *et al*. (2013) [23] in okra, and Arvindkumar *et al*. (2014) [4] in tomato.

4.5.4 Vigour index

The information on seed vigour index is detailed in Table 10. Various NAA treatments exert an influence on the vigour index. The study indicates that all NAA treatments significantly affected the vigour index compared to the control. The most significant vigour index was noted in treatment T_9 (90 ppm NAA) at 2299.38, followed by treatment T_8 (80 ppm NAA) at 2254.30, in comparison to other treatments and the control. The lowest vigour index was observed in T0 (control) at 1873.99. The Seedling Vigour Index is crucial for monitoring and ensuring the survival and growth of seedlings post-germination. Similar results were reported by Hilli *et al*. (2008) [14] for ridge gourd, Therakam (2001) [49] for brinjal, and Jyoti *et al*. (2016) [20] for ridge gourd.

Table 10: Effect of foliar spray of NAA on Seed quality parameters

Treatments	Root length (cm)	Shoot length (cm)	Germination%	Vigour index
T_1 (NAA 10 ppm)	10.11	13.58	82.43	1,952.27
T_2 (NAA 20 ppm)	10.22	13.82	82.76	1,989.27
T_3 (NAA 30 ppm)	10.46	14.03	82.97	2,031.59
T_4 (NAA 40 ppm)	10.87	14.21	83.26	2,088.24
T_5 (NAA 50 ppm)	11.29	14.36	83.49	2,140.88
T_6 (NAA 60 ppm)	11.44	14.58	83.89	2,182.73
T_7 (NAA 70 ppm)	11.55	14.67	84.28	2,210.16
T_8 (NAA 80 ppm)	11.72	14.92	84.61	2,254.30
T_9 (NAA 90 ppm)	11.88	15.13	85.12	2,299.38
T_0 (Control)	9.54	13.31	82.04	1,873.99
SE(m)±	0.10	0.11	0.10	13.04
C.D.@ 5%	0.31	0.31	0.30	39.05

4.6 Correlation studies for yield and yield contributing traits

An essential statistical constant that shows how closely the different features are related to one another is the correlation coefficient. Summarized results from correlation studies of yield and yield-contributing features were statistically examined and shown in Table 11. The results of yield and yield-contributing character correlation studies showed that while relative growth rate (RGR) and absolute growth rate (AGR) found non-significant and negative correlations with seed yield, plant height, number of branches per plant, leaf area, total dry weight, number of pods per plant, length of pod (1 seeded, 2 seeded, or 3 seeded), harvest index, and net assimilation rate (NAR) had positive and significant correlations with seed yield. This suggests that traits such as plant height, number of branches per plant, leaf area, total dry weight, number of pods per plant, length of pod (one, two, or three seeds), biological yield, and harvest index were strongly correlated with seed output. and the parameters of the growth analysis (Table 11). The data indicates that various factors such as plant height, number of branches per plant, leaf area, total dry weight, number of pods per plant, length of pod (one, two, or three seeded), biological yield, harvest index, relative growth rate (RGR), and net assimilation rate (NAR) can all impact the yield of seeds. This rise may have resulted from the plant producing more photosynthetic assimilates, which immediately increased seed output. Similar outcomes were noted in studies on soybean by Ghalge and Kadu (1993) [10], green gram by Patil (2001) [34], pigeon pea by Singh *et al*. (2013) [45], and green gram by Narayanan *et al*. (2018) [29].

Table 11: Correlation studies of yield with yield contributing characters

Characters	Plant height (cm)	Number of branches	Leaf area (cm2)	Total dry weight (g)	Number of pods per plant	Length of 1 seeded pod (cm)	Length of 2 seeded pod (cm)	Length of 3 seeded pod (cm)	Absolute growth rate (AGR)	Relative growth rate (RGR)	Net assimilation rate (NAR)	Biological yield per plot (kg)	Harvest index (%)	Seed yield per plot (kg)
Plant height (cm)	0.0000	0.5106**	0.6612**	0.2014	0.6459**	0.4494	0.8609**	0.5516**	0.0906	-0.0939	0.5423**	0.6509**	-0.0235	0.5897**
Number of branches		1	0.6978**	0.4078	0.6964**	0.4590*	0.5930**	0.4986*	-0.2384	-0.1367	0.1638	0.3798	0.3370	0.6228**
Leaf area (cm2)			1	0.6933**	0.8475**	0.6509**	0.7970**	0.7950**	-0.1695	-0.1104	0.4430	0.6060**	0.3371	0.8314**
Total dry weight (g)				1	0.7170**	0.6670**	0.4403	0.6088**	-0.3292	-0.2042	0.1442	0.4845*	0.1464	0.5658**
Number of pods per plant					1	0.6980**	0.8125**	0.7048**	-0.2250	-0.0724	0.2661	0.6968**	0.1596	0.7684**
Length of 1 seeded pod (cm)						1	0.6950**	0.6872**	-0.1233	-0.0520	0.3711	0.6148**	0.0205	0.5843**
Length of 2 seeded pod (cm)							1	0.7779**	0.0458	0.0296	0.4544	0.8184**	0.0051	0.7614**
Length of 3 seeded pod (cm)								1	-0.1486	0.0692	0.3584	0.6670**	0.1169	0.7034**
Absolute growth rate (AGR)									1	0.6648**	0.5093*	0.1875	-0.2183	-0.0056
Relative growth rate (RGR)										1	0.3049	0.1454	0.0367	0.1560
Net assimilation rate (NAR)											1	0.2785	0.2560	0.4659*
Biological yield per												1	-0.3309	0.6590**

plot (kg)														
Harvest index (%)													1	0.4905*
Seed yield per plot (kg)														1

Significance at 1% = 0.458 Significance at 5% = 0.532

5. Conclusion

NAA is applied foliar to help with growth and yield contributing characteristics such as plant height, number of branches per plant, leaf area, total dry matter, and number of pods per plant. Treatment T_9 (90 ppm NAA) was shown to be superior to all other treatments in this regard. At 40–61 DAS, the physiological growth analysis parameter study showed that treatment T_9 (90 ppm NAA) produced better results than other treatments in terms of AGR, RGR, and NAR. In terms of yield components, T_9 (90 ppm NAA) produced the best results in terms of number of pods, length of pod treatment, biological yield per plot, and seed yield per hectare. But T_6 has the highest harvest index (NAA 60 ppm). The results about the oil and protein contents of the seed. Treatment T_9 had the higher value, which was 90 ppm NAA. The treatment T_9 (90 ppm NAA) produced the greatest results in terms of seed quality metrics, such as seedling root length, seedling shoot length, germination percentage, and vigour index. With the exception of AGR, every growth and yield-contributing trait has a strong, positive connection with seed yield. Generally speaking, foliar NAA treatments had a significant impact on soybean growth, yield, and seed quality.

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