"Optimization of seed treatment techniques for enhancement of physiological efficiency, productivity and seed quality attributes in Soybean [*Glycine Max* (L.) Merr.]"

THESIS

Submitted to the

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

In partial fulfillment of the requirements for the Degree of

MASTER OF SCIENCE

In

AGRICULTURE

(PLANT PHYSIOLOGY)

By

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2022

CERTIFICATE - I

This is to certify that the thesis entitled **"Optimization of seed treatment techniques for enhancement of physiological efficiency, productivity and seed quality attributes in Soybean [*Glycine Max* (L.) Merr.]"** submitted in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE in AGRICULTURE** in the **Department of Plant Physiology** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Mr. Ramkrishna Birla** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.

All the assistance and help received during the course of the investigations has been acknowledged by her.

Place: Jabalpur

Date: (**Dr. R.S. Ramakrishnan)**

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(Student)

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ABBREVIATIONS

ANOVA	:	Analysis of Variance
BMD	:	Biomass Duration
Cal	:	calories
CCI	:	Chlorophyll Content Index
CD	:	Critical Difference
CGR	:	Crop Growth Rate
Cont.	:	Continue
DAS	:	Days After Sowing
d.f.	:	Degree of Freedom
DM	:	Dry Matter
Fig.	:	Figure
HI	:	Harvest Index
LAD	:	Leaf Area Duration
LAI	:	Leaf Area Index
MSS	:	Mean Sum of Square
NAR	:	Net Assimilation Rate
RGR	:	Relative Growth Rate
SEm±	:	Standard error of mean
TDM	:	Total Dry Matter
Viz.,	:	Namely
*	:	Significant at 5% Level of significance
@	:	At The Rate
%	:	Percent

INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] is the main crop mostly cultivated worldwide, it is known as the Golden bean of the 21st century which belongs to Leguminosae family. It is designated as a Wonder crop and has confirmed its potential as an industrially important and valuable oilseed crop in many areas of India. It is the world's first ranking crop as a source of vegetable oil and plays a vital role in fighting the edible oil deficit in the country. Nowadays, there is vast scope for soybean production due to its high nutritional quality, more production, short duration (90-110 days) and tolerance to long dry spells. Being a leguminous crop, it helps in improving the soil fertility and productivity of the soil. Hence, it is known as the "Gold of soil". It is the most important crop in terms of protein and fat content. It contains about 35-40% good quality protein, 20 % oil having about 85% saturated fatty acids, including 55% polyunsaturated fatty acids (PUFA), 25 – 30% carbohydrates. It is an abundant source of protein and oil, and it is also known as vegetarian meat.

As it is the cheapest source of protein it is called as the Poor man's meat (Mahajan *et al.* 1994)**.** A large number of Indian and Western dishes such as bread, chapati, soyamilk and milk products, sweets *etc.*, can be prepared with soybean. Wheat flour fortified with soybean flour makes good quality and more nutritious 'chapati'. Soybean is a legume crop which builds up the soil fertility by fixing large amounts of atmospheric nitrogen through the root nodules, and also through leaf fall on the ground at maturity. Its root nodules fix atmospheric nitrogen to the extent of 100 to 120 kg ha^{-1}. It adds organic matter to the soil for increasing its productivity of the soil. It can be used as fodder, forage can be made into hay, silage *etc.,* It's forage and cake are excellent nutritive foods for livestock and poultry.

Recent data reveals that India ranks fourth in area with 11.40 million hectares (28.16 million acres) accounting for 9.12% of the world area and fifth in production with 13.78 million tonnes. In2020-21, world soybean production is projected as 364.40 million tonnes compared to the previous year 338.30 million tonnes. The production of soybean in India is dominated by Madhya Pradesh and Maharashtra which contributes 89 percent of total production while Rajasthan, Karnataka, Chhattisgarh and Gujarat contribute remaining. Among the other crops, Soybean is the principal *Kharif* crop of Madhya Pradesh (The Soy State) and is also known as the bowl of soybean in India, covering over 58.54 lakh hectares area and production of 41.77 lakh tonnes with average productivity of 921 kg ha^{-1} (SOPA, 2020).

Seed germination and seed development represent critical phases in which the optimal temperature range is about 22–24˚C. The high temperature during this phase inhibits seed germination slows down growth, and reduces yield and seed quality. Soybean yield is constrained by poor seed quality and field emergence due to improper handling of seeds during use of combined harvester causing mechanical damage to seed coat. Another reason for poor seed quality is climate change as the crop phase frequent droughts and flooding in the kharif season from last few years. Accordingly, it has become fundamental to help plants to resist abiotic stresses by using cost-effective new and faster alternative solutions. So far, different approaches to enhance germination and plant growth; however, some seed treatments may be applied. These techniques consist of partial hydration of the seeds followed by a dehydration step, activating various processes without completing germination. They exhibit faster and more homogeneous germination with different seed treatments. Likewise, seed treatments make the seed more responsive to external stimuli and neutralize stress conditions before seedling emergence.

To maximize the production of soybean, various chemical fertilizers are being used. However, they pose some health and environmental risks; contaminants may be present and excess fertilizers may enter the water table (Loan *et al*., 2018). Environmental risks may involve degradation of soil quality and agricultural nonpoint pollution from overuse of chemical fertilizers (Liu & Diamond, 2005; Yin *et al*., 2018). To minimize the retention of harmful chemical residues in the soil, producers are nowadays using naturally occurring andbiodegradable options in agriculture to increase crop yield (Savci, 2012; Siddiqui *et al*., 2011).Currently, it is very relevant to introduce the technologies in which the reduction of the effects of adverse environmental factors, the enhancement of the adaptive ability of the plants, and the maximum use of the crop's potential are achieved by the use of effective and environmentally friendly biological products, along with preserving the yield of the crops, contribute to reducing environmental pollution and agricultural products (Cunha and Filho, 2010; Shabaldas and Hoffman, 2007)

According to Du Jardin (2012), "Plant biostimulant is any substance or microorganism, in the form in which it is supplied to the user, applied to plants, seeds or the root environment with the intention to stimulate natural processes of plants to benefit their nutrient use efficiency and tolerance to abiotic stress, regardless of its nutrients content, or any combination of such substances and/or microorganisms intended for this use. From a regulatory point of view, there is no agreement worldwide defining plant biostimulants and many countries lack a legal framework. Plant biostimulants are defined more by the plant response they elicit than by their makeup since the category entails diverse substances and microorganisms such as humic acids, protein hydrolysates, seaweed extracts, silicon, mycorrhizal fungi, and nitrogen-fixing bacteria (Colla and Rouphael, 2015).

Plant biostimulants can influence phenotypic traits and improve yield by enhancing crop stress tolerance and nutrient uptake and assimilation. In most species, seed treatment, foliar and root application of plant biostimulants improves leaf pigmentation, photosynthetic efficiency, leaf number and area, shoot and root biomass, as well as fruit number and/or mean weight, especially under adverse environmental conditions (Ertani *et al*., 2013, 2014;

Colla *et al*., 2015; Lucini *et al*., 2015, 2018; Rouphael *et al*., 2017). Kauffman et al. (2007) classified organic biostimulant compounds, into three major groups on the basis of their source and content: humic substances, seaweed extracts, and amino acids containing products.

It is a new generation of products available on the market for a few years, could play a role as seed treatment agents. In this context, seed treatments using biostimulants are proposed as agro-physiological tools to neutralize the negative effects of abiotic stresses. The establishment of seedlings in the soil is an important and foremost need for better crop production. This depends largely on the germination and vigor potential of seeds used for sowing. Rapid germination and emergence are important determinants of the successful establishment (Heydecker, 1973). Obtaining high and stable yields of soybean largely depends on the quality of the seed material. In agricultural practice, increasing attention is paid to the use of growth stimulants. Seed treatment with growth stimulants is currently a scientifically substantiated technique (Sagitov *et al*., 2014; Agaev *et al*., 2009). It allows achieving the maximum germination rate and germination vigor, reducing the environmental factors, and improving the quality and quantity of the products (Shabaldas and Hoffman 2007)

Hence, we tested soybean seed with different seed coating treatment of bio stimulants and micro nutrients for its improvement in final plant stand establishment and seed yield. Therefore, study was undertaken in soybean to evaluate the influence of various pre sowing seed enhancement treatments on growth, physiological efficiency, seed yield and seed quality parameters. With this background, the present study was undertaken with the following objectives.

1. To investigate the effect of seed treatment with different biostimulants on phenology and physiological efficiency in soybean.
2. To study the effect of seed treatment with different bio-stimulant on productivity and seed quality attributes.

REVIEW OF LITERATURE

Soybean is rapidly emerging as the most important oilseed crop in India. The low productivity of the crop in the state is due to several constraints. Soybean being a rainy season crop suffers severely due to biotic and abiotic streses. Though many attempts have been made by scientists in soybean to investigate the effect of seed treatment on physiological processes. A brief work carried out in different parts of world pertaining to the investigations has been described as following categories:

2.1 Phenophases

2.2 Physiological growth parameters

2.3 Biophysical

2.4 Yield and yield components

2.5 Seed quality traits

2.1 Effect of seed treatment with biostimulants on crops phenology

Dias *et al. (2018)* reported that some qualitative parameters of mycorrhiza establishment, such as frequency and intensity of mycorrhization, both synthetic and natural biostimulants presented significant improvements, with EME and for providing higher values in general. The phenological stage of soybean significantly influenced AMF, bacterial and fungal community structures in the rhizosphere, while the biostimulant seed treatments significantly influenced the bacterial community.

Gurmani *et al.* (2020) experimented with Moringa leaf extract at the ratio of 1:10, 1:20, 1:30, 1:40, 1:50, seaweed extract at 1%, 2%, 3%, 4%, 5%, Thiourea at 100 ppm, 200 ppm, 300 ppm, 400 ppm, 500 ppm, and Chitosan at 25 ppm, 50 ppm, 100 ppm, 125 ppm, 150 ppm and it was observed that seaweed extract @ 2% outperforms other treatments in enhancing days to flowering.

Paraikovic *et al*. (2018) investigated biostimulants at all plant growth stages, from germination to full plant and fruit or flower commercial maturity, using the seed treatment, foliar application, or irrigation and observed that evaluated biostimulants mostly enhanced seed vigour, stimulated vegetative growth, improved nutrient acquisition and distribution within the plant, increased antioxidative capacity of plant tissues, contributing to higher stress tolerance, and improved plant yield and fruit/flower quality.

Adhikari and Pandey (1982) reported that seed yield was positively and directly affected by days to flower initiation.

Kumar *et al.* (2004) observed that seed yield was positively and directly influenced by days to flower initiation.

Oktem and Oktem (2020) noted that humic acid treatments positively affected tassel flowering day, grain number per ear, grain yield, protein ratio, leaf surface temperature and chlorophyll content (SPAD) values ($P \leq 0.05$). The longest tassel flowering duration value was seen at control application whereas the shortest tassel flowering duration value was found at seed+foliar treatment of humic acid.

Oktem *et al*. (2017) analyzed that humic acid concentrations were applied to corn seed and observed that tassel flowering duration decreased with humic acid seed treatment whereas leaf number per plant, grain weight of ear, thousand kernel weights and grain yield values increased with a humic acid seed treatment.

Brownell *et al*. (1987) observed that the extract that contains the greatest amount of the humic substances is used as an early-season soil treatment, seed treatment, while the other is used as a post-emergence foliar spray. The extracts, when used singly or in tandem, trigger a flowering response in many species of plants.

Zaiter and Barakat (1995) reported patterns of flower production, pod retention, number of flowers produced and percentage of flowers and pods abscised varied with cultivars.

Khan and Khalil (2010) suggested that soybean genotypes had slow TDM accumulation and LAI during the first 35 DAS followed by a rapid increase after the commencement of flowering. Flowering was started at 45 to 50 DAS, depending on genotypes.)

Ahmad *et al.* (2013) reported that applications of HA applied to the seed of wheat, proved best for early and uniform sprouting, more foliage growth per plant, greater leaf area, and total leaf chlorophyll contents, earlier spike emergence, a greater number of florets per spike, longer stems and spikes, and greater diameter of a spike, higher flower quality, longer vase life, the higher number of cormels per clump, and greater cormel diameter and weight.

Ali *et al.* (2014) obtained that adding organic substances either alone or in combinations has an effective role in the enhancement of studied characteristics of plant growth and flowering pattern (count and distribution of flowers and flowering duration); yield components (pods number plant^{-1}, 100-seed weight, seed yield plant^{-1}, pod duration, seed yield pod^{-1} and straw yield fed^{-1} as compared to the untreated plants in faba bean.

2.2 Effect of seed treatment with biostimulants on growth analytical parameter

2.2.1 Leaf Area Index (LAI)

Noli *et al*. (2021) conducted an experiment on species of seaweeds viz.,*Padina minor, Sargassum crassifolium, Sargassum cristaefolium and Turbinariadecurrens* and the concentration of liquid extracts were control, 0.1%, 0.2%, 0.3%, and 0.4%. The result showed that *P. minor* liquid extract increased leaf area, number of branches, fresh weight, and decreasing light transmission ratio.

Wilson *et al*. (2015) observed the beneficial effects of gelatin capsule seed treatment on enhanced plant growth and tolerance to abiotic stress. The gelatin treated plants had greater total leaf area, fresh weight, frozen weight, and nitrogen content.

Amirkhani *et al.* (2016) observed that the soy flour seeds coatings improved fresh weight (FW) and dry weight (DW), leaf area, plant height, leaf development, Soil-Plant Analyses Development (SPAD) index (chlorophyll measurement), and nitrogen (N) per plant than the non-coated control.

Ambika and Sujatha (2016) reported that in the field experiment *Sargassum myricocystum* extract at 1% concentration for 3 h soaking with seed treatment @ 5%. recorded higher plant height, total chlorophyll content, leaf area index, crop growth rate, relative growth rate and yield attributes, such as pod yield plant^{-1} and seed yield ha$^{-1.}$

Cakmake *et al.* (2006) reported that inoculation of plants with *Azospirillum* could result in significant changes in the increase in leaf area index of most of the cereals.

2.2.2 Leaf Area Duration (LAD)

Hussain *et al.* (2021) comprised that the application of MLE (moringa leaf extract) alone and in combination (MLE + MC) showed the promoting effect on the crop growth rate, net assimilation rate, leaf area index, leaf area duration, sympodial branches and number of bolls leading to higher seed cotton yield of both cotton cultivars grown under conventional row spacing.

2.2.3 Crop Growth Rate (CGR)

Soares *et al*. (2016) results showed that seed treatment of soybean with biostimulant increased the activity of nitrate reductase (NR) by 51%, the net photosynthesis (NP) by 50%, the chlorophyll content (SPAD value - Soil Plant Analysis Development) by 52%, and the plant growth rate (GR) by 28%, as compared to the control.

Sagitov *et al.* (2020) analyzed that the treatment of soybean seeds with stimulants in combination significantly improved their sowing qualities, suppresses fungal and bacterial infections, and intensifies the growth of plants and the root system.

Qiu *et al*. (2020) evaluated that red clover and perennial ryegrass seeds were coated with different combinations of soy flour, diatomaceous earth and biostimulants. Coated treatments significantly improved germination rate and uniformity with no reduction in total germination, compared to the non-treated controls in red clover. In contrast, for perennial ryegrass, the total germination percentage of all coated seeds was reduced and displayed a delayed germination rate, compared with the non-treated controls. Plant growth, shoot length, seedling vigor index, and dry weight of seedlings of coated seed treatments of both crops was significantly higher when compared to controls for both species.

Sekar *et al.* (1995) reported the fresh weight of green gram seedlings tested with all the six seaweed extracts treatment was gradually decreased with increasing concentration of seaweed extract from *Ulva lactuca* promoted the growth of *Vigna unguiculata*.

Lucini *et al*. (2015) reported that plants were sprayed with a solution containing 2.5 ml L^{-1} of biostimulant increased fresh yield, dry biomass and root dry weight of lettuce under salinity conditions.

Lima *et al.* (2020) conducted an experiment on eight biostimulant doses (0.0, 4.0, 8.0, 12.0, 16.0, 20.0, 24.0- and 28.0-mL kg^{-1} of seeds) and observed that best dose of biostimulant were 12.4, 15.3, 13.7, 12.4, 15.7, 16.4, 15.4- and 12.5-mL kg^{-1}, respectively for plant height, first ear insertion height, stem diameter, final population, number of ears per hectare, ear mass with and without straw and ear index.

Paradikovic *et al*. (2018) investigated effect of biostimulants on all plant growth stages, from germination to full plant and fruit or flower commercial maturity, using the seed treatment, foliar application, or irrigation and observed that biostimulants stimulated vegetative growth, improved nutrient acquisition and distribution within the plant, increased antioxidative capacity of plant tissues, contributing to higher stress tolerance, and improved plant yield and fruit/flower quality.

2.2.4 Relative Growth Rate (RGR)

Bernal *et al.* (2021) concluded that the rare earth element (REE) cerium (Ce) can act as a biostimulant in diverse crop plants and observed that shoot length dry weight and relative growth of the shoots increased significantly with the treatments of 5, 10, and 15 µM Ce along with dry.

Agliassa *et al*. (2021) analyzed that biostimulant-primed plants increased above ground relative growth rate and final fruit yield of stressed plants.

Arif *et al*. (2019) results revealed a positive effect of exogenously applied bio-stimulan MLE and potassium nitrate produced significantly higher absolute and relative growth rate, leaf area index, no. of branches, number of green bolls, seed index, cotton seed and lint yield of Bt while plant height, fiber maturity and uniformity ratio in the conventional cotton cultivar.

Paul *et al.* (2019) studied a screening protocol based on the use of a high-throughput phenotyping platform for screening new vegetal-derived protein hydrolysates (PHs) for biostimulant activity followed by a metabolomic analysis to elucidate the mechanism of the most active PHs on tomato crop and reported that digital biomass of the plants, relative growth rate and the growth performance were significantly improved by PHs A as compared to the untreated control plants.

2.2.5 Net Assimilation Rate (NAR)

Przybysz *et al*. (2014) stated that the application of the biostimulant, increased the fresh weight and dry matter of whole plant along with increased net assimilation rate in oilseed rape plants,

Jalakas *et al*. (2018) analyzed that stomatal conductance (g_s), CO_2 assimilation rate (Anet), fungal diseases, grain yield and yield components of seven European malting barley genotypes treated with fungicides alone or together with biostimulants in the field over three consecutive seasons and revealed that stomatal conductance, net assimilation rate and grain yield were affected by genotype, treatment and year.

Hussain *et al.* (2020) reported that the application of MLE alone and in combination (MLE + MC) showed a promoting effect on crop growth rate, net assimilation rate, leaf area index, leaf area duration, sympodial branches and number of bolls leading to higher seed cotton yield of both cotton cultivars grown under conventional row spacing.

Silva *et al.* (2021) conducted the experiment in a greenhouse under suboptimal temperatures with biostimulant, applied on seed, which make plants more tolerant to low temperature by maintaining net assimilation rate (A) by increasing the activity of antioxidant enzymes.

2.2.6 Biomass Duration

Colla *et al*. (2014) reported that the biostimulant-like effect of the protein hydrolysate on corn has been also observed in the rooting experiment of tomato cutting and it was found that the shoot, root dry weight, root length, and root area were significantly higher by 21, 35, 24, and 26%, respectively, Increasing the concentration of the protein hydrolysate from 0 to 10 ml/L increased the total dry biomass, SPAD index, and leaf nitrogen content by 20.5, 15, and 21.5%, respectively.

Lima *et al.* (2020) conducted an experiment on eight biostimulant doses (0.0, 4.0, 8.0, 12.0, 16.0, 20.0, 24.0- and 28.0-mL kg^{-1} of seeds) and observed that best dose of biostimulant were 12.4, 15.3, 13.7, 12.4, 15.7, 16.4, 15.4- and 12.5-mL kg^{-1}, respectively for plant height, first ear insertion height, stem diameter, final population, number of ears per hectare, ear mass with and without straw and ear index.

Amirkhani *et al* (2019) conducted the experiment on micronized vermi compost (MVC) and soy flour (SF) seed coating blends and observed that the biomass of the plant increased as compared to the control.

Campobenedetto *et al* (2020) reported that the application of the biostimulant as a seed treatment increased the percent germination (+6.54%)

and fresh biomass (+13%) and decreased the content of H_2O_2 in treated seeds at 28°C (−70%) and at 35°C (−80%) in cucumber (*Cucumis sativus* L.).

Cortivo *et al.* (2017) investigated the potential biostimulant effects of sedaxane and related physiological changes in disease-free maize seedlings (3-leaf stage) at increasing application doses (25, 75 and 150 μg a.i. seed−1) under controlled sterilized conditions. Result revealed that the maximum benefits were attained at the intermediate dose, which significantly increased root length (+60%), area (+45%) and forks (+51%), and reduced root diameter as compared to untreated controls.

Neta *et al.* (2018) evaluated the effects of a biostimulant on gherkin seeds, under conditions of salt stress and observed that in the absence of salt stress, biostimulant use led to an increase in the number of leaves and branches, the length of the largest branch and biomass accumulation.

2.3 Effect of seed treatment with biostimulants on biophysical traits

2.3.1 Chlorophyll Content Index (CCI)

Boruah *et al*. (2003) demonstrated that seed inoculation with PGPB improved the chlorophyll content of leaves of *Phaseolus vulgaris.*

Bashan *et al*. (2006) conducted experiment on wheat seedlings inoculated with *Azospirillum brasiliense* and observed that treatments led to significantly increased quantity of several photosynthetic pigments, such as chlorophyll a, chlorophyll b, and the auxiliary photoprotective pigments, such as violaxanthin, zeaxanthin, antheroxanthin, lutein, neoxanthin, and β-carotene.

Swedrzynska and Sawicka (2000) reported that increase in chlorophyll content due to the effect of inoculation with PGPR.

Mehrvarz *et al.* (2008) stated that mycorrhiza along with *Pseudomonas putida* increased leaf chlorophyll content in barley

Bulgari *et al.* (2014) analyzed that in leafy vegetables, biostimulants increased leaf pigments (chlorophyll and carotenoids) and plant growth by stimulating root growth and enhancing the antioxidant potential of plants. In floriculture, biostimulants used in bedding plant production stimulated the growth of plants, which reached the blooming and commercial stages earlier, thus optimizing space in the greenhouse.

Malik *et al.* (2020) stated that biostimulants have been gaining interest as they stimulate crop physiology and biochemistry such as the ratio of leaf photosynthetic pigments (carotenoids and chlorophyll), enhanced antioxidant potential, tremendous root growth, improved nutrient use efficiency (NUE), and reduced fertilizers consumption.

2.3.2 Energy interception

Briglia *et al*. (2019) stated that the use of plant biostimulants are increasingly recognized as a sustainable solution to optimize nutrient uptake, crop yield, quality, tolerance to abiotic stresses, and energy interception by higher leaf area.

Puglisi *et al.* (2020) observed that the *S. quadricauda extract* positively affected the growth of lettuce seedlings, mainly acting at the shoot level, determining an increase in dry matter, energy interception, chlorophyll, carotenoids, proteins, and influencing the activities of several enzymes involved in the primary metabolism.

2.3.3 Light transmission ratio %

Noli and Aliyyanti (2021) conducted an experiment on *Padina minor, Sargassum crassifolium, Sargassum cristaefolium* and *Turbinaria decurrens* and concentration of liquid extracts was control, 0.1%, 0.2%, 0.3%, and 0.4%. The result showed that *P. minor* liquid extract increased height, number of leaves, leaf area, number of branches, fresh weight decreasing light transmission ratio in soybean.

2.4 Effect of seed treatment on yield &yield component

2.4.1 Plant height (cm)

Przybysz *et al*. (2014) observed that Atonik-treated plants were taller than the control, and produced slightly more pods (0.1–4.1%) and seeds in pods (0.9–2.8%).

Dey *et al*. (2004) reported that phosphate-solubilizing bacteria increased shoot length in maize.

Hameeda *et al.* (2006) observed significant improvement in plant height in maize because of bacterial inoculation

Burd *et al*. (2000) reported that plant growth promoting rhizobacteria might enhance the plant height. In maize, the inoculation of plants with *Azospirillum* could result in significant changes in plant height

Gholami *et al*. (2009) reported that innoculation of maize seeds with six bacterial strains which includes *P.putida* strain R-168, *P.fluorescens* strain R-93, *P.fluorescens* DSM 50090, *P.putida* DSM291, *A.lipoferum* DSM 1691, *A.brasilense* DSM 1690 bacteria strains significantly increased the plant height and similar results were observed in different crops inoculated with *Azospirillum*.

Bashan *et al*. (2004) reported that seed treatment with with *Azospirillum* significantly increased the plant height.

Bashan (2004) stated that inoculation of plants with *Azospirillum* could result in significant changes in various growth parameters, such as increase in plant biomass, nutrient uptake, tissue N content, plant height, leaf size and root length of cereals.

Wang *et al*. (2009) reported that greenhouse experiments with tobacco plants demonstrated that treatment with the *Bacillus* spp. significantly enhanced the plant height and fresh weight.

2.4.2 No. of branches plant^{-1}

Noli *et al*. (2021) conducted an experiment on species of seaweeds viz., *Padina minor, Sargassum crassifolium, Sargassum cristaefolium and*

Turbinariadecurrens and the concentration of liquid extracts were control, 0.1%, 0.2%, 0.3%, and 0.4%. The result showed that *P. minor* liquid extract increased some parameters including height, number of leaves, number of branches, fresh weight, and decreasing light transmission ratio.

Neta *et al.* (2018) evaluated the effects of a biostimulant on gherkin seeds, cultivar Liso de Calcuta, under conditions of salt stress with five biostimulant doses applied as a seed treatment (0, 5,10,15 and 20 mL kg^{-1}) that led to an increase in the number of leaves and branches, the length of the largest branch and biomass accumulation.

Arif *et al*. (2019) revealed positive effect of exogenously applied bio-stimulant and various potassium sources on the growth, no. of branches, yield and fiber quality of cotton cultivars at both sites.

2.4.3 No. of pods plant^{-1}

Petropoulos *et al.* (2020) reported that the application of biostimulants could be considered as an eco-friendly and sustainable means to increase the pod yield and the quality of common bean green pods and seeds under normal irrigation conditions. Promising results were also recorded regarding the alleviation of negative effects of drought stress, especially for the application of arbuscular mycorrhizal fungi (AMF; seed treatment), which increased the total yield of green pods.

Burbulis *et al.* (2021) evaluated the effect of exogenously applied amino acids L-proline (30 mM L^{-1}) and L-glutamic acid (1.5 M L^{-1}) on the productivity of winter rapeseed (*Brassica napus* L. subsp. *oleifera* (Delile) Sinskaya) and it was observed that higher 1000-seed weight and seed yield were obtained with L-glutamic acid in autumn and spring, while the higher number of siliques per plant was observed without amino acid application.

Silva *et al*. (2021) analyzed that the application of an oil-based solution of tyrosol (10 mg/L) to soybean seeds showed no significant difference from soybean seeds without tyrosol in terms of number of pods per plant.

Kocira (2018) analyzed that the application of biostimulant increased (compared to the control) number of pods per plant and seeds (32%), plant height (38%), phenolic content (34%) and flavonoids content (74%).

2.4.4 No. of seeds pod^{-1}

Sevov and Delibaltova (2013) revealed that the biostimulant fertigrain have positive effect on the productivity of bread wheat Sadovo 772 variety with higher values of structural elements of the yield, such as; length of the spike, number of the spikelets per spike, number of the grains per spike, weight of the grains per spike and thousand grain weight.

Beckett and Staden (1988) noted that the effect of the seaweed concentrate 'Kelpak' on the growth and yield of wheat grown under conditions of varying K supply were investigated and it was observed that Kelpak had no significant effect on the yield of wheat receiving an adequate K supply, but significantly increased the yield of K stressed plants.

Petropoulos *et al.* (2020) reported that the application of biostimulants could be considered as an eco-friendly and sustainable means to increase the pod yield and the quality of common bean green pods and seeds under normal irrigation conditions. Promising results were also recorded regarding the alleviation of negative effects of drought stress, especially for the application of arbuscular mycorrhizal fungi (AMF; seed treatment), which increased the total yield of green pods.

2.4.5 Seed index (100g)

Burbulis *et* ***al.*** (2021) evaluated the effect of exogenously applied amino acids L-proline (30 mM L^{-1}) and L-glutamic acid (1.5 M L^{-1}) on the productivity of winter rapeseed (*Brassica napus* L. subsp. *oleifera* (Delile) Sinskaya) Higher 1000-seed weight and seed yield were obtained with L-glutamic acid in autumn and spring, while the higher number of siliques per plant was observed without amino acid application. Application of both amino acids led to an increase in seed yield of winter rapeseed from 3.5% to 11.8%.

Sevov and Delibaltova (2013) revealed that the biostimulant fertigrain have positive effect on the productivity of bread wheat Sadovo 772 variety with significant effect on weight of the grains per spike and thousand grain weight.

Jalakas *et al*. (2018) treated seed with fungicides alone or together with biostimulants and observed that 1000-kernel weight and higher water use efficiency were associated with higher grain yield, whereas a negative correlation was detected between grain yield and the number of ears per area.

2.4.6 Seed yield

Silva *et al.* (2021) analyzed that the application of an oil-based solution of tyrosol (10 mg/L) to soybean seeds showed no significant difference from soybean seeds without tyrosol in terms of germination percentage, number of nodules, number of seeds per plant, and number of pods per plant. Metabolomic analysis of the soybean leaves using GC–MS showed differences in the chemical composition between the treatments, with significant differences in the abundance of 11 metabolites.

Kocira (2019) reported that the application of biostimulant increased (compared to the control) number of pods and seeds (32%), plant height (38%), phenolic content (34%), flavonoids content (74%).

Szparaga *et al.* (2018) conducted the experiment on biostimulant. It was also found that plant growth and seed yield were significantly decreased the protein and lipid contents in seeds with positive impact on soybean seed number and soybean seed yield.

Teixeira *et al*. (2018) reported that the application of Cys and Phe as ST (seed treatment) increased the production of soybean plants by atleast 21%. The isolated application of Cys(cystine), Phe(phenylalanine), Gly(glysine), Glu(glutamate) and the set of these amino acids as ST increased the productivity of soybean plants in the field experiment by at least 22%.

Sadak *et al*. (2014) observed that Irrigation of faba bean plant with different levels of seawater decreased seed yield and total dry weight per plant compared with those irrigated with tap water. Amino acid application as seed treatment significantly improved all the reduced parameters due to seawater stress.

Petropoulos *et al*. (2020) evaluated the biostimulants application on the yield and chemical composition of green pods and seeds of common bean (*Phaseolus vulgaris* L.). For this purpose, four commercially available biostimulant products, namely Nomoren (G), EKOprop (EK), Veramin Ca (V), and Twin-Antistress (TW), were tested under two irrigation regimes: normal irrigation (W+) and water-holding (W-) conditions with highest increase (20.8%) of pods total yield was observed in EKW+ treatment due to the formation of more pods of bigger size compared to control treatment (CW+). In addition, the highest yield under drought stress conditions was recorded for the GW- treatment (5691 ± 139 kg/ha).

2.4.7 Biological yield (g plant^{-1}, kgha^{-1})

Waqas *et al.* (2014) observed that seed priming with 0% (water soaked), 1%, 2% HA solution and foliar spray with 0.01%, 0.05% and 0.1% of HA solution. It is concluded that HA application in all the three methods significantly enhances grain yield and yield components of mungbean.

Ahmad *et al.* (2017) reported that the application of humic acid in the form of the liquid fertigation fertilizer and liquid foliar fertilizer along with 50 kg of urea per acre and with seed treatment showed the best results of biological yield (grain plus straw yield).

Anwar *et al. (2016)* stated that humic acid at the rate of 15 kg ha^{-1} and nitrogen at the rate of 150 kg ha^{-1} produced maximum plant height (109 cm), tillers m^{-2} (267), productive tillers m^{-2} (261), 1000 grain weight (46.3 g), grains spike^{-1} (49), grain yield (3316 kg ha^{-1}), biological yield (9641 kg ha^{-1}) and harvest index (36.0 %). It was concluded that wheat yield increased by increasing the application of humic acid and nitrogen levels up to 15 kg ha^{-1} and 150 kg ha^{-1}, respectively.

2.4.8 Harvest index (%)

Tollenaar *et al.* (2004) The distribution of dry matter at maturity between stover and grain is referred to as the harvest index (HI). Harvest index is a function of kernel number and kernel size, that is, the capacity to accumulate dry matter.

Mehrvarz *et al.* (2008) stated that the positive effect of the mycohrizza application was observed on harvest index and 1000 grain weight.

Saad and Hammad (1998) reported that highest straw yield was with the inoculation of phosphate solubilizing bacteria there by significant increase in harvest index.

2.5 Effect of seed treatment with biostimulants on post-harvest Seed quality traits

2.5.1 Field emergence (%)

Oktem *et al.* (2018) reported that humic acid seed treatments were significant at grain weight of ear, thousand kernel weights and grain yield ($P \leq 0.01$). Tassel flowering duration decreased with humic acid seed treatment whereas field emergence, leaf number per plant, grain weight of ear, thousand kernel weights and grain yield values increased with humic acid seed treatment. The highest values were found in % 7.5 humic acid seed treatment.

Kaya*et al* (2020) observed that seed pretreatment with Zn or pretreatment of seeds + foliar spray of humic acid substances at three to six leaf stage significantly increased yield and yield components in common bean. Correlation coefficients of various agronomic characteristics showed that a unit increase in common bean field emergence, and seed yield was positively associated with number of seeds per plant number of pods per plant seed weight per plant plant height harvest index and raw protein yield.

Churilov *et al.* (2015) observed those humic acids in the ultrafine state stimulate the germination of corn seeds in vitro (by 3.4%) and in field experiments (up to + 10.2% compared to control). At the initial stages of germination, the growth of the root system increased: the mass of roots exceeded the control in 3 times.

2.5.2 Seed germination (%)

Campobenedetto *et al* (2020) reported that the application of the biostimulant as a seed treatment increased the percent germination (+6.54%) and and decreased the content of H_2O_2 in treated seeds at 28°C (−70%) and at 35°C (−80%) in cucumber (*Cucumis sativus* L.).

Gonzalez and Sommerfeld (2015) stated that Cellular extracts and dry biomass of the green alga *Acuto desmusdimorphus* were applied as a seed primer, foliar spray, and biofertilizer, to evaluate seed germination, plant growth, and fruit production in Roma tomato plants and it was observed that seed priming triggers faster seed germination as compared to the control.

Zulfiqar *et al*. (2019) reported that Moringa leaf extracts have been shown to improve seed germination, plant growth and yield, nutrient use efficiency, crop and product quality traits (pre- and post-harvest), as well as tolerance to abiotic stresses.

Douglas *et al.* (1990) conveyed that the commercially available biostimulants Agro-Lig, Enersol (humic acids), and Ergostim (folic acid) were added at a concentration of 1.5% (w/v) to Laponite 508 (magnesium sulfate) gel used in fluid drilling. Agro-Lig, Enersol and Ergostim increased carrot emergence > 2-fold as measured by number of roots as compared to untreated seed. Number of carrots increased 50% to 75% when biostimulants were incorporated into the gel, compared to fluid-drilled seed without the biostimulants.

Kumar and Sahoo (2011) documented the effect of seaweed liquid extract (SLE) of Sargassum wightii on germination, growth and yield of *Triticum aestivum* var. Pusa Gold was studied. Application of a lower concentration (20%) of SLE enhanced the percentage of seed germination, growth and yield, as measured by kernel number and seed dry weight as compared to control.

Kavipriya *et al.* (2015) examined seaweed extracts obtained from, *Ulva lactuca, Caulerpa scalpelliformis*, the brown algae, *Sargassum plagiophyllum, Turbinariaconoides, Padina tetrastromatica,* and *Dictyotadichotama* on the *Vigna radiata* seeds were analyzed Aitkin and Senn recorded lower concentration seaweed extract showed increased seed germination on ornamental plants, Tobacco, Pea and cotton.

2.5.3 Seedling length (cm)

Deka Boruah *et al.* (2003) demonstrated that seed inoculation with PGPB improved shoot length of french bean (*Phaseolus vulgaris*).

Sharma and Johri (2003) statedthat inoculation of maize seeds with PGPR significantly increased the maximum shoot length.

Mishra *et al.* (2010) observed that the isolates of bacteria treated in seeds resulted in a significant increase in shoot length, root length and dry matter production of shoot and root of *Cicer arietinum* seedlings.

2.5.4 Seedling dry weight (g)

Kavadia *et al.* (2021) observed that one of the most often reported PGPR inoculants significantly increased root dry weight in cow pea.

Pandy *et al.* (1998) reported that there was a enhancing effect of seed inoculation with rhizobacteria on shoot dry weight.

Dobbelaere *et al*. (2001) observed the inoculation effect of PGPR and *Azospirillum* sp. on growth of spring wheat and observed that inoculated plants resulted in better increase in dry weight of both root and shoot system.

Kozdroja *et al*. (2004) observed that the inoculation effect of PGPR and *Azospirillum*sp. lead to increase the dry weight of both root and shoot system in different crops.

Mustafa *et al.* (2006) suggested that seed inoculation of barley with Bacillus RC01, Bacillus RC02, Bacillus RC03 and Bacillus M-13 increased root weight by 16.7, 12.5, 8.9 and 12.5 % as compared to the control (without bacteria inoculation and mineral fertilizers) and shoot weight by 34.7, 34.7, 28.6 and 32.7 %, respectively.

Qiu *et al* (2019) conducted an experiment on red clover and perennial ryegrass seeds coated with different combinations of soy flour, diatomaceous earth, micronized vermicompost, and concentrated vermicompost extract and it was observed that shoot length, seedling vigor index, and dry weight of seedlings of coated seed treatments of both crops were significantly higher when compared to controls for both species.

2.5.5 Seed vigour index

Paneri *et al*. (2020) analyzed that combination of *C. majus* and *A. nodosum* (C7+ST), as a biostimulant both 1g L^{-1}, was the most beneficial treatment and significantly increased shoot height (13.2%), dry mass (10.7%), and photosynthetic rate (20.3%). applications with 1 g L^{-1} of *A. nodosum* (ST) significantly enhanced the dry mass (23.5%), and the photosynthetic rate was increased even at 10 days after application (22.5%) in soybean.

Colla *et al*. (2014) reported that the biostimulant-like effect of the protein hydrolysate on corn has been observed in the rooting experiment of tomato cuttings. The shoot, root dry weight, root length, root area, and also vigour was significantly higher by 21, 35, 24, and 26%, respectively, Increasing the concentration of the protein hydrolysate from 0 to 10 ml/L increased the total dry biomass, SPAD index, and leaf nitrogen content by 20.5, 15, and 21.5%, respectively.

Ngoroyemoto *et al*. (2019) reported the effects of some natural biostimulants such as smoke-water (SW), karrikinolide (KAR1), vermicompost leachate (VCL), Kelpak (KEL) and eckol (ECK) on seed germination, growth, nutrition and phytochemical levels under different modes of application (drenching, foliar spray, seed treatment and combined drenching and foliar spray). SW (1:500 v/v), KAR1 (10^{-6} M), VCL (1:5 v/v) and KEL (0.8%) showed a significant increase in shoot/root length, shoot fresh/dry weight, number of leaves, total leaf area and stem thickness compared with the control. Plant fresh and dry weights were significantly influenced by all the tested biostimulants.

Rouphael *et al.* (2020) stated that the application of pH alone or in combination with *Trichoderma* elicited significant increase (+16.6%) in the shoot biomass compared to untreated maize plants, whereas inoculation with AMF + *Trichoderma* elicited significant increase in root dry biomass (+48.0%) compared to untreated plants. Distinctive metabolomic signatures were achieved from the different treatments, hence suggesting that different molecular processes were involved in the plant's response to the biostimulants. The metabolic reprogramming triggered by the treatments including the protein hydrolyzate was hierarchically more pronounced than the application of microorganisms alone.

Cortivo *et al.* (2017) investigated the potential biostimulant effects of sedaxane and related physiological changes in disease-free maize seedlings (3-leaf stage) at increasing application doses (25, 75 and 150 μg a.i. $seed^{-1}$) under controlled sterilized conditions. Maximum benefits were attained at the intermediate dose, which significantly increased root length (+60%), area (+45%) and forks (+51%), and reduced root diameter as compared to untreated controls.

Kavipriya *et al.* (2011) suggested that seaweed extracts strongly induced seed germination and other growth parameters.

MATERIALS AND METHODS

The present investigation entitled **"Optimization of seed treatment techniques for enhancement of physiological efficiency, productivity and seed quality attributes in Soybean [*Glycine Max* (L.) Merr.]''** was carried out in the year 2021 during the Kharif season. Details about materials utilized and procedures employed during field and laboratory investigations are briefly discussed in this chapter under the respective headings.

During the Kharif season of 2021, a field experiment was undertaken at the Seed Technology Research Center, Department of Plant Breeding and Genetics, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (Madhya Pradesh). The experimental field area's terrain was quite consistent. On the research farm, all of the necessary resources, such as labourers, agrochemicals, equipment, and irrigation, were readily accessible to conduct the field experiment.

Jabalpur is situated at 23'90" N longitude and 79' 58"E longitude at an altitude of 411.78 meter above the mean sea level. It falls under subtropical climatic conditions, which is characterized by the features of hot dry summers and cool dry winters. The 10-years mean annual rainfall of the area is 1284mm and nearly 90% of the total annual rainfall is mainly received during the period between ends of June to end of September. The rainfall is often erratic and ill-distributed along with an occasional long dry spells or frequent heavy rainy days during rainy season. There is possibility of occasional and little rainfall during rest period of the year. The maximum and minimum temperature ranges between 17.2°C to 41.6°C and 1.2°C to 28.9°C, respectively within a year. In some of the years, maximum temperature reaches as high as 45°C in the month of May or June, while minimum temperature falls 2°C down to a limit of 4°C during end of December or January months. The relative humidity varied from season to season. It ranges between 80 to 90% during rainy season, which reduces as 60 to 70 and 30 to 40% during winter and summer seasons respectively.

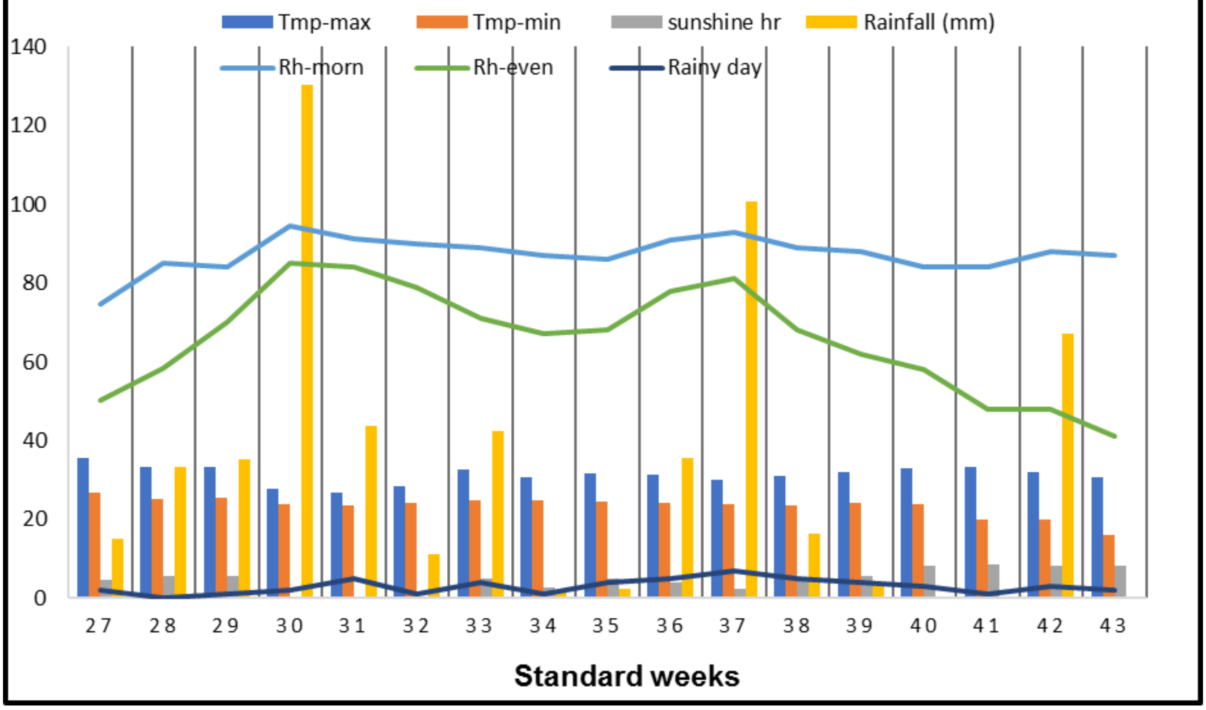
Weather during the experimental period

Table 3.1 Weekly Meteorological data during the *Kharif* season 2021

Month	Met. Week	Temp. (^0C)		Relative humidity (%)		Sunshine hours (hrs day^{-1})	Rainfall (mm)	Rainy days (No.)
		Max.	Min.	Mor.	Eve.			
July	27	35.7	26.7	74.7	50.3	4.7	15.0	1
	28	33.3	25.1	85.1	58.3	5.5	33.2	2
	29	33.4	25.4	84.1	70.0	5.5	35.4	3
	30	27.7	23.8	94.6	85.1	0.2	130.4	5
August	31	26.8	23.4	91.1	84.1	0.3	43.7	6
	32	28.5	24.2	90	79	0.5	11.1	2
	33	32.6	24.7	89	71	4.9	42.3	3
	34	30.7	24.7	87	67	2.6	2.2	0
	35	31.6	24.5	86	68	5.1	2.5	0
September	36	31.4	24.1	91	78	4.1	35.7	4
	37	30.0	23.8	93	81	2.3	100.8	4
	38	30.9	23.6	89	68	4.7	16.3	2
	39	31.9	24.1	88	62	5.6	3.8	1
October	40	32.9	23.7	84	58	8.2	0.0	0
	41	33.3	20.0	84	48	8.6	0.0	0
	42	31.9	19.9	88	48	8.1	67.0	2
	43	30.7	16.0	87	41	8.3	0.0	0
Total		533.5	397.5	1485.3	1116.7	79.2	539.4	35.0
Maximum		35.7	26.7	94.6	85.1	8.6	130.4	6
Minimum		26.8	16.0	74.7	41	0.2	0	0
Average		31.4	23.4	87.4	65.7	4.7	31.7	2.1

Source: **Department of Physics and Agro-meteorology, College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidhyalaya, Jabalpur (Madhya Pradesh).**

Fig.3.1 : Weekly meteorological data during the crop season august 2021 to october 2021



3.4 Soil characteristics

The soils adjoining Jabalpur are classified as “vertisol “as per US Classification of soil. The soils of the region have medium to deep depth and black color with sandy clay-loam texture and neutral soil reaction. The experimental field having a gentle slope, proper drainage and uniform clay loam soil was selected. The soil of the experimental field was neutral in reaction to mildly alkaline with an average pH of 7.3. It swells by wetting and shrinks by drying. Therefore, deep and wide cracks develop during winter season. The soil of the experimental field was analyzing low in organic carbon as well as with medium available nitrogen, medium available phosphorus and Medium in available potassium contents with normal electrical conductivity.

3.5 Land preparation

To get a good tilth for the sowing of soybean in the present experimental field, one summer ploughing followed by one pass of tractor driven cultivator and two pass of disc harrow were made and then the field was finally leveled before seeding of the soybean crop in the experimental field.

3.5 Layout of the experiment

The treatments were laid out in Factorial Randomized Block Design with eight replications. The different treatments were randomized within each replication using a random table. The layout plan of the present experiment has been graphically illustrated in Figure 2.

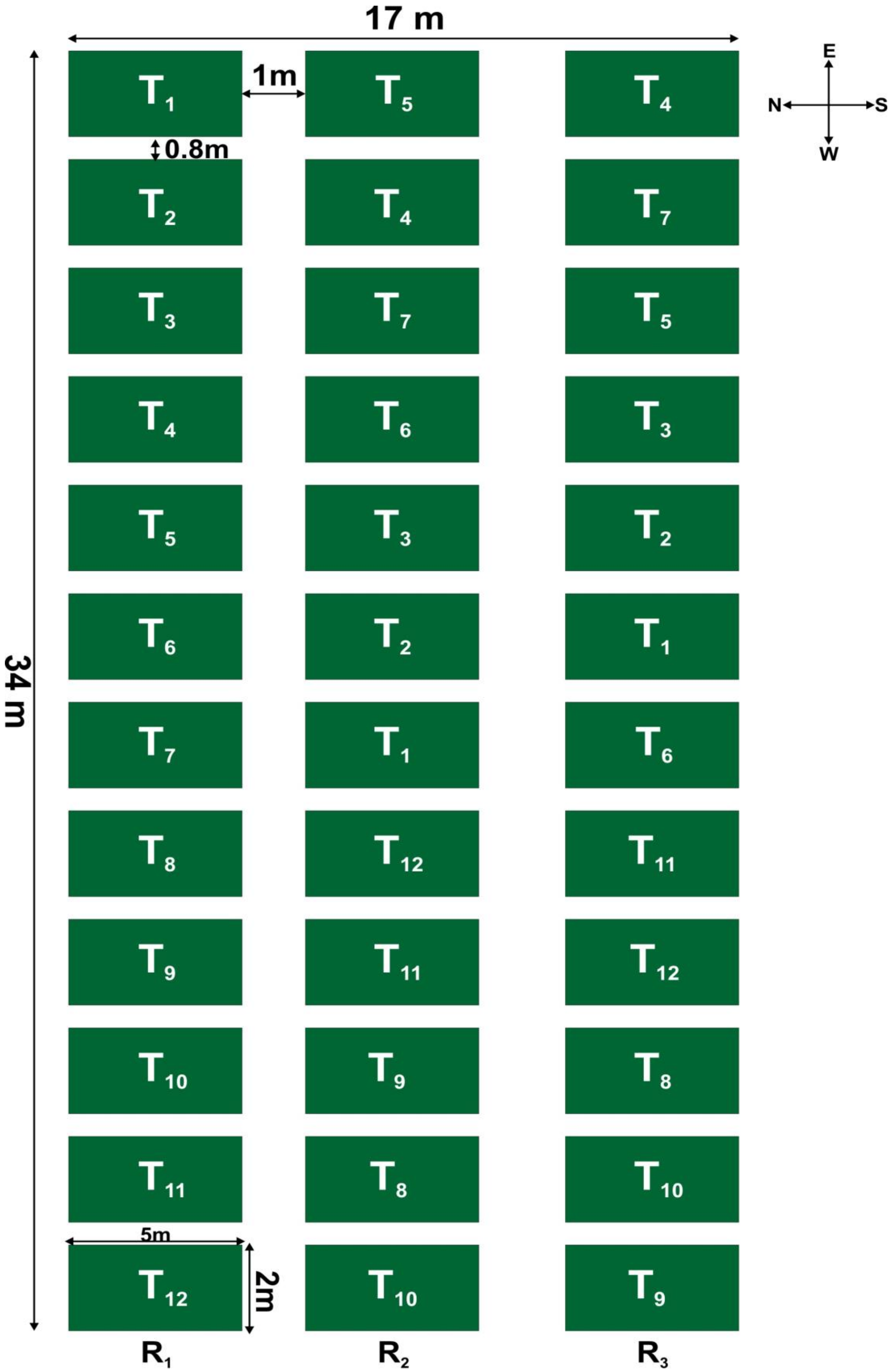
3.6 Experimental details

The experimental details of the present investigation are given below:

Season	:	*Kharif* (2021)
Design	:	Randomized Block Design (RBD)
Replications	:	03
Distance between rows	:	0.40 m
Distance between plots	:	0.80 m
Distance between replications	:	1.0 m
Gross plot size	:	2.40 m x 5.00 m
Net plot size	:	1.80 m x 4.00 m
Total experimental area	:	17.00 m x 34.00 m (578 m^2)
No. of rows $plot^{-1}$	:	7
No. of plots	:	36
Recommended Fertilizer dose	:	20:40:20 kg ha^{-1} ($N:P_2O_5:K_2O$)
Total treatment combinations	:	12
Variety	:	JS 20-116 (late maturity)
Date of Sowing	:	02.08.2021
Date of Harvesting	:	09.11.2021

Treatment – 12 in No.

Treatments.	Treatment details
T_1	Control
T_2	seed treatment with bio-stimulant Take-off ST @ 1ml/kg
T_3	Seed treatment with Take-off ST @ 2ml/kg
T_4	Seed treatment with Take-off ST @ 3ml/kg
T_5	Seed treatment with Take-off ST @ 4ml/kg
T_6	Seed treatment with state recommended dose (rhizobium @ 5g/kg seed+ Vitavax@5g/kg seed)
T_7	Seed treatment with seed 100 cl @ 2ml/kg
T_8	Seed treatment with $ZnSO_4$ @ 0.3%
T_9	Seed treatment with K_2HPO_4 @ 0.5%
T_{10}	Seed treatment with $MnSO_4$ @ 0.5%
T_{11}	Seed treatment with Salicylic acid @ 100 ppm
T_{12}	Seed treatment with KNO_3 @ 0.3%



2 Layout plan of experiment

3.10 Seed sowing

Hand dibbling was used to sow seed of soybean cultivars JS 20-116 in the field, with a gap of 0.40m between rows and 0.05m between plants.

3.11 Intercultural operations

Weeds were kept out of the experimental plots, and hand weeding was done as needed.

3.12 Application of fertilizer

In order to maintain the uniform fertility status in the experimental soil, the NPK @ 20:40:20 kg per hectare was applied prior to sowing. The NPK were applied as urea, single super phosphate and murate of potash respectively.

3.13 Harvesting

On November 9, 2021, the last harvesting was completed. Each plot's border rows were harvested first and removed, leaving a net plot. For post-harvest observations, five plants from each plot were chosen and harvested independently. The net plot was then harvested by cob plucking and above-ground cutting of the plants. Plants were sun dried, threshed, and different yield components and seed yield were measured.

3.14 Observations

For the following parameters, observations were made on five randomly selected plants from each treatment, and per plant data was derived by averaging the results:

3.14.1 Phenophasic Developments

Throughout the growing period, daily visual phenological observations of soybean crop, were made from five chosen and tagged plants.

3.14.1 Phenological parameters:

3.14.1.1 Days to flower initiation

3.14.1.2 Days to 50% flowering

3.14.1.3 Days to pod initiation

3.14.1.4 Days to 50% podding

3.14.1.5 Days to physiological maturity

3.14.2 Physiological Growth parameters:

3.14.2.1 LAI (Leaf Area Index) at 60, 70, 80 DAS (Gardner et al., 1985)

3.14.2.2 LAD (Leaf Area Duration) (cm^2 day^{-1}) (Watson, 1952)

3.14.2.3 CGR (Crop Growth Rate) (g cm^{-2} day^{-1}) (Watson, 1952)

3.14.2.4 RGR (Relative Growth Rate) ($g.g^{-1}$ day^{-1}) (Watson, 1952)

3.14.2.5 NAR (Net Assimilation Rate) (g cm-2 day-1) (Williams, 1946)

3.14.2.6 Biomass Duration (g days) (Kvet, 1962)

3.14.3 Biophysical traits

3.14.3.1 Chlorophyll Content Index :(SPAD-502)

3.14.3.2 Energy Interception (cal. cm^{-2} min^{-1})

3.14.3.3 Light Transmission Ratio (%)

3.14.4 Yield and yield components

3.14.4.1 Plant height (cm)

3.14.4.2 No. of branches plant-1

3.14.4.3 No. of pods plant-1

3.14.4.4 No. of seeds pod-1

3.14.4.5 Seed index (g)

3.14.4.6 Seed yield ($gplant^{-1}kg$ ha^{-1})

3.14.4.7 Biological yield ($gplant^{-1}kg$ ha^{-1})

3.14.4.8 Harvest Index (%)

3.14.5 Seed quality parameters

3.14.5.1 Field emergence (%)

3.14.5.2 Seed germination (%)

3.14.5.3 Seedling shoot length (cm)

3.14.5.4 Seedling root length (cm)

3.14.5.5 Seedling dry weight (g)

3.14.5.6 Seed Vigour Index I

3.14.5.7 Seed Vigour Index II

Physiological Growth parameters in details:

3.14.2.1Leaf area (cm^2)

Leaf area was estimated at 60, 70 and at 80 days' stages. Using Leaf area meter (model CI 203)

3.14.2.3 Leaf area index (LAI)

LAI expresses the ratio of leaf surface (One side only) to the ground area occupied by the plant or a crop stand worked out as per specifications of Gardner et al. (1985).

$$LAI = \frac{\text{Total leaf area}}{\text{Land area}} \qquad LAI = \frac{(LA_2 + LA_1)}{2/p}$$

Where, LA_1 and LA_2 represents leaf area during two consecutive intervals and 'P' ground area.

3.14.2.4 Leaf area duration (LAD)

Leaf area duration expresses the magnitude and persistence of leaf area or leafiness during the period of crop growth. It reflects the extent of seasonal integral of light interaction and correlated with yield. LAD was computed as follows: (Watson, 1952).

$$LAD = \frac{(LA_2 + LA_1)}{2} \times (t_2 - t_1)\ (m^2.\ \text{days})$$

Where,

LA_1 and LA_2 represents the leaf area at two successive time intervals (t1 and t_2).

3.14.2.5 Crop growth rate (CGR)

The daily increment in plant biomass is termed as crop growth rate (Watson, 1952) or productivity rate (Leith, 1965) or rate of dry matter production. It was determined as per the following formula suggested by Watson, 1952).

$$CGR = \frac{W_2 - W_1}{p\,(t_2 - t_1)} \quad (gcm^{-2}\ day^{-1})$$

Where,

p = ground area (m^2)

W_1 = dry weight per unit area at t_1

W_2 = dry weight per unit area at t_2

t_1 = first sampling and

t_2 = second sampling

3.14.2.6 Relative growth rate (RGR)

The Relative growth rate expresses the dry weight increase in time interval in relation to initial weight. In practical situations, the mean relative growth rate is calculated from measurements at t_1 and t_2. It was calculated as per formula given by (Watson, 1952).

$$RGR = \frac{Ln\ W_2 - Ln\ W_1}{t_2 - t_1} \quad (gg^{-1}day^{-1})$$

Ln represents natural log

3.14.2.8 Net Assimilation Rate (NAR) (g cm^{-2} day^{-1})

The term NAR was used by Williams (1946). NAR is defined as dry matter increment per unit leaf area or per unit leaf dry weight per unit of time. The NAR is a measure of the average photosynthetic efficiency of leaves in a crop community.

$$NAR \quad \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{(Log\ L_2 - Log\ L_1)}{(L_2 - L_1)} \quad (g\ cm^{-2}\ day^{-1})$$

Where, W_1 and W_2 is dry weight of whole plant at time t_1 and t_2 respectively L_1 and L_2 are leaf weights or leaf area at t_1 and t_2 respectively $t_2 - t_1$ are time interval in days.

3.14.2.9 Biomass Duration (BMD) (g days)

This is the parameter that represents dry weight losses or gains during a unit time period (Kvet, 1962).

$$BMD = \frac{W_2 - W_1}{(L_n W_2 - L_n W_1)} (t_2 - t_1) \text{ (g days)}$$

3.14.3 Biophysical traits

3.14.3.1 Chlorophyll Content Index (SPAD-502)

Chlorophyll content index which is expressed as grams of chlorophyll per unit ground area and it was determined in the 4th leaf of five weeks old plant using a non-destructive method that uses an optical instrument called chlorophyll meter (Model: CCM 200 Made in USA).

3.14.3.2 Energy Interception (cal. cm $^{-2}$ min $^{-1}$)

The total incident light at the canopy crown and transmitted light within the crop were converted into average incident and transmitted energy on the basis of value reported by Gaastra (1963).

71 K.Lux = 1 Cal.cm^{-2}min^{-1}

The efficiency of the crop canopy for solar energy interception (Ei) was calculated as per the formula given by Hayashi (1966).

Ei = Total incident – transmitted energy

3.14.3.3 Light Transmission Ratio (%)

The light intensity, incident on crop canopy surface and infiltration profile within the canopy at the ground level was recorded by Lux-meter (Model – LX - 105). The LTR was calculated as per Golingai and Mabbayad's (1969) formula.

$$LTR (\%) = \frac{I}{I_o} \times 100$$

Where,

“I” and “I_0” refers to the light intensities at the ground level and incident on the plant respectively.

3.14.4 Yield and Yield components

3.14.4.1 Plant height (cm)

Plant height was recorded at harvest from the soil surface to the tip of uppermost node.

3.14.4.2 No. of branches plant^{-1}

Number of branches was recorded of the crop in all the plots. It was measured in five plants, which were selected randomly and tagged.

3.14.4.3 Number of pods plant^{-1}

The number of pods plant^{-1} was calculated by tagging five plants at maturity.

3.14.4.4 Number of seeds pod^{-1}

The number of seeds pod^{-1} was recorded from five tagged plants at maturity.

3.14.4.5 Seed Index (100 seed weight g)

100 seeds were taken from the produce of each plot and their weight was recorded by electronic balance.

3.14.4.6 Seed yield (gplant^{-1} and kgha^{-1})

The Seed yield gplant^{-1} and kgha^{-1} was recorded after threshing, cleaning and drying the grains. It is also known as economical yield.

3.14.4.7 Biological yield (gplant^{-1} and kgha^{-1})

Biological yield is the total yield of crop including economic yield and the Stover yield. The biological yield per plant and kg/ha was recorded after harvesting.

3.14.4.8 Harvest index

Harvest index is the ratio of economic yield to the total biological yield expressed in percentage. It represents the efficiency of photosynthates translocation to economic parts (Synder and Carlson, 1984).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

While calculating the biological yield only the above ground parts were taken into consideration.

3.14.5 Seed quality traits:

3.14.5.1 Germination (%)

Three replications of 100 seeds from respective treatments were used for germination by using paper towel methods (BP) at 25 ± 20 °C in seed germinator for 8days at 90% relative humidity (Anonymous, 1999). The seeds were categorized as normal seedlings, abnormal seedlings, hard seed, and dead seed. The germination percentage was recorded based on normal seedlings only.

3.14.5.2 Seedling length (cm)

Paper Towel is moistened with distilled water. Twenty seeds are placed on it in a straight line and paper towel is folded Kept in a germinator at an angle of 75 and optimum temperature. Only 10 competitive seedlings are selected for observations. It is determined by dividing mean increase in length from previous measure by number of days the seedlings are placed in germinator. Length of 10 normal seedlings in cm is measured during the final count. The lot exhibiting maximum seedling length is considered vigorous.

3.14.5.3 Root length (cm)

Length of 10 normal seedlings roots in cm is measured during the final count. The lot exhibiting maximum seedling root length is considered vigorous.

3.14.5.4 Seedling dry weight (g)

The weight of seedling excluding the cotyledons is taken on 10th day after drying them at 60-80^{0}C in an oven for 24 hrs in g. The lot exhibiting maximum dry weight is considered as vigorous

3.14.5.5 Seed Vigour index-I

A combination of standard germination test with seedling length provides evaluation for seed vigor (Abdul Baki and Andreson, 1972).

Vigor index- I = Germination percentage x seedling length at final count

3.14.5.6 Seed Vigour index-II

Vigour index by weight is determined by the multiplication of seedling dry weight on the final count and germination percentage (Abdul Baki and Andreson, 1972).

Vigor index- II = Germination percentage x seedling dry weight at final count.

3.15 Statistical analysis

Analysis of observations taken on different variables was carried out to know the degree of variation among all the treatments. The data was statistically analyzed through randomized block design (Fisher, 1967). The results obtained through analysis of variance are given in appendix and the skeleton of analysis of variance table is given below:

Table no. 3.2 Analysis of variance (ANOVA)

S.No.	Source of variance	Degree of freedom (d.f.)	Sum of square (SS)	Mean sum of square (MSS)	Calculated F. value	Table value (5%)
1.	Replications	(r-1) = 2				
2.	Treatments	(t-1) = 11				
3.	Error	(r-1) (t-1) = 22				
	Total	(rt-1) = 35				

SEm± = $\sqrt{EMS/r}$

SEd± = $\sqrt{2EMS/r}$

CD = SEd ± x t at 5%

Where,

r = No. of replications

EMS = Error mean square

SEm± = Standard error of treatment mean

SEd± = Standard error of difference to two treatment mean

CD = Critical difference to two treatments mean

The SEm± and CD (5%) for seed rate, sowing method and their interaction has been giving along with each table. The results of various characters were influenced by different treatments have been represented.

Treatment effects were determined by analyzes of variance using the general linear model procedure of the Statistical Analysis System (SAS Windows Version 9.3). Difference among the various treatment combinations were separated by using mean value as well as applying ANOVA following the general linear model procedure. Further treatment means were separated with the use of Tukey's Honest Significant Difference (HSD) test at a 5% level of significance.

RESULTS

Under the experiment titled "**Optimization of seed treatment techniques for enhancement of physiological efficiency, productivity, and quality attributes in Soybean [*Glycine Max* (L.) Merr.]**". studied the effects of different seed treatment techniques on phenophases, physiological growth determinants, physiological mechanisms, biophysical constituents, and morphological structural attributes on seed yield and seed quality in soybean planted in a completely randomized block design. The data was statistically examined, and the experimental findings of the current research were reported under the following headings:

4.1 Phenophases

4.2 Physiological Growth parameters

4.3 biophysical traits

4.4 Yield and yield attributing traits

4.5 seed quality traits

4.1 phenophases

The findings demonstrated substantial variations in 50 percent podding development across all treatments over the course of the reproductive phase (Table 4.1, Fig.3).

4.1.1 Days to floral initiation

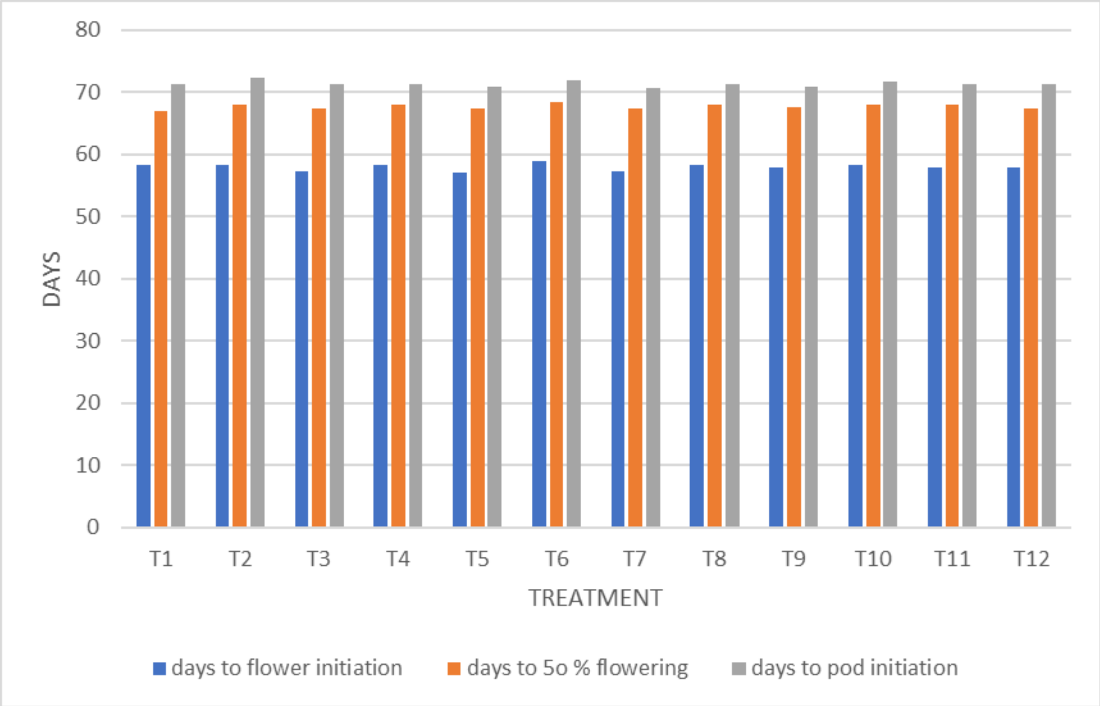
The average number of days until floral start across all treatments was 58.02. The days to first blooming ranged from 57.00 to 59.00. Treatment T6 has the highest expression of maximum days to first blooming (59.00), followed by T1, T2, T4, T8, and T10, all of which are comparable (58.33). In comparison to the other treatments, treatment T5 had the shortest days to first flowering (57.00).

4.1.2 days to 50% flowering

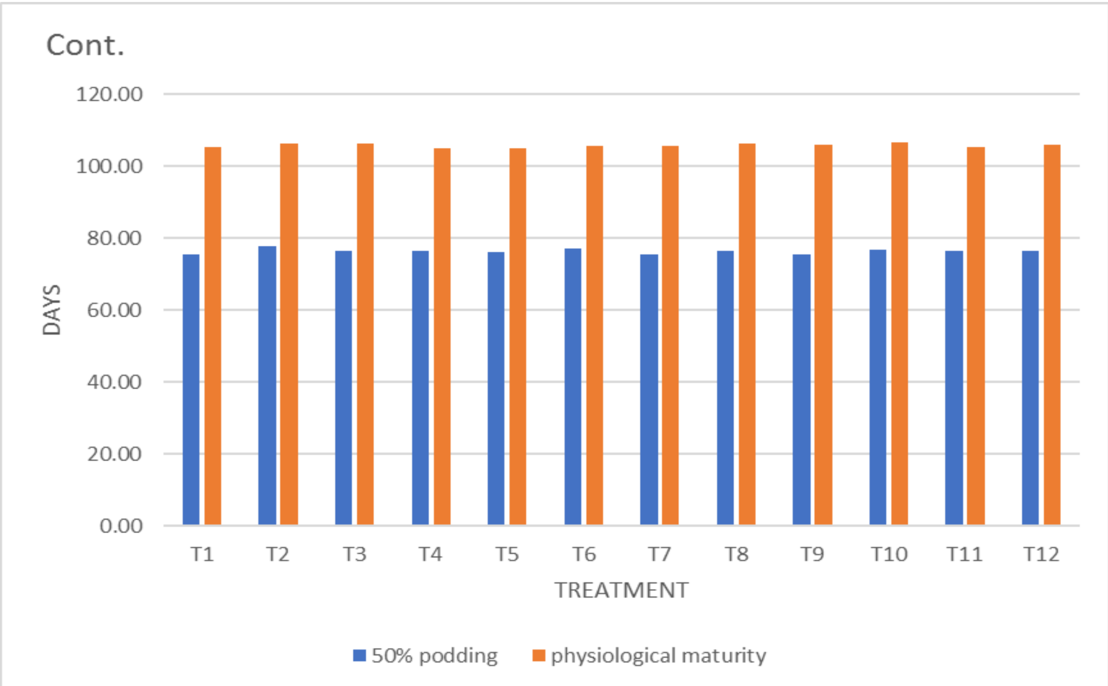
The average number of days to 50% blooming across all treatments was 67.69. The days to 50 percent blooming ranged from 67.00 to 68.33. In terms of expression of maximum days to 50% blooming (68.33), treatment T6 is preferable, followed by treatment T2, T4, T8, T9, (68.00). In comparison to the other treatments, treatment T5 had the shortest days to 50 % flowering (67.00).

Table 4.1 Phenophases in soybean during reproductive growth period under different seed treatments

Treatments	Days to floral initiation	Days to 50 % flowering	Days to pod initiation	Days to 50 % podding	Days to physiological maturity
T_1	58.33	67.33	71.33	75.33	105.33
T_2	58.33	68.00	72.33	77.67	106.33
T_3	57.33	67.33	71.33	76.33	106.33
T_4	58.33	68.00	71.00	76.33	105.00
T_5	57.00	67.00	7200.00	76.00	105.00
T_6	59.00	68.33	72.00	77.00	105.67
T_7	57.33	67.33	70.67	75.33	105.67
T_8	58.33	68.00	71.33	76.33	106.33
T_9	58.00	67.66	71.00	75.33	106.00
T_{10}	58.33	68.00	71.67	76.67	106.67
T_{11}	58.00	68.00	71.33	76.33	105.33
T_{12}	58.00	67.33	71.33	76.33	106.00
SEm ±	0.3946	0.545	0.384	0.429	0.478
CD at 5 %	1.15	1.59	1.12	1.25	1.40



3. **Days to flower initiation, days to 50% flowering and days to pod initiation under different seed treatments**



4. **50% podding and physiological maturity under different seed treatments**

4.1.3 Days to pod initiation

The findings revealed that therapy T2 (72.33) had the highest time to reach this level. T7 (70.67), on the other hand, was shown to be related with the shortest time required to reach this stage.

4.1.4 Days to 50% podding

For days to 50% podding, there was a significant difference related to therapy (P>0.05). The average number of days reaching 50 percent podding during the course of the therapy is 76.25. The days to 50 percent podding ranged from 75.33 to 77.67. In terms of maximum days to 50% podding expression, treatment T2 is (77.67), followed by treatment T10 (76.67). When compared to other treatments, treatment T1, T7 and T9 had the shortest days to first flowering (75.33).

4.1.5 Days to physiological maturity

According to the findings, treatment T10 (106.67) had the longest time to reach physiological maturity, followed by T2, T3, and T8 (106.33), respectively. In contrast the treatments T4 and T5 (105.00) took the shortest time to reach this level.

4.2 Physiological growth parameter

4.2.1 Leaf Area Index (LAI)

The findings demonstrated that there was a substantial variation in LAI levels owing to treatment at various phases of crop growth.

45 DAS

The leaf area index showed a significant variation owing to treatment (P>0.05). The leaf area index is 2.98 on average across all treatments. The leaf area index ranged from 1.45 to 3.80. In terms of expression of maximum leaf area index (3.80), treatment T5 is best, followed by treatment T11 and T4 (3.57). In comparison to the other treatments, T10 had the smallest leaf area index (1.45). treatments.

65 DAS

The leaf area index showed a significant variation owing to treatment (P>0.05). Leaf area index had a mean of 4.8 across all treatments. The leaf area index ranged from 4.20 to 6.83. In terms of expression of maximum leaf area index (6.83), treatment T5 is best, followed by treatment T6 (5.59). In comparison to the other treatments, treatment T1 had the smallest leaf area index (4.20).

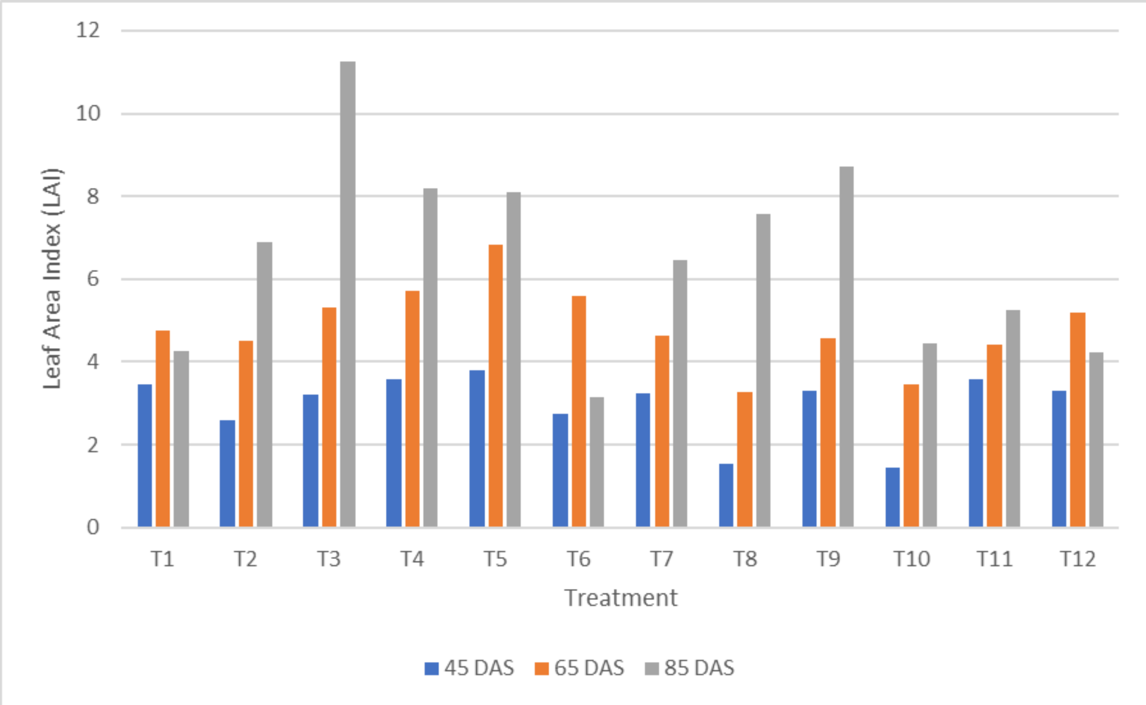
85 DAS

The leaf area index showed a significant variation owing to treatment (P>0.05). Leaf area index is 6.29 on average across all treatments. The leaf area index ranged from 1.29 to 11.26. Treatment T5 is superior in terms of maximum leaf area index expression (11.26), followed by treatment T9 (8.71). In comparison to the other treatments, treatment T1 had the smallest leaf area index (1.29).

4.2 Leaf area index (LAI) in soybean during successive growth intervals under different seed treatments

	Leaf Area Index (LAI)		
Treatment	**45 DAS**	**65 DAS**	**Mean**
T1	**3.46**	**4.20**	**3.83**
T2	**2.59**	**4.50**	**3.54**
T3	**3.20**	**5.32**	**4.26**
T4	**3.57**	**5.73**	**4.65**
T5	**3.80**	**6.83**	**5.31**
T6	**2.73**	**5.59**	**4.16**
T7	**3.22**	**4.64**	**3.93**
T8	**1.53**	**4.31**	**2.92**
T9	**3.30**	**4.57**	**3.93**
T10	**1.45**	**4.29**	**2.87**
T11	**3.57**	**4.43**	**4.00**
T12	**3.30**	**5.19**	**4.24**
SEm ±	**0.28**	**0.26**	
CD at 5%	**0.84**	**0.77**	

5. Leaf area index (LAI) in soybean during successive growth intervals under different seed treatments



4.2.2 Leaf Area Duration (cm^2 days)

65 DAS

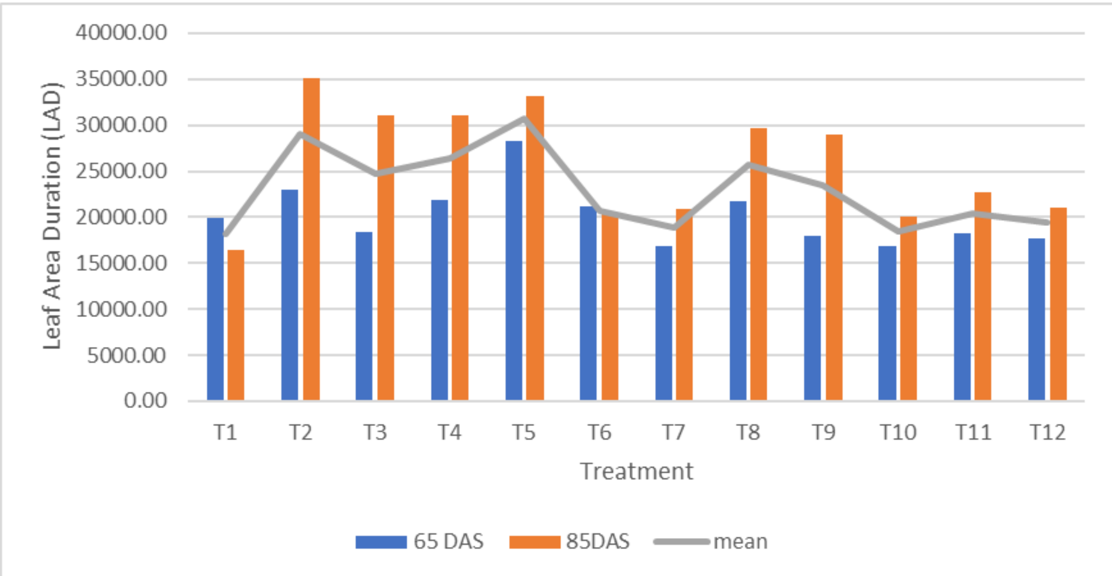
The average leaf area duration across the treatment is 20149.32. The leaf area duration ranged from 16908.66 to 28242.62. In terms of expression of maximum leaf area duration (28242.62), treatment T5 is best, followed by treatment T2 (22998.53). In comparison to the other treatments, treatment T10 had the shortest leaf area duration (16908.66).

85 DAS

The leaf area duration showed a nonsignificant variation owing to treatment ($P>0.05$). The average leaf area duration across the treatment is 25856.04. The leaf area duration ranged from 24465.92 to 33164.00. In terms of expression of maximum leaf area duration (33164.00), treatment T5 is best, followed by treatment T4 (31060.78). In comparison to the other treatments, treatment T1 had the shortest leaf area duration (24465.92).

Table 4.3 Leaf area duration (LAD) (cm^2 days) in soybean during successive growth intervals under various treatments

	Leaf Area Duration (cm^2 days)		
Treatment	65 DAS	85 DAS	Average
T1	19944.56	24465.92	22205.24
T2	22998.53	30047.05	26522.79
T3	18384.80	31007.71	24696.26
T4	21829.38	31060.78	26445.08
T5	28242.62	33164.00	30703.31
T6	21111.03	25288.70	23199.87
T7	16908.66	26400.00	21654.33
T8	21685.78	29607.10	25646.44
T9	17939.45	28949.63	23444.54
T10	16902.49	25028.85	20965.67
T11	18189.07	27736.00	22962.54
T12	17655.51	26077.84	21866.68
SEm ±	4465.32	937.87	2701.59
CD at 5 %	13096.34	2750.68	7923.34



6. Leaf area duration (LAD) (cm^2 days) of soybean during successive growth intervals in various seed treatments

4.2.3 Crop Growth Rate (g cm^{-2} day^{-1})

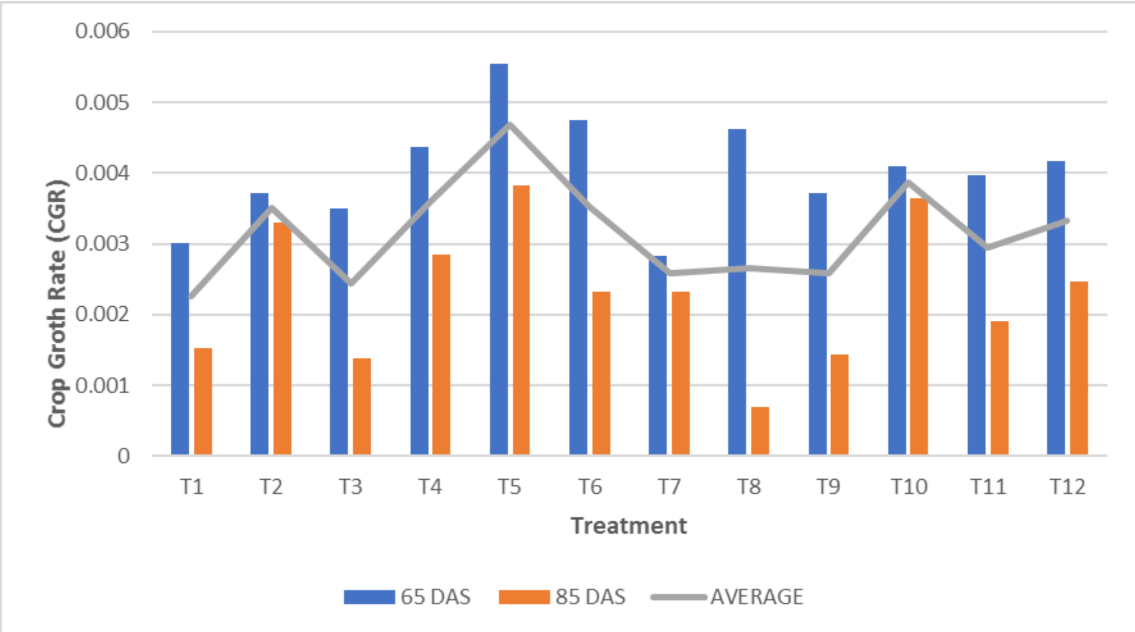
The results revealed that nonsignificant difference due to treatment was observed for CGR during different crop growth stages.

65 DAS

Crop growth rate is 0.0040 on average across all treatments. The crop growth rate ranged from 0.0028 to 0.0055. In terms of expression of maximum crop growth rate (0.0055), treatment T5 is best, followed by treatment T6 (0.0047). In comparison to the other treatments, treatment T7 had the lowest crop growth rate (0.0028).

85 DAS

Crop growth rate is 0.0023 on average across all treatments. The leaf area index ranged from 0.0013 to 0.0038. In terms of expression of maximum crop growth rate (0.0038), treatment T5 is best, followed by treatment T10 (0.0036). In comparison to the other treatments, treatment T3 had the lowest crop growth rate (0.0013).



7. Crop growth rate (CGR) (g$cm^{-2}$$day^{-1}$) of soybean during crop life span under different seed treatments

Table 4.4 Crop growth rate (CGR) ($gcm^{-2}day^{-1}$) of soybean during crop life span under different seed treatments

	Crop Growth Rate (g cm^{-2} day^{-1})		
Treatment	65 DAS	85 DAS	Average
T1	0.0030	0.0015	0.0022
T2	0.0037	0.0033	0.0035
T3	0.0035	0.0013	0.0024
T4	0.0043	0.0028	0.0036
T5	0.0055	0.0038	0.0046
T6	0.0047	0.0023	0.0035
T7	0.0028	0.0023	0.0025
T8	0.0046	0.0007	0.0026
T9	0.0037	0.0014	0.0025
T10	0.0040	0.0036	0.0038
T11	0.0039	0.0019	0.0029
T12	0.0041	0.0024	0.00332
SEm ±	0.001143	0.000949	
CD at 5 %	0.00335	0.00278	

4.2.4 Relative Growth Rate (g g^{-1} day^{-1})

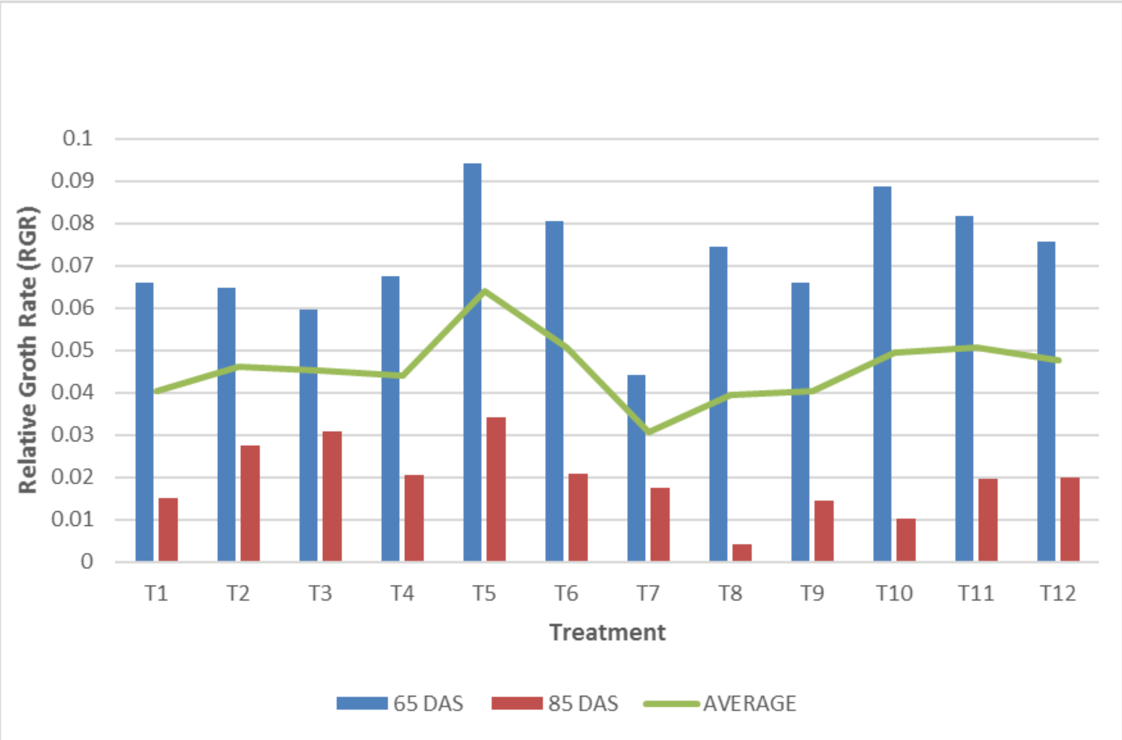
The results revealed that nonsignificant variations were observed for RGR during different crop growth stages.

65 DAS

The average relative growth rate across all treatments is 0.07193. The relative growth rate ranged from 0.044034 to 0.094184. In terms of expression of maximum relative growth rate (0.094184), treatment T5 is preferable, followed by treatment T10 (0.088653). In comparison to the other treatments, therapy T7 had the slowest relative growth rate (0.044034).

85 DAS

Relative growth rate is 0.01962031, which is the mean over the treatment. 0.00418221-0.03403334, was the relative growth rate's range. In terms of expression of maximal relative growth rate (0.03403334), treatment T5 is superior, which is followed by treatment T3 (0.03089715). When compared to the other treatments, treatment T7 had the lowest relative growth rate (0.001750).



8. Relative growth rate (g $g^{-1}day^{-1}$) of soybean during crop life span under different seed treatments

Table 4.5 Relative growth rate (g g^{-1}day^{-1}) of soybean during crop life span under different seed treatments

	Relative Growth Rate (g g^{-1} day^{-1})		
Treatment	65 DAS	85 DAS	Average
T1	0.065	0.015	0.040
T2	0.064	0.027	0.046
T3	0.059	0.030	0.045
T4	0.067	0.020	0.043
T5	0.094	0.034	0.064
T6	0.080	0.020	0.050
T7	0.0044	0.001	0.030
T8	0.074	0.004	0.039
T9	0.065	0.014	0.040
T10	0.088	0.010	0.049
T11	0.081	0.019	0.050
T12	0.075	0.019	0.047
SEm ±	0.021	0.0098	
CD at 5 %	0.0629	0.0289	

4.2.5 Net assimilation rate (g cm^{-2} day^{-1})

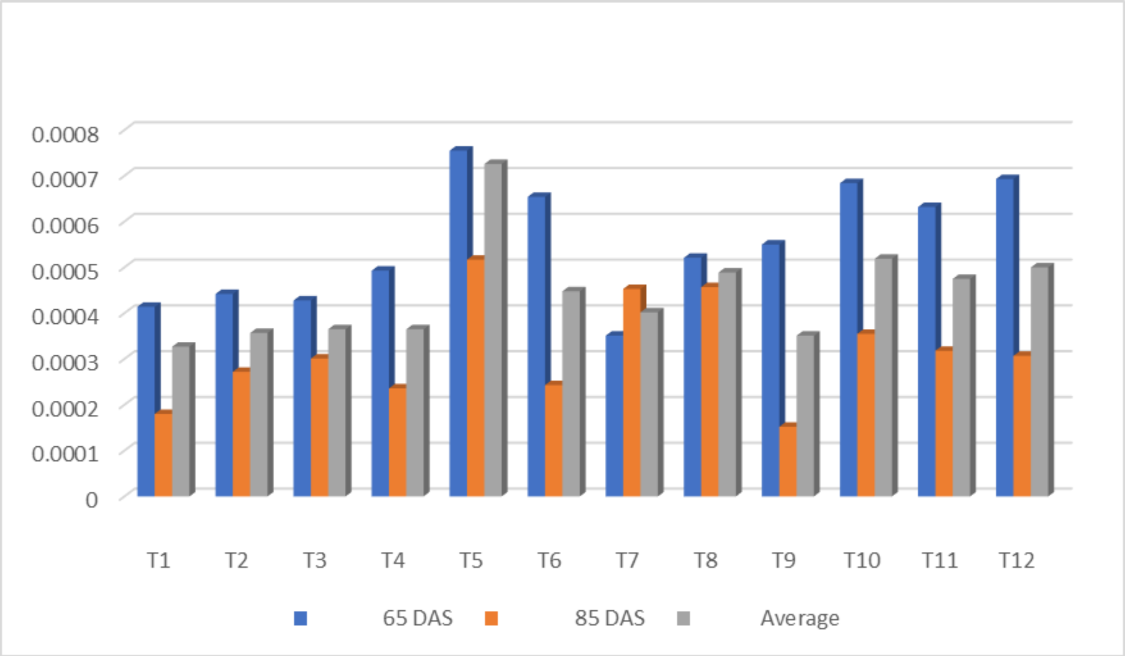
The results revealed that nonsignificant variations were observed for CGR during different crop growth stages.

65 DAS

The net assimilation rate is 0.000568 on average across all treatments. The net assimilation rate ranged from 0.000351 to 0.000755. In terms of expression of maximum net assimilation rate (0.000755), treatment T5 is preferable, followed by treatment T12 (0.000693). In comparison to the other treatments, treatment T7 had the lowest net assimilation rate (0.000351).

85 DAS

The average net assimilation rate across all treatments is 0.000415. The net assimilation rate ranged from 0.000152 to 0.000517. In terms of expression of maximum net assimilation rate (0.000517), treatment T5 is best, followed by treatment T8 (0.000457). In comparison to the other treatments, treatment T9 had the lowest net assimilation rate (0.000152).



9. Net assimilation rate (g cm^{-2} day^{-1}) of soybean during crop life span due to different seed treatments

Table 4.6 Net assimilation rate (g cm^{-2} day^{-1}) of soybean during crop life span due to different seed treatments

	Net assimilation rate (g cm^{-2} day^{-1})		
Treatment	65 DAS	85 DAS	Average
T1	0.000414	0.000180	0.000327
T2	0.000442	0.000272	0.000357
T3	0.000428	0.000301	0.000365
T4	0.000493	0.000236	0.000365
T5	0.000755	0.000517	0.000726
T6	0.000654	0.000243	0.000448
T7	0.000351	0.000453	0.000402
T8	0.000521	0.000457	0.000489
T9	0.00055	0.000152	0.000351
T10	0.000684	0.000355	0.000519
T11	0.000632	0.000318	0.000475
T12	0.000693	0.000307	0.0005
SEm ±	0.000194	0.000131	
CD at 5 %	0.000569	0.000383	

4.2.6 Bio Mass Duration (g days)

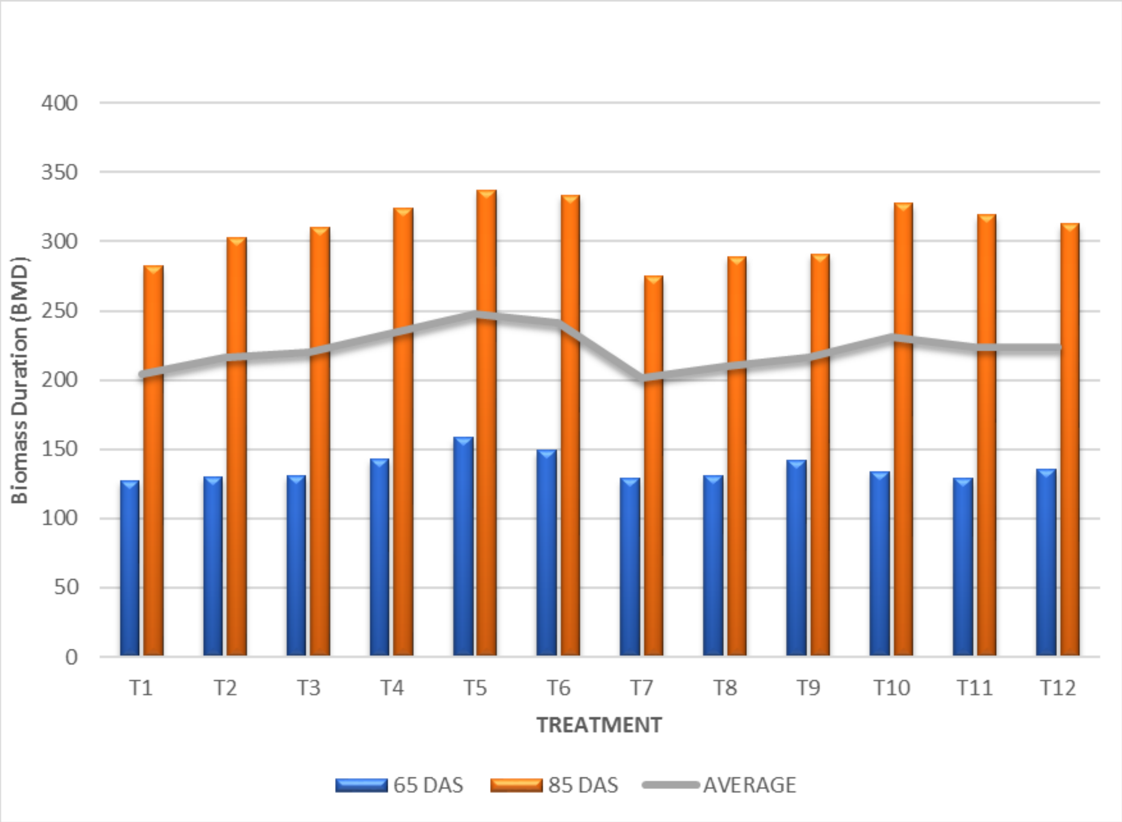
The results revealed that nonsignificant variations were observed for CGR during different crop growth stages.

65 DAS

The average bio mass duration during the course of the therapy is 136.51. The bio mass duration ranged from 127.19 to 158.41 minutes. In terms of expression of maximal bio mass duration (158.41), treatment T5 is superior, followed by treatment T6 (148.28). In comparison to the other treatments, treatment T1 had the shortest bio mass duration (127.19).

85 DAS

The average bio mass duration during the course of the therapy is 308.5888. The bio mass duration ranged from 275.0137 to 336.9968. In terms of expression of maximal bio mass duration (336.9968), treatment T5 is best, followed by treatment T6 (333.419). In comparison to the other treatments, treatment T7 had the shortest bio mass duration (275.0137).



10. BMD (g days) of soybean during successive growth intervals in different seed treatments

Table 4.7 BMD (g days) of soybean during successive growth intervals under different seed treatments

	Bio Mass Duration (g days)		
Treatment	65 DAS	85 DAS	Average
T1	127.19	282.03	204.61
T2	129.89	302.30	216.10
T3	131.06	309.70	220.38
T4	142.94	324.09	233.51
T5	158.41	336.99	247.70
T6	148.82	333.41	241.12
T7	128.88	275.01	201.94
T8	131.21	289.31	210.26
T9	141.56	291.03	216.29
T10	134.01	327.56	230.79
T11	128.50	319.08	223.79
T12	135.64	312.49	224.07
SEm ±	20.10	26.26	
CD at 5 %	58.96	77.04	

4.3 Biophysical traits

4.3.1 Total chlorophyll content (CCI - 200)

45 DAS

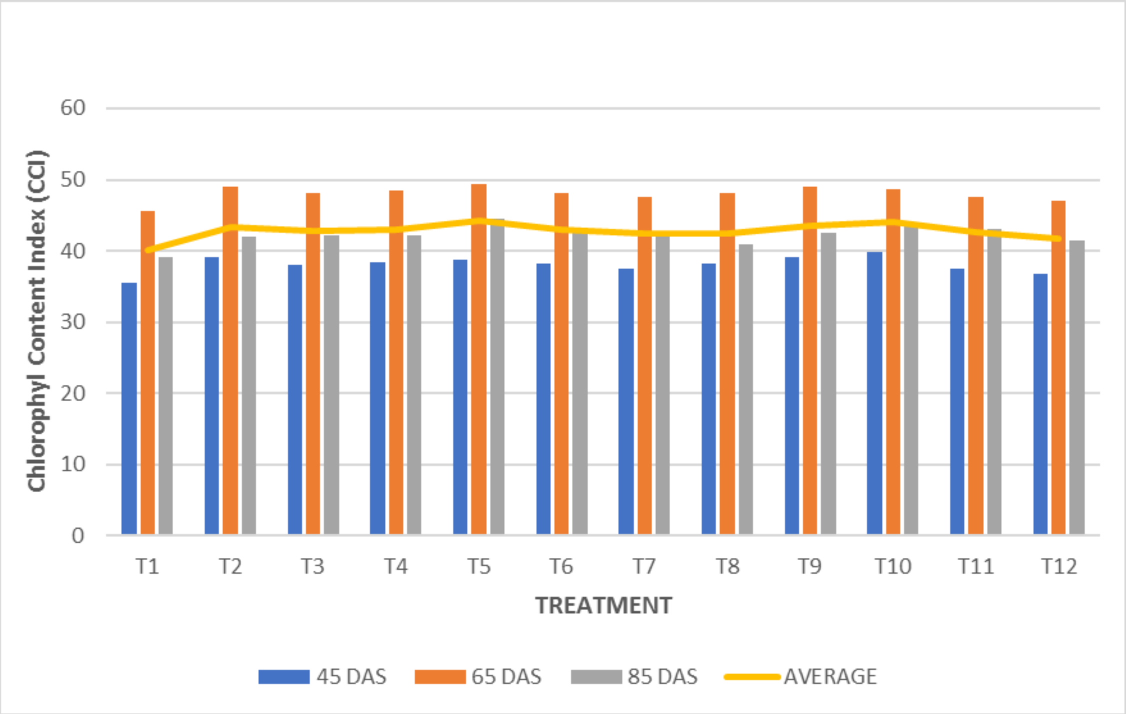
Total chlorophyll content is 38.07694 on average across all treatments. The total chlorophyll content ranged from 36.68667 to 39.87333. In terms of expression of maximum total chlorophyll content (39.87333), treatment T5 is best, followed by treatment T2 (39.08667). In comparison to the other treatments, treatment T1 had the lowest total chlorophyll content (35.55333).

65 DAS

Total chlorophyll content is 48.04444 on average across all treatments. The total chlorophyll content ranged from 45.55 to 49.44333. In terms of expression of maximum total chlorophyll content (49.44333), treatment T5 is preferable, followed by treatment T9 (49.06667). In comparison to the other treatments, treatment T1 had the lowest total chlorophyll content (45.55).

85 DAS

Total chlorophyll content is 42.25222 on average across all treatments. The total chlorophyll content ranged from 39.19 to 44.54333. In terms of expression of maximum total chlorophyll content (44.54333), treatment T5 is preferable, followed by treatment T10 (43.88333). In comparison to the other treatments, treatment T1 had the lowest total chlorophyll content (39.19).



11. Chlorophyll content index in soybean under different seed treatments

Table: 4.8 Chlorophyll content index in soybean under different seed treatments

	Total chlorophyll content (CCI - 200)			
Treatments	**45 DAS**	**65 DAS**	**85 DAS**	**Average**
T1	**35.55**	**45.55**	**39.19**	**40.09**
T2	**39.09**	**49.01**	**42.05**	**43.38**
T3	**37.96**	**48.08**	**42.17**	**42.74**
T4	**38.37**	**48.43**	**42.24**	**43.01**
T5	**38.73**	**49.44**	**44.54**	**44.23**
T6	**38.24**	**48.10**	**42.73**	**43.02**
T7	**37.56**	**47.64**	**42.32**	**42.51**
T8	**38.29**	**48.11**	**40.94**	**42.44**
T9	**39.07**	**49.06**	**42.53**	**43.55**
T10	**39.87**	**48.62**	**43.88**	**44.12**
T11	**37.50**	**47.5**	**43.03**	**42.67**
T12	**36.69**	**46.96**	**41.36**	**41.67**
SEm ±	**1.49**	**1.55**	**1.02**	
CD at 5 %	**4.39**	**4.56**	**58.96**	

Table: 4.9 Energy interception (cal. cm^{-2} min^{-1}) and Light transmission ratio (%) in soybean during successive growth intervals under various seed treatments

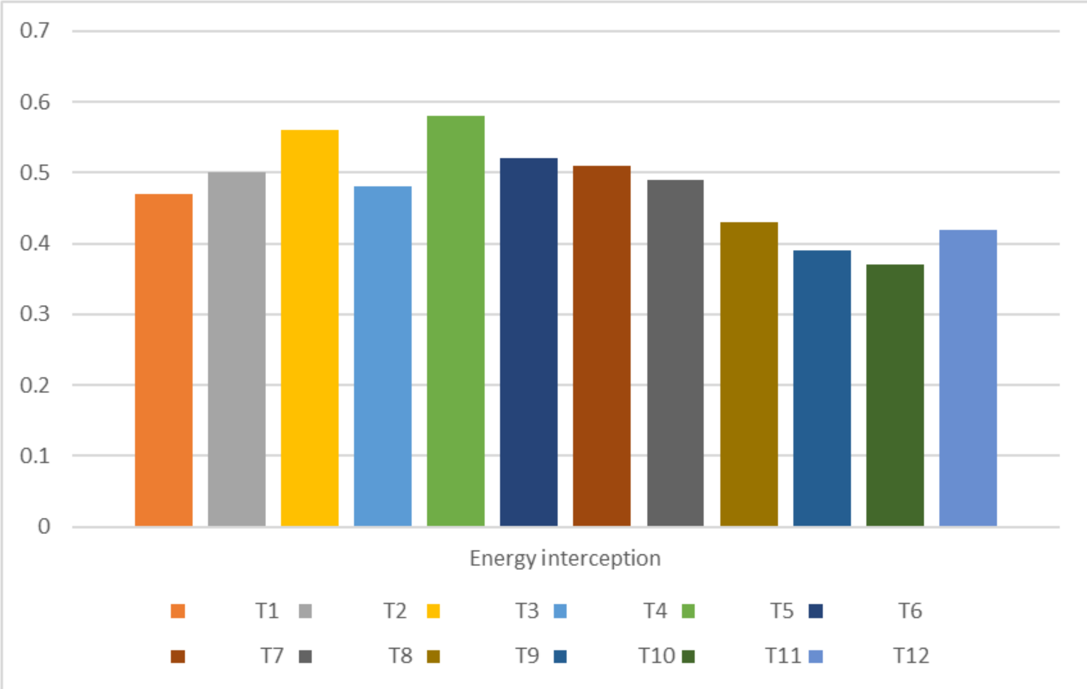
Treatments	Energy interception (cal. cm^{-2} min^{-1})	Light transmission ratio (%)
T1	0.47	56.66
T2	0.50	51.51
T3	0.56	47.97
T4	0.48	56.66
T5	0.58	47.95
T6	0.52	52.47
T7	0.51	53.61
T8	0.49	55.14
T9	0.43	58.32
T10	0.39	60.81
T11	0.37	60.07
T12	0.42	59.73
SEm ±	0.042	2.81
CD at 5 %	0.12	8.25

4.3.2 Energy interception (cal. cm^{-2} min^{-1})

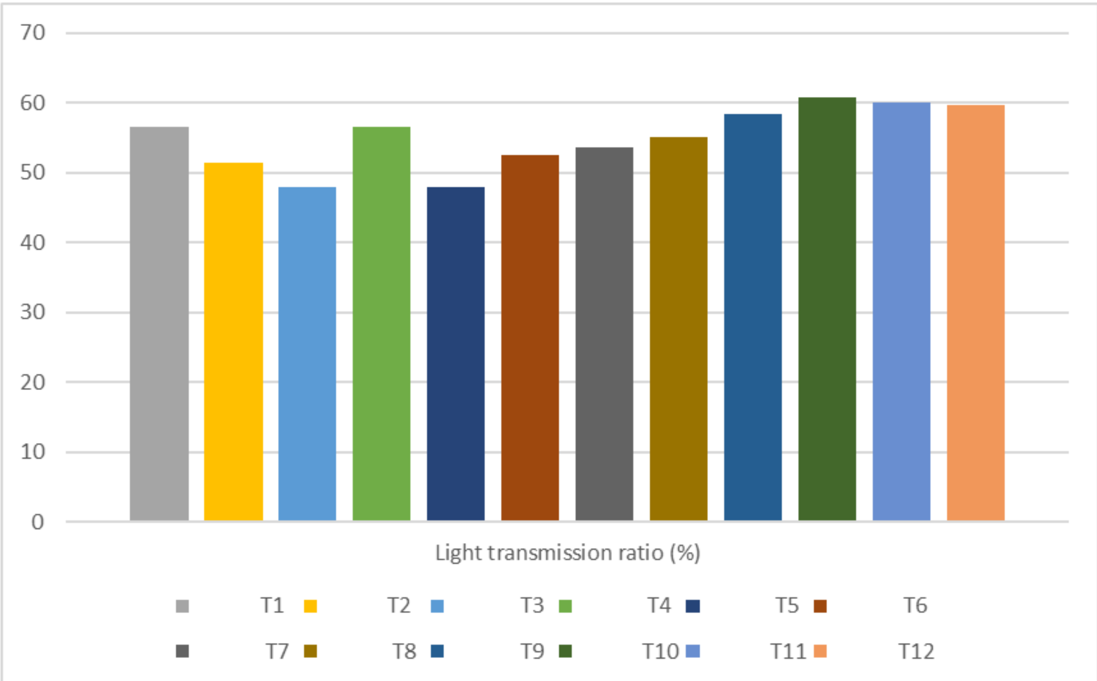
For energy interception, there was a significant difference related to treatment and replication ($P>0.05$). The energy intercepted ranged from 0.37 to 0.58. The maximum energy interception was obtained in treatment T5 (0.58), followed by T3 (0.56). T11 (0.37), on the other hand, was discovered to be the characteristic with the smallest magnitude.

4.3.3 Light transmission ratio (%)

The light transmission ratio showed a significant variation related to treatment and replication ($P>0.05$). The light transmission range was 47.95-60.81. The results revealed that treatment T10 (60.81) had the best light transmission, followed by T11 (60.07). T5 (47.95) was found to be connected with the trait's smallest magnitude.



12.Energy interception (cal. cm^{-2} min^{-1}) of soybean during successive growth intervals in different seed treatments



13. Light Transmission Ratio (%) of soybean during successive growth intervals in different seed treatments

4.4 Yield and yield components

4.4.1 Plant height at harvest

Plant height showed a significant variation related to treatment and replication ($P>0.05$). The results revealed that treatment T5 (44.90) had the highest plant height, followed by T6 (33.67). The lowest magnitude for this feature was found to be connected with T1 (29.33).

4.4.2 No. of branches plant $^{-1}$

The results showed that treatment T5 (4.84) had the highest number of plant^{-1} branches, while it was at par with T4 (4.19) and T2 (4.18). T9, on the other hand, had the lowest score (3.69).

4.4.3 No. of pod plant^{-1}

Treatment for the number of pods plant^{-1} resulted in a substantial change. T5 (81.57) achieved the highest number of pods plant^{-1}, followed by T10 (77.73). At harvest, treatment T1 (58.73) had a lower number of pods plant^{-1}.

4.4.4 No. of seed pod^{-1}

The results showed that treatment T5 (1.82) produced the most seed pod^{-1} compared to the other treatments, however T12 came in second (1.72). T4 had the lowest score (1.63).

4.4.5 Seed index (100).

The average number of days to floral start across all treatments was 13.02. The days to initial blooming ranged from 12.61 to 13.55. Treatment T7 (13.55) had the highest seed index, albeit it did not differ substantially from the other treatments. The treatment T10 had the lowest seed index (12.61).

4.4.6 Seed yield (gm plant^{-1})

Treatments T5 (14.51) and T4 (14.30) had larger seed yields, although Treatment T2 came in third (12.49). However, compared to the other treatments, showed a considerable increase in seed output. The lowest value for this character was reported by T1 (9.60).

4.4.7 Seed yield kg ha^{-1}

Though they were at par, treatments T5 (1228) and T4 (1219) had better grain yields. T6 (1163) was on level with T3 (1111) and lagged behind the latter, but outperformed the others significantly. The lowest value for this character was T1 (846).

4.4.8 Biological yield gm plant^{-1}

The average biological output per plant across all treatments is 20.42. The biological output per plant ranged from 16.63 to 23.57. In terms of expression of maximum biological yield per plant (23.57), treatment T5 is best, followed by treatment T10 (22.20). In comparison to the other treatments, treatment T1 had the lowest biological output per plant (16.63).

4.4.9 Biological yield kg ha^{-1}

The biological yield kg ha^{-1} showed a significant change owing to treatment ($P>0.05$). The average biological output per ha. across all treatments is 2162.52. The biological output per ha ranged from 1616.04 to 2809.92. In terms of expression of maximum biological output per ha (2809.92), treatment T5 is best, followed by treatment T6 (2722.32). Treatment T1, on the other hand, had the lowest biological output per plant (1616.04) when compared to the other treatments.

4.4.10 Harvest index (%)

Harvest index had a mean of 55.44 across all treatments. The harvest index ranged from 46.07 to 65.91. In terms of expression of maximum harvest index (65.91), treatment T4 is best, followed by treatment T2 (62.37). In comparison to the other treatments, treatment T12 had the lowest harvest index (46.07).

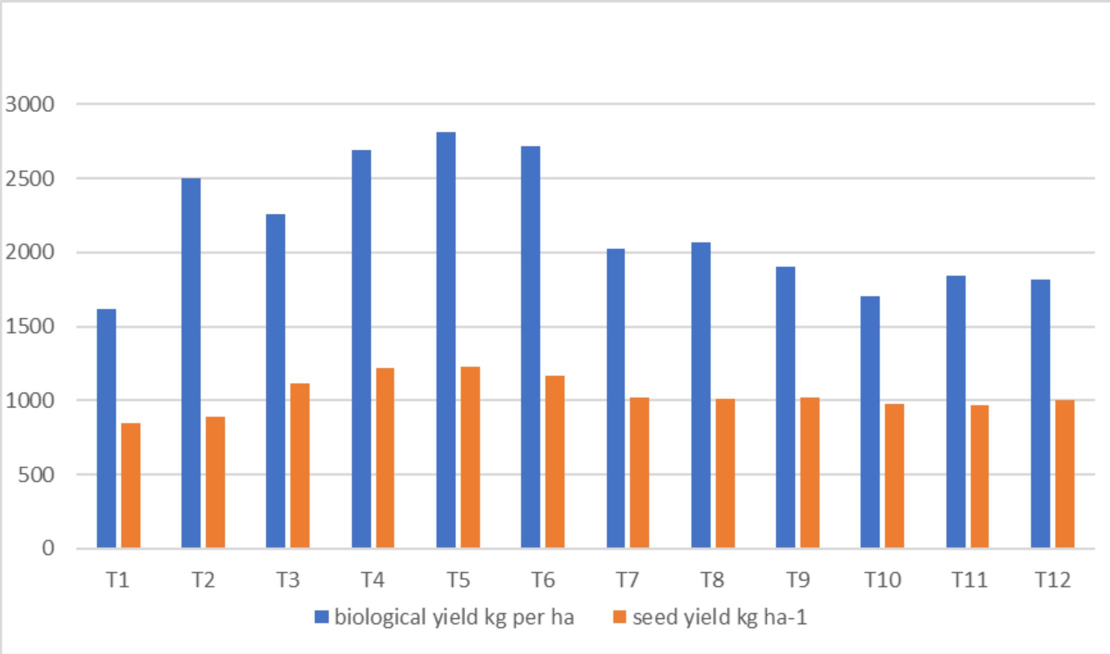
Table: 4.10 plant height, no. of branches plant^{-1}, no. of pods plant^{-1} and no. of seed pod^{-1} of soybean under different seed treatments

Treatment	Plant height (cm)	No. of branches plant^{-1}	No. of pods plant^{-1}	No. of seed pod^{-1}
T1	29.33	3.70	58.73	1.69
T2	32.37	4.18	68.27	1.65
T3	32.27	3.99	60.27	1.69
T4	33.60	4.19	71.33	1.63
T5	44.90	4.84	81.57	1.82
T6	33.67	3.94	63.80	1.69
T7	31.07	4.17	66.53	1.64
T8	31.07	4.10	66.53	1.67
T9	29.87	3.69	65.07	1.69
T10	31.13	4.13	77.73	1.64
T11	31.53	3.83	60.73	1.82
T12	30.40	3.99	66.80	1.72
SEm ±	1.37	0.24	4.84	0.074
CD at 5 %	4.00	0.73	14.21	0.21

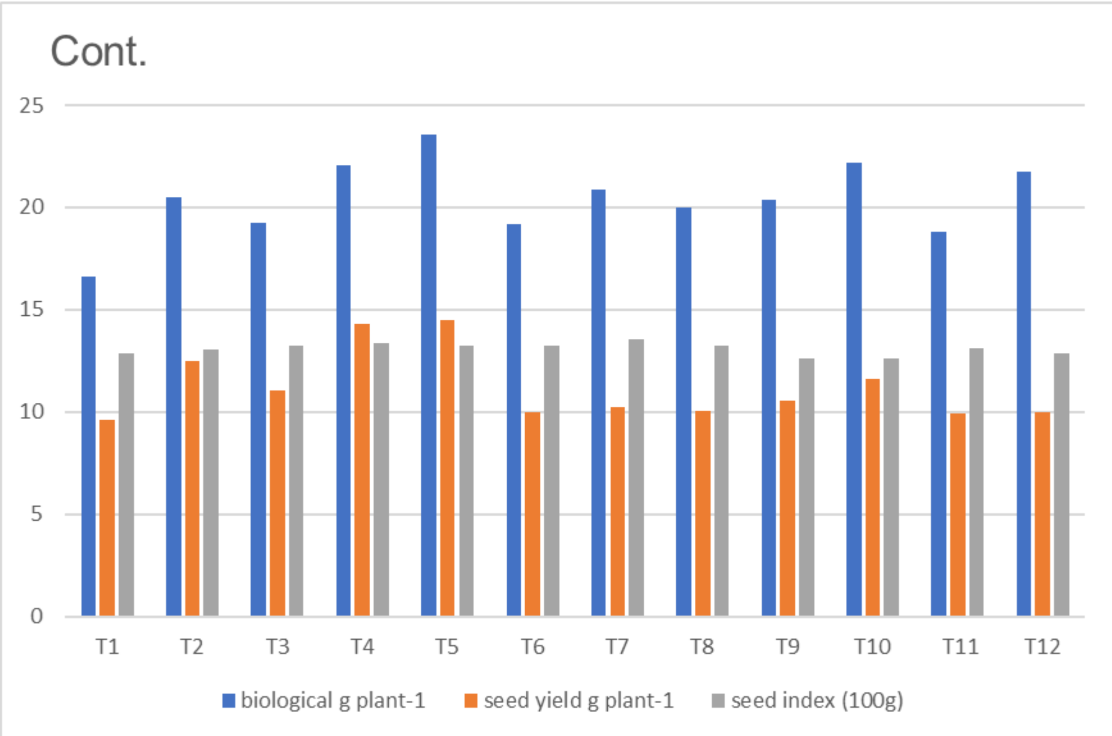
Table 4.11 seed index (100), seed yield, biological yield and harvest index (%) of soybean under different seed treatments

Treatment	Seed index (100)	Seed yield		Biological yield		Harvest index (%)
		g plant^{-1}	kg ha^{-1}	g plant^{-1}	kg ha^{-1}	
T1	12.84	9.60	846	16.63	1616.04	58.59
T2	13.07	12.49	891	20.47	2504.73	62.37
T3	13.26	11.07	1112	19.25	2256.82	57.62
T4	13.35	14.30	1219	22.04	2688.57	65.91
T5	13.24	14.51	1228	23.57	2809.92	62.06
T6	13.25	9.98	1163	19.17	2722.32	52.40
T7	13.55	10.22	1017	20.87	2022.72	52.05
T8	13.23	10.03	1010	20.00	2065.24	50.55
T9	12.63	10.53	1024	20.40	1900.26	51.95
T10	12.61	11.58	973	22.20	1705.07	52.35
T11	13.14	9.95	972	18.80	1839.01	53.44
T12	12.83	10.00	1006	21.77	1819.55	46.07
SEm ±	0.21	0.24	0.24	1.78	240.25	4.74
CD at 5%	0.63	0.72	0.72	5.24	19.25	13.91

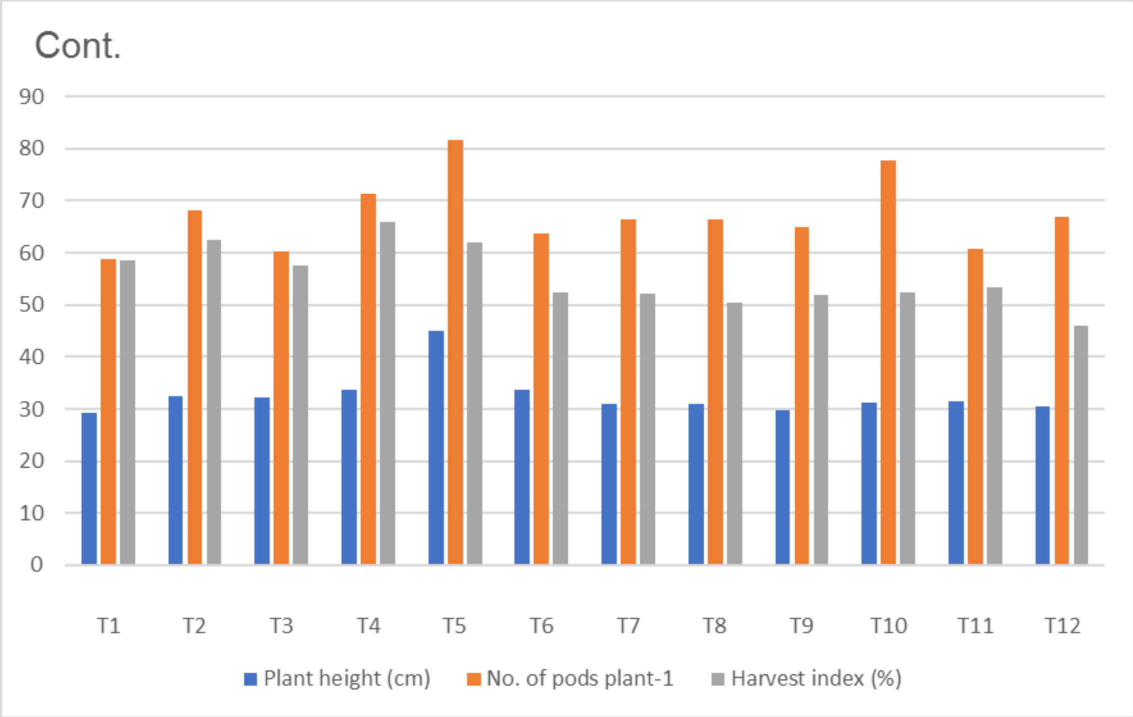
Morpho-physiological Characters



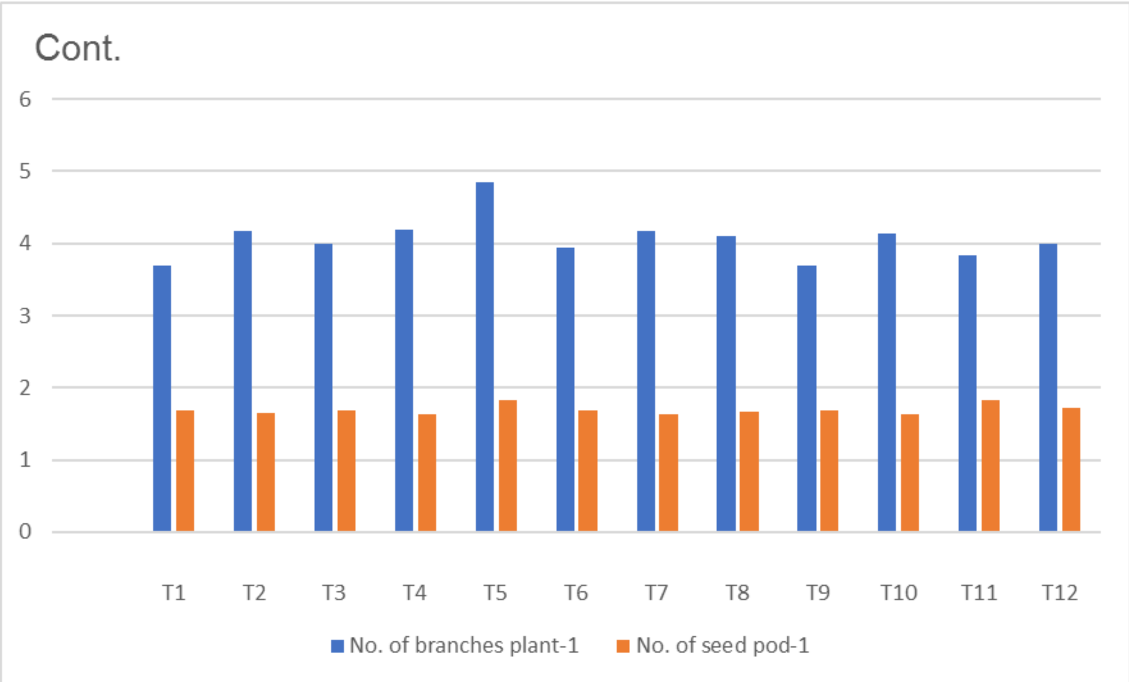
14. biological yield kg per ha and seed yield kg per ha of soybean under different seed treatments



15. biological yield g plant^{-1}, seed yield g plant^{-1} and seed index (100) of soybean under different seed treatments



16. plant height (cm), no. of pods plant^{-1} and harvest index (%) of soybean under different seed treatments



17. no. of branches plant^{-1} and no. of seed pod^{-1} of soybean under different seed treatments

4.5 Seed quality traits

4.5.1 Field emergence %

Field emergence showed a significant change related to treatment (P>0.05). For field emergence, the mean over the treatment is 179.77. The field emergence ranged from 151.66-259.66. In terms of expression of maximal field emergence (259.66), treatment T5 is best, followed by treatment T4 (247.66). In comparison to the other treatments, treatment T1 had the least amount of field emergence (151.66).

4.5.2 Seed germination %

Germination percent showed a significant change related to treatment (P>0.05). The average germination percent across all treatments is 77.33. The germination percent ranged from 70.66 to 86.66. In terms of expression of maximum germination percent (86.66), treatment T5 is preferable, followed by treatment T6 (84). In comparison to the other treatments, treatment T9 had the lowest germination percent (70.66).

4.5.3 Seedling length (cm)

Seedling length showed a significant variation related to treatment (P>0.05). Seedling length is 28.04 on average across all treatments. The seedling lengths ranged from 25.99 to 33.23 centimeters. In terms of expression of maximum seedling length (33.23), treatment T5 is preferable, followed by treatment T4 (29.65). In comparison to the other treatments, treatment T11 had the shortest seedling length (26.07).

4.5.4 Seedling dry weight (mg)

For dry weight, the average over the treatment is 750.14. The dry weight ranged from 650.93 to 891.10. Treatment T5 is best in terms of maximal dry weight expression (891.10), followed by treatment T4 (856.86). In comparison to the other treatments, treatment T1 had the lowest dry weight (650.93).

4.5.5 Seed vigour index I

The vigour index-I showed a significant change owing to therapy (P>0.05).

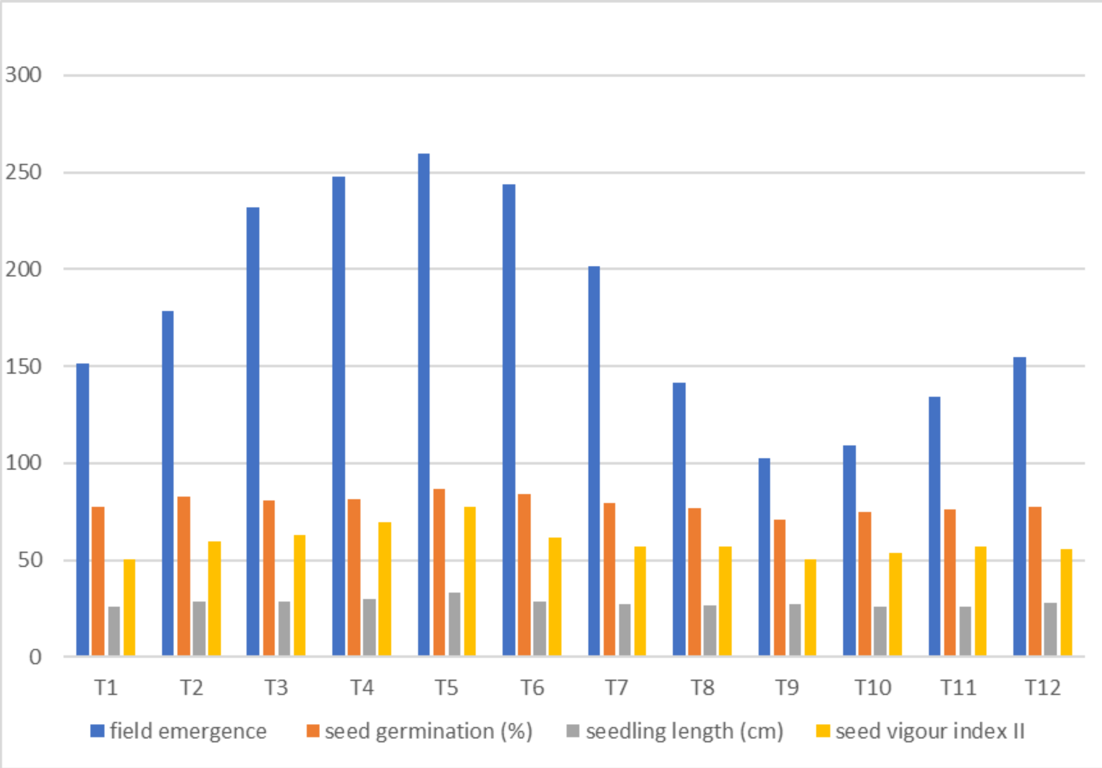
The mean vigour index-I for the therapy is 2218.93. The vigour index-I ranged from 1934.76 to 2875.35. In terms of expression of maximal vigour index-I (2875.60), therapy T5 is best, followed by treatment T4 (2408.39). In comparison to the other treatments, treatment T10 had the lowest vigour index-I (1934.76).

Seed vigour index II

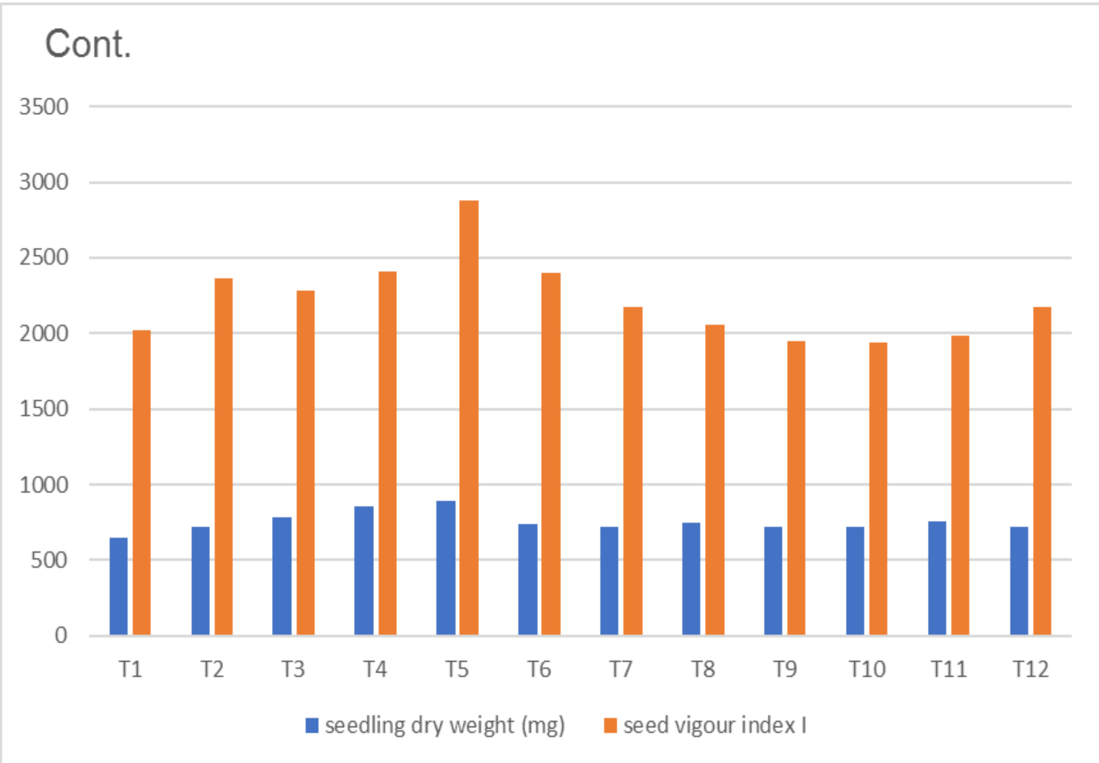
The vigour index-II showed a significant change owing to therapy ($P>0.05$). The treatment's average vigour index-II is 59.39. The vigour index-II ranged from 50.31 to 77.23. In terms of expression of maximal vigour index-II (77.23), treatment T5 is best, followed by treatment T4 (69.60). Treatment T1, on the other hand, had the lowest vigour index-II (50.31) when compared to the other treatments.

Table: 4.12 Post-harvest seed quality traits of soybean in different seed treatments

Treatments	field emergence	seed germination (%)	seedling length (cm)	seedling dry weight (mg)	seed vigour index I	seed vigour index II
T1	151.66	77.33	26.21	650.93	2023.69	50.31
T2	178.66	82.66	28.55	718.13	2362.09	59.34
T3	232.00	80.66	28.32	780.53	2283.13	62.97
T4	247.66	81.33	29.65	856.86	2408.39	69.60
T5	259.66	86.66	33.23	891.10	2875.61	77.23
T6	244.00	84.00	28.60	737.86	2402.69	61.89
T7	201.33	79.33	27.44	718.53	2175.68	57.05
T8	141.66	76.66	26.81	746.83	2057.35	57.19
T9	102.66	70.66	27.53	717.83	1944.99	50.71
T10	109.33	74.66	25.99	722.36	1934.77	53.92
T11	134.00	76.00	26.07	751.33	1980.85	57.09
T12	154.66	77.33	28.16	716.66	2177.98	55.43
SEm ±	25.24	2.28	1.87	28.31	99.92	2.57
CD at 5%	74.04	6.69	3.48	82.50	293.06	7.56



18. field emergence, seed germination (%), seedling length (cm) and seed vigour index II of soybean in various treatments



19. seedling dry weight (mg) and seed vigour index I of soybean in various treatments

DISCUSSION

The discussion on the relevant findings on various morpho-physiological traits, biophysical traits, yield constituents and seed quality as affected by various seed treatments have been presented as follows:

5.1 Phenophases

5.2 Physiological growth parameters

5.3 Biophysical

5.4 Yield and yield components

5.5 Seed quality traits

5.1 Phenophases

Phenology**,** the study of phenomena or happenings. It is applied to the recording and study of the dates of recurrent natural events (such as the flowering of a plant or the first or last appearance of a migrant bird) in relation to seasonal climatic changes. Phenology thus combines ecology with meteorology.

Phenology refers to the timing of major developmental events in the life of a crop, such as germination, flower, bud initiation, flowering and grain maturity. The earliest flowering and maturity with low grain filing rates are general observations that resulted in competition for assimilates between vegetative and reproductive organs at the reproductive phase which results in poor translocation of assimilates towards sink resulting in low yield.

5.1.1 Days to flower initiation

The seed yield was positively and directly influenced by the days of flower initiation (Kumar *et al*., 2012). Early flower initiation is a key factor in the early formation and maturation of pods before the occurrence of abiotic stresses (Anbessa *et al.,* 2006)

A significant difference was observed for days to flower initiation due to treatment. The range for days to flower initiation is 57.00 days – 59.00 days. An early flower appearance was significantly induced by treatment T5, which acquired minimum days to flower initiation, resulting in prolongation of the reproductive phase. On the other hand, treatment T6 showed maximum days to flower initiation.

The pattern of flower production, pod retention, number of flowers produced and percentage of flowers and pods abscised varied with cultivars (Zaiter and Barakat, 1995). Soybean genotypes had slow TDM accumulation and LAI during the first 35 DAS followed by a rapid increase after the commencement of flowering. Flowering was started at 45 to 50 DAS, depending on genotypes (Khan and Khalil., 2010) The results showed that treatments T6 required a maximum time for completion of 50% flowering (68.33 days). On the other hand, the lowest time was recorded in T5 (67.00 days). It might be due to the early production of florigen and other flower inducing substances in Take-off ST treated plants. These results are corroborated with the findings of Shinde *et al*. (2010) in Marigold and Bhargavi *et al*. (2018) in chrysanthemum.

5.1.4 Days to pod initiation

Pod initiation is an important phenological stage sensitive to environmental stress and determines the crop yield in soybean. Pod formation to full seed development stage is the most sensitive stage of a Soybean crop to all kinds of biotic and abiotic stresses. Rainfall and higher daytime temperature are the most significant weather variables for soybean seed yield under rainfed conditions (Nath *et al.*, 2018).

The present study showed that treatment T2 (72.33 days) registered a maximum time for the formation of pods. On the other hand, T5 and T9 (71.00 days) needed minimum time to attain this stage.

Earlier investigations had shown that early pod formation resulted in high productivity. Applications of biostimulants humic acid applied on the seed of wheat, proved best for early and uniform sprouting, more foliage growth per plant, greater leaf area, and total leaf chlorophyll contents, earlier spike emergence, the greater number of florets per spike, longer stems and spikes, and greater diameter of a spike, higher flower quality, longer vase life, a higher number of cormels per clump, and greater cormel diameter and weight (Ahmad *et al.,* 2013)

Pod formation to the full seed development stage is the most sensitive stage of the Soybean crop. Rainfall and higher day time temperature are the most significant weather variables for soybean seed yield under rainfed conditions (Nath *et al.,* 2008). Soybean their pods developed slowly and the apical seed developed most rapidly in the second phase just after full elongation of the pod; the basal seed showed more rapid growth (Kato and Naito, 1954).

The investigations indicated that the treatment T1, T7and T9(75.33 days) took minimum time for completion of 50% podding, whereas treatment T2 (77.67 days) required maximum time for completion of flowering. These results are corroborated with the findings of Shinde *et al*. (2010) in Marigold and Bhargavi *et al*. (2018) in chrysanthemum.

5.1.6 Days to physiological maturity

The physiological maturity is characterized by the stage when the seeds gain maximum DM. The accumulated dry matter and LAI peaked around R5 or the beginning of seed and R7 at physiological maturity, respectively (Mottaghian *et al*., 2010). After physiological maturity DM was not partitioned into the sink resulting in reduced productivity as biochemical reactions are continuing which may cause draining of the reserved food material (Gontia *et al*.,1995). In Seed physiological deterioration will be initiated once harvesting is delayed beyond the physiological maturity stage (Meera *et al*., 2000).

Treatment T4 and T5 required a minimum of 105 days to physiological maturity. The range for days to physiological maturity is 105.00 - 106.67 DAS. The superior treatment T4 and T5 showed a 2.26% reduction in completion of physiological maturity over T1 (control), which is good for the crop to skip abiotic stress in the last period of monsoon.

5.2 Physiological growth parameters

5.2.1 Leaf area index (LAI)

Significant variations were found for LAI between soybean genotypes Mottaghian *et al*. (2010). The leaf weight per plant decreases while the leaf area index (LAI) increases with plant population density (Chandraker *et al*., 2016). The maximum absolute growth rate (AGR) was observed during the pod filling stage in all genotypes due to maximum leaf area (LA) development and leaf area index (LAI) at this stage. The plant characters like LAI and AGR contributed to higher TDM production (Malek *et al.,* 2012).

The present study indicated that LAI in treatments exhibited an increasing trend from the early growth phase onwards attaining the peak at 65 DAS, thereafter it declined in the remaining period of growth. The decline was attributed to the reduction in the quantum of assimilatory surface area as a result of drying and senescence of leaf and movement of photoassimilates to other sinks of the plant particularly economic sinks which generally have higher sink demands. Treatments T5 (3.79) and T8 (2.96) recorded an average higher and lower LAI, respectively. An increase in the quantum of assimilatory surface area has been reported to enhance productivity as long as shading of lower leaves does not occur. Treatment T5 exhibited a maximum average leaf area index with enhancement to the tune of 26.49% over T1 (control). The present finding is inconsistent with Noli *et al*. (2021); Wilson *et al*. (2015); (Ambika and Sujatha, 2016); Cakmake *et al*. (2006) reported a positive effect of seed treatment with biostimulants enhancing leaf area and dry matter accumulation in different crops.

5.2.2 Leaf area duration (LAD) (cm^2 days)

The duration of the leaf area indicates the active phase of leaf growth and photosynthetic longevity. The longer the leaf is green, the more photosynthate accumulates. If photosynthate is adequately translocated to the developing sink, economic productivity increases. Chauhan *et al*. (1999) reported that the leaf area duration measured at 30-45 days after sowing had a positive and significant association with dry matter accumulation at 50% flowering.

The superior treatment T5 exhibited maximum leaf area duration at all the growth stages 45, 65 and 85 days after sowing. The treatment T5 shows maximum average leaf area duration (30703.31) with an enhancement to the tune of 27.67% over T1 (control). The drop in LAI during later growth phases was attributable to the decline in LAD. Enhancing crop productivity through breeding procedures has been a difficult undertaking because while the quantity of one component increases, the quantity of the other yield attributing component decreases, and the economic yield remains relatively constant. However, certain characteristics, such as LAD, aid in the improvement of economic production. LAD stands for leaf area persistence. The longer leaves are active, the more photoassimilates are created during that time, which, effectively mobilized to the economic sink, can considerably increase productivity. The present finding is inconsistent with Hussain *et al.* (2021) comprised that the application of MLE (moringa leaf extract) alone and in combination (MLE + MC) showed the promoting effect on the crop growth rate, net assimilation rate, leaf area index, leaf area duration, sympodial branches and number of bolls leading to higher seed cotton yield of both cotton cultivars grown under conventional row spacing.

5.2.3 Crop growth rate (CGR) (g $cm^{-2}day^{-1}$)

The yield is significantly and positively correlated with the crop growth rate (Shirawa *et al.* 2004).

The average crop growth rate ranged from 0.0022 to 0.0046 g cm^{-2} day^{-1}. From 65 days after sowing to 85 days after sowing, the crop growth rate gradually increases. The crop growth rate of treatment T5 was 0.0046 g cm^{-2} day^{-1}, which is statistically superior with a 51.81 % increase in performance over T1 (control). This may be owing to effective dry matter build up, photosynthesis, and vegetative and reproductive growth. Soares *et al*. (2016)

confirmed that seed treatment of soybean with biostimulant increased the activity of nitrate reductase (NR) by 51%, the net photosynthesis (NP) by 50%, the chlorophyll content (SPAD value - Soil Plant Analysis Development) by 52%, and the plant growth rate (GR) by 28%, all compared to the control. Sagitov *et al.* (2020) analyzed that the treatment of soybean seeds with stimulants in combination with a treater significantly improves their sowing qualities, suppresses fungal and bacterial infections, and intensifies the crop growth rate of plants and the root system.

5.3.4 Relative growth rate (RGR) (g g^{-1}day^{-1})

The relative growth rate shows the increase in existing biomass, which could be a key component in increasing production during a given growth period. The ranking of the varieties grown in isolation changed in time because of the differences in relative growth rate (Spatters *et al.,* 2005). In eight soybean cultivars, the highest relative growth rate (RGR) was observed during 30-60 DAS which decreased during 60-90 DAS. The RGR at 30-60 DAS showed a significant and positive correlation with seed yield (Tandale and Ubale ,2007).

The superior treatment T5 exhibited a maximum relative growth rate (0.0641 g g^{-1}day^{-1}) with enhancement in the tune of 36.81% over T1 (control). Bernal *et al.* (2021) concluded that the rare earth element (REE) cerium (Ce) can act as a biostimulant in diverse crop plants which is applied on tomato seeds and they were evaluated significantly in the treatments with 5, 10, and 15 µM Ce. This tendency was also observed in the dry biomass weight and relative growth of the shoots. Agliassa *et al*. (2021) analyzed that biostimulant-primed plants showed a quicker decrease of stem water potential with respect to untreated plants upon drought imposition. The biostimulant priming increased above ground relative growth rate and final fruit yield of stressed plants. Similar result was founded by Arif *et al*. (2019); Paul *et al.* (2019) in different crops which is similar to the current research.

5.2.5 Net assimilation rate (g cm^{-2} day^{-1})

The assimilation of dry matter per unit, leaf area per unit time is known as the net assimilation rate. The key component of a crop community's average photosynthetic efficiency is the net assimilation rate. It is also important in determining the average net CO_2 exchange rate per unit of leaf area, which is highest when the majority of the plant leaves are present. The average photosynthetic rate is dominated by the net assimilation rate. The average net assimilation rate ranges from 0.0307 to 0.0641. T5 out performs in terms of the highest net assimilation rate, with a 51 % improvement over T1 (control). The net assimilation rate promoting effect of treatment T5 is attributed to enhancement in LAI, LAD, CGR and RGR by stimulating the internal and natural metabolism of plants (hormonal activity, genomics, absorption of nutrients, growth, flowering, fruiting, etc. Hussain *et al.* (2020) reported that the application of MLE alone and in combination (MLE + MC) showed a promoting effect on the crop growth rate, net assimilation rate, leaf area index, leaf area duration, sympodial branches and number of bolls leading to higher seed cotton yield of both cotton cultivars grown under conventional row spacing. Serafy *et al* (2020) reported that oligo-chitosan induced rapid growth of cordyline seedlings, in terms of larger specific leaf weight (SLW) and higher relative growth rate (RGRA), as well as improving the efficiency of plant photosynthesis (high net assimilation rate (NAR) or low specific leaf area (SLA).

5.2.6 Biomass duration (g. days)

Biomass (B) is a measurement of how much living tissue mass for a population is present at one instant in time (or averaged over several periods of time). It is defined as the persistence of biomass over time. The average biomass duration ranges from 204.61 to 247.70. T5 outperforms in terms of the highest biomass duration, with a 17.39 % enhancement over T1 (control). Colla *et al*. (2014) reported that the biostimulant-like effect of the protein hydrolysate on corn has been also observed in the rooting experiment of tomato cuttings. The shoot, root dry weight, root length, and root area were significantly higher by 21, 35, 24, and 26%, respectively. Increasing the concentration of the protein hydrolysate from 0 to 10 ml/L increased the total dry biomass, SPAD index, and leaf nitrogen content by 20.5, 15, and 21.5%, respectively (Colla *et al.*, 2014).

5.3 Biophysical traits

5.3.1 Chlorophyll Content Index (CCM -200)

The chlorophyll content is the indicator of net photosynthesis and growth. The chlorophyll content index has a positive correlation with photosynthesis and seed yield (Zewail *et al*., 2014). Hence, the measurement of chlorophyll indirectly explains the efficiency of photosynthesis and photosynthate production. Total chlorophyll content was steadily increased in T5 up to pod initiation stage (49.44) and thereafter it decreased at the grain filling stage (44.23) due to the initiation of the senescence phase. During senescence, assimilates are largely transported to the sink, hence the leaf started drying which leads to a reduction in leaf area. Chlorophyll content index increased upto pod initiation stage and thereafter gradual reduction was noticed. Moderate P deficiency managed by the addition of phosphorus solubilizers like *P. bilaii, Bacillus subtilis* (biostimulants), increased the chlorophyll content similar to the works of Mehrvarz (2008) who found that phosphorus solubilizing microorganisms were able to increase the chlorophyll content under P deficit condition in plants. Wang *et al*. (2008) reported that chlorophyll content was higher in phosphate solubilizing microorganism treated plants than in the uninoculated plants and the increase might be due to *Bacillus sp*. which enhanced the absorption of iron from rhizosphere and increased translocation to the shoots without any chelation inside the roots. Bulgari *et al.* (2014) analyzed that in leafy vegetables, biostimulants increased leaf pigments (chlorophyll and carotenoids) and plant growth by stimulating root growth and enhancing the antioxidant potential of plants. And also, a similar result was found by Colla *et al*. (2014); Malik *et al.* (2020); Amirkhani *et al* (2019) which supports the present finding.

5.3.2 Energy Interception (cal. cm^{-2} min^{-1})

Model simulations indicated that there is a linear relationship between intercepted photosynthetically active radiant energy (PAR) and above-ground dry matter production. Intercepted radiation (Si) is often estimated as the difference between the quantity of incident radiation (S) and that transmitted through the canopy to the soil (St). Grace *et al.* (1987) reported that the amount of captured radiation energy increases, crop production will also increase. When plant leaves absorb the energy of the sun for photosynthesis, the temperature of the leaf surface increases. Plants respond by releasing water through the stomata to cool the leaf surface.

The energy interception ranges from 0.37 to 0.58. T5 outperforms in terms of the highest energy interception, with a 36.16 % improvement over T1 (control). The present finding is in consistent with Briglia *et al*. (2019) who notified that the decrease in the area of arable land, it becomes crucial to ensure high yield and quality using alternative strategies, such as the use of plant biostimulants. These compounds are increasingly recognized as a sustainable solution to optimize nutrient uptake, crop yield, quality, tolerance to abiotic stresses, and energy interception by higher leaf area. Puglisi *et al.* (2020) observed that the *S. quadricauda* extract positively affected the growth of lettuce seedlings, mainly acting at the shoot level, determining an increase in dry matter, energy interception, chlorophylls, carotenoids, proteins, and influencing the activities of several enzymes involved in the primary metabolism.

5.3.3 Light Transmission Ratio (%)

Light transmission means the ratio of the amount of total visible light to pass through a product or material to the amount of the total light falling on the product or material.

Photosynthesis is the conversion of light energy from the sun into chemical energy. During this process, light energy is absorbed by the chlorophyll molecule (a green pigment found in chloroplasts of plant cells) and is then used to convert carbon dioxide and water into simple sugars, glucose.

In the present study, treatment T5 is superior for this trait with a lower light transmission ratio (47.95%), with a 20.17% reduction because of high chlorophyll content, high LAI. Noli and Aliyyanti, (2021) analyzed that the *P. minor* liquid extract increased some parameters including height, number of leaves, leaf area, number of branches, fresh weight, and decreasing light transmission ratio in soybean.

5.4 Yield & Yield components

5.4.1 Plant height (cm)

Plant height is considered as an important trait related to the growth and development of a plant. The data on the plant height of maize plants was significantly increased when the seed was treated with biostimulant Take off ST. Variations in plant height due to treatment with different doses of biostimulant were found to be significant at all stages of the crop. A higher magnitude of plant height increase was observed between the vegetative and reproductive stages of soybean. The plant height was significantly higher in T5 (Take off ST seed treatment @ 4ml/kg seed) at all the growth stages of soybean when compare with other treatments. At the grain filling stage, T5 recorded significantly higher plant height (44.90 cm) with a 34.67 % enhancement over T1 (control) due to the high concentration of seed treatment with taking off ST. The increase in plant height is due to the effect of PGPR which has the ability to produce phytohormones (Egamberdiyeva *et al*., 2007; Gholami *et al*., 2009). Phosphate solubilizing bacteria influence was also noticed in the increased plant height in soybean which was reported by Imam (2008). These results are supported by the findings of Bashan *et al.* (2004) and Vahid and Seidi (2011).

5.4.2 No. of branches plant^{-1}

Leguminous crops, such as soybean, are highly plastic in the number of lateral branches they produce. When grown in isolation, a soybean plant grows numerous branches which many reaches full maturity. However, when grown at high population densities, the same soybean plant can produce as few branches. In such cases the plant invests more biomass in height growth, rather than in lateral growth, to prevent being completely shaded by neighbouring plants.

There was a little variation in the number of branches per plant between the various seed treatments with biostimulants and other chemicals. A minimum number of branches per plant was observed for the treatment T1. The number of branches per plant ranges from 3.70 to 4.84. T5 (Take off ST 4ml/kg seed) outperformed over T1 (control) by 23.55%. Seaweed extract P. minor significantly improves all parameters of vegetative growth of soybean including height, number of leaves, leaf area, number of branches, fresh weight, and decreasing light transmission ratio. And also, supported by Neta *et al.* (2018); Arif *et al*. (2019)

5.4.3 No. of pods plant^{-1}

Biostimulant improve number of pods per plant due to faster emergence, efficient use of resources such as soil, nutrient and production of vigorous plant with high efficiency. Since the seed yield largely depends on the number of flowers that translate into pods, flowering is usually considered as an important factor to predict yield. The present investigations showed (Table 4.14, Fig.16) that treatment T5 attained the maximum number of pods per plant (81.57) which is outperformed with a 28% improvement over control T1 (58.73). Petropoulos *et al.* (2020) reported that the application of biostimulants could be considered as an eco-friendly and sustainable means to increase the pod yield and the quality of common bean green pods and seeds under normal irrigation conditions. Our findings were in consistent with the study of Burbulis *et al.* (2021); Silva *et al.* (2021). Our result is in conformity with Kocira (2018) who reported that the application of biostimulant increased (compared to the control) a number of pods per plant in soybean.

5.4.4No. of seeds pod^{-1}

The number of seeds per pod differed non significantly between treatments. T1 produced the little number of seeds in each pod. The number of seeds per pod ranges from 1.63 to1.70. In comparison to T1 (control), T5 showed a 4.11% improvement. Beckett and Staden (1988) also noted that the effects of the seaweed concentrate 'Kelpak' on the growth and yield of wheat grown under conditions of varying K supply and found that Kelpak had no significant effect on the yield of wheat receiving an adequate K supply but significantly increased the yield of K stressed plants. The increase in yield was caused by an increase in both grain number and individual grain weight.

5.4.5 Seed index (100g)

Seed index is an important yield component determining seed yield and it is highly influenced by biotic and abiotic stresses. 100 seed weight is determined by photosynthesis, translocation and assimilate partitioning ability of crop plants. The range of seed index (100g) varied from 12.61 to 13.55. In comparison to T1 (control), the superior therapy T7 (seed treatment with biostimulant 100 CL @ 2ml/kg seed) showed a 6.93% improvement. Burbulis *et al.* (2021) evaluated the effect of exogenously applied amino acids L-proline (30 mM L^{-1}) and L-glutamic acid (1.5 M L^{-1}) on the productivity of winter rapeseed (*Brassica napus* L. sub sp. *oleifera* (Delile) Sinskaya) and inferred that 1000-seed weight and seed yield increased with its application. Higher 1000-seed weight and seed yield were obtained with the biostimulant fertigrain which have a positive effect on the productivity of bread wheat Sadovo 772 variety (Sevov and Delibaltova, 2013).

5.4.6 Seed yield (g plant^{-1}, kg ha^{-1})

Seed yield per plant is the culmination of a plant's physiological and metabolic activities, as well as the result of the combined action of all factors that contribute to better growth, such as the number of pods plant^{-1}, the number of seeds pod^{-1}, the number of branches plant^{-1} and the seed index. Jain *et al.* (2002) found that number of branches per plant, no. of pods per plant, and number of seeds per pod was positively and significantly correlated with seed yield in soybean. Seed yield g plant^{-1} was shown to change significantly among the seed treatments with biostimulants and other chemicals. A minimum grain yield was observed for treatment T1. The grain yield ranges from 9.60 to 14.51 g plant^{-1}. In comparison to T1 (control), the superior treatment T5 showed a 33.83% improvement. Seed yield kg ha^{-1} was shown to change significantly among the seed treatments with biostimulants and other chemicals. A minimum grain yield was observed for treatment T1. The grain yield ranges from 846 to 1228 kg ha^{-1}. In comparison to T1 (control), the superior treatment T5 showed a 31.10% improvement. Increased grain yield as a result of treatment T5 is known for improving yield components such as the number of branches per plant, number of pods per plant, number of seeds per pod, biological yield, and harvest index. Treatment T5's effect in generating physiological efficiency attributes including Leaf Area Index, Leaf Area Duration, Crop Growth Rate, and Net Assimilation Rate attributed grain yield enhancement in our research. Our result is inconsistent with Szparaga *et al.* (2018) who reported that the biostimulant type, as well as the number of its applications and its concentration, modified the biometric traits, crop productivity, as well as yield quality and the nutraceutical and antioxidative potential of soybean seeds. Teixeira *et al*. (2018) reported that the application of Cys and Phe as ST (seed treatment) increased the production of soybean plants by at least 21%. The isolated application of Cys (cystine), Phe (phenylalanine), Gly (glysine), Glu (glutamate) and the set of these amino acids as ST increased the productivity of soybean plants in the field experiment by at least 22%. Oktem *et al.* (2018) reported that the humic acid seed treatments were significant at grain weight of ear, thousand kernel weights and grain yield in wheat ($P \leq 0.01$). Our result is in contrast with Silva *et al.* (2021) who stated that the application of an oil-based solution of tyrosol (10 mg/L) to soybean seeds showed no significant difference from soybean seeds without tyrosol in terms of germination percentage, number of nodules, number of seeds per plant, and number of pods per plant.

5.4.7 Biological yield (g plant^{-1}, kg ha^{-1})

The overall plant biomass, which includes economic production, is referred to as biological yield. The total dry matter generated, 99 percent of which may be divided into root and shoot dry matter, is referred to as biological yield. Biological yield (g plant^{-1}) was shown to change significantly among the seed treatments with biostimulants and other chemicals. A minimum biological yield was observed for the treatment T1. The biological yield ranges from 16.63 to 23.75 g plant^{-1}. In comparison to T1 (control), the superior therapy T5 showed a 29.97 % improvement. And also, biological yield kg ha^{-1} was shown to change significantly among the seed treatments with biostimulants and other chemicals. A minimum biological yield was observed for the treatment T1. The biological yield ranges from 1616.04 to 2809.92 kg ha^{-1}. In comparison to T1 (control), the superior treatment T5, showed a 42.46 % improvement. The treatment applying biostimulant Take off ST 4ml/kg seed treatment enhanced biological yield compared to the treatment using other chemicals. The present outcome is in line with Waqas *et al.* (2014) who observed that seed priming with 0% (water soaked), 1%, 2% humic acid solution and foliar spray with 0.01%, 0.05% and 0.1% of HA solution and concluded that HA application in all three methods significantly enhanced grain yield and yield components of mungbean. Ahmad *et al.* (2017) reported that the application of humic acid in the form of the liquid fertigation fertilizer and liquid foliar fertilizer along with 50 kg of urea per acre and with seed treatment showed the best results in biological yield (grain plus straw yield). Campobenedetto *et al* (2020) reported that the application of the biostimulant as a seed treatment increased the percent germination (+6.54%) and fresh biomass (+13%) at 48 h, and decreased the content of H_2O_2 in treated seeds at 28°C (−70%) and at 35°C (−80%) in cucumber (*Cucumis sativus* L.).

5.4.8Harvest index (%)

The harvest index (HI) measures the percentage of economic yield to biological yield, and higher HI has been linked to higher crop plant economic productivity. Seed yield was significantly and positively correlated with harvest index (Choudhary *et al.,* 2016). HI was found to be in range between 46.07 and 65.91 percent. Bio-stimulant Take off ST @ 4ml/kg enhance harvest index over control in the tune of 30.10%. As a result, using biostimulants in seed treatment formulations might minimize the amount of fertilizer used, saving production costs and reducing the danger of contamination. No. of branches per plant, number of pods per plant, number of seeds per pod, and seed output are all reasons for treatment T5's superiority. According to our findings, Harvest index improvement by treatment T5 might be attributed to quicker remobilization and translocation of current and reserve assimilates. Saad and Hammad (1998) reported the seed treatment of phosphate solubilizing bacteria enhance straw yield with a significant increase in harvest index. Haghighi *et al.* (2011) reported that seed treatment with humic acid in horse bean significantly enhance all the characteristics of yield attributes like the number of seeds per pod, seed yield, harvest index, and grain protein percentage.

5.5 Seed quality traits

5.5.1 Field emergence (%)

Seed treatment plays an important role in protecting the seeds and seedlings from seed and soil-borne diseases and insect pests affecting crop emergence and growth. Under field conditions, tillage practices potentially would enhance seedling emergence, whereas, under conventional tillage practices, emergence will be more dependent on the effect that tillage has on the vertical distribution of seeds in the soil. Treatment T9 had the least amount of field emergence. Field emergence ranges from 25.66% to 64.91%. T5 enhance field emergence over T1(control) by 41.59%. Biostimulant has a positive and stimulatory effect on emergence of seed as evident in maize (Wilson *et al*., 2018), soybean (Vinkovik *et al*., 2007). Noman *et al.,* (2018) reported that sugar beet extract as natural biostimulant that enhance seedling in wheat. Seed treatment with micro-organism have a biostimulant effect influencing germination and seedling growth of crop (Cardarelli *et al*., 2022).

5.5.2 Post harvest seed quality attributes

Seed quality is an important aspect of the modern cultivation strategies since uniform germination and high seedling vigor contribute to successful establishment and crop performance. Germination is one of the most crucial phases in the establishment of plants in agriculture, and it is critical for crop quality. Slow germination exposes the early seedling, which is one of the most sensitive phases of the plant life cycle, to a variety of environmental stress conditions or infections, resulting in reduced vigour and crop yield, as well as financial losses for farmers. Germination % ranged from 70.66% to 86.66%. T5 (better treatment) outperformed over T1 (control) and T6 (application of state-approved dose of rhizobium+vitavax) by 10.76% and 18.46%, respectively.

Seedling length is adirect estimate of plant vigour. The seedling length ranges from 25.99 to 33.23 cm. Seedling length differed significantly across the various seed treatments with biostimulants and other chemicals. With respect to seedling length, T5 outperformed T1 (control) and T6 (application of state-approved dose of rhizobium+vitavax) by 21.12% and 13.93%, respectively. Seedling dry weight differed significantly across the various seed treatments with biostimulant and other chemicals. A minimum seedling dry weight observed for treatment T1. The seedling dry weight ranges from 650.93 mg to 891.10 mg. T5 (better treatment) outperformed over T1 (control) and T6 (application of state-approved dose of rhizobium+vitavax) by 26.95% and 17.19%, respectively.

Biostimulants induce cellular mechanisms by improving the abiotic stress tolerance and plant growth enhancement leading to an increase in yield and performance of seed in terms of seed vigor and field emergence. Seed vigour index-I varied greatly depending on the biostimulant and other chemicals used in the seed treatments. Treatment T10 (treatment with MnSo4) recorded a minimum seed vigour index-I. The vigour index of seedlings ranges from 1934.77 to 2875.61.T5 (superior treatment) beat T1 (control) and T6 (application of state-approved dosage of rhizobium+vitavax) by 29.62% and 16.44%, respectively. Similarly, Colla *et al.* (2015) elucidated seed vigor promoting effect of biostimulants in horticultural crops. Biostimulants also help to minimize dormancy, enrich the efficiency of the root system, boost the photosynthetic rate and activities of other vegetative tissues, promote growth, increase nutrient absorption, enhance crop productivity, seed vigor, and consistency, monitor flowering, promote fruit set, and increase fruit size and ripening (Rouphael *et al.* 2017). Seed vigour index-II differed significantly depending on the biostimulant and other compounds employed in seed treatments. A minimum seed vigour index-II was observed in treatment T1 (control). Seed vigour indexes II varied from 50.31 to 77.23. T5 outperformed superior over T1 (control) and T6 (use of state-approved rhizobium+vitavax dose) by 34.85% and 19.86% improvement, respectively. Carvalho et al. (2013) reported seed vigour enhancement effect owing to treatment with sea weed extract as a bio-stimulant. Qiu et al. (2020) reported bio-stimulator enhancing effect on shoot length, seedling vigour index and seedling dry weight on perennial ryegrass and red clover. The present research is comparable to the Gonzalez and Sommerfeld (2015) who reported that the cellular extracts and dry biomass of the green alga *Acutodesmus* *dimorphus* were applied as a seed primer, foliar spray, and biofertilizer, and found a positive effect on seed germination, plant growth, and fruit production in Roma tomato plants. Mzibra *et al*. (2021) reported that Polysaccharides extracted from seaweeds applied as plant biostimulants on tomato leads to enhance germination percentage (GP), germination speed (GS) and mean germination time (MGT). Mishra *et al.* (2010) revealed seeds treated with PGPR resulted in a significant increase of shoot length, root length and dry matter production of shoot and root of *Cicer arietinum* seedlings.

SUMMARY, CONCLUSIONS AND SUGGESTIONSFOR FURTHER WORK

The present research experiment entitled **“Optimization of seed treatment techniques for enhancement of physiological efficiency, productivity and seed quality attributes in Soybean [*Glycine Max* (L.) Merr.]’’** was conducted at Research Farm, Department of Agronomy, J.N.K.V.V., Jabalpur (M.P.) during *Kharif* season of 2021. The research experiment was laid out in a Completely Randomized Block design with three replications. Treatments comprised of twelve seed treatment combinations. *viz.,* T_1(Untreated seeds-Control), T_2(Take-off ST @ 1ml/kg), T_3 (Take-off ST @ 2ml/kg), T_4 (Take-off ST @ 3ml/kg), T_5 (Take-off ST @ 4ml/kg), T_6 (rhizobiuam+vitavax) and T_7 (seed 100 Cl @ 2ml/kg), T_8 (Znso$_4$ @ 0.3%), T_9(K_2HPO_4 @ 0.5%), T_{10}($MnSO_4$ @ 0.5%), T_{11}(salicylic acid @ 100 ppm), T_{12}(KNO_3 @ 0.3%), The phenophasic development, growth analytical parameters, physiological parameters, seed yield and quality parameters were studied and result were summarized below.

Phenological studies revealed that treatment T6 (seed treatment with biostimulant 100 CL) exhibited maximum days to floral initiation (59days), 50% flowering (68.33 days), days to pod initiation (72 days), and treatment T2 was found to be superior for 50% podding (77.67 days). Treatment T10 was superior for days to physiological maturity (106.67days). In contrast, minimum days to floral initiation and days to physiological maturity were observed for T5 and T1, respectively.

Growth analytical studies revealed superior performance of treatment T5 (Take off ST @ 4ml per kg seed) for average LAI (5.31), average LAD (30703.31 cm2 days), crop growth rate (0.004692 g.cm-2days-1), average relative growth rate (0.064109 g g-1day-1), average net assimilation rate (0.000726 g cm-2 day-1), average biomass duration (247.70 g days) with respect to 26.49 %, 27.67%, 51.81%, 36.81%, 51% and 17.39% enhancement over control.

Biophysical traits studies revealed superior performance of treatment T5 (Take off ST @ 4ml per kg seed) for average chlorophyll content index (44.23), energy interception (419.20) with 32%, and 44% enhancement over control.

Yield and yield component studies revealed that treatment T5 (Take off ST @ 4ml per kg seed) stand superior for plant height at harvest (44.90cm), number of branches per plant (4.84), no. of pods per plant (81.57), seed yield (14.51 g plant^{-1} and 1220.00 kg ha^{-1}), biological yield (23.57 g plant^{-1} and 8429.75 kg ha^{-1}) with respect to 34.67%, 23.55%, 28%, 33.83%, 31.10%, 29.97% and 42.46% enhancement over control. seed index was found to be maximum for treatment T7 (13.55g), harvest index was found to be superior for treatment T4 (65.91).

Seed quality attributes studies revealed that treatment T5 (Take off ST @ 4ml per kg seed) stands superior for field emergence (64.75%), seed germination percentage (86.66%), seedling length (33.23cm), seedling dry weight (0.891gm), seed vigor index I (2875.60) and seed vigor index II (77.23)with respect to 41.59%, 10.76%, 21.12%, 26.95%, 29.62% and 34.85% enhancement over control.

Conclusion

Soybean yield is constrained by poor seed quality and field emergence due to improper handling using combined harvester causing mechanical damage to seed coat. Another reason for poor seed quality is climate change as the crop phase frequent droughts and flooding in the kharif season from last few years. Hence, we tested soybean seed with different seed coating treatment of bio stimulants and micro nutrients for improvement in final plant stand establishment and seed yield. It was concluded that seed treatment with bio stimulant take off ST @ 4ml per kg seed was found to enhance seed yield and seed quality due to enhancement of growth parameters *viz.,* Crop growth rate (0.004692 g. cm^{-2} days^{-1}), Relative growth rate (0.064109 g.g^{-1}.days^{-1}) Net assimilation rate (0.000726 g cm^{-2} days^{-1}), Leaf area index (5.31), Biomass duration (247.70 g. days), Leaf area duration (30703.31 cm^2. days), chlorophyll content index (44.23). Seed treatment with bio-stimulant Take off ST @ 4ml per kg seed improve yield components exhibited through superior performance of plant height at harvest (44.90 cm), number of branches per plant (4.84), no. of pods per plant (81.57), seed yield (14.51 g $plant^{-1}$ and 1220.00 kg ha^{-1}), biological yield (23.57 g $plant^{-1}$ and 8429.75 kg ha^{-1}) with respect to 34.67%, 23.55%, 28%, 33.83%, 31.10%, 29.97% and 42.46% enhancement over control. The superior treatment of Take-off ST @ 4ml per kg seed leads to improve post-harvest seed quality attributes *viz.* field emergence (259.66;64.75%), seed germination percentage(86.66%), seed vigor index I(2875.60) and seed vigor index II(77.23) with respect to 71.21%, 12.06%, 42.09%, 53.50% increase over control, respectively. Hence, seed treatment with bio-stimulant Take off ST @ 4 ml per kg is recommended to farmers for higher plant stand, physiological efficiency, productivity and seed quality.

Suggestion for future work

The superiority of seed treatment with Take-off ST @ 4ml per kg seed needs to be verified at different locations.

The treatment needs further exploration for yield stability studies under rainfed, late sown, or summer sowing conditions.

In-depth exploration deciphering the biochemical and molecular mechanism induced by superior treatment for yield enhancement under Kharif and summer-sown conditions will be planned for future studies.

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APPENDICES

(A) MSS of phenophases in Soybean during reproductive growth period under different treatments

Source of variation	d.f	days to first flower initiation	days to 50 % flowering	days to pod initiation	days to 50 % podding	days to physiological maturity
Treatment	11	0.9368	0.5126	0.5959	1.4621	0.9369
Replication	2	0.1994	0.1994	0.1111	0.25	0.1111
Error	22	0.4672	0.8914	0.4444	0.553	0.6869

(B) MSS of leaf area index (LAI) of Soybean during successive growth Intervals in various treatments

Source of variation	d.f	45 DAS	65 DAS	85 DAS
Treatment	11	1.8796	2.8506	22.718
Replication	2	0.0604	0.0813	3.8931
Error	22	0.2493	0.2539	1.6879

(c) MSS of leaf area duration (LAD) (cm^2.days) of Soybean during successive growth Intervals in various treatments

Source of variation	d.f	65 DAS	85 DAS
Treatment	11	32419	1.16
Replication	2	51398	5134
Error	22	59817	4777

(d) MSS of crop growth rate (CGR) (g $cm^{-2}day^{-1}$) of Soybean during crop life span in various treatments

Source of variation	d.f	65 DAS	85 DAS
Treatment	11	1.7	1.2
Replication	2	3.1	3.0
Error	22	3.9	3.7

(e) MSS of relative growth rate (g $g^{-1}day^{-1}$) of Soybean during crop life span in different treatments

Source of variation	d.f	65 DAS	85 DAS
Treatment	11	**0.00055**	**0.00021**
Replication	2	**0.000306**	**0.00021**
Error	22	**0.00138**	**0.00029**

(f) MSS of net assimilation rate (g cm^{-2} day^{-1}) of Soybean during crop life span in different treatments

Source of variation	d.f	65 DAS	85 DAS
Treatment	11	5.91	4.49
Replication	2	5.88	3.38
Error	22	1.13	5.12

(g) MSS of BMD (g days) of Soybean during successive growth Intervals in various treatments

Source of variation	d.f	65 DAS	85 DAS
Treatment	11	277.07	1282.40
Replication	2	2068.38	1261.01
Error	22	1212.07	2070.1

(h) MSS of chlorophyll content index (CCI) in leaves of Soybean during successive growth Intervals in various treatments

Source of variation	d.f	45 DAS	65 DAS	85 DAS
Treatment	11	713.70	3.35	5.66
Replication	2	24.59	20.87	0.71
Error	22	6.72	7.27	3.12

(i) MSS of biophysical traits of Soybean during successive growth Intervals in various treatments

Source of variation	d.f	energy interception (cal cm^{-2} min^{-1})	light transmission ratio (%)
Treatment	11	0.012	59.47
Replication	2	0.020	137.69
Error	22	0.005	23.77

(j) MSS of yield and yield attributing traits of Soybean during successive growth Intervals in various treatments

Source of variation	d.f	Plant height (cm)	No. of branches plant^{-1}	No. of pods plant^{-1}	No. of seeds pod^{-1}
Treatment	11	8.24	0.27	177.21	0.0074
Replication	2	22.18	0.34	219.44	0.0217
Error	22	2.77	0.18	70.47	0.0164

Cont.

Source of variation	d.f	Seed index (100g)	seed yield		biological yield		harvest index
			g per plant	kg per ha	g per plant	kg per ha	
Treatment	11	0.258	8.78	4.34	10.30	535422	102.11
Replication	2	0.008	0.827	0.39	2.00	75085	8.31
Error	22	0.142	0.183	0.181	9.57	173168	67.53

(k) MSS of post harvested seed quality traits of Soybean during successive growth Intervals in various treatments

Source of variation	d.f	Field emergence	Seed germination%	Seedling length (cm)
Treatment	11	9323.47	58.29	12852
Replication	2	2157.03	25.44	57.04
Error	22	1911.91	15.62	2374.1

Cont.

Source of variation	d.f	Seedling dry weight (mg)	Seed vigour index I	seed vigour index II
Treatment	11	12852	219750	180.21
Replication	2	57.04	2354.9	11.30
Error	22	2374.04	29953	19.94

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