GERMINATION AND PLANT GROWTH RESPONSES IN ASHWAGANDHA (*WITHANIA SOMNIFERA* (L.) DUNAL) AND KIRIYATHU (*ANDROGRAPHIS PANICULATA* (BURM.F.) NEES) TO SEED PRETREATMENTS

by

NAMITHA NADESH

(2018-12-018)

THESIS

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DEPARTMENT OF PLANTATION CROPS AND SPICES

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM- 695 522

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2020

DECLARATION

I, hereby declare that this thesis entitled **"GERMINATION AND PLANT GROWTH RESPONSES IN ASHWAGANDHA (*WITHANIA SOMNIFERA* (L.) DUNAL) AND KIRIYATHU (*ANDROGRAPHIS PANICULATA* (BURM.F.) NEES) TO SEED PRETREATMENTS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship or other similar title, of any other University or Society.

Place : Vellayani
Date : 17.12.2020

NAMITHA NADESH
(2018-12-018)

CERTIFICATE

Certified that this thesis entitled **"GERMINATION AND PLANT GROWTH RESPONSES IN ASHWAGANDHA (*WITHANIA SOMNIFERA* (L.) DUNAL) AND KIRIYATHU (*ANDROGRAPHIS PANICULATA* (BURM.F.) NEES) TO SEED PRETREATMENTS"** is a record of research work done independently by MS. NAMITHA NADESH (2018-12-018) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place : Vellayani
Date : 17.12.2020

Dr. DEEPA S. NAIR
(Major Advisor, Advisory Committee)
Assistant Professor and Head
Department of Plantation Crops and Spices
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of advisory committee of **Ms. NAMITHA NADESH (2018-12-018)**, a candidate for the degree of **Master of Science in Horticulture** with major in Plantation Crops and Spices agree that the thesis entitled **"GERMINATION AND PLANT GROWTH RESPONSES IN ASHWAGANDHA (*WITHANIA SOMNIFERA* (L.) DUNAL) AND KIRIYATHU (*ANDROGRAPHIS PANICULATA* (BURM.F.) NEES) TO SEED PRETREATMENTS"** may be submitted by Ms. NAMITHA NADESH (2018-12-018) in partial fulfillment of the requirement for the degree.

Deepa 14.12.2020

Dr. Deepa S. Nair

(Major advisor, Advisory Committee)
Assistant Professor and Head
Department of Plantation Crops
and Spices, College of Agriculture
Vellayani, Thiruvananthapuram

14/12/2020

Dr. G. S. Sreekala

(Member, Advisory Committee)
Assistant Professor
Department of Plantation Crops
and Spices, College of Agriculture
Vellayani, Thiruvananthapuram

Dr. Anith K.N. 14/12/2020

(Member, Advisory Committee)
Professor
Department of Agricultural Microbiology
College of Agriculture, Vellayani
Thiruvananthapuram

Dr. Viji. M. M

(Member, Advisory Committee)
Professor and Head
Department of Plant Physiology
College of Agriculture,
Vellayani, Thiruvananthapuram

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NAMITHA NADESH

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LIST OF ABBREVATIONS

%	Per cent
@	At the rate
µM	Micro molar
^{0}C	Degree Celsius
CD	Critical difference
Cm	Centimeter
CRD	Completely Randomized Design
et al.	And others
Fig.	Figure
G	Gram
HI	Harvest index
L^{-1}	Per litre
GA	Gibberellic acid
TDZ	Thidiazuron
IAA	Indole-3 acetic acid
BA	Benzyl adenine
NAA	Naphthalene Acetic Acid
gL^{-1}	Gram per litre
H	Hour
Cfu	Colony Forming Unit
mL	Millilitre
Min	Minute
DAS	Days after sowing
Ha	Hectare
^{0}E	Degree East
^{0}N	Degree North
SE	Standard Error
MSL	Mean Sea Level
FYM	Farm Yard Manure
SA	Salicylic Acid
PG	Phloroglucinol

N	Nitrogen
P	Phosphorus
K	Potassium
PGPR	Plant Growth Promoting Rhizobacteria
mg/L	Milligrams per litre
PPM	Parts per million
mM	Milli molar
Kg	Kilo gram
T. No.	Treatment Number
SC	Scarification
WS	Water soaking
HW	Hot water
CSA	Concentrated Sulphuric Acid
Gn (%)	Germination per cent
S (%)	Survival per cent
GI	Germination Index
SL	Shoot length
RL	Root length
Sdl L	Seedling Length
AI	Allometric Index
SVI	Seedling Vigour Index
CH	Chitosan
BP	*Bacillus pumilus*
BA	*Bacillus amyloliquefaciens*
PF	*Pseudomonas fluorescens*
BV	*Bacillus velezensis*

INTRODUCTION

1. INTRODUCTION

India is considered as an abode of innumerable medicinal and aromatic plant species. These species are gaining commercial importance, as being utilized for ayurvedic and allopathic pharmaceutical preparations (Agarwal and Ghosh, 1985; Nostro, 2000). The plant parts or extracts from plants are used in combating disease and in healthcare. The plant extracts are considered as one of the most important strategic materials in the pharmaceutical industry (Djaafar and Ridha, 2014). A number of medicinal plants are under threat in their habitats due to indiscriminate and unscientific collection, without replenishment. This makes the domestication and conservation inevitable for highly exploited medicinal plant species. The candidate species of the present study, Ashwagandha (*Withania somnifera L.* Dunal; Family: Solanaceae) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees; Family: Acanthaceae) are two such highly exploited medicinal plant species.

W. somnifera commonly known as 'Indian ginseng' is highly exploited for it's an inexhaustible source of bioactive compounds and pharmacological value. It is a treasure house of metabolites *viz.,* alkaloids, steroids, flavones, glycosides, carbohydrates, tannins, coumarin, saponins and terpenoids. Withanolides, a steroidal lactone is the most biologically active constituent localised in its leaves (Poojari *et al*., 2019). The roots, with Withaferin A as the bioactive constituent, are used in the preparation of Ayurvedic and Unani medicines. The adaptogenic and rejuvenating properties of the plant classifies it as a 'rasayana' herb. The root and leaf extracts of the plant have been used for the treatment of anxiety, inflammation, tumor and various neurological disorders (Kaur *et al*., 2017). It has been used in the Ayurvedic and indigenous systems of medicine for more than 3,000 years (Barathkumar and Manivannan, 2018). The major threat in its commercial cultivation is its low germination and dormancy of the seeds (Sapra *et al.,* 2020).

Andrographis paniculata, known as the King of Bitters, is an annual profusely branching herb with extreme bitter taste. The whole plant, is used in Siddha and Ayurveda for their healing, anti-inflammatory, antipyretic properties (Madav *et al.,* 1995; Shen *et al*.,

2002). It has hypoglycemic (Zhang and Tan, 2000), hepatoprotective (Trivedi and Rawal, 2001), anticancer (Rajagopal *et al.,* 2003), anti-malarial (Dua,2004), antibacterial (Mishra *et al*.,2009) and anti-oxidant (Lin *et al.*,2009) properties. The main bioactive constituent of the plant is andrographolide, a bicyclic diterpene lactone (Chao and Lin, 2010; Hossain *et al*., 2014). The plant is in huge demand in national and international pharmaceutical industries. Seed being the commercial and conventional propagule of the crop, the major impediment in the domestication of this crop is its germination problems (Verma *et al.,* 2019).

W. somnifera and *A. paniculata* generally have poor seed germination and high mortality rate of seedlings under field conditions (Kumar *et al.,* 2001; Khanna *et al.,* 2013). The role of plant growth regulators, biostimulants, microorganisms and physical scarification techniques have been demonstrated for breaking morpho-physiological dormancy, enhancing seed germinability and seedling vigour in various plant species. Seed priming is one of the treatment strategies that could be applied to agricultural and horticultural crop seeds to accelerate seedling emergence, germination uniformity, seedling health and ensure optimum crop stand (Bhardwaj *et al.,* 2016; Cendales *et al.,* 2016; Gadomska *et al.,* 2017; Masondo *et al*., 2018). Seed traits and germination strategies have a profound influence on their population dynamics, survival and growth (Duncan *et al*., 2019)

The study has been proposed with the objective to standardize the pretreatment of seeds for enhanced germination and plant growth in *W. somnifera* and *A. paniculata.*

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The present study entitled "Germination and plant growth responses in Ashwagandha (*Withania somnifera* (L.) Dunal) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees) to seed pretreatments" has been taken up with the objective to standardize pretreatment of seeds for enhanced germination and plant growth in *W. somnifera* and *A. paniculata.* The relevant literature on the effect of different seed pretreatments on germination, seedling parameters and plant growth are reviewed in this chapter.

Withania somnifera and *Andrographis paniculata* are two important medicinal plant species commercially exploited for therapeutic and nutraceutical purposes (Puranik *et al*., 2012; Raj *et al*., 2016). These herbs have been identified by the National Medicinal Plant Board of India as priority medicinal plants for cultivation in India (CIMAP, 2004). Both the herbs are seed propagated, in spite of low germination potential of their seeds (Vakeswaran and Krishnaswamy, 2003; Valdiani *et al.*, 2012; Kumar *et al.*, 2011). Saraswathy *et al.* (2004) opined that the hard seed-coat and existence of unknown inhibitor proteins in the seed and seed coat are the main reasons for the dormancy, and low germination in *A. paniculata*.

2.1 Seed pretreatment

The successful commercial production of any crops relies on knowledge about their propagation techniques. When the seed is the route of propagation, the principal parameters of consideration are seed viability, germination per cent and seedling vigour. Good quality seeds without dormancy would contribute to high germination per cent, field emergence and establishment of crop stand (Cendales *et al.*, 2016; Gadomska *et al.*, 2017; Masondo *et al*., 2018). It was observed that the dormancy of the seeds resulted in low germination of medicinal plants species (Bhuse *et al*., 2001; Suryavamshi *et al*., 2001).

Seed pretreatment or priming is an important treatment applied to both agricultural and horticultural crop seeds to improve seed germination, germination uniformity, germination rate, seedling health, seed vigor, seedling emergence and optimum crop stand (Rowse, 1995; Asgedom and Becker, 2001; Farooq *et al*., 2006; Cendales *et al.*, 2016; Gadomska *et al.*, 2017; Masondo *et al*., 2018). The seeds of medicinal plants were subjected

to physical and chemical treatments to overcome dormancy (Bhuse *et al*., 2001; Suryavamshi *et al.,* 2001). The effect of varied seed pretreatments using plant growth regulators (hormones), biostimulants, microorganisms, chemicals and physical scarification techniques have been explored to overcome morpho-physiological dormancies of the seeds (Cendales *et al.,* 2016; Gadomska *et al.*, 2017; Masondo *et al*., 2018).

2.2 Effect of physical seed pretreatments on germination and plant growth

The physical invigoration treatments are found to evoke less harmful influence on the environment and are observed to be effective over conventional treatments based on chemical substances. It not only offers positive biological changes in morpho-structural aspects of a crop, but also gives positive changes in gene expression and protein or metabolite accumulation (Arajuo *et al*., 2016; Govindaraj *et al.,* 2017)

2.2.1 Scarification

Seed scarification is a technique used to physically damage the seed coat to reduce its hardness while keeping the seed viable. The seed scarification methods encompass heat, acid and mechanical scarification (Kimura *et al.,* 2012). Mechanical scarification is carried out using either a scarifier or a sandpaper which creates scars on the seed surface to increase water imbibition of the seeds (Jayasuriya *et al.,* 2012).

When seeds of *Medicago* and *Trifolium* species were scarified using sandpaper, the germination enhanced from 18 to 97 per cent and 40 to 95 per cent, respectively in these species (Uzun and Aydin, 2004). According to Khatuna *et al*. (2008), the germination process was hastened by a week in mechanically scarified seeds than the control treatments in *W. somnifera*.

Mechanical scarification using sand paper gave a faster and higher germination in *A. paniculata.* The germination of scarified seeds was increased up to 71.33 per cent on the 3rd day and to 94 per cent after 20 days with a mean germination time of 4 days (Talei *et al.,* 2012).

Khanna *et al*. (2013) reported 65 per cent germination and Niyaz and Siddiqui (2014) reported 68.80 to 78.60 per cent germination in *W. somnifera* on mechanical scarification of seeds using sand paper.

Bhoyar (2015) demonstrated that soaking of *W. somnifera* seeds in water for 24 h followed by mechanical scarification improved germination in ½ MS medium under *in vitro* culture system.

Germination, seedling growth and vigor were found to be enhanced by sand paper scarification in five medicinal plants *viz*., *Saussurea lappa, Rheum webbianum, Inula racemosa, Carum carvi* and *Bunium persicum* (Bhardwaj *et al.,* 2016).

2.2.2 Water soaking treatment

Hydropriming (water soaking) is a technique that involves soaking of seeds in water which promotes the initiation of germination of the seeds. Soaking the seeds in water at room temperature helps in softening the seed coat, removal of inhibitors, reducing the time required to reach optimum moisture level with constant supply of oxygen, increasing the level of intermediate metabolites associated with germination, germination percentage and yield (Duffus, 1985; Hartman *et al*., 2007; Raza *et al*., 2013).

Sabongari and Aliero (2004) demonstrated that a higher germination per cent, seedling length, stem girth and dry matter was obtained in water soaking treatment for 24 h in *Lycopersicum esculentum* over the control treatment.

A study on *W. somnifera* by Suvanthini *et al.,* (2013) showed that the water soaking treatment of seeds significantly increased the germination to 33.75 per cent, whereas the control treatments showed only 12.5 per cent germination.

Hydropriming of *Carum carvi* seeds for 12 h enhanced the germination per cent, germination rate and shoot length compared to the control treatment (Mirmazloum *et al.,* 2020).

2.2.3 Hot water treatment

Hot water treatment or heat scarification is a seed treatment method that uses high temperatures to break or crack hard seed coats (Staker, 1925; Tomer and Maguire, 1989).

Suvanthini *et al*. (2013) observed a higher germination of about 52.75 per cent in *W. somnifera* seeds treated with hot water which far exceeds the germination of 12.50 per cent, given by the control treatment.

Application of hot water at 50^{o}C for 5 min in *A. paniculata* gave 93.30 per cent germination. The germination declined to 66.60 per cent and 46.60 percent when the seeds were treated for 10 min and 15 min, respectively (Kumar *et al*., 2011).

Hot water soaking @ 80^{o}C for 5 min resulted in a high germination percentage in *Rauvolfia serpentina* (Bhuyar *et al*., 2000). Another study on the same plant revealed that a germination of 70.00 per cent could be obtained by applying hot water treatment (Mohan *et al*., 2012).

Hot water treatment @80°C for 20 min had a pronounced effect in increasing the seedling length of the medicinal plant *Bunium persicum* (Bhardwaj *et al.,* 2016).

Seeds treated in hot water treated at 35˚C for 2 min showed an increase in the plant height, branch number, fruit weight and minimum days to flowering of *Capsicum frutescens* plants (Normasari *et al.,* 2016).

Seed treatment with hot water @ 50-52 °C for 30 min had a positive effect on germination, seedling length, seedling dry weight, seed vigour index of bell pepper (*Capsicum annuum*), under *in vitro* conditions. Same treatment under nursery conditions showed maximum values in terms of total emergence, seedling height, seedling dry weight and seed vigour index in comparison to the control treatment (Singh *et al.,* 2019).

2.2.4 Concentrated sulphuric acid treatment

Among the various scarification methods followed, acid scarification is considered to be the most effective method for seed scarification (Rusdy *et al.,* 2017).

According to Can *et al*. (2009), sulphuric acid is the most popular and effective chemical used to reduce hard seed coat of legume seeds.

Aniat-ul-haq *et al.* (2010) observed an increase in the germination by 17.70 per cent over the control treatment in *A. paniculata* seeds when exposed to 25 per cent sulphuric acid.

The different concentrations of H_2SO_4 were tried on *W. somnifera* and *W. coagulans* seeds to study the effect on germination and growth of seedlings. The application of 20 per cent H_2SO_4 for 20 min enhanced the germination of *W. somnifera* and *W. coagulans* to a maximum of 82.50 per cent and 78.40 per cent, respectively (Sharma *et al*., 2015).

Bhardwaj *et al.* (2016) observed a considerable increase in the seedling length of *Saussurea. lappa* (24.30 cm), *Rheum webbianum* (23.80 cm) and *Carum carvi* (22.20 cm) in response to H_2SO_4 treatment for 5 min, in a duration of 30 days.

When treated with H_2SO_4 @ 95 per cent, about 3-15fold increment in seed germination was observed in six medicinally important plants *viz., Abelmoschus moschatus, Asparagus racemosus, Bixa orellana, Cassia angustifolia, Operculina turpetham* and *Psoralea corylifolia,* both under *in vitro* and *in vivo* conditions (Singh *et al*., 2018).

2.3 Effect of hormonal seed pretreatments on germination and plant growth.

Plant hormones or plant growth regulators (PGRs) are known to influence the balance between primary and secondary metabolism, which stimulates the growth and development, biosynthesis of secondary metabolites, translocation of photoassimilates and photosynthetic ability in medicinal and aromatic plants (Audus, 1959; Steward and Krikorian, 1971; Zlatev *et al.*, 1978; Roitsch and Ehneb, 2000; Iqbal *et al.*, 2011).

PGRs such as indole acetic acid (lAA) and indole butyric acid (IBA), gibberellic acid (GA_3), kinetin (Kn) ,benzyl amino purine (BAP), triacontanol (Tria), methyl jasmonate (MJ), salicylic acid (SA), Benzyl adenine(BA), Phloroglucinol (PG), Cycocel (CCC) and ethylene have been used as an important tool in hormonal priming to increase germination and crop yield (Larissa, 2015).

2.3.1 Seed priming with gibberellic acid (GA)

Gibberellins are important plant hormones that play a vital role in seed germination, bolting and induction of flowering in plants (Kim and Park, 2007).

Seed priming studies in *W. somnifera* by Verma *et al*. (2000) revealed that seeds pretreated with GA_3 at 100 µg L^{-1} showed vigorous growth of seedlings under laboratory conditions. A study by Fathima *et al.* (2003) demonstrated that soaking in 100 ppm GA_3 for 6 h could improve the germination and plant growth in *W. somnifera.*

Seeds of two medicinal plants *viz., Calendula officinalis* and *Foeniculum vulgare* were primed with GA_3 for 24 h at 25°C. The treatment induced metabolic reactions in seeds and thus improved seed germination and seedling establishment (Mohammad *et al*., 2010).

Rawat and Vashistha (2011) found that seed priming with GA_3 @75ppm improved the germination to 82 per cent in *A. paniculata.* Another investigation on the effect of GA_3 priming on seed quality enhancement in the *A. paniculata* variety CIM-Megha and wild, demonstrated higher germination rates of 99.20 and 88.30 per cent, respectively (Kumari *et al.*, 2012).

The enhancement of germination per cent and speed of germination with gibberellic acid (GA_3) at 150µg mL^{-1} was observed in two accessions of *W. somnifera*, AGB-001 and AGB-004 (Khanna *et al.*, 2013).

Niyaz and Siddiqui (2014) studied the effect of GA_3 on germinability of *W. somnifera* seeds under laboratory and field conditions. The treatment with GA_3 @ 500 µg $^{-1}$ recorded a germination of 86 and 84 per cent, under laboratory and field conditions, respectively, whereas the corresponding values of control treatments were 61.30 per cent under laboratory and 53 per cent in field conditions. Also, the treatment reduced mean germination time to 5 days under laboratory and 10 days under field condition.

The highest germination per cent, seedling length and seedling vigour indices were expressed in *W. somnifera* on seed treatment with GA_3 @ 200 ppm for 48 h (Thakur and Himangini, 2015).

The speed of germination (2.47), germination per cent (54.67), seedling length (19.61 cm) and vigour index (1072.31) of *Rauvolfia serpentina* seeds were observed in seeds subjected to overnight priming with GA_3@ 50 ppm, over the control treatment which recorded the lowest speed of germination (0.30), germination per cent (14.33) and vigour index (199.38) (Phatak *et al.*, 2017).

2.3.2 Seed priming with indole acetic acid (IAA)

Indole acetic acid (IAA) is an endogenous plant hormone which plays a commendable role in root development (Prusty *et al.*, 2004).

The problem of low germination with *W. somnifera* seeds due to immaturity of embryo was overcome by treating 8-12 months old seeds with IAA which exhibited 70-80 per cent germination (Hussain and Ilahi, 1988).

The tomato seeds when subjected to presoaking in IAA @ 100 mg L^{-1}, seedling growth and yield were observed to be enhanced (Olaiya *et al*., 2010).

Kumar *et al*. (2010) reported that IAA @ 10 ppm alone and also, IAA @ 10 ppm along with kinetin @ 10 ppm had a positive effect on seed germination and final germination percentage of *A. paniculata*.

IAA @ 5 µg mL^{-1}, when applied as a seed pretreatment significantly improved germination per cent, root length, shoot length, fresh weight, dry weight, germination relative index and seedling vigour of *A. paniculata* seedlings (Kaur and Setia, 2012).

Priming with IAA @ 200 ppm to seeds of *W. somnifera* showed a substantial increase in the fresh weight per plant (29.05g) and dry weight per plant (6.32g) over the control, which recorded a fresh weight of 27.82 g and dry weight of 6.04g (Shukla and Shukla, 2012).

Seeds soaked in a mixture of IAA and GA_3 after mechanical scarification at temperature of 25°C resulted in an increased germination capacity of about 70-80 per cent in *W. somnifera* (Naveen *et al*., 2015).

Qadir and Khan (2018) suggested that seed priming with IAA @ 50 ppm enhanced germination to 86 per cent in *Baliospermum montanum* over the control, which gave a germination of 11 per cent.

2.3.3 Seed priming with benzyl adenine (BA)

Benzyl adenine is a synthetic cytokinin that induces plant growth, bud development, leaf expansion, delay of senescence, and chloroplast formation in plants (Werner *et al*., 2001).

The tomato seeds primed for 24 h with BA @ 10, 50 and 100 ppm were observed to give better germination percentage, germination index, shoot length and seedling fresh weight than that of non-primed seeds (Nawaz *et al*., 2012).

A study by Khanna *et al.* (2013) indicated a hike in germination per cent and speed of germination in two accessions of *W. somnifera,* AGB-001 and AGB-004 by pre-sowing seed treatment with BA @ 150 µg mL^{-1}.

BA @ 50 ppm was also found beneficial to induce better seedling quality in terms of seedling vigour in *W. somnifera* (Thakur and Himangini, 2015).

Seeds of anise (*Pimpinella anisum* L.) when subjected to pre-sowing treatments with BA @ 10 mM, gave higher a radical length (1.7232 mm), over the control which recorded a radicle length of 0.5647 mm (Shahrajabian *et al.,* 2019)

2.3.4 Seed priming with thidiazuron (TDZ)

Thidiazuron, chemically known as N-phenyl-N-1,2,3-thidiazol-5-yl urea is a potent plant growth regulator which exhibits cytokinin-like activities (Wang *et al*., 1986). Improved seed germination, stimulation of sprouting, growth and development of cotyledons and enhanced berry weight has been induced by TDZ in grapes (Babiker *et al.,* 1992; Lin *et al*., 1994). *In vitro* and *in vivo* application of TDZ in plants induces varied biological responses, including the production of economically important secondary metabolites (Nabila *et al*., 2003; Guo *et al.,* 2011)

Kulkarni *et al.* (2000) reported that TDZ @ 10.0 µM significantly enhanced multiple shoot bud induction, shoot multiplication and subsequent elongation of shoots in *W. somnifera*. Seeds of soybean *cv*. 'White hilum' pretreated with TDZ @ 0.1 mg L^{-1} for 1 week

resulted in the best multiple bud formation under *in vitro* conditions (Shan *et al*., 2005). TDZ was found to be effective in improving the plant growth under *in vitro* culture systems of *W. somnifera* (Fatima and Anis, 2011). The shoot induction in *W. somnifera* and *Jatropha curcas* was enhanced with TDZ application at 0.11 mg L^{-1} and 2.0 mg L^{-1} concentrations, respectively under *in vitro* conditions (Kumar and Reddy, 2012; Fatima *et al.*, 2015).

Peanut (*Arachis hypogea*) plants when treated with 2.27 µM TDZ for 12 h prior to sowing recorded a higher number of pods than that of the control plants (Singh *et al.*, 2008). When the seeds of *Bunium persicum* were exposed to TDZ @ 6.3µM L^{-1}, a higher seed germination of 53.30 per cent was observed (Emamipoor and Maziah, 2014). A seed pretreatment using TDZ @ 20 µM in chickpea (*Cicer arietinum* L.) by Kumari *et al*. (2018) demonstrated better regeneration, rooting and higher number of shoots per explant.

Kim *et al.* (2019) demonstrated that the addition of TDZ in the growth medium enhanced the frequency of asymbiotic seed germination in the orchid, *Pecteilis radiata.*

2.4 Effect of biostimulant seed priming on germination and plant growth

Biostimulants are a class of compounds of biological origin that modifies physiological processes in plants such as stimulating germination, growth, increasing yield and mitigating to abiotic stresses (Yakhin *et al.*, 2017). Biostimulant priming of seeds triggers faster seed germination (Gonzalez and Sommerfeld, 2016). In addition, during imbibition at subsequent germination stages, biostimulants would induce tolerance to adverse environmental conditions (Pichyangkura and Chadchawan, 2015; Van *et al.*, 2017).

2.4.1 Seed priming with chitosan

Chitosan is a cationic polysaccharide formed by the acetylation of β-1, 4- linked D-glucosamine derived from biological sources such as crustacean shells, insect cuticle and fungal cell wall. It is used for varied applications on plant systems *viz.*, seed coating, seedling dip, foliar spray and for soil enrichment and as a supplement in plant tissue culture media (Rinaudo, 2006; Pichyangkura and Chadchawan, 2015). Chitosan enhances the physiological and biological properties like biodegradability, seed germination, growth and development, nutrient uptake, chlorophyll content, photosynthetic and chloroplast enlargement in the leaves and defence in plants mechanisms (El Hadrami *et al.*, 2010; Hadwiger, 2013).

The chitosan application @ 500 mg L^{-1} on *in vitro* plantlets of potato showed an increment in the shoot weight. It also enhanced the root weight when 5 and 15 mg L^{-1} of soluble chitosan was applied (Asghari-Zakaria *et al*., 2009).

Tomato seeds treated with chitosan germinated faster with improved emergence, germination percentage and seedling weight (Algam *et al.,* 2010).

Seed soaking of watermelon using chitosan @ 0.40 mg mL^{-1} decreased seedling death, increased fresh (1.99g) and dry (0.29g) seedling weight than control treatment (1.63g fresh weight and 0.19g dry weight) (Li *et al.,* 2013).

Mahdavi and Rahimi (2013) also opined that, in plants, stimulation of seed germination is one of the main bioactivities of chitosan. The chitosan priming of rice seeds for 1h significantly increased germination by 46.06 per cent over the untreated control.

Better germination percentage, germination rate, seedling vigour index, length and dry weight of hypocotyl and radicle could be achieved by applying chitosan seed treatment @ 0.2% concentration in ajowan. This also alleviated the inhibitory effect of salt stress on the plant growth (Mahdavi and Rahimi, 2013).

The lentil seeds when treated with chitosan @ 0.05 per cent (w/v) for 1 hr and foliar application at same concentration gave better results in yield and yield components *viz.*, pod yield per plant, grain yield per pod, 100 seed weight, economic yield and harvest index (Janmohammadi *et al*., 2014)

According to Samarah *et al.* (2016), soaking seeds with chitosan solution @ 0.05 per cent improved seed germination in *Capsicum annuum*.

Chitosan solutions @ 10g L^{-1} applied as a seed soaking agent in combination with ascorbic acid showed a 100 per cent and 96.40 per cent germination in tomato and coriander, respectively. The control treatment gave only 79.60 per cent germination (Castro, 2017).

2.4.2 Seed priming with salicylic acid (SA)

Salicylic acid (2-hydroxybenzenecarboxcylic acid) is a colourless crystalline organic acid used in priming. This phenolic compound, produced by plants, functions as an important

endogenous signal mediating compound that induces the biosynthesis of secondary metabolites (Taguchi *et al.*, 2001). SA application influences the tolerance to abiotic stresses like salinity and drought (Stevens *et al*., 2006), growth and development, photosynthesis, transpiration, seed germination (Hayat *et al*., 2007), antioxidant chemistry (Shi and Zhu, 2008) and defence responses against pathogens (Vicente and Plasencia, 2011).

Seeds of spring wheat when treated with SA @ 50 ppm, improved final germination count and reduced germination time. SA primed seeds enhanced seedling length, fresh and dry weight of shoot than non-primed seeds (Afzal *et al*., 2006).

It was observed that tomato seedlings raised from primed seeds with SA @ 150 ppm increased the length of root and shoot significantly (Ghoohestani *et al*., 2012).

Presoaking of *A. paniculata* seeds for two hours in IAA @ 5 μg mL^{-1} and SA @ 50 μg mL^{-1} improved seed germination, seedling growth, root and shoot length of seedlings, fresh and dry weight of seedlings, germination relative index and seedling vigour. A higher content of various biochemical reserves was observed in seedlings raised from SA treated seeds (Kaur and Setia, 2012).

Seed soaking with SA @ 75 mg L^{-1} improved antioxidative activities of catalase (CAT) and peroxidase (POD) in okra (Raza *et al.*, 2013).

The aged seeds of fenugreek primed with SA @ 2800 μM increased the germination from 41 to 100 per cent. The same treatment promoted the highest seedling length, plumule dry weight and seedling dry weight (Moghaddam *et al.,* 2018).

On priming sesame seeds with SA solutions ranging from 0.1-0.9 per cent, it was observed that priming with 0.9, 0.8 and 0.7 per cent of SA solutions took less days to germination (7.6 days) while control seeds took more days to germination (12.5 days). A higher germination of 72.30 per cent was recorded in seeds primed with SA@ 0.9 and 0.8 per cent. Mean germination time was higher (1.07) in untreated seeds. SA @ 0.6 to 0.8 per cent recorded taller seedlings (8.4 cm). Shoot weight (0.67 mg $plant^{-1}$) and root weight (0.38 mg $plant^{-1}$) were found maximum in SA @ 0.9 per cent (Ahmad *et al.*, 2018).

2.4.3 Seed priming with phloroglucinol (PG)

Phloroglucinol (1, 3, 5 - trihydroxybenzene) is a degradation product of phloridzin, which is considered as a promoter of plant growth due to its cytokinin-like and auxin-like activity (Jani *et al*., 2015). This phenolic compound is observed to have a positive effect on shoot multiplication and elongation, growth and rate of axillary shoots, initiation of adventitious roots, survival of meristems and shoot tips and on root proliferation in *in vitro* plant systems (Kumar *et al*., 2010; Bairwa *et al.,* 2012; Silva *et al.,* 2013; Londe *et al.,* 2017).

Sarkar and Naik (2000) found that a medium containing 0.8 mM PG and 0.2 M sucrose produced maximum response in *in vitro* derived shoot tips in six potato (*Solanum tuberosum* L.) genotypes in terms of shoots per shoot tip, shoot fresh weight, and roots induced per shoot tip. About 5.8 - 8.2 shoots and 0.3 - 6.1 roots per shoot tip were produced in the medium with PG, whereas the control gave only 1 shoot and zero roots per shoot tip.

MS medium containing 0.6 mM PG exerted a positive effect on plant multiplication (1.2 to 3.6 plantlets per explant) in the medicinal plant, *Arnica montana* (Keul and Deliu, 2001).

The presence of PG in the bud induction medium of *Capsicum annuum* @ 400µM increased the bud induction response by 17-18 per cent (Kumar *et al*., 2005).

Rooting of *Asparagus racemosus* was most effectively induced by using PG @ 198.25µM which increased the rooting frequency to 85 per cent from that of 41.37 per cent in control (Bopana and Saxena, 2008).

PG @15.84µM was a critical ingredient in the medium used for pulse treatment for 7 days in *Pterocarpus marsupium* micro shoots. The maximum frequency of root formation (70 per cent), highest number (3.8±0.37) of roots, and maximum root length (3.9±0.05 cm) were observed as a result of PG dip (Husain *et al*., 2008).

An enhancement of shoot regeneration could be achieved in *Vitex negundo* by supplementing phloroglucinol PG at 100 mg L^{-1} (Steephen *et al*., 2010). With red raspberry, 1 mM PG in the presence of IAA @ 3 µM synergistically promoted the number of roots up to 5-fold (De Klerk *et al*., 2011).

The phloroglucinol (1 per cent) containing PVS2 vitrification solution used for seed cryopreservation of dendrobium hybrid seeds and protocorms for 60 min resulted in 79 per cent seed germination (Galdiano *et al*., 2012).

Supplementation of 2.5 µM IBA and 238 µM PG in the medium improved the rooting percentage as high as 83 per cent with an average of 3.1 roots per shoot in *Jatropha curcas* L. (Daud *et al.,* 2013).

Rengaswamy *et al.* (2014) observed that maize seeds primed with PG @ 10^{-7} M, recorded significantly higher shoot and root lengths in the seedlings compared to control treatments.

Jani *et al*. (2015) studied the effect of PG on *in vitro* culture of *Tinospora cordifolia* and observed that the treatment containing PG 79.4 µM increased shoot bud induction from 52.20 per cent to 84.80 per cent and multiple shoot production per cent from 12.90 to 60.30 percent. It was also successful in promoting shoot length (3.9 cm), number of shoots per explant (7.5) and number of leaves per shoot (4.3).

Seed priming with PG supported maximum seed germination and seedling growth in *Ceratotheca triloba* plants (Masonda *et al.,* 2018).

2.5 Effect of biopriming on germination and plant growth

Biopriming is an emerging seed treatment technique, that involves soaking of seeds in bacterial suspension for specific period of time, for bacterial imbibition and subsequent colonization into the seeds (McQuilken *et al*., 1998; Abuamsha *et al*., 2011). Biopriming promotes faster and even germination and better plant growth (Moeinzadeh *et al.,* 2010). Seed priming with PGPR enhances germination and seedling establishment, plant growth and yield. Biopriming favours uniformity in germination and better plant stand (Gururani *et al.,* 2012; Mirshekari *et al.,* 2012; Anitha *et al*., 2013). Bio-priming enables seed hydration to improve uniform seed germination, seed quality, seedling vigour, productivity and resistance to various seed and soil borne diseases in many horticultural crops (Bisen *et al*., 2014).

A variety of bacterial species such as *Pseudomonas* and *Bacillus,* potential biocontrol agents and biofertilisers are used for priming of seeds for improving germination, abiotic

stress tolerance, plant growth and yield (Kasim *et al*., 2013; Keswani *et al*., 2015(a); Mahmood *et al*., 2016). Sureshrao *et al*. (2016) opined that biopriming could amplify the hydrolytic and detoxifying enzyme activities, reactive oxygen species (ROS), alteration in internal plant hormone levels, and even expression of genes in plants.

2.5.1 Seed priming using *Bacillus pumilus*

Bacillus pumilus is an endophytic bacterium that has been identified as a biological control agent against plant pathogens (Yi *et al.,* 2013). This bacterium produces auxin, gibberellin and iron carriers which enabled its commercial exploitation for cell elongation, escalating ACC deaminase activity, and plant growth promotion (Sgroy *et al*., 2009; Liu *et al.,* 2018b; Wang *et al.,* 2019a).

Joo *et al.* (2004) examined the effects of *B. pumilus* @ 10^{9}cfu mL^{-1} in red pepper plug seedlings and observed an increased plant height and root fresh weight of the seedlings by 12 and 20 per cent, respectively.

Hafeez *et al.* (2006) reported that the inoculation of 1 mL *B. pumilus* strain @ 10^{6}–10^{7}cfu mL^{-1} resulted in the maximum increase in plant biomass, root length, and total N and P content in wheat.

Inoculation of chickpea *(Cicer arietinum* L.*)* plants with 10 mL of *B. pumilus* suspension @10^{7} cfu mL^{-1}, markedly increased the shoot dry mass, pod number, chlorophyll content, nitrogen, phosphorus and potassium levels over uninoculated control plants (Akhtar and Siddiqui, 2007).

The bacterial suspensions of *B. pumilus* and *Pseudomonas alcaligenes* @ 1.5×10^{7}cfu mL^{-1} inoculated on lentil seedlings resulted in increased the plant growth, number of pods, nodulation, and root colonization by rhizobacteria (Akhtar *et al*., 2010).

Application of *B. pumilus* strain INR7 @ $10^{8\text{-}9}$cfu mL^{-1} to pepper plants prior to their transplantation into the field caused a significant enhancement in the seedling growth, shoot and root fresh weight compared to plants treated with water control (Yi *et al.,* 2013).

Cendales *et al.* (2016) reported that seed priming of tomato seeds with *B. pumilus* validated the capacity to solubilize phosphates.

B. pumilus LZP02 added to the culture medium of rice plants promoted the growth of roots by enhancing carbohydrate metabolism and phenylpropanoid biosynthesis. *B. pumilus* LZP02 @10^8cfu mL^{-1} significantly enhanced the growth parameters *viz*., number of roots, root length and number of nodes (Liu *et al.*, 2020).

2.5.2 Seed priming using *Bacillus amyloliquefaciens*

B. amyloliquefaciens is a gram-positive, plant associated bacterium that mitigates soil-borne fungal plant diseases, stimulates plant growth and secondary metabolite production. *B. amyloliquefaciens* have been applied in a variety of agriculture and horticulture crops to promote its growth and development (Elsorra *et al*., 2004; Chen *et al*., 2007).

B. amyloliquefaciens strain FZB45 treatment to the maize seedlings at 10^9cfu mL^{-1} increased presence of phytate, development of the root system and overall plant growth promotion (Idriss *et al*., 2002). The culture supernatants of *B. amyloliquefaciens* FZB24 and *B. amyloliquefaciens* FZB37 strains at 0.05 or 0.10 per cent dilutions applied to the maize coleoptiles showed two fold increase in the elongation of the segments than the control (Elsorra *et al.*, 2004).

B. amyloliquefaciens KPS46 strain @ 10^8cfu mL^{-1} as seed treatment triggered root length, shoot length, biomass and number of lateral roots by more than 40, 20, 30 and 20 per cent, respectively compared to distilled water control (Buensanteai *et al.*, 2008).

Nautiyal *et al.* (2013) demonstrated the beneficial action of the *B. amyloliquefaciens* SN13 treatment in rice seedlings. The root length, shoot length and dry weight of the plants were increased by 3.20 per cent, 15.40 per cent, 11.70 per cent, respectively at 10^{7-8} cfu mL^{-1} under hydroponic conditions. The same treatment under greenhouse conditions showed significantly high shoot length (33.50 per cent), root length (84.50 per cent), and dry weight (156.90 per cent) compared to control plants.

B. amyloliquefaciens subsp. *plantarum* strain UCMB5113 culture extracts @ 20 µL, when applied to *Arabidopsis thaliana* seedlings indicated a significant effect on growth with around 2-fold increase in fresh weight, dry biomass and total root length (Asari *et al.*, 2016).

Gouthamy and Manonmani (2018) observed that tomato seed primed with *B. amyloliquifaciens* VB7 @ 6 per cent improved the speed of germination, germination per cent, seedling root length, shoot length, dry matter production and vigour index.

The seed germination (84.75 per cent), seedling vigor (1423.8), disease resistance against anthracnose disease (71 per cent) and vegetative growth parameters were significantly higher for chilli when seeds were treated with *B. amyloliquefaciens* @ 10^{7-9} cfu mL^{-1} (Gowtham *et al.*, 2018).

2.5.3 Seed priming using *Pseudomonas fluorescens*

Pseudomonas fluorescens belonging to plant growth-promoting rhizobacteria (PGPRs) are a specific group of non pathogenic, obligate aerobic, gram negative, rod-shaped bacterium which secretes a soluble greenish fluorescent pigment called fluorescein (Ganeshan and Kumar, 2005). Various strains of *Pseudomonas* have been reported to enhance the plant growth *via* suppression of plant disease, improved nutrient acquisition or phytohormone production (Keswani *et al*., 2015a).

Hot pepper seeds when primed with *P. fluorescens* (PG01) suspension (2:1.5 by weight) improved germination, plant growth and yield parameters such as root length (4.8 cm), fruit yield (31.6 g), germination percentage (75 per cent), and seedling vigour index (32) than that of control seeds having 3.6 cm root length, 24.8 g fruit yield, 62 per cent seed germination and seedling vigour index of 21 (Kumalasari, 2005).

P. fluorescens @ 10^{7}cfu mL^{-1} primed *Catharanthus roseus* seeds recorded increased plant growth parameters and ajmalicine content of the plant. The highest plant height (50 cm) and root length (39 cm) was recorded at 90 DAP in *C. rosea.* On the other hand, control treatment gave only 36 cm plant height and 24 cm root length (Karthikeyan *et al.,* 2009).

In a study by Rao *et al.* (2009), it was demonstrated that biopriming sun flower seeds with *P. fluorescens* effectively controlled seed-borne infections by *Alternaria helianthi*. *P. fluorescens* treatment significantly promoted yield (15.92 q ha^{-1}) and head diameter (23.50 cm) compared to yield (11.66 q ha^{-1}) and head diameter (13.33 cm) of the untreated control.

The results of the study conducted in tomato by Manikandan, *et al.* (2010) established a significant enhancement on germination (92 per cent), shoot length (6.2 cm), root length (14.11 cm) and seedling vigor index (1868) when seeds were primed with *P. fluorescens* (Pf_1 cultures) @ 10 mL kg^{-1} of seeds and 150 mL ha^{-1} of seedlings or seed treatment and seedling root dip respectively. This was far ahead of the control treatment, which recorded a germination of 72.56 per cent, shoot length (4.51cm), root length (8.23 cm) and seedling vigor index of (993.72).

According to Hosseinzadah *et al*. (2011), inoculation of 1 g pot marigold (*Calendula officinalis* L.*)* seeds with 3 mL *P. fluorescens* 168 (PS) suspension @10^8cfu mL^{-1} for 8 h substantially increased root and shoot dry weight, chlorophyll a and b, carotene, xanthophylls, and the content of N, P, and K in leaves and roots.

Priming of *W. somnifera* seeds with *Pseudomonas* @ 10^9cfu mL^{-1}, showed a significant enhancement in plant height of seedlings and root length. Alkaloid content @ 0.80 mg g^{-1} of root dry weight were obtained in primed seeds, whereas the control treatment had only 0.70 mg g^{-1} of root dry weight (Rajasekar and Elango, 2011).

P. fluorescens strain P-35 @10^{-7c}cfu mL^{-1} have been reported to enhance seed germination rate as well as root and shoot growth in *W.somnifera* (Rathaur *et al.*, 2012).

Priming of *Salvia officinalis* seeds using *P. fluorescens* (PF-23) and *P. putida* @ 10^9cfu mL^{-1} showed a germination of 78.5 per cent against the control which recorded 41.25 per cent germination. The biopriming treatment had also improved the root and shoot length, seedling vigor index and mean germination time when compared to control treatments (Ghorbanpour *et al.*, 2015).

2.5.4 Seed priming using *Bacillus velezensis*

Bacillus velezensis is a gram-positive, endospore producing aerobic bacteria that can be easily cultured, stored, manipulated and utilised in varied industries and in agriculture. The plant growth promoting activity of this bacterium has been established (Rabbee *et al.*, 2019).

Bacillus velezensis strain @ 10^6cfu mL^{-1} applied to roots of potato reduced disease severity by 57 per cent and increased tuber weight by 33 and 26 per cent, respectively under greenhouse and field conditions (Meng *et al.*, 2013).

Nine different plants *viz.*, beet, carrot, cucumber, pepper, potato, radish, squash, tomato, and turnip treated with *B. velezensis* strain BAC03 @ 10^5 cfu cm^3, ten days after planting were able to give positive effects for all plant species for various growth parameters, including plant height, number of flowers, and biomass of plant (Meng *et al.*, 2016).

Meng and Hao (2017) indicated that soaking of radish seeds in *B. velezensis* BAC03 culture @ 10^6 cfu mL^{-1} for 20 min significantly increased the weight of leaves and swollen roots.

Chen *et al.* (2018) inferred that an elevated production of growth hormones and nutrients was obtained by applying *B. velezensis* extract LM2303 in wheat seedlings, which in turn increased its growth parameters. *B. velezensis* Bs006 inoculation at 1×10^7 cfu mL^{-1} resulted in promotion of leaf area (262.70 cm^2) and the shoot dry weight (1.6 g) of cape gooseberry seedlings when compared to control which gave only 136.9 cm^2 leaf area and 0.9 g shoot dry weight (Moreno-Velandia *et al.*, 2018).

B. velezensis LHSB1 @ 10^8cfu mL^{-1} seed priming has been reported to be efficient in plant growth and biocontrol in pot experiments of peanut plants (Chen *et al.*, 2019). The assessment of plant growth, photosynthetic activity and survival under stress conditions, after soaking the wheat grains in *B. velezensis* subsp. *plantarum* UCMB5113 solution (10^7 cfu mL^{-1}) for 2 h showed higher impact when compared untreated plants (El-Daim *et al.*, 2019).

Root length and root fresh weight were significantly enhanced by soaking germinated maize and rice seeds in suspension of *B. velezensis* WRN031 bacterial strain @ 10^{-4} cfu mL^{-1}. The root length of maize was found to increase by 32.20 per cent and root fresh weight by 43.10 per cent over the uninoculated control. A relative increase of root length by 20.70 per cent and root fresh weight by 17.40 per cent was observed in rice plant (Wang *et al.*, 2020).

A considerable increase in the plant height (59.77cm), stem diameter (7.32cm), leaf area (52.49cm^2), pods per plant (8.83), fresh weight (17.16) and dry weight (2.00) of the shoot was recorded for *Sesamum indicum* when applied with 10^5cfu mL^{-1} *B. velezensis* AR1

at two weeks old, against untreated control plants that recorded the plant height (51.45 cm), stem diameter (6.20 cm), leaf area (35.64 cm^2), pods per plant (5.17), fresh weight (11.92g) and dry weight (1.20 g) of the shoot (Bayisa, 2020).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study on "Germination and plant growth responses in Ashwagandha (*Withania somnifera*) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees) to seed pretreatments" was carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during 2018-2020. The aim of this experiment was to standardize pretreatment of seeds for enhanced germination and plant growth in *W. somnifera* and *A. paniculata.*

The details of the materials used and methods adopted for the study are presented in this chapter.

3.1 MATERIALS

3.1.1 PHASE 1 - PRETREATMENT OF THE SEEDS FOR ENHANCED GERMINATION

3.1.1.1 Seed source

The seeds of *W. somnifera* and *A. paniculata* used for the experiment were sourced from Anand Agricultural University, Gujarat.

3.1.1.2 Protrays

50 celled polythene protrays were used for the germination studies.

3.1.1.3 Protray medium

The seed germination studies were done in portrays filled with coirpith compost and FYM in the ratio 1:1.

3.1.1.4 Design of the experiment

The experiment was laid out in Completely Randomized Design (CRD). The treatments were replicated thrice with 50 seeds per replication. The seeds subjected to germination without any pretreatment were kept as control treatment for the study.

3.1.2. PHASE 2 - EVALUATION OF SEEDLINGS FOR PLANT GROWTH

3.1.2.1. Planting material

In the second phase, 30 days old *W. somnifera* and *A. paniculata* seedlings of the first experiment were used.

3.1.2.2 Grow Bags

UV stabilized grow bags of size of 40 cm × 24 cm × 24 cm with 600 gauge thickness and 15 kg capacity were used for raising plants. Each grow bag was filled with 13 kg of the potting medium. Three bags were prepared per replication for each treatment.

3.1.2.3 Potting Mixture

A mixture of soil and dried cow dung powder in the ratio of 2:1 was used as the potting medium for the phase 2 experiment.

3.1.2.4 Design of the experiment

Experiments were laid out in Completely Randomized Design (CRD). Ten seedlings each (from the phase 1 experiment) in three replicates were planted in growbags and evaluated for plant growth and yield.

3.2 METHODS USED IN THE STUDY

3.2.1 TREATMENT DETAILS

Seeds were subjected to various pretreatments *viz.*, physical treatments, hormonal priming, biostimulant priming and biopriming (using microbes) to study their effect on seed germination (phase 1 study) and subsequently on plant growth, after transplanting at 30 DAS (phase 2 study).

3.2.1.1 Physical treatments

Seeds were subjected to various physical treatments such as scarification, water soaking, hot water treatment and concentrated H_2SO_4 treatment. The details of the treatments are depicted in Table 1.

Table 1: Physical treatments

Treatment	Physical pretreatments
T_1	Scarification (Using sand paper)
T_2	Water soaking (Overnight)
T_3	Hot water treatment (65^{o}C for 10 min)
T_4	Concentrated sulphuric acid (1 min)
T_5	Control

3.2.1.2 Hormonal priming

Seeds were pretreated with two levels of various hormones *viz*., GA_3, BA, IAA and TDZ for 24 h. The details of hormonal priming are presented in Table 2.

Table 2: Hormonal priming

Treatments	Hormones
T_1	GA_3 @ 1500 µM
T_2	GA_3 @ 3000 µM
T_3	IAA @ 0.1 µM
T_4	IAA @ 1 µM
T_5	BA @ 100 µM
T_6	BA @ 300 µM
T_7	TDZ @ 200 µM
T_8	TDZ @ 400 µM
T_9	Control

3.2.1.3 Biostimulant priming

Seeds were pretreated for 3 h with two levels of various biostimulants *viz.,* chitosan, salicylic acid and phloroglucinol. The details of the biostimulant priming are given in Table 3.

Table 3: Biostimulant priming

Treatments	Biostimulants
T_1	Chitosan @ $5gL^{-1}$
T_2	Chitosan @ 10 gL^{-1}
T_3	Salicylic acid @ 1500 µM
T_4	Salicylic acid @ 3000 µM
T_5	Phloroglucinol @ 1 µM
T_6	Phloroglucinol @ 10 µM
T_7	Control

3.2.1.4 Biopriming

Seeds were primed with bacterial cultures of *Bacillus* spp and *Pseudomonas fluorescens.* The bacterial cultures for biopriming were procured from the Department of Agricultural Microbiology, College of Agriculture, Vellayani, Thiruvananthapuram. The cultures of *Bacillus* spp were heavily cross streaked on nutrient agar medium and *Pseudomonas fluorescens* on Kings medium B. After 48 h of incubation at 28^{o}C, the plates were drenched with 10 mL of sterile water to get a suspension of bacterial isolates. The OD values of the suspension cultures at 600 nm measured in spectrophotometer was made to 0.5 by adding sterile water as required to maintain the suspension @ 10^8 cfu mL^{-1}. Seeds were immersed for 24 h in the cell suspension of the following bacteria, after which the seeds were sown in protrays with potting mixture composed of coirpith compost and FYM in the ratio of 1:1 for germination. The microbial isolates used for biopriming of seeds are given in Table 4.

Table 4: Biopriming

Treatments	Organisms
T_1	*Bacillus pumilus*VLY17@ 10^8 cfu mL^{-1}

T_2	*Bacillus amyloliquefaciens*VLY24@ 10^8 cfu mL^{-1}
T_3	*Pseudomonas fluorescens*PN026@ 10^8 cfu mL^{-1}
T_4	*Bacillus velezensis*PCSE10@ 10^8 cfu mL^{-1}
T_5	Control

3.2.2 PHASE 1 - PRETREATMENT OF THE SEEDS FOR ENHANCED GERMINATION

The seeds of *A. paniculata* and *W. somnifera* were exposed to seed priming agents of various pretreatment experiments for specified periods and sown immediately in the protrays. While in case of concentrated sulphuric acid treatment, seeds after the exposure for 1 min, were washed in distilled water and allowed to air dry at room temperature, prior to sowing. Fifty seeds from each pretreatment were sown in 3 numbers of 50 cell protrays (three replicates). A small depression (0.5 cm) was made with fingertip in the centre of the cell of the protray for sowing. The seeds were sown at the rate of one seed per cell and lightly covered with soil. The trays were irrigated lightly every day using a fine sprinkling rose can.

3.2.2.1 OBSERVATIONS ON SEED GERMINATION AND SEEDLING PARAMETERS

3.2.2.1.1 Germination per cent

Germination percentage is an estimate of the viability of seed population. Pretreated seeds were sown in a 50 celled portray at the rate of one seed per cell for germination. Germination per cent was calculated by using the following equation.

$$\text{Germination per cent} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown for germination}} \times 100$$

3.2.2.1.2 Survival per cent

The count of total seedlings that survived in relation to the total number of seeds sown was recorded daily from first day of germination to final day of the phase 1 experiment. The formula for calculating survival per cent is as given below.

Survival per cent = Number of surviving plants at end of the study x 100

Number of seeds sown

3.2.2.1.3 Germination index

Germination index was calculated as described in the association of official seed analysis (AOSA, 1983) by the following equation.

Germination index = No. of germinating seeds + …. + No. of germinating seeds

Days of first count Days of final count

3.2.2.1.4 Mean germination time

Mean time to germination (MGT) is a measure of the rate and time spread of germination. The following formula was used to compute the MGT (Bewley and Black, 1994).

Mean germination time (MGT) = $\Sigma(ti*ni)/\Sigma ni$

Whereas, ti - Number of days starting from the date of sowing

ni - Number of seeds germinated at each day

3.2.2.1.5 Seedling shoot length

Three seedlings were tagged from each replication. Using a ruler the height of the longest tiller was measured from the base of the plant to the top of the fully opened terminal leaf. The mean value was recorded and expressed in centimetres (cm).

3.2.2.1.6 Seedling root length

After uprooting the three tagged plants root length was estimated from the base of the plant to tip of primary roots. The length of longest root was measured using a measuring tape and the mean length was calculated and expressed in centimetres (cm).

3.2.2.1.7 Seedling length

The seedling length was estimated from the tip of the primary roots to the tip of the youngest fully opened leaf using a measuring tape and mean length was calculated and expressed in centimeters (cm).

3.2.2.1.8 Allometric index

The allometric index was calculated based on shoot length and root length of the seedlings, using the following formula

$$\text{Allometric Index} = \frac{\text{Root length}}{\text{Shoot length}}$$

3.2.2.1.9 Seed vigor index

Seedling vigour index is defined as the sum total of those properties of the seed which determine the level of activity and performance of the seed or seed lot during germination and seedling emergence.

The seed vigor index was calculated by using the following formula as suggested by Hossain *et al*. (2014).

Seed vigor index = Germination per cent × Seedling length

3.2.3 PHASE 2 - EVALUATION OF SEEDLINGS FOR PLANT GROWTH

The thirty day old seedlings of *W. somnifera* and *A. paniculata* from all the treatments of the phase 1 experiment were transplanted in grow bags at a depth of 5-6 cm. Organic manures such as cow dung slurry and vermicompost were applied uniformly to all the plants both at 45 and 60 days after transplanting for *A. paniculata* and at 45 and 90 days after sowing for *W. somnifera*. The plants were irrigated daily upto one MAP. Further irrigation was limited to alternate days. Hand weeding was done in grow bags whenever weeds were noticed. *A. paniculata* were harvested when the plants were in bloom (110 days). The maturity of Ashwagandha is judged when leaves start drying and berries become orange red (120 days) in colour. Harvesting was done by uprooting the whole plant without damaging the roots.

3.2.3.1 Observations on plant growth

Three plants per replication of each treatment were tagged as observational-plants.

3.2.3.1.1 Morphological parameters

The observations on plant height, number of branches, collar girth and no of flowers were taken at 30 DAS (at transplanting), 60 DAS, 90 DAS and at harvest.

3.2.3.1.1.1 Plant height

Plant height was measured with a measuring tape from the base of the plant to the top of the young fully opened leaf. The mean value was calculated and expressed in centimetres (cm).

3.2.3.1.1.2 Number of branches

The total number of branches arising from the main stem of the selected plants were counted and the mean number was recorded.

3.2.3.1.1.3 Collar girth

The girth of the stem was recorded by measuring the circumference at the collar region using a thread and scale. The mean value was calculated and expressed in centimetres (cm).

3.2.3.1.1.4 Number of flowers

The number of fully opened flowers from the tagged sample plants was counted and the total number of flowers per plant was recorded and mean value estimated.

3.2.3.1.2 Phenological parameters

3.2.3.1.2.1 Days to flowering

The days to flower initiation was recorded by counting the number of days taken from sowing to the initiation of the first flower in the tagged plant.

3.2.3.1.2 .2 Days to fruit set

The days to fruit set were recorded by counting the number of days taken from the initiation of the flower to fruit set in the tagged plant.

3.2.3.1.3 Yield and yield components

The observations on shoot weight (fresh and dry), number of fruits per plant, fruit weight per plant (fresh and dry), seed yield per plant, thousand (1000) seed weight, root length, root diameter, root volume, root yield (fresh and dry) and harvest index were recorded at harvest (120 DAS).

3.2.3.1.3.1 Shoot weight

The above ground part of the selected observational plant was separated from the root portion and weighed to record the fresh weight. It was then dried in hot air oven at 70°C till a constant weight was obtained. It was then weight again to record the dry weight. The shoot weight was expressed in g plant^{-1}.

3.2.3.1.3.2 Root weight

The roots were separated out from the selected observational plants and weighed to record the fresh weight. The root sample was then oven dried at 70ºC till a constant weight was obtained and weighed to record the dry weight. The root yield was expressed in g plant^{-1}.

3.2.3.1.3.3 Whole plant weight

A. paniculata is being used on a whole plant basis in pharmaceutical industry. Hence, the whole plant weight was estimated in case of *A. paniculata*, by taking the sum of both root and shoot weight of the observational plants and expressed in g plant^{-1}.

3.2.3.1.3.11 Harvest Index

Harvest Index was calculated at harvest as the ratio of economic yield to the biological yield. Harvest index is estimated when economic yield forms a portion of the biological yield. In *A. paniculata*, the whole plant forms the economic yield, hence, harvest index was not determined. In case of *W. somnifera*, leaves and roots have medicinal uses and hence the leaf yield and root yield root, accounts for the economic yield. Hence, harvest index is calculated on the basis of leaf yield and root yield.

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

Where,

Economic yield –dry weight of the shoot/roots

Biological yield –dry weight of the whole plant

3.2.3.1.3.7 Root length

The plants were carefully uprooted without damaging the roots. The length of the longest roots was measured and the mean length was estimated and expressed: in centimetres (cm).

3.2.3.1.3.8 Root diameter

The diameter of the root was recorded by measuring the circumference of the proximal end of the root using a micrometer screw gauge. The mean value was recorded and expressed in cm.

3.2.3.1.3.9 Root volume

The root volume was calculated using the water-displacement method. The roots of sample plants were washed free of soil and submerged into a 10 ml graduated cylinder filled with 5 ml of water. The volumes of the water before and after submerging the roots into the cylinder were observed. The volume of roots was calculated using the following equation.

Root volume = V_1-V_2

V_1= volume of the water after submerging the roots into the cylinder

V_2= volume of the water before submerging the roots

3.2.3.1.3.3 Number of fruits per plant

The number of fully matured fruits from the sample plants was counted and the total number of fruits per plant was recorded to estimate the mean value.

3.2.3.1.3.4 Fruit weight per plant

Mature fruits were separated from the plants and weighed to record the fresh weight. The fruit samples were the dried in hot air oven at 70°C till constant weight was obtained and weighed to record dry weight. The fruit weight was expressed in g plant^{-1}.

3.2.3.1.3.5 Seed yield per plant

The matured fruits were harvested and split open transversely to obtain the seeds from each pod in case of *A. paniculata*. In case of W. somnifera, seeds were extracted from the dried fruits (berries). The seeds were dried in hot air oven at 70°C till constant weight was obtained and the weight of seeds obtained from each plant was recorded and expressed in g plant^{-1}.

3.2.3.1.3.6 Thousand (1000) seed weight

The weight of 1000 seeds (dried in hot air oven at 70°C) were recorded and expressed in grams.

3.2.4 Incidence of pest and diseases

Pest and disease incidence during the experiment was observed visually and noted in each treatment.

3.2.5 Statistical analysis

The experiments in the study were laid out in completely randomized design. The data generated from the experiments were subjected to analysis of variance (ANOVA).

RESULTS

4. RESULTS

The study entitled "Germination and plant growth responses in Ashwagandha (*Withania somnifera* (L.) Dunal) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees) to seed pretreatments" was carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during 2018-2020. The data collected from the experiment were statistically analysed and the results are presented in this chapter.

4.1 *W. SOMNIFERA*

4.1.1 PHASE 1: SEED PRETREATMENTS FOR ENHANCED GERMINATION IN *WITHANIA SOMNIFERA*

The different seed pretreatments *viz*., physical, hormonal, biostimulant and biopriming were carried out in *W.somnifera* for evaluating the seed performance and subsequent seedling growth parameters. The observations on germination parameters *viz*., germination per cent, survival per cent, germination index, mean germination time and seedling parameters (shoot length, root length, seedling length, allometric index and seedling vigor index) were recorded. The seedling parameters were recorded 30 DAS.

4.1.1.1 Effect of physical pretreatment of seeds on germination and seedling parameters in *W.somnifera*

The effect of physical treatments on various seed germination and seedling parameters upto 30 days after sowing are presented in Table 5.

4.1.1.1.1 Germination per cent

The germination per cent showed significant variation among the physical treatments tried. Water soaking treatment (T_2) recorded the highest germination of 84.00 per cent, which was on par with hot water treatment (T_3). The concentrated sulphuric acid (T_4) recorded the lowest germination of 46.00 per cent which was on par with control treatment (T_5).

4.1.1.1.2 Survival per cent

There was significant variation in survival per cent among the treatments. The highest value (83.67per cent) of survival was noticed in water soaking treatment (T_2) and was found on par with T_3. Treatment T_4 recorded the least value (42.67per cent) and it was on parwith T_1 and T_5.

4.1.1.1.3 Germination index (GI)

The GI showed significant variations among the physical treatments tried. The maximum GI was recorded in T_2 (4.87), which was statistically on par with T_3. The T_4 plants recorded the lowest GI (2.20) and was found on par with T_1 and T_5.

4.1.1.1.4 Mean germination time (MGT) (Days)

The data presented in Table 5 indicated the effect of different physical treatments on MGT of the *W. somnifera* seeds. The data showed that no significant variation existed with respect to MGT among the treatments tried.

4.1.1.1.5 Seedling shoot length

The shoot length of the seedlings showed significant variation among the treatments tried. The seeds subjected to hot water treatment (T_3) recorded highest value (9.67cm) and was observed to be on par with T_1 and T_2. The lowest seedling shoot length (4.70 cm) was observed in control treatment (T_4).

4.1.1.1.6 Seedling root length

The seedling root length varied significantly in *W. somnifera* among the different physical seed pretreatments. *W. somnifera* seeds subjected to concentrated sulphuric acid (T_4) produced higher root length (5.20cm) which was on par with T_2 and T_3. Seeds exposed to control treatment (T_5) recorded the lowest mean value of 1.87cm which was found to be on par with T_1.

4.1.1.1.7 Allometric index

No significant variation was observed among the physical seed pretreatments on the basis of allometric index.

4.1.1.1.8 Seedling length

There was a significant difference in seedling length observed among the treatments. Hot water treatment (T_3) showed maximum seedling length (14.40 cm) which was found to be on par with T_1, T_2 and T_4. The least seedling length (6.57cm) was recorded in the control treatment (T_5) and was on par with T_1.

4.1.1.1.9 Seedling vigor index

Among the various physical seed pretreatments, significant variation was observed in seedling vigor index. Water soaking treatment (T_2) produced maximum seedling vigor index (11.16) and was on par with T_3. The lowest value of seedling vigor index (3.36) were obtained with control treatment (T_5) which was found to be on par with T_1 and T_4.

4.1.1.2 Effect of hormonal priming of seeds on germination and seedling parameters in *W.somnifera*

The effect of hormonal priming treatments on various seed germination, and seedling parameters upto 30 days after sowing are presented in Table 6.

4.1.1.2.1 Germination per cent

Germination per cent showed significant variation, among the various hormonal treatments tried. The highest germination (82.00per cent) was recorded in the treatment with GA_3 @ 1500µM (T_1) which was on par with GA_3 @3000µM (T_2). The lowest germination (51.33per cent) was obtained in the control treatment (T_9) which was on par with all other treatments except T_1, T_2, T_9 and T_5. Seed priming with IAA @ 0.1 and 1 µM, BA @ 300 µM and TDZ @ 200 and 400 µM were found to inhibit germination and the germination per cent was on par with that of control treatment.

4.1.1.2.2 Survival per cent

The various hormonal priming treatments showed a significant difference in survival per cent. Among the hormonal treatments, GA3 @ 1500 µM (T_1) recorded maximum survival per cent (82.00per cent) and was found to be on par with T_2 (79.00 per cent). Minimum value (50.67per cent) for was recorded in the control treatment (T_5) and was on par with T_3, T_4, T_6 and T_8

4.1.1.2.3 Germination index (GI)

The data illustrated in Table 6, demonstrated that no significant variation existed among the hormonal seed priming treatments with respect to GI.

4.1.1.2.4 Mean germination time (MGT)

Significant difference was observed among the hormonal priming treatments for MGT. The seeds primed with BA @ 100µM (T_5) recorded the lowest (7.00days) and untreated seeds recorded the highest (10.67days) values for MGT. The MGT was found to be lower in all the hormonal priming except the control treatment (T_9). It can be inferred that hormonal priming of seeds shortened the MGT.

4.1.1.2.5 Seedling shoot length

The data described significant enhancement in shoot length of seedlings. GA_3 @ 1500µM (T_1) recorded maximum shoot length (9.50cm) and was comparable with T_2, T_3 and T_5. The least seedling shoot length (4.70 cm) was recorded in the control treatment (T_9).

4.1.1.2.6 Seedling root length

The data pertaining to the effect of hormonal treatments on root length of *A.paniculata* seedlings indicated that significant variation existed with respect to root length among the treatments tried. GA_3 @1500µM (T_1) gave maximum value (4.90cm). This was observed to be on par with all other treatments except T_5, T_7 and T_9. The least seedling vigor index (1.87cm) was recorded in control treatment (T_9), which was on par with all other treatments except T_1 and T_8.

4.1.1.2.9 Allometric index

The data in Table 6 indicated that hormonal seed pretreatments had no influence on allometric index.

4.1.1.2.7 Seedling length

The data in Table 6 revealed hormonal seed priming treatments had significant effect on seedling length. GA_3 @1500 µM (T_1) showed maximum seedling length (14.40 cm) was on par with T_2 and T_5. The control treatment (T_9) recorded the lowest value (6.57cm).

4.1.1.2.8 Seedling vigor index

The seed pretreatments varied significantly with respect to seedling vigour index. GA_3 @1500µM (T_1) recorded significantly higher seedling vigor index (11.80) and was on par with that of T_2. The control treatment registered 3.36 seedling vigour index, which was the lowest and was on par with T_4.

4.1.1.3 Effect of biostimulant seed priming on germination and seedling parameters in *W.somnifera*

The effect of biostimulant priming treatments on various seed germination and seedling parameters upto 30 days after sowing are presented in Table 7.

4.1.1.3.1 Germination per cent

The germination per cent of seeds differed significantly due to biostimulant treatments. The highest germination (64.00 per cent) was recorded in the treatment with PG @10µM (T_6) comparable with T_5 and the control (T_7). The lowest germination (32.67per cent) was observed in the treatments T_1 and T_2 that was on par with T_3 and T_4.

4.1.1.3.2 Survival per cent

The survival per cent differed significantly due to biostimulant seed priming treatments. The highest survival (64.00 per cent) was recorded in the treatment with PG

@10µM (T_6) comparable with T_5 and the control (T_7). The lowest germination (32.33 per cent) was observed in the treatments T_1 and was on par with T_2, T_3 and T_4.

4.1.1.3.3 Germination index (GI)

The influence of various biostimulant treatments on GI is illustrated in Table 7. No significant difference was noticed in germination index among the treatments.

4.1.1.3.4 Mean germination time (MGT)

During germination, plants treated with PG @ 1µM (T_5) and (T_6) recorded significantly lower MGT (6.67days) which was observed to be on par SA @ 3000 µM (T_4). The MGT was found to be the highest (10.67days) in the control treatment (T_7), which was found to be on par with T_1, T_2 and T_3.

4.1.1.3.5 Seedling shoot length

The response of *W. somnifera* seedlings to different biostimulant treatments with respect to shoot length were analysed and the results are presented in Table 7. The treatment PG @ 1µM (T_5) was found to be significantly superior (7.80 cm) in shoot length, and was on par with all except T_7. The lowest value (6.83cm) was registered in the control treatment (T_7).

4.1.1.3.6 Seedling root length

Table 7 represents the data on seedling root length of *W. somnifera*, in response to different biostimulant treatments. No significant difference in seedling root length was observed among the treatments.

4.1.1.3.7 Allometric index

The data on allometric index recorded showed no significant difference among the biostimulant seed priming treatments.

4.1.1.3.8 Seedling length

There was significant difference in seedling length among the various biostimulant seed priming treatments. Seedlings obtained from SA @ 1500µM primed seeds (T_3) recorded the highest seedling length (10.63cm), while the control recorded the lowest value (6.57cm).

4.1.1.3.9 Seedling vigor index

Significant difference existed in the seedling vigor index, among the treatments. The highest seedling vigor index exhibited by PG@10µM (T_6) with a mean value of 6.67cm and was on par with T_5. The treatment, CH @10 gL^{-1} (T_2) recorded the lowest value (3.27cm) among the treatments and was on par with all treatments, except T_5 and T_6.

4.1.1.4 Effect of biopriming of seeds on germination and seedling parameters in *W.somnifera*

The effect of biopriming treatments on various seed germination and seedling parameters upto 30 days after sowing are presented in Table 8.

4.1.1.4.1 Germination per cent

There was no significant difference in the germination on biopriming the seeds with microbes.

4.1.1.4.2 Survival per cent

Survival per cent showed no significant variation among the various treatments biopriming treatments tried.

4.1.1.4.3 Germination index (GI)

The data presented in Table 8 demonstrated that biopriming treatments had no significant effect on GI.

4.1.1.4.4 Mean germination time (MGT)

The MGT did not show any significantly variation among the biopriming treatments tried.

4.1.1.4.5 Seedling shoot length

Significant variation was observed in shoot length among the biopriming treatments. Seedlings generated from the seeds primed with *P. fluorescens* (T_4) held the highest shoot length of 8.10 cm. The lowest shoot length (4.70 cm) was observed in the control treatment.

4.1.1.4.6 Seedling root length

There was no significant difference in seedling root length, among the biopriming treatments.

4.1.1.4.7 Allometric index

The data on allometric index given in Table T_8 indicated that there was no significant difference among the treatments.

4.1.1.4.8 Seedling length

The data on seedling length given in Table T_8 indicated that there was no significant difference among the treatments.

4.1.1.4.8 Seedling vigor index

Biopriming treatments of seeds showed significant variation with respect to seedling vigor index. B. *pumilus* (T_1) gave the highest value (6.90) of seedling vigor index which was on par with all the treatments except the control treatment (T_5). The least seedling vigor index was noticed in T_5 (3.36), which was on par with T_2 and T_3.

4.1.1.5 Effect of various seed pretreatments on germination and seedling parameters in *W. somnifera*

The effect of various seed pretreatments on germination and seedling parameters upto 30 days after sowing are presented in Table 9.

4.1.1.5.1 Germination per cent

Significant difference was observed in germination per cent to various seed pretreatments in *W. sominfera*. The seeds subjected to water soaking (T_2) recorded significantly higher value (84.00 per cent) among the treatments. This was on par with T_3, T_5

and T_6. The lowest germination per cent (32.67per cent) was noticed in chitosan @5g L^{-1} (T_{13}) and CH @10 gL^{-1} (T_{14}) treatments and this was found to be on par with T_{15} and T_{16}.

4.1.1.5.2 Survival per cent

The survival per cent of the seedlings differed significantly due to various seed priming treatments. T_2 recorded the highest value (83.67 per cent) of survival which was on par with T_3, T_5 and T_6. T_{13} recorded the least value (32.33per cent) which was found to be par with T_4, T_9, T_{14}, T_{15} and T_{16}.

4.1.1.5.3 Germination index (GI)

A significant variation was observed in germination index among the seed pretreatments. The highest value (4.87) was recorded in water soaking treatment (T_2) and GA_3 @1500 µM (T_5) which was on par with T_6, T_9, T_{17} and T_{18}. The lowest GI (1.80) was registered in the treatment, CH @10 gL^{-1} (T_{14}), which was comparable with T_4, T_{13}, T_{15}, T_{16} and T_{23}.

4.1.1.5.4 Mean germination time (MGT)

Significant difference existed in the MGT, among the treatments. During germination, treatments, PG @ 1 µM (T_{17}) and PG @ 10 µM (T_{18}) recorded minimum mean value (6.67days) for MGT. Treatment T_4 recorded the maximum value (11.00days) which were on par with T_1, T_3 and T_{23}.

4.1.1.5.5 Seedling shoot length

The maximum shoot length (9.67cm) was obtained in the treatment with hot water (T_3), which was on par with T_2, T_5 and T_6. T_{23} recorded the lowest seedling shoot length with 4.70 cm.

4.1.1.5.6 Seedling root length

Significant difference was observed in seedling root length among the various treatments tried. Maximum root length was observed in T_4 (5.20 cm) and was on par with T_2, T_3, T_5 and T_{12}. The least value was noticed in T_{23} (1.87cm) which was on par with treatments T_7, T_9, T_{11}, T_{13}, T_{15}, T_{16}, T_{17} and T_{18}.

4.1.1.5.7 Allometric index

There was no significant difference in allometric index among: the various seed pretreatments tried.

4.1.1.5.8 Seedling length

There was significant difference in seedling length among: the various seed pretreatments. Seedlings obtained from Hot water treated seeds (T_3) and GA_3 @1500µM primed seeds (T_5) recorded the highest seedling length (14.40 cm) which was statistically on par with T_2 and T_6. The control treatment (T_{23}) recorded the lowest seedling length with 6.57cm.

4.1.1.5.9 Seedling vigor index

The data represented significant enhancement in seedling vigor index, with GA_3 @1500µM (T_5) giving maximum value (11.80). This was observed to be on par with T_2 (11.16cm) and T_3 (11.00cm). The least seedling vigor index (3.27) was recorded in treatment, CH@10gL^{-1} (T_{14}) which was on par with $T_{13,}$ T_{15}, T_{16} and T_{23}.

4.1.2 PHASE 2: EVALUATION OF TRANSPLANTED SEEDLINGS FOR ENHANCED PLANT GROWTH IN *W.SOMNIFERA.*

4.1.2.1. Morphological Parameters

The effect various seed pretreatments on morphological parameters *viz.*, plant height, number of branches per plant, collar girth and number of flowers per plant were recorded at various stages of growth (30, 60, 90 DAS and at harvest (120 DAS) of the *W.somnifera* plants

4.1.2.1.1 Effect of Physical Seed Treatments on Morphological Parameters in Transplanted *W.somnifera.*

4.1.2.1.1.1 Plant height (cm)

The effect of different seed treatments on plant height of *W.somnifera*, at various growth periods are presented in Table 10. At 30 DAS, a significant variation was observed among the various physical treatments. Hot water treatment (T_3) recorded the highest plant height (9.67cm) and was on par with all treatments except T_4 and T_5. The control treatment (T_4) recorded the lowest height (4.70cm).

At 60 DAS, the plant height showed significant variation among the treatments. Water soaking treatment (T_2) recorded a plant height of 16.57 cm, which was observed to be on par with T_1 and T_3 treatments. The control treatment (T_5) recorded the lowest plant height of 6.03 cm which was on par with that recorded in the concentrated sulphuric acid treatment (T_4) with 8.167cm plant height.

At 90 DAS, scarification treatment (T_2) recorded the maximum plant height of 19.27 cm, which was on par with T_3. The lowest plant height (13.00) was observed in control treatment, which was on par with T_5.

The plant height differed significantly due to physical seed treatments at harvest stage also. At harvest, the highest plant height (60.80 cm) was recorded in the water soaking treatment (T_2) which was on par with hot water treatment (T_3). The lowest plant height (33.07 cm) was observed in the concentrated sulphuric acid treatment (T_4) which was found to be on par with control treatment (T_5).

4.1.2.1.1.2 *Number of branches per plant*

Table 10 represents the effect of different physical seed treatments on number of branches of the *W.somnifera* plants at different periods of observation. No branches were formed from the main shoots at 30 DAS. Significant variation was not observed in number of branches at 60 DAS and 90 DAS stages of observations. But the number of branches showed significant variation at harvest.

At harvest, T_2 recorded the highest number of branches (5.00) which was statistically on par with T_3 (21.67). The control plants recorded the lowest number of branches with a mean value of 1.67 and was on par with T_1, T_3 and T_4.

4.1.2.1.1.3 *Collar girth (cm)*

The data on the influence of different physical seed pretreatments on collar girth in *W.somnifera*, at different growth periods is depicted in Table 11. Collar girth showed significant variation among the treatments tried at harvest. At 30, 60 and 90 DAS, no significant variation was observed in collar girth among the physical treatments.

At harvest, T_3 and T_5 recorded significantly superior value (0.50 cm) for collar girth. This was on par with T_2 (0.47cm). The lowest collar girth (0.23) was observed in T_4, which was on par with T_1.

4.1.2.1.1.4 *Number of flowers per plant*

The data pertaining to the effect of physical treatments on number of flowers of *W.somnifera* at different growth periods is presented in Table 11. There was no flowering at 30, 60 and 90 DAS. At harvest, the number of flowers (27.33) was significantly higher in plants generated from seeds subjected to scarification treatment (T_1) at harvest. The lowest number of flowers was recorded in T_4 and T_5 (3.00), which was on par with T_3.

4.1.2.1.2 Effect of Hormonal Seed Priming on Morphological Parameters in Transplanted *W.somnifera.*

4.1.2.1.2.1 *Plant height (cm)*

The plant height of *W.somnifera* at various growth stages as influenced by hormonal treatments are presented in Table 12. There was significant difference in plant height among the hormonal priming treatments at all the stages of observations.

At 30 DAS, there was significant increase in the plant height (9.50 cm) in treatment GA_3 @ 1500µM (T_1) compared to other treatments and was on par with T_2, T_3, and T_5. The lowest value was recorded in T_4 (4.70 cm).

At 60 DAS, maximum plant height was recorded in T_1 (16.27cm). The control plants recorded the lowest plant height (6.03 cm).

At 90 DAS, T_1 recorded the highest plant height (20.70 cm). The least value (13.00 cm) was observed in control treatment (T9).

At harvest, the plants from seeds treated with GA_3 @ 1500µM (T_1) recorded significantly higher value (55.57 cm) among the treatments. This was on par with treatments (T_2) and (T_5). The lowest plant height (33.53cm) was noticed in T_4 which was on par with T_3, T_6, T_7, T_8 and T_9.

4.1.2.1.2.2 ***Number of branches per plant***

The data on the influence of different hormonal seed priming treatments on number of branches of *W.somnifera* at different growth periods is presented in Table 12.

No branches were formed from the main stem at 30 DAS. At all other stages of observation except harvest, there was no significant difference in number of branches among the hormonal treatments tried.

At harvest, GA_3 @ 3000µM (T_2) produced maximum number of branches (3.67). The lowest value (1.67) was obtained in control treatment (T_9). This was found to be on par with the treatments T_3 and T_4.

4.1.2.1.2.3 ***Collar girth (cm)***

The results on the effect of different hormonal treatments on collar girth in *W.somnifera* at different growth periods are illustrated in Table 13. The data described no significant enhancement in collar girth at all stages of observation.

4.1.2.1.2.4 ***Number of flowers per plant***

Table 13 represents the data on number of flowers of *W.somnifera* in response to different hormonal treatments, at various growth stages. At 30, 60 and 90 DAS, there was no flowering in the plants.

At harvest, T_1 recorded the highest number of flowers (13.33) at harvest, which was found on par with T_2 and T_4. The least number of flowers was noticed in T_5, T_7 and T_9 (3.00) which was on par with T_3, T_6 and T_8.

4.1.2.1.3 Effect of Biostimulant Seed Priming on Morphological Parameters in Transplanted *W.somnifera*

4.1.2.1.3.1 *Plant height (cm)*

The influence of various biostimulant seed priming treatments on plant height of *W.somnifera* is illustrated in Table 14. At 30, 60, 90 DAS and at harvest significant: difference in plant height was observed among the treatments.

At 30 DAS, control treatment (T_7) showed maximum plant height (8.03 cm) and the least plant height (4.70 cm) was recorded in control treatment. The highest value treatment was observed to be on par with all the other treatments tried except T_7.

At 60 DAS, PG @ 10µM (T_6) recorded maximum plant height (11.30 cm) followed by those treated with T_5 (11.17cm), which were also on par with each other. The lowest plant height (6.03 cm) among the treatments was observed in control plants (T7) which was on par with T_2 and T_4.

At 90 DAS, the highest value (17.40 cm) was recorded in T_6. T_1 registered minimum value (9.67 cm) for plant height.

At harvest also, the highest value (46.37cm) was recorded in T_6 and was on par with T_5. T_1 recorded the least value (27.27 cm) for plant height, which was observed to be on par with T_4.

4.1.2.1.3.2 *Number of branches per plant*

The results of the effect of biostimulant seed priming on number of branches of *W.somnifera* plants at different growth periods are presented in Table 14. Among the various pretreatments, no significant variation was observed in number of branches at 60 and 90 DAS stages of growth. No branching was observed at 30 DAS. At harvest, plants showed a significant variation in number of branches.

At harvest, plants from the treatment, PG @ 1µM (T_5) recorded significantly superior number of branches (4.67). The number of branches was found to be the lowest in T_7 (1.67) which was observed to be on par with treatments T_1 and T_6.

4.1.2.1.3.3. Collar girth (cm)

The response of collar girth of *W.somnifera* to different biostimulant seed priming treatments recorded at various stages of plant growth is presented in Table 15. At 30 DAS, no significant difference was given in collar girth among the treatments.

At 60 DAS, T_5 and T_6 recorded same maximum value (0.2 cm) of collar girth. (0.73 cm). All other treatments except T_5, T_6 and T_3 recorded the lowest collar girth (0.09 cm).

At 90 DAS all treatments except T_1 recorded the highest collar girth (0.2cm) and lowest collar girth was observed in T_1. were the same for all the treatments. The control treatment (T_7) held the highest collar girth of 0.50 cm. The lowest collar girth (0.20cm) was observed in T_1, T_5 and T_6 which was on par with all treatment T_2.

4.1.2.1.3.4 *Number of flowers per plant*

The results of number of flowers per plant of *W.somnifera* at 30, 60, 90 DAS and at harvest, due to different biostimulant treatments, are depicted in table 15. There was no flowering at 30, 60 and 90 DAS. A significant difference was noticed in number of flowers per plant at harvest. Plants from CH @ $5gL^{-1}$ treated seeds registered the highest value (30.00) for number of flowers. The lowest value was observed inT_5 and T_7 (3.00) which was on par with T_4.

4.1.2.1.4 Effect of Seed Biopriming on Morphological Parameters in Transplanted *W.somnifera*

4.1.2.1.4.1 *Plant height (cm)*

The result on the effect: of various biopriming treatments on plant height of *W.somnifera* is shown in Table 16. From the table it is: clear that the biopriming treatments given to seeds had significant effect on plant height at all stages of observation.

At 30 DAS, T_4 showed maximum plant height (8.10cm) which was on par with the all other treatments except the control treatment (T_5) which recorded the lowest plant height (4.70 cm). T_5 was on par with the all other treatments except the T_4. At 60 DAS, T_4 recorded the highest plant height (12.27cm) and observed to be on par with T_1. T_5 recorded the lowest plant height (6.03cm). At 90 DAS and at harvest, T_1 exhibited the higher plant height of 17.93and 47.63 cm, respectively. T_1 was on par with T_2 and T_4. At 90 DAS and at harvest, the lowest plant height (13.00 and 35.07cm respectively) was recorded in T_5, which were observed to be on par with all treatments except T_2 and T_3.

4.1.2.1.4.2 ***Number of branches per plant***

The data presented in Table 16 showed the results of number of branches in *W.somnifera* plants at 30 ,60 ,90 DAS and at harvest. At 30 DAS, the plant did not produce any branches. The seed treatments with microbial cultures showed no significant variation in number of branches at 60 and 90 DAS stages of observation. At harvest, the plants from the seeds primed with *Bacillus amyloliquefaciens* (T_2) recorded significantly higher number of branches (3.67) which was on par to treatments T_1 and T_3, while the control treatment (T_5) recorded the lowest (1.67) value which was on par with T_4.

4.1.2.1.4.3 ***Collar girth(cm)***

The collar girth of *W.somnifera* in response to various biopriming treatments at 30, 60, 90 DAS and at harvest are presented in Table 17. Significant variation was observed in collar girth among the various treatments at all stages of observation except 30 DAS.

At 60 DAS, the maximum collar girth (0.20cm) was obtained in T_1 and was observed on par with T_4. The control treatment (T_5), T_2 and T_3 recorded the lowest value with 0.09 cm collar girth. At 90 DAS and at harvest, plants from T_1 produced higher collar girth 0.20 cm. The treatments T_2 and T_3 recorded the lowest mean value of 0.10 cm which was found to be on par with control treatment (T_5).

4.1.2.1.4.4 ***Number of flowers per plant***

Table 17 represents the number of flowers per plants in response to various biopriming treatments in *W.somnifera*. At 30, 60 and 90 DAS, no flowers were formed in the

plant. However, significant variation was observed among the treatments at harvest. Treatment, T_2 scored the significantly higher value (41.67) for number of flowers. The lowest number of flowers (3.00) was observed in the control treatment (T_5), which was on par with T_1 and T_4.

4.1.2.1.5 Effect of Various Seed Pretreatments on Morphological Parameters in Transplanted *W.somnifera.*

4.1.2.1.5.1 *Plant height (cm)*

Table 18 illustrates the plant height of *W.somnifera* plants in response to various seed pretreatments. There was a significant difference in plant height at all stages of observation.

At 30 DAS, plants from hot water treatments (T_3) primed seeds recorded maximum plant height (9.67 cm) which was observed to be on par with T_2, T_5 and T_6. The least mean value (4.70 cm) of plant height was noticed in plants from untreated seeds.

At 60 DAS, among the various treatments, the highest (16.57 cm) plant height was seen in plants from water soaked seeds (T_2) and was on par with GA @ 1500µM (T_5), whereas the lowest value (6.03 cm) was given by control treatment (T_{23}) which was on par with T_{14}.

At 90 DAS, the higher plant height (20.70 cm) was shown by T_5. T_{13} was found to be the lowest (9.67cm).

At harvest, the treatment T_2 had maximum plant height (60.80cm) which was comparable with T_3. The minimum plant height of 27.27 cm was observed in T_{13}.

4.1.2.1.5.2 *Number of branches (No plant^{-1})*

The effect of different seed treatments on *W.somnifera* plants at 30, 60, 90 DAS and at harvest is shown in Table 18. No Significant difference existed in the total number of branches, among the treatments at 60 and 90 DAS of observation. Also, no branching was observed in plants at 30 DAS.

At harvest, plants from water soaked seeds (T_2) held the highest value (5.00) for number of branches and found to be on par with T_{17}. The plants from untreated seeds (T_{23})

recorded the lowest value (1.67) and was found to be on par with treatments T_4, T_7, T_8, T_{13}, T_{16} and T_{22}.

4.1.2.1.5.3 *Collar girth(cm)*

The influence of different seed treatments on collar girth of *W.somnifera* at 30,60,90 DAS and at harvest is illustrated in Table 19. The collar girth varied significantly in *W.somnifera* among the different seed treatments except those at 30 DAS.

The maximum collar girth (0.2 cm) was obtained in treatments T_1, T_2, T_3, T_5, T_6, T_9, T_{10}, T_{12}, T_{17}, T_{18}, and T_{19} at 60 DAS. Treatments T_8, T_{11}, T_{13}, T_{14}, T_{16}, T_{20}, T_{21} and T_{23} recorded the lowest collar girth with the value 0.09 cm which was found to be on par with T_4, T_7 and T_{15}.

At 90 DAS, all seed treatments except T_7, T_{10}, T_{12}, T_{13}, T_{19}, T_{20}, and T_{22} produced higher quantity of collar girth (0.20cm). Plants from T_{12}, T_{13}, T_{19} and T_{20} recorded the lowest mean value of 0.10 cm.

At harvest, the collar girth (0.50 cm) was observed to be significantly higher in hot water treatment (T_3) and control treatment, which was on par with T_2, T_{15} and T_{22}. The lowest collar girth was recorded in T_{10}, T_{13}, T_{17} and T_{18} (0.20 cm). However, it was on par with T_2, T_3, T_{10}, T_{13}, T_{15}, T_{22} and T_{23}.

4.1.2.1.5.4 *Number of flowers per plant*

Table 19 gives the number of flowers per plant of the crop at 30,60,90 DAS and at harvest in response to various seed pretreatments. No flowering was observed at 30, 60 and DAS. A significant variation was observed at harvest only. At harvest, T_1 and T_{20} showed maximum number of flowers (41.67). T_4, T_9, T_{11}, T_{17} and T_{23} recorded the lowest value (3.00) for number of flowers per plant and was found on par with T_3, T_7, T_{10}, T_{12}, T_{16}, T_{19} and T_{22}.

4.1.2.2 Phenological Parameters

4.1.2.2.1 Effect of Physical Seed Pretreatments on Phenological Parameters in Transplanted *W.somnifera*

The influence of various physical seed treatments on days to flower initiation and days to fruitset in *W.somnifera* is depicted in Table 20.

4.1.2.2.1.1 *Days to flower initiation*

There was a no significant variation in days to flower initiation among the physical pretreatments tried. Water soaking (T_2) took only 92.33 days for flower initiation, which was on par with T_1 and T_3. The longest days (101.33) for flower initiation was observed in the control treatment.

4.1.2.2.1.2 *Days to fruit set*

No significant variation was observed among the treatments with respect to days to fruit set.

4.1.2.2.2 Effect of Hormonal Seed Pretreatments on Phenological Parameters in Transplanted *W. somnifera*

The data on days to flower initiation and days to fruit set in *W.somnifera* in response to various hormonal seed priming treatments is depicted in Table 21.

4.1.2.2.2.1 *Days to flower initiation*

There was significant variation in days to flower initiation among the treatments. GA_3 @1500 µM recorded the lowest number of days to flowering (92.33) which was on par with T_2 and T_5. The control treatment took maximum days (101.33) to flower initiation.

4.1.2.2.2.2 *Days to fruit set (Days)*

The data on days to fruit set of *W. somnifera* in response to various hormonal seed treatments is depicted in Table 21. There was a no significant variation observed among the treatments.

4.1.2.2.3 Effect of Biostimulant Seed Priming on Phenological Parameters of Transplanted *W.somnifera*

Table 22 shows the result of days to flower initiation and fruit set in *W.somnifera*.

4.1.2.2.3.1 *Days to flower initiation (Days)*

Significant variation was observed among the biostimulant treatments for days to flower initiation.

The data indicated minimum 92.67 days to fruit set in plants from PG @ 10 µM primed seeds, which was on par with T_5. SA @ 3000 µM (T_4) showed maximum 101.67 days to flower initiation among the treatments and was on par with T_1, T_2, T_3 and the control (T_7).

4.1.2.2.3.2 *Days to fruit set (Days)*

The data revealed that no significant variation existed among the biostimulant seed priming treatments with respect to days to fruitset.

4.1.2.2.4 Effect of Biopriming of Seeds on Phenological Parameters in Transplanted *W.somnifera*

The result of days to flower initiation and days to fruit set of the crop in response to various biopriming treatments is presented in Table 23.

4.1.2.2.4.1 *Days to flower initiation (Days)*

The data confirmed that treatment with microbial cultures significantly influenced days to flower initiation. T_1 registered the lowest (92.33) and T_5, the highest (101.33) number of days to flower initiation.

4.1.2.2.4.2 *Days to fruit set (Days)*

The treatment with microbial cultures did not significantly influenced days to fruit set.

4.1.2.2.5 Effect of Various Seed Pretreatments on Phenological Parameters in Transplanted *W.somnifera*

The result of days to flower initiation and days to fruit set in *W.somnifera* is illustrated in Table 24.

4.1.2.2.5.1 *Days to flower initiation (Days)*

Plants obtained from seeds primed with T_2, T_5 and T_{19} recorded the lowest number of days (92.33) to flower initiation and were on par with T_1, T_3, T_6, T_9 and T_{18}. While maximum (101.67) days to flower initiation was observed in T_{16} and on par with T_{13}, T_{15}, and T_{23}.

4.1.2.2.5.2 *Days to fruit set (Days)*

T_1 and T_{18} registered minimum days to fruit set (24.33) which was on par with T_{17}. T_{19} recorded maximum days (26.67) for fruit set and was found to be on par with T_{20} and T_{21}. The treatments T_7, T_8, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16} and T_{23}.

4.1.2.3 Yield Parameters

4.1.2.3.1 Effect of Physical Seed Pretreatments on Yield Parameters in Transplanted *W.somnifera*

Table 25 shows the effect of physical treatments on yield parameters *viz.,* shoot weight, root weight, harvest index(in terms of shoot and root weight), root length, root diameter and root volume of *W.somnifera* plants at harvest (120 DAS). The yield parameters with respect to fruits and seeds *viz.*, number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are illustrated in Table 26.

4.1.2.3.1.1 *Shoot weight (fresh and dry) (g plant^{-1})*

The highest shoot weight (fresh -37.61 g plant^{-1}; dry-7.17 g plant^{-1} was obtained in plants raised from water soaked seeds (T_2). The minimum shoot fresh weight (16.67 g plant^{-1}) and dry weight (3.14 g plant^{-1}) was observed in T_5. These were on par with that of T_4.

4.1.2.3.1.2 *Root weight (fresh and dry) (g plant^{-1})*

The various treatments showed a significant difference in the root fresh and dry weight. Treatment T_3 recorded maximum root weight (fresh-5.60 g plant^{-1}; dry-0.79 g plant^{-1})

and was found to be on par with treatment T_2. The lowest (fresh-2.62 g plant^{-1}, dry-0.37 g plant^{-1}) root weight was observed in the T_4.

4.1.2.3.1.3 Harvest Index

There was a significant variation observed among the treatments in harvest index with respect to shoot and root yield. Treatment T_2 recorded maximum shoot harvest index (0.90) and was found to be on par with treatment T_4. The lowest value (0.87) for shoot harvest index was observed in the T_3 and T_5 which was on par with T_1. While, T_5 recorded the highest harvest index (0.128) in terms of root yield which was on par with T_1 and T_3. The lowest harvest index (0.097) was observed in T_2 and was on par with T_4.

4.1.2.3.1.4 Root length (cm)

The root length exhibited significant variation among the physical pretreatments. The highest root length was recorded in T_3 (28.63 cm). The minimum root length was recorded in control treatment and T_2(7.87 cm).

4.1.2.3.1.5 Root diameter (cm)

At harvest, a significant difference in root diameter was observed among the physical treatments. Water soaking treatment (T_2) showed maximum root diameter (1.00 cm). The least root diameter (0.20 cm) was recorded in T_4 and T_5.

4.1.2.3.1.6 Root volume (cm^3)

The maximum root volume (7.40 cm^3) was obtained in plants raised from seeds subjected to water soaking treatment (T_2). T_4 recorded the lowest (2.61cm^3) root volume, which was on par with control treatment (T_5).

4.1.2.3.1.7 Number of fruits per plant

The number of fruits per plant in *W.somnifera* at harvest as influenced by physical seed treatments are presented in Table 26. There was significant increase in the number of fruits per plant (12.33) derived from water soaked seeds (T_2). The lowest value (2.67) was recorded in T_1. T_4 and T_5 did not set fruits.

4.1.2.3.1.8 Fruit weight (Fresh and dry) (g plant^{-1})

There was a significant difference in both fresh and dry weight of fruits at harvest. T_2 recorded the highest fruit weight on both fresh (12.56 plant^{-1}) and dry weight (1.87g plant^{-1}) basis. T_1 plants recorded the lowest fruit weight under fresh (2.74g plant^{-1}) and dry (0.45g plant^{-1}) conditions.

4.1.2.3.1.9 Seed yield (g plant^{-1})

The various treatments showed a significant difference in the seed yield (g plant^{-1}). T_3 and T_1 recorded the highest seed yield (0.072 g plant^{-1} and 0.56g plant^{-1}, respectively).

4.1.2.3.1.10 Thousand (1000) seed weight (g)

The thousand (1000) seed weight did not vary significantly among the physical treatments (T_1, T_2, T_3) that gave fruits. Treatments T_4 and T_5 did not set fruits.

4.1.2.3.2 Effect of hormonal seed priming on yield parameters in transplanted *W. somnifera*

Table 27 depicts the effect of hormonal seed priming treatments on yield parameters *viz.,* shoot weight, root weight, harvest index (on the basis of shoot and root yield), root length, root diameter and root volume of *W. somnifera* plants at harvest (120 DAS). The yield parameters with respect to fruits and seeds *viz.,* number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are presented in Table 28.

4.1.2.3.2.1 Shoot (fresh and dry) weight (g plant^{-1})

GA3 @ 3000 µM (T_2) showed significantly higher shoot weight (fresh-27.77 g plant^{-1}; dry-5.17 g plant^{-1}) which were on par with T_1. The minimum shoot fresh weight was recorded in the control treatment, T_9 (fresh -16.67g plant^{-1}) which was on par with T_3. The minimum shoot dry weight (9.93 g plant^{-}1) was also recorded in T_9, which was on par with T_3 and T_7.

4.1.2.3.2.2 Root weight (fresh and dry) (g plant^{-1})

The root weight varied significantly among the treatments. The root weight (fresh-5.60 g plant^{-1}; dry-0.79 g plant^{-1}) was found to be significantly higher in GA3 @ 1500 µM (T_1). T_9 recorded the lowest root weight (fresh -3.20 g plant^{-1}; dry-0.46 g plant^{-1}) which was on par with T_6 and T_7.

4.1.2.3.2.3 Harvest Index

There was a significant variation observed among the treatments in harvest index with respect to both leaves and roots. T_2, T_4 and T_6 recorded highest harvest index (0.89), for shoot yield and was on par with T_3 and T_8. T_1 recorded highest harvest index (0.135) in terms of root yield. The harvest index in terms of root yield was on par with T_5 and T_7. The lowest harvest index for shoot yield (0.87) was observed in T_1, T_5, T_7 and T_9 treatments while in root yield (0.108) it was observed in T_2 which was on par with T_4, T_6 and T_8.

4.1.2.3.2.4 Root length (cm)

There was significant variation in root length among the treatments. The highest value for root length was noticed in treatment T_3 (14.63 cm) and found on par with treatment T_6. T_7 recorded the least value (4.03 cm). This was found to be on par with T_8.

4.1.2.3.2.5 *Root diameter (cm)*

From the table 27, it is clear that hormonal seed priming treatments had significant effect on root diameter. GA_3 @1500µM (T_1) showed maximum root diameter (1.10 cm). The control treatment (T_9) and T_4 recorded the lowest value (0.20 cm) which was on par with the treatments T_3, T_6 and T_8.

4.1.2.3.2.6 Root volume (cm^3)

The root volume varied significantly in *W.somnifera* among the different hormonal seed pretreatments. *W.somnifera* plants raised from GA_3@1500 µM (T_1) primed seeds

produced higher root volume (9.15 cm^3). The plants raised from T_9 recorded the lowest (2.63 cm^3) root volume. This was found to be on par with T_3.

4.1.2.3.2.7 Number of fruits per plant

At harvest, the treatment with GA_3@1500µM (T_1) recorded higher number of fruits per plant (9.00). Both T_2 and T_5 held the minimum value (4.33) for number of fruits. No fruiting occurred in plants subjected to other treatments including the control.

4.1.2.3.2.8 Fruit weight (fresh and dry) (g $plant^{-1}$)

The observations recorded significant variation in the case of fruit fresh weight and dry weight. GA_3@1500µM (T_1) recorded maximum fruit weight under both fresh (9.49 g $plant^{-1}$) and dry (1.36 g $plant^{-1}$) conditions. The lowest value was observed in T_2 (4.43 g $plant^{-1}$) and T_5 (0.64 g $plant^{-1}$) on fresh and dry basis, respectively. In the case of dry weight, T5 was found to be on par with T_2.

4.1.2.3.2.9 Seed yield (g $plant^{-1}$)

The seed yield did not show significant variation among the hormonal seed priming treatments.

4.1.2.3.2.10 Thousand (1000) seed weight (g)

The thousand (1000) seed weight did not show any significant variation among the hormonal seed priming treatments.

4.1.2.3.3 Effect of Biostimulant Seed Priming on Yield Parameters in Transplanted *W.somnifera*

The effect of biostimulant seed priming treatments on yield parameters *viz.,* shoot weight, root weight, harvest index (on the basis of shoot and root yield), root length, root diameter and root volume of *W. somnifera* plants at harvest (120 DAS) is presented in Table 29. The yield parameters with respect to fruits and seeds *viz.*, number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are depicted in Table 30.

4.1.2.3.3.1 Shoot weight (fresh and dry) (g plant^{-1})

The maximum shoot weight (fresh-21.40 g plant^{-1}; dry-3.96 g plant^{-1}) was recorded in treatment PG @ 10 µM (T_6) at harvest and was comparable with the T_5 in dry condition. CH @ 5 g L^{-1} (T_1) showed the least shoot fresh weight (fresh-13.80 g plant^{-1}; dry 2.69 g plant^{-1}) among the treatments, which was on par with T_4 for fresh weight.

4.1.2.3.3.2 Root weight (fresh and dry)(g plant^{-1})

The data in Table 29 confirmed the profound influence of biostimulant treatments on root weight. T_6 recorded the highest (fresh- 4.36 g plant^{-1}; dry- 0.64 g plant^{-1}) root weight. SA @ 3000 µM (T_4) recorded the lowest root weight (fresh-2.53 g plant^{-1}, dry- 0.36 g plant^{-1}) which was on par with T_1 and T_5.

4.1.2.3.3.3 Harvest Index

Significant variation was observed among the treatments in harvest index with respect to both shoot and root. T_5 and T_6 recorded the highest harvest index 0.90 and 0.14 for shoot and root yield, respectively. T_5 was on par with T_1 and T_4 ,in terms of shoot yield and T_6 was on par with T_1, T_2, T_3 and T_7 in terms of root yield. The lowest harvest index (0.86) for shoot yield was observed in the T_2 and T_6 which was on par with T_3 and T_7 whereas, the harvest index with respect to root yield was lowest (0.097) in PG @ 1 µM (T_5) and was on par with treatments T_1 and T_4.

4.1.2.3.3.4 Root length (cm)

The various biostimulant priming treatments showed a significant difference in the root length. T_5 recorded the maximum value (14.27 cm) and minimum root length was recorded in treatment T_2 (4.37 cm).

4.1.2.3.3.5 Root diameter (cm)

Plants raised from PG @ 10 μM (T_6) primed seeds recorded maximum root diameter (0.57 cm). The least value (0.20 cm) was given by all treatments except T_5 and T_6.

4.1.2.3.3.6 Root volume (cm^3)

The root volume (4.13 cm^3) was observed to be significantly higher in T_5. This was observed to be on par with T_6. The lowest root volume was recorded in T_4 (1.27cm^3) and was on par with T_1.

4.1.2.3.3.7 Number of fruits per plant

At harvest, no significant difference was observed in number of fruits per plant among the biostimulant priming treatments. Plants derived from seeds subjected to all other pretreatments except T_5 and T_6 did not set fruits.

4.1.2.3.3.8 Fruit weight (Fresh and dry) (g $plant^{-1}$)

The fruit weight did not vary significantly among the biostimulant treatments under both conditions.

4.1.2.3.3.9 Seed yield (g $plant^{-1}$)

T_5 recorded the highest (0.069 g $plant^{-1}$) seed weight and T_6 registered a lower value (0.057 g $plant^{-1}$) for seed yield.

4.1.2.3.3.10 Thousand (1000) seed weight (g)

No significant variation was observed among the biostimulant priming treatments for thousand (1000) seed weight.

4.1.2.3.4. Effect of Seed Biopriming on Yield Parameters in Transplanted *W.somnifera*

The response of *W.somnifera* plants at harvest (120 DAS) on yield parameters *viz.*, shoot weight (fresh and dry), root weight(fresh and dry), harvest index (on the basis of shoot and root yield), root length, root diameter and root volume due to seed bio priming treatments is presented in Table 31. The yield parameters with respect to fruits and seeds *viz.*, number of fruits plant $^{-1}$, fruit weight $plant^{-1}$ (fresh and dry), seed yield $plant^{-1}$ and thousand (1000) seed weight are illustrated in Table 32.

4.1.2.3.4.1 Shoot weight (fresh and dry) (g plant^{-1})

The shoot weight varied significantly among the treatments, with maximum value (fresh-23.07 g plant^{-1}; dry 4.39 g plant^{-1}) obtained in plants from seeds subjected to priming with *B. pumilis* (T_1). This was found to be on par with that of *P. fluorescens* (T_4). The least shoot weight (fresh-16.47 g plant^{-1}; dry-2.99 g plant^{-1}***)*** was observed in treatment T_3 (*B. velezensis*). The lowest fresh weight was on par with treatments T_2 and T_5, while the lowest dry weight was on par withT_3 and T_5.

4.1.2.3.4.2 Root weight (fresh and dry) (g plant^{-1})

The root yield varied significantly among the treatments with respect to fresh weight and dry weight. Maximum (fresh-4.43 g plant^{-1}; dry-0.63 g plant^{-1}) root weight was obtained from the plants raised from seeds primed with *B. pumilis* (T_1). The control treatment and *B. velezensis* (T_3) recorded minimum mean value (3.20 g plant^{-1} and 0.45 g plant^{-1}, respectively) on fresh and dry weight basis. The least root fresh weight was observed to be on par with treatments T_3 and T_4. With respect to dry weight, T_3 was on par with T_4 and T_5.

4.1.2.3.4.3 Harvest Index

The data on harvest index of *W.somnifera* in response to various physical seed treatments is depicted in Table 25. There was a significant variation observed among the treatments in harvest index with respect to both shoot and roots. When compared with other treatments, T_1 and T_4 recorded highest (0.88) and T_2 recorded the lowest harvest index (0.85) in terms of shoot yield. For root harvest index, the highest value (0.150) was observed in T_2, while the lowest (0.119) was observed in T_4 and was on par with T_1, T_3 and T_5.

4.1.2.3.4.4 Root length (cm)

The data (Table 31) indicated that there was significant variation among the treatments with respect to the root length. The root length (15.83 cm) was found to be higher in plants obtained from the seeds primed with *P. fluorescens* (T_4). The control treatment (T_5) was recorded the lowest root length with a mean value of 7.87 cm, which was observed to be on par with T_1 and T_3.

4.1.2.3.4.5 Root diameter (cm)

Significant variation was observed in terms of root diameter among the treatments of which B. *pumilis* (T_1) showed maximum root diameter (0.50 cm). The control treatment (T_5) recorded the lowest value (0.20 cm) which was on par with T_2 and T_3.

4.1.2.3.4.6 Root volume (cm^3)

A significantly higher root volume was observed in treatment T_1 (4.47 cm^3). The control treatment (T_5) recorded the lowest root volume (2.63 cm^3), which was found to be on par with treatment T_4.

4.1.2.3.4.7 Number of fruits per plant

The data (Table 32) demonstrated that biopriming did not show significant variation with respect to number of fruits per plant. The control plants did not set fruit.

4.1.2.3.4.8 Fruit weight (Fresh and dry) (g $plant^{-1}$)

The biopriming treatments had no significant effect on fruit weight under both fresh and dry conditions.

4.1.2.3.4.9 Seed yield (g $plant^{-1}$)

The seed yield varied significantly among the treatments among the biopriming treatments tried. T_1 showed the highest seed yield (0.065 g $plant^{-1}$) and was on par with T_2 and T_4. The lowest value (0.027 g $plant^{-1}$) was recorded in T_3.

4.2.3.4.10 Thousand (1000) seed weight (g)

The thousand (1000) seed weight did not vary significantly among the treatments that set fruits.

4.1.2.3.5 Effect of Various Seed Pretreatments on Yield Parameters in Transplanted *W. somnifera.*

The effect of various seed priming treatments on yield parameters *viz.,* shoot weight (fresh and dry), root weight (fresh and dry), harvest index (on the basis of shoot and root yield), root length, root diameter and root volume due to seed bio priming treatments is presented in Table 33. The yield parameters with respect to fruits and seeds *viz.*, number of fruits plant $^{-1}$, fruit weight plant^{-1} (fresh and dry), seed yield plant^{-1} and thousand (1000) seed weight are illustrated in Table 34.

4.1.2.3.5.1 Shoot weight (fresh and dry) (g plant^{-1})

The highest shoot weight (fresh -37.61 g plant^{-1}; dry-7.17 g plant^{-1}) was observed in T_2. The lowest (fresh-13.80 g plant^{-1}; dry -2.69 g plant^{-1}) shoot weight was recorded in T_{13}.

4.1.2.3.5.2 Root weight (fresh and dry) (g plant^{-1})

The root weight (fresh-5.60 g plant^{-1}; dry-0.79 g plant^{-1}) of *W.sommifera* was found to be higher in both, T_3 and T_5. The dry weight was on par with T_2. The lowest value for root weight (fresh- 2.53 g plant^{-1}; dry- 0.36 g plant$^{-1)}$ was observed in $T_{16.}$ Both values were observed to be on with $T_{4.}$

4.1.2.3.5.3 Harvest Index

The data on harvest index of *W.somnifera* in response to various seed treatments is depicted in Table 33. There was significant variation observed among the treatments in harvest index with respect to both shoot and roots. When compared with other treatments, T_2 and T_{17} recorded highest (0.90) and lowest harvest index (0.85) in terms of shoot yield. The highest value was on par with T_4, $T_{6,}$ $T_{8,}$ T_{10} and T_{16} and treatments T_{14} and T_{18} was on par with the lowest value. The highest (0.150) harvest index in case of root yield was observed in $T_{20,}$ which was on par with T_5, T_{14} and T_{18}. The lowest harvest index (0.097) was observed in T_2 and T_{17}. The value was on par with T_4, $T_{6,}$ T_{10} and T_{16}.

4.1.2.3.5.4 Root length (cm)

The data confirmed the profound influence of various seed treatments on root length. T_3 recorded the highest value (28.63 cm) and T_{11} recorded the lowest root length with a mean value of 4.03 cm which was found to be on par with T_{14}.

4.1.2.3.5.5 Root diameter (cm)

Significant difference was observed in root diameter among the treatments. T_5 recorded the highest root diameter (1.10 cm) which was statistically on par with T_2. T_{23} recorded the lowest root diameter with a mean value of 0.20 cm and this was found to be on par with T_7, T_{20} and T_{21}.

4.1.2.3.5.6 Root volume (cm^3)

There was significant difference in root volume, among the treatments. Out of all the treatments, T_5 recorded the highest root volume (9.15 cm^3) and least (1.27 cm^3) root volume was noticed in T_{16}.

4.1.2.3.5.7 Number of fruits per plant

At harvest, there was significant variation in number of fruits per plant, among the treatments. Plants from seeds subjected to T_2 recorded maximum number of fruits per plant (12.33). T_{18} gave the least value (1.67) which was on par with T_{17}, T_{20}, T_{21} and T_{22}.

4.1.2.3.5.8 Fruit weight (fresh and dry) (g $plant^{-1}$)

Significant difference was found in the fresh weight and dry weight of *W.somnifera* fruits in response to various seed treatments at harvest. T_2 recorded significantly higher value for fruit (fresh-12.56 g $plant^{-1}$; dry - 1.87 g $plant^{-1}$), among the treatments. The dry fruit weight was on par with T_1, T_{17}, T_{20}, T_{21} and T_{22}. The lower fruit weight (fresh- 1.74 g $plant^{-1}$; dry-0.26 g $plant^{-1}$) was observed in T_{18}.

4.1.2.3.5.19 Seed yield (g $plant^{-1}$)

The seed yield (g $plant^{-1}$) of *W.somnifera* was found to be the highest (0.072 g $plant^{-1)}$ in T_3.The lowest value (0.027 g $plant^{-1}$) for seed yield was observed in T_{21}.

4.1.2.3.5.10 Thousand (1000) seed weight (g)

There was significant variation among the treatments, with respect to thethousand (1000) seed weight. The highest (2.677 g) thousand (1000) seed weight as recorded in T_{20}. The lowest (2.503) thousand (1000) seed weight was recorded in T_6.

4.1.2 INCIDENCE OF PESTS AND DISEASES

After transplanting, an unidentified leaf eating caterpillar was observed till harvest at random irrespective of the treatments, which could be controlled by hand picking.

4.2 *ANDROGRAPHIS PANICULATA*

4.2.1 PHASE 1: SEED PRETREATMENTS FOR ENHANCED GERMINATION IN *A. PANICULATA*

The different seed pretreatments *viz*., physical, hormonal, biostimulant and biopriming were carried out in *A. paniculata* for evaluating the seed performance and subsequent seedling growth parameters. The observations on germination parameters *viz*., germination per cent, survival per cent, germination index, mean germination time, shoot length, root length, seedling length, allometric index and seedling vigor index, were recorded.

4.2.1.1 Effect of physical pretreatment of seeds on germination and seedling parameters in *A. paniculata*

The effect of physical treatments on various seed germination and seedling parameters upto 30 days after sowing are presented in Table 35.

4.2.1.1.1 Germination per cent

The germination per cent showed significant variation among the treatments. Hot water treatment @ 65^0c for 10 min (T_3) recorded the highest germination of 84.67per cent, which was on par with scarification (T_1) and water soaking (T_2). The control treatment (T_5) recorded the lowest germination of 46.67per cent which was on par with concentrated sulphuric acid (T_4).

4.2.1.1.2 Survival per cent

There was significant variation in survival per cent among the treatments. The highest value (83.33per cent) of survival was noticed in hot water treatment (T_3) and was found on par with T_1 (82.00per cent), T_2 (78.66per cent) and T_3 (83.33per cent). Treatment T_5 recorded the least value (46.66per cent) and it was comparable with T_4 (52.66per cent).

4.2.1.1.3 Germination index (GI)

The GI showed significant variations among the physical treatments tried. The maximum GI was recorded in T_2 (16.20), which was on par with all physical treatments. The control plants recorded the lowest GI (4.78). The data indicates that physical seed pretreatments could significantly increase the germination index in *A.paniculata.*

4.2.1.1.4 Mean germination time (MGT) (Days)

The data presented in Table 5 indicated the significant effect of different physical treatments on MGT of the *A. paniculata* seeds. T_4 was found to give minimum mean germination time (2.00days) among the various physical seed treatments. The highest value (5.00days) found in the control treatment (T_5).

4.2.1.1.5 Seedling shoot length

The shoot length of the seedlings showed significant variation among the treatments tried. The seeds subjected to hot water treatment (T_3) recorded significantly superior value (10.67cm). This was on par with T_1 (9.83cm). The lowest seedling shoot length (3.13cm) was observed in control treatment (T_5).

4.2.1.1.6 Seedling root length

The seedling root length varied significantly in *A.paniculata* among the different physical seed pretreatments. *A. paniculata* seeds subjected to hot water treatment (T_3) produced higher root length (5.27cm). Seeds exposed to concentrated sulphuric acid (T_4) recorded the lowest mean value of 2.43cm which was found to be on par with all other physical treatments (except T_3) and the control.

4.2.1.1.7 Seedling length

There was a significant difference in seedling length observed among the treatments. Hot water treatment (T_3) showed maximum seedling length (15.93cm). The least seedling length (5.80cm) was recorded in the control treatment (T_5).

4.2.1.1.8 Seedling vigor index

Among the various physical seed pretreatments, significant variation was observed in seedling vigor index. Hot water treatment (T_3) produced maximum seedling vigor index (13.38). The lowest value of seedling vigor index (2.67) were obtained with control treatment (T_5).

4.2.1.1.9 Allometric index

T_1 showed maximum allometric index (2.91) and this was found on par with T_3 (2.05) and T_4 (2.44). Treatment T_2 (1.63) was found on par with the control (T_5) which recorded the lowest value of allometric index (1.19).

4.2.1.2 Effect of hormonal priming of seeds on germination and seedling parameters in *A. paniculata*

The effect of hormonal priming treatments on various seed germination and seedling parameters upto 30 days after sowing are presented in Table 36.

4.2.1.2.1 Germination per cent

Germination per cent showed significant variation, among the various hormonal treatments tried. The highest germination (82 per cent) was recorded in the treatment with GA_3 @ 1500µM (T_1) which was on par with IAA @ 1µM (T_4) and BA @ 300µM (T_6). However, it was observed that higher concentration of GA_3, lower concentration of BA and IAA and TDZ recorded lower germination per cent, but significantly higher than the control. The lowest germination (46.67 per cent) was obtained in the control treatment (T_9).

4.2.1.2.2 Survival per cent

The various hormonal priming treatments showed a significant difference in the survival per cent. Among the hormonal treatments, GA3 @ 1500 µM (T_1) recorded

maximum survival per cent (82.00) and was found to be on par with treatment T_4 (70.67per cent). Minimum value (46.66per cent) for was recorded in the control treatment (T_9).

4.2.1.2.3 Germination index (GI)

From the data illustrated in Table 36, it can be inferred that significant variation existed among the hormonal treatments with respect to GI. The seeds treated with TDZ @ 200µM (T_7) recorded significantly higher value (9.47) among the treatments. This was on par with T_1, T_2, T_3, T_5 and T_8. The lowest germination index (4.78) was noticed in control treatment (T_9) and this was found on par with T_4 and T_6.

4.2.1.2.4 Mean germination time (MGT)

A significant difference was observed among the hormonal treatments for MGT. The seeds primed with, TDZ @ 400 µM (T_8) recorded the lowest (3.33days) and IAA @ 400 µM (T_4) recorded the highest (6.67days) values for MGT. The highest value was found to be on par with T2 and T4.

4.2.1.2.5 Seedling shoot length

The data described significant enhancement in shoot length of seedlings. GA_3 @ 1500µM (T_5) recorded maximum shoot length (11.57cm). The least seedling shoot length (3.13cm) was recorded in control treatment (T_9).

4.2.1.2.6 Seedling root length

The data pertaining to the effect of hormonal treatments on root length of *A.paniculata* seedlings indicated that no significant variation exist with respect to root length among the treatments tried.

4.2.1.2.7 Seedling length

From the table 36, it is clear that hormonal treatments at different concentrations had significant effect on seedling length. GA_3 @1500µM (T_1) showed maximum seedling length (16.37cm) and control treatment (T_9) recorded the lowest value (5.80cm).

4.2.1.2.8 Seedling vigor index

The seed pretreatments varied significantly with respect to seedling vigour index. GA_3 @1500µM (T_1) recorded significantly higher seedling vigor index (13.42) compared to all other treatments, while control treatment recorded 2.67 seedling vigour index, which was the lowest.

4.2.1.2.9 Allometric index

The data in Table 36 indicates that hormonal pretreatments had profound influence on allometric index. T_1 showed maximum allometric index (2.41) among the treatments and it was found to be on par with T_8 with value of 1.87. The lowest value 1.19 were observed in the control treatment (T9).

4.2.1.3 Effect of biostimulant seed priming on germination and seedling parameters in *A. paniculata*

The effect of biostimulant priming treatments on various seed germination and seedling parameters upto 30 days after sowing are presented in Table 37.

4.2.1.3.1 Germination per cent

The germination per cent of seeds differed significantly due to biostimulant treatments. The highest germination (66.67 per cent) was recorded in the treatment with PG@10µM (T_6). The lowest germination (41.33 per cent) was observed in the treatment (T_1) with chitosan @5g L^{-1}concentration which was on par with T_2, T_3, T_4, T_5 and control.

4.2.1.3.2 Survival per cent

The survival per cent showed significant variation among the treatments. PG@10µM (T_6) recorded a survival of 64.66per cent. The treatment, CH@5gL^{-1} (T_1) recorded the lowest survival of 41.33 per cent which was comparable with all other treatments (T_1, T_2, T_3, T_4, T_5 and the control).

4.2.1.3.3 Germination index (GI)

The influence of various biostimulant treatments on GI is illustrated in Table 37. No significant difference was noticed in germination index among the treatments.

4.2.1.3.4 Mean germination time (MGT)

During germination, plants treated with SA@1500µM (T_3) recorded significantly lower MGT (4.00days) which was observed to be on par with T_1, T_2, and T_7. The MGT was found to be the highest (6.67days) in seeds primed with SA@3000µM (T_4), which was found to be on par with T_5 and T_6. The result indicated that SA at higher concentration increased the germination time; while at lower concentration shortened the germination time.

4.2.1.3.5 Seedling shoot length

The response of *A. paniculata* seedlings to different biostimulant treatments with respect to shoot length were analysed and the results are presented in Table 37. PG@1µM (T_5) was found to be significantly superior in shoot length, among the treatments. The shoot length recorded was 6.20 cm in T_5. This was on par with T_2, T_3 and T_6. The lowest value (3.13cm) was registered in the control treatment (T_7).

4.2.1.3.6 Seedling root length

Table 37 represents the data on seedling root length of *A.paniculata*, in response to different biostimulant treatments. No significant difference in seedling root length was observed among the treatments.

4.2.1.3.7 Seedling length

Seeds that are treated with PG @ 1µM (T_5) recorded maximum seedling length (10.23cm) which was observed to be on par with T_2, T_3 & T6. The least value was given by non-treated seeds (T_7) which gave a seedling length of 5.80 cm.

4.2.1.3.8 Seedling vigor index

Significant difference existed in the seedling vigor index, among the treatments. The highest seedling vigor index exhibited by PG@10µM (T_6) with a mean value of 6.03 and was significantly superior compared to all other treatments. The control (T_7) recorded the lowest value (2.67) among the treatments.

4.2.1.3.9 Allometric index

The data on allometric index recorded showed no significant difference within the hormonal treatments.

4.2.1.4 Effect of biopriming of seeds on germination and seedling parameters in *A. paniculata*

The effect of biopriming treatments on various seed germination and seedling parameters upto 30 days after sowing are presented in Table 38.

4.2.1.4.1 Germination per cent

There was significant increase in the germination (82.67 per cent) on priming with *B.velezensis* (T_3) compared to other treatments. The lowest value was recorded in control plants T_5 (46.67 per cent).

4.2.1.4.2 Survival per cent

Survival per cent showed significant variation among the various treatments tried. The maximum mean value (82.66 per cent) for survival per cent was observed in seeds primed with *B. velezensis* (T_3). The minimum value was recorded for T_5 (46.66per cent).

4.2.1.4.3 Germination index (GI)

From Table 38, it is clear that biopriming treatments had significant effect on GI. Seeds primed with *B. velezensis* (T_3) showed maximum GI (6.68). The lowest value (4.78) was recorded in T_5. This was comparable with T_1, T_2 and T_4.

4.2.1.4.4 Mean germination time (MGT)

During germination, plants treated with SA@1500µM (T_3) recorded significantly lower MGT (4.00days) which was observed to be on par with T_1, T_2, and T_7. The MGT was found to be the highest (6.67days) in seeds primed with SA@3000µM (T_4), which was found to be on par with T_5 and T_6. The result indicated that SA at higher concentration increased the germination time; while at lower concentration shortened the germination time.

4.2.1.4.5 Seedling shoot length

Significant variation was observed in shoot length among the biopriming treatments. Seedlings generated from the seeds primed with B. *velezensis* (T_3) held the highest shoot length of 8.97cm. The lowest seedling shoot length (2.77cm) was observed in seedlings from seeds primed with *P. fluorescens* (T_4), which was on par with T_5. From the data it is evident that biopriming had influenced the shoot length in the seedlings.

4.2.1.4.6 Seedling root length

There was significant difference in seedling root length, among the biopriming treatments. T_1 recorded the highest root length of 3.93cm. The lowest root length was noticed in T_3 (2.37) and was comparable with all the other treatments except T_1.

4.2.1.4.7 Seedling length

Significant variation among treatments was observed, of which *B. velezensis* (T_3) showed maximum seedling length (11.33cm) which was comparable with T_1 (10.87cm). T_4 recorded the lowest value (5.20cm) which was on par with T_5 (5.80cm).

4.2.1.4.8 Seedling vigor index

Biopriming of seeds showed significant variation among the treatments tried. B. *velezensis* (T_3) gives the highest value (9.29) of seedling vigor index. But least seedling vigor index was noticed in T_5 (2.67), which was on par with T_4 (3.43).

4.2.1.4.9 Allometric index

The maximum value of allometric index was obtained in treatment T_3 (3.79) which was significantly higher than all other treatments. The lowest allometric index (1.18) was recorded in treatment T_4 which was on par with T_5 (1.19).

4.2.1.5 Effect of various seed pretreatment on germination and seedling parameters in *A. paniculata*

The effect of various seed pretreatments on germination and seedling parameters upto 30 days after sowing are presented in Table 39.

4.2.1.5.1 Germination per cent

Significant difference was observed in *A.paniculata* in response to various seed pretreatments. The seeds treated with hot water (T_3) recorded significantly higher value (84.67 per cent) among the treatments. This was on par with T_1, T_2, T_3, T_5 and T_{21}. The lowest germination per cent (41.33 per cent) was noticed in chitosan @5g L^{-1} (T_{13}) treatment and this was found to be on par with T_{14}, T_{15}, T_{16}, T_{17} and control.

4.2.1.5.2 Survival per cent

The survival per cent of the seedlings differed significantly due to seed priming. T_3 recorded the highest value (83.33) of survival per cent which was on par with T_1, T_2, T_3, T_5 and T_{21}. T_{13} recorded the least value (41.33 per cent) which was found to be par with T_{14}, T_{15}, T_{16} and T_{23}.

4.2.1.5.3 Germination index (GI)

A significant variation was observed in germination index among the seed pretreatments. The highest value (16.20) was recorded in overnight water soaking treatment (T_2) which was on par with T_3 which recorded a germination index of 15.77. The control (T_{16}) recorded the lowest value (3.84) which was comparable with T_8, T_{10}, T_{13}, T_{14}, T_{15}, T_{17}, T_{18}, T_{19}, T_{20}, T_{21}, T_{22} and T_{23}.

4.2.1.5.4 Mean germination time (MGT)

Significant difference existed in the MGT, among the treatments. During germination, treatment T_4 recorded minimum mean value (2.00days) for MGT. Treatments T_{10}, T_{16}, T_{19} and T_{22} recorded the maximum value (6.67days) which were on par with T_6, T_8, T_{17}, T_{18} and T_{21}.

4.2.1.5.5 Seedling shoot length

The maximum shoot length (11.57cm) was obtained in the treatment GA_3 @1500µM (T_5), which was on par with hot water treatment (T_3) with 10.67cm shoot length. T_{22} recorded the lowest seedling shoot length with 2.77cm which was on par with T_{23} (3.13cm).

4.2.1.5.6 Seedling root length

Significant difference was observed in seedling root length among the various treatments tried. Maximum root length was observed in T_6 (5.67cm) followed by T_3 (5.27cm) and T_5 (4.80cm) which were on par with each other. The least value was noticed in T_{21} (2.37cm) which was on par with all other treatments except T_3, T_5, T_6 and $T_{17.}$

4.2.1.5.7 Seedling length

There was significant difference in seedling length among the various seed pretreatments. Seedlings obtained from GA_3 @1500µM primed seeds (T_5) recorded the highest seedling length (16.37cm) which was statistically on par with T_3. T_{22} recorded the lowest seedling length with 5.20±0.35cm, which was on par with the control treatment.

4.2.1.5.8 Seedling vigor index

The data represented significant enhancement in seedling vigor index, with GA_3 @1500µM (T_5) giving maximum value (13.42). This was observed to be on par with T_3 (13.38). The least seedling vigor index (2.67) was recorded in control treatment (T_{23}), which was on par with $T_{13,}$ T_{14}, T_{16} and T_{22}.

4.2.1.5.9 Allometric index

Allometric index recorded the highest value in treatment T_{21} (3.79). The lowest value was observed in treatment T_{22} (1.18) which was on par with treatments T_6 and T_{23}.

4.2.2 PHASE 2: EVALUATION OF TRANSPLANTED SEEDLINGS FOR ENHANCED PLANT GROWTH IN *A. PANICULATA*.

4.2.2.1 Morphological Parameters

The effect various seed pretreatments on morphological parameters *viz.*, plant height, number of branches per plant, collar girth and number of flowers per plant were recorded at various stages of growth (30, 60, 90 DAS and at harvest (110 DAS) of the *A. paniculata* plants

4.2.2.1.1 Effect of Physical Seed Treatments on Morphological Parameters in Transplanted *Andrographis paniculata*

4.2.2.1.1.1 Plant height (cm)

The effect of different seed treatments on plant height of *A.paniculata*, at various growth periods are presented in Table 40. At 30 DAS, a significant variation was observed among the various physical treatments. Hot water treatment (T_3) recorded the highest plant height (10.67cm) and was on par with T_1 (9.83cm). The control (T_5) recorded the lowest height (3.13cm).

At 60 DAS, the plant height showed significant variation among the treatments. Scarification using sand paper (T_1) recorded a plant height of 26.63 cm, which was observed to be on par with T_2 and T_3 treatments. The control treatment (T_5) recorded the lowest plant height of 14.77 cm which was on par with that recorded in the concentrated sulphuric acid treatment (T_4) with 17.87 cm plant height.

At 90 DAS, scarification treatment (T_1) recorded the maximum plant height of 48.27 cm, which was on par with T_2 and T_3. The lowest plant height (32.47) was observed in T_4, which was on par with control treatment.

The plant height differed significantly due to physical seed treatments at harvest stage also. At harvest, the highest plant height (57.87 cm) was recorded in the scarification treatment (T_1) which was on par with hot water treatment (T_3). The lowest plant height (36.10 cm) was observed in the control treatment (T_5) which was found to be on par with T_4.

4.2.2.1.1.2 *Number of branches per plant*

Table 40 represents the effect of different physical seed treatments on number of branches of the *A.paniculata* plants at different periods of observation. No branches were formed from the main shoots at 30 DAS. Significant variation in number of branches was observed at all other stages of observations (60 DAS, 90 DAS and at harvest). At 60 DAS, (T_3) showed maximum number of branches (7.67) which was on par with T_1 (7.33) and T_2 (5.33). The control treatment (T_5) recorded the lowest value (1.33) which was on par with T_4 (3.33 plant^{-1}).

The number of branches was did not show any variation at 90 DAS and at harvest. At 90 DAS and at harvest, T_1 and T_2 recorded the highest number of branches (22.00) which was statistically on par with T_3 (21.67). The control plants recorded the lowest number of branches with a mean value of 13.67 and was on par with T_4 (14.00).

4.2.2.1.1.3 *Collar girth (cm)*

The data on the influence of different physical seed pretreatments on collar girth in *A.paniculata*, at different growth periods is depicted in Table 41. Collar girth showed significant variation among the treatments tried at 30, 90 DAS and at harvest.

At 30 DAS, hot water treatment (T_6) gave the highest value (0.13cm) of collar girth. But least collar girth was noticed in T_2 (0.09cm) and T_4 (0.09cm), which was on par with the control (T_5) (0.10cm) and T_1 (0.10cm)

At 60 DAS, no significant variation was observed in collar girth among the physical treatments.

All the treatments recorded the same collar girth at 90 DAS and at harvest. T_3 recorded significantly superior value (1.83 cm) for collar girth at both the stages. This was on par with T_1 (1.40) and T_2 (1.40). The lowest collar girth (0.87) was observed in T_5, which was on par with T_4.

4.2.2.1.1.4 *Number of flowers per plant*

The data pertaining to the effect of physical treatments on number of flowers of *A.paniculata* at different growth periods is presented in Table 41. There was no flowering at both 30 and 60 DAS. Though flowering initiated at 90 DAS, no significant variation was observed among the treatments. The number of flowers (27.33) was significantly higher in plants generated from seeds subjected to hot water treatment (T_3) at harvest. This was observed to be on par with T_1. The lowest number of flowers was recorded in T_5 (2.00), which was on par with T_2 and T_4.

4.2.2.1.2 Effect of Hormonal Seed Priming on Morphological Parameters in Transplanted *A. paniculata.*

4.2.2.1.2.1 *Plant height (cm)*

The plant height of *A. paniculata* at various growth stages as influenced by hormonal treatments are presented in Table 42. There was significant difference in plant height among the hormonal priming treatments at all the stages of observations.

At 30 DAS, there was significant increase in the plant height (11.57 cm) in treatment GA_3 @ 1500µM (T_1) compared to other treatments. The lowest value was recorded in control plants, T_9 (3.13 cm).

At 60 DAS, maximum plant height was recorded in T_1 (26.63cm), which was on par with treatments T_2, T_5, T_6 and T_8. The control plants recorded the lowest plant height (14.77 cm), which was found to be on par with T_3, T_4 and T_7.

At 90 DAS, T_1 recorded the highest plant height (49.97 cm), which was found to be on par with T_2, T_4 and T_5. The least value (34.33 cm) was observed in control treatment (T9), which was on par with T_6, T_7 and T_8.

At harvest, the plants from seeds treated with GA_3 @ 1500µM (T_1) recorded significantly higher value (56.80 cm) among the treatments. This was on par with treatments (T_2) and (T_4). The lowest plant height (36.10±1.22cm) was noticed in (T_9), which was on par with T_6, T_7 and T_8.

4.2.2.1.2.2 *Number of branches per plant*

The data on the influence of different hormonal seed priming treatments on number of branches of *A.paniculata* at different growth periods is presented in Table 42.

No branches were formed from the main stem at 30 DAS. At all other stages of observation, there was significant difference in number of branches among the hormonal treatments tried. At 60 DAS, T_1 recorded the highest number of branches (8.00) and the control plants recorded the lowest number of branches with a mean value of 1.33.

No change in number of branches was observed at harvesting stage from that at 90 DAS in any of the hormonal treatments tried. At 90 DAS and at harvest, GA_3 @ 1500µM (T_1) produced maximum number of branches (20.00). This was found on par with T_2, T_3, T_4 and T_5. The lowest value (13.67) was obtained in control treatment (T_9). This was found to be on par with the treatments T_5, T_6, T_7 and T_8.

4.2.2.1.2.3 *Collar girth (cm)*

The results on the effect of different hormonal treatments on collar girth in *A.paniculata* at different growth periods are illustrated in Table 43. The data described significant enhancement in collar girth at all stages of observation, except at 30 DAS.

GA_3 @ 1500µM (T_1) recorded maximum collar girth (1.10 cm) at 60 DAS. The least collar girth (0.63 cm) was recorded in BA @ 100µM (T_5), which was on par with all other treatments, except T_1.

No change in collar girth was observed at harvest from the values obtained at 90 DAS. At 90 DAS and at harvest, maximum collar girth (1.90 cm) was recorded in the treatment T_1, which was on par with T_2 (1.47 cm). The lowest collar girth (0.87 cm) was recorded in T_4 and T_9 which was on par with all other treatments, except T_1 and T_2.

4.2.2.1.2.4 *Number of flowers per plant*

Table 43 represents the data on number of flowers of *A.paniculata* in response to different hormonal treatments, at various growth stages. At 30 and 60 DAS, there was no flowering in the plants.

The highest number of flowers is observed in treatment T_1 (11.33) at 90 DAS which was significantly superior over all other treatments. Treatments T_3, T_5, T_6, T_8 and T_9 recorded the lowest number of flowers (2.00), which was found to be on par with T_2, T_4 and T_7 having a mean value of 3.33.

At harvest, T_1 recorded the highest number of flowers (21.33) at harvest, which was found on par with T_2. The least number of flowers was noticed in T_9 (2.00).

4.2.2.1.3 Effect of Biostimulant Seed Priming on Morphological Parameters in Transplanted *A.paniculata*

4.2.2.1.3.1 *Plant height (cm)*

The influence of various biostimulant seed priming treatments on plant height of *A. paniculata* is illustrated in Table 44. At 30, 60, 90 DAS and at harvest significant difference in plant height was observed among the treatments.

At 30 DAS, PG @ 1µM (T_5) showed maximum plant height (6.20 cm) which was observed to be on par with T_2, T_3 and T_6. The least plant height (3.13 cm) was recorded in T_7, the control treatment.

At 60 DAS, PG @ 1µM (T_5) recorded maximum plant height (20.80 cm) followed by those treated with T_1, T_2, T_3 and T_6, which were also on par with each other. The lowest plant height (14.77 cm) among the treatments was observed in control plants (T7) which was on par with T4 (16.07cm).

At 90 DAS, the highest value (42.30 cm) was recorded in T_5. T_4 registered minimum value (30.60 cm) for plant height and was found to be on par with all other treatments except T_5.

As at 90 DAS, at harvest also, the highest value (48.57 cm) was recorded in T_5. T_2 recorded the least value (35.57 cm) for plant height, which was observed to be on par all other treatments T_5.

4.2.2.1.3.2 Number of branches per plant

The results of the effect of biostimulant seed priming on number of branches of *A.paniculata* plants at different growth periods are presented in Table 44. Among the various pretreatments, significant variation was observed in number of branches at all stages of growth. No branching was observed at 30 DAS. At 60 DAS, plants obtained from seeds primed with SA @ 3000µM (T_4) and CH @ 5gL^{-1} (T_1) produced maximum number of branches (6.00). This was found on par with all the treatments except the control treatment (T_7), which recorded the lowest value (1.33).

At 90 DAS and at harvest, the number of branches remained same with respect to all the treatments. Plants from the treatment, PG @ 10µM (T_6) recorded significantly superior number of branches (18.00), which was found to be on par with T_5.The number of branches was found to be the lowest in T_4 and T_7 (13.67) which was observed to be on par with all other treatments except T_6.

4.2.2.1.3.3. Collar girth (cm)

The response of collar girth of *A. paniculata* to different biostimulant seed priming treatments recorded at various stages of plant growth is presented in Table 45.

At 30 DAS, T_1, T_2 and T_7 were found to have a significantly higher collar girth (0.10 cm) among the treatments. The rest of the treatments showed same values which was the lowest (0.09 cm) among the biostimulant pretreatments.

At 60 DAS, T_1 and T_2 recorded maximum value (0.87 cm) of collar girth. This was found to be on par with the control treatment, T_7 (0.73 cm). All other treatments except T_1 and T_2, were on par with SA @ 1500µM (T_3) which was recorded the lowest collar girth (0.63 cm).

At 90 DAS and at harvest, the collar girth were the same for all the treatments. PG @ 1µM (T_5) held the highest collar girth of 1.20 cm, which was found to be on par with treatment T_2 (1.00 cm). The lowest collar girth (0.83cm) was observed in PG @ 10 µM (T_6) which was on par with all other treatments except T_5.

4.2.2.1.3.4 *Number of flowers per plant*

The results of number of flowers per plant of *A.paniculata* at 30, 60, 90 DAS and at harvest, due to different biostimulant treatments, are depicted in table 45. There was no flowering both at 30 and 60 DAS. No significant difference was noticed in number of flowers per plant at 90 DAS and at harvest.

4.2.2.1.4 Effect of Seed Biopriming on Morphological Parameters in Transplanted *A.paniculata*

4.2.2.1.4.1 *Plant height (cm)*

The result on the effect of various biopriming treatments on plant height of *A.paniculata* is shown in Table 46. From the table it is clear that the biopriming treatments given to seeds had significant effect on plant height at all stages of observation.

At 30 DAS, T_3 showed maximum plant height (8.97cm) and T_4 recorded the lowest plant height (2.77 cm), which was on par with the control treatment (T_5). At 60 DAS, T_3 recorded the highest plant height (27.90 cm) and T_5 recorded the lowest plant height (14.77cm). At 90 DAS and at harvest, T_3 exhibited the higher plant height of 48.90 and 55.77 cm, respectively. At 90 DAS and at harvest, the lowest plant height (33.90 cm) was recorded in T_1 and T_5, respectively, which were observed to be on par with all other treatments except T_3.

4.2.2.1.4.2 *Number of branches per plant*

The data presented in Table 46 showed the results of number of branches in *A.paniculata* plants at 30 ,60 ,90 DAS and at harvest. The seed treatments with microbial cultures showed significant variation in number of branches at all stages of observation. At 30 DAS, the plant did not produce any branches. The plants from the seeds primed with *Bacillus velezensis* (T_3) recorded significantly higher number of branches (6.33) which was on par to treatments T_1 and T_4, while the control treatment (T_5) recorded the lowest (1.33) value.

There was no change in the number of branches at 90 DAS and at harvest for the different biopriming treatments. .At 90 DAS and at harvest, T_3 registered significantly higher number of branches (19.33). T_5 recorded the lowest value (13.67) which was on par with T_1.

4.2.2.1.4.3 *Collar girth(cm)*

The collar girth of *A.paniculata* in response to various biopriming treatments at 30, 60, 90 DAS and at harvest are presented in Table 47. Significant variation was observed in collar girth among the various treatments at all stages of observation.

At 30 DAS, T_1 and T_5 held the highest collar girth of 0.10 cm. The lowest collar girth (0.09 ±0.00cm) was observed in T_2, T_3 and T_4. At 60 DAS, the maximum collar girth (1.07±0.30cm) was obtained in T_3. The control treatment (T_5) and T_2 recorded the lowest value with 0.73 cm collar girth which was on par with T_1 and T_4. At 90 DAS and at harvest, plants from T_3 produced higher collar girth 1.50 cm. The control treatment (T_5) recorded the lowest mean value of 0.87 cm which was found to be on par with T_1, T_2 and T_4.

4.2.2.1.4.4 *Number of flowers per plant*

Table 47 represents the number of flowers per plants in response to various biopriming treatments. At 30 and 60 DAS, no flowers were formed in the plant. However, significant variation was observed among the treatments both at 90 DAS and at harvest. Treatment, T_3 scored the significantly higher value (5.33) for number of flowers. All the other treatment gave the same number of flowers which is also the lowest value (2.00). At harvest also, T_3 was found to give significantly higher number of flowers (22.67). The lowest number of flowers (2.00) was observed in the control treatment (T_5), which was on par with T_2.

4.2.2.1.5 Effect of Various Seed Pretreatments on Morphological Parameters in Transplanted *A. paniculata*

4.2.2.1.5.1 *Plant height (cm)*

Table 48 illustrates the plant height of *A.paniculata* plants inresponse to various seed pretreatments. There was a significant difference in plant height at all stages of observation.

At 30 DAS, plants from GA_3 @1500 µM (T_5) primed seeds recorded maximum plant height (11.57 cm) which was observed to be on par with hot water (T_3) which gave a plant height of 10.67 cm The least mean value (2.77 cm) of plant height was noticed in plants from *P. fluorescens* primed seeds and was found to be on par with control treatment (T_{23}).

At 60 DAS, among the various treatments, the highest (26.63 cm) plant height was seen in plants from sand paper scarified seeds (T_1) and seeds primed with GA @ 1500µM (T_5), whereas the lowest value (14.77 cm) was given by control treatment (T_{23}) which was on par with T_4, T_7, T_{14} and T_{16}.

At 90 DAS, the higher plant height (49.97 cm) was shown by T_5. This was on par with T_1, T_3, T_6, T_7, T_8, T_9, T_{17}, T_{21} and T_{22}. T_{16} was found to be the lowest (30.60 cm) and was on par with T_2, T_4, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{18}, T_1, T_{20} and T_{23}.

At harvest, the treatment T_1 had maximum plant height (57.87±1.34cm) which was comparable with T_3, T_5, T_6 and T_{21}. The minimum plant height of 35.57 cm was observed in T_{14} which was on par with T_4, T_{10}, T_{11}, T_{13}, T_{15}, T_{16}, T_{18}, T_{19}, T_{20}, T_{22} and T_{23}.

4.2.2.1.5.2 *Number of branches (No plant^{-1})*

The effect of different seed treatments on *A.paniculata* plants at 30, 60, 90 DAS and at harvest is shown in Table 48. Significant difference existed in the total number of branches, among the treatments at all the periods of observation. No branching was observed in plants at 30 DAS.

The highest number of branches was exhibited by GA_3 @1500µM (T_5) at 60 DAS with a mean value of 8.00 and was on par with T_1, T_3, T_{13}, T_{16} and T_{21}. The number of branches was found to be the lowest (1.33) in the control treatment (T_{23}) and was on par with T_4.

At 90 DAS and at harvest, plants from sand paper scarified seeds (T_1) and water soaked seeds (T_2) held the highest value (22.00) for number of branches and found to be on par with T_3, T_5, T_6, T_7, T_8, T_{18} and T_{21}. The plants from untreated seeds (T_{23}) and SA @3000 µM primed seeds (T_{16}) recorded the lowest value (13.67) and was found to be on par with all the other remaining treatments.

4.2.2.1.5.3 *Collar girth(cm)*

The influence of different seed treatments on collar girth of *A.paniculata* at 30,60,90 DAS and at harvest is illustrated in Table 49. The collar girth varied significantly in *A.paniculata* among the different seed treatments.

The maximum collar girth (0.13 cm) was obtained in the hot water treatment (T_3) at 30 DAS. Treatments T_2, T_4, T_{15}, T_{16}, T_{17}, T_{18}, T_{20}, T_{21} and T_{22} recorded the lowest collar girth with the value 0.09 cm which was found to be on par with all the treatments except T_3.

At 60 DAS, seed treatment with GA_3 @1500µM (T_5) produced higher quantity of collar girth (1.10 cm) which was observed to be on par with T_1 (0.97 cm) and T_{21} (1.07 cm). Plants form sulphuric acid treated seeds (T_4) recorded the lowest mean value of 0.60 cm which was found to be on par with T_2, T_6, T_7, T_9, T_{10}, T_{11} and T_{15}, T_{16}, T_{17}, T_{18}, T_{20} and T_{23}.

At 90 DAS and at harvest, the collar girth (1.90 cm) was observed to be significantly higher in GA_3 @1500µM (T_5), which was on par with T_3 and T_{21} with a collar girth of 1.83 cm and 1.50 cm, respectively. The lowest collar girth was recorded in T_{18} (0.83 cm). However, it was on par with T_4, T7, T_8, T_9, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}, T_{19}, T_{20}, T_{22} and T_{23}.

4.2.2.1.5.4 *Number of flowers per plant*

Table 49 gives the number of flowers per plant of the crop at 30,60,90 DAS and at harvest in response to various seed pretreatments. No flowering was observed at 30 and 60 DAS. A significant variation was observed both at 90 DAS and at harvest. At 90 DAS, T_5 was found to be significantly superior with a mean value of 11.33. The plants recorded the least value (2.00±0.00) for number of flowers in T_2, T_4, T_7, T_9, T_{10}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{19}, T_{20}, T_{22} and T_{23}. At harvest, T_3 showed maximum number of flowers (27.33) and was found to be on par with T_1 (19.33), T_5 (21.33) and T_{21} (22.67). T_{23} recorded the lowest value (2.00) for number of flowers per plant and was found on par with T_2, T_4, T_7, T_8, T_{10}, T_{11}, T_{12}, T_{14}, T_{15}, T_{16}, and T_{22}.

4.2.2.2 Phenological Parameters

4.2.2.2.1 Effect of Physical Seed Pretreatments on Phenological Parameters in Transplanted *A.paniculata*

4.2.2.2.1.1 *Days to flower initiation*

The influence of various physical seed treatments on days to flower initiation in *A.paniculata* is depicted in Table 50. There was no significant variation in days to flower initiation among the physical pretreatments tried.

4.2.2.2.1.2 *Days to fruit set*

The influence of various physical seed treatments on days to fruit set in *A.paniculata* is depicted in Table 50. Significant variation was observed among the treatments with respect to days to fruit set. Hot water treatment (T_3) took maximum (22.67) days to fruit set. Water soaking (T_2) took minimum 15.00 days to fruit set. T_4 and control treatment did not set fruits.

4.2.2.2.2 Effect of Hormonal Seed Pretreatments on Phenological Parameters of Transplanted *A.paniculata*

4.2.2.2.2.1 *Days to flower initiation*

The data on days to flower initiation of *A. paniculata* in response to various hormonal seed treatments is depicted in Table 51. There was no significant variation in days to flower initiation among the treatments

4.2.2.2.2 *Days to fruit set (Days)*

The data on days to fruit set of *A.paniculata* in response to various hormonal seed treatments is depicted in Table 51. There was no significant variation observed among the treatments.

4.2.2.2.3 Effect of Biostimulant Seed Priming on Phenological Parameters of Transplanted *A.paniculata*

4.2.2.2.3.1 *Days to flower initiation (Days)*

Table 52 shows the result of days to flower initiation in *A.paniculata* due to biostimulant seed priming. The data revealed that no significant variation existed among the biostimulant seed priming treatments with respect to days to flower initiation.

4.2.2.2.3.2 *Days to fruit set (Days)*

Table 52 shows the result of days to fruit set of *A.paniculata*.No Significant variation was observed among the biostimulant treatments for days to fruit set.

4.2.2.2.4 Effect of Biopriming of Seeds on Phenological Parameters of Transplanted *A.paniculata*

4.2.2.2.4.1 *Days to flower initiation (Days)*

The result of days for flower initiation of the crop in response to various biopriming treatments is presented in Table 53. The data confirmed that treatment with microbial cultures did not significantly influence days to flower initiation.

4.2.2.2.4.2 *Days to fruit set (Days)*

The result of days to fruit set of the crop in response to various biopriming treatments is presented in Table 53. The treatment with microbial cultures did not significantly influenced days to fruit set.

4.2.2.2.5 Effect of Various Seed Pretreatments on Phenological Parameters of Transplanted *A.paniculata*

4.2.2.2.5.1 *Days to flower initiation (Days)*

The result of days to flower initiation is illustrated in Table 54 indicated no significant variation in among the various seed pretreatments tried.

4.2.2.2.5.2 *Days to fruit set (Days)*

The result of days to fruit set in *A.paniculata* is illustrated in Table 54. Days to fruit set recorded significantly higher number of days (24.00) to fruit set in plants obtained from seeds primed with GA_3 @3000µM (T_6). While minimum (15.00) days to fruit set was observed in T_2. Treatments T_4, T_7, T_8, T_{10}, T_{11}, T_{12}, T_{15}, T_{16} and T_{23} did not set fruit until harvest (110 days).

4.2.2.3 Yield Parameters

4.2.2.3.1 Effect of Physical Seed Pretreatments on Yield Parameters in Transplanted *A.paniculata*

Table 55 shows the effect of physical treatments on yield parameters *viz.*, shoot weight, root weight, whole plant weight, root length, root diameter and root volume of *A.paniculata* plants at harvest (110 DAS). The yield parameters with respect to fruits and seeds *viz.*, number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are illustrated in Table 56.

4.2.2.3.1.1 *Shoot weight (fresh and dry) (g plant^{-1})*

The highest shoot weight (Fresh -52.47 g plant^{-1}; dry-20.77 g plant^{-1} was obtained in plants raised from hot water treated seeds (T_3), followed by T_1. The fresh weight of T_3 was observed to be on par with that of T_1. The minimum shoot fresh weight (28.63 g plant^{-1}) was observed in T_4 which was on par with T_2 and T_5, while lowest dry weight (10.63 g plant^{-1}) was observed in T_5, which was on par with all other treatments except T_1.

4.2.2.3.1.2 *Root weight (fresh and dry) (g plant^{-1})*

The various treatments showed a significant difference in the root fresh and dry weight. Treatment T_1 recorded maximum root weight (fresh-7.83 g plant^{-1}; dry-1.42 g plant^{-1}) and found to be on par with treatment T_3. The lowest (fresh-3.1 g plant^{-1}, dry-0.45 g plant^{-1}) root weight was observed in the control treatment T_5 and was on par with T_2.

4.2.2.3.1.3 ***Whole Plant biomass (fresh and dry) (g plant^{-1})***

The result of days to flower initiation indicated significant variation among the various seed pretreatments tried. Treatment T_3 recorded maximum root weight (fresh-59.60 g plant^{-1}; dry-21.90 g plant^{-1}). The highest fresh weight was found to be on par with treatment T_1. The lowest (fresh-32.87g plant^{-1}, dry-11.08 g plant^{-1}) root weight was observed in the control treatment T_5 and was on par with T_2 and T_4.

4.2.2.3.1.4 Root length (cm)

The root length exhibited significant variation among the physical pretreatments. The highest root length was recorded in T_3 (40.23 cm) followed by T_2 (37.77 cm) and T_1 (33.27 cm) which were found to be on par with each other. The minimum root length was recorded in control treatment (16.37 cm).

4.2.2.3.1.5 Root diameter (cm)

At harvest, a significant difference in root diameter was observed among the physical treatments. Scarification treatment (T_1) showed maximum root diameter (3.70 cm) which was on par with T_3 (3.30 cm). The least root diameter (2.37 cm) was recorded in T_5, which was on par with T_2 and T_4.

4.2.2.3.1.6 Root volume (cm^3)

The maximum root volume (9.17 cm^3) was obtained in plants raised from seeds subjected to scarification treatment (T_1), which was on par with that of hot water treated seeds (T_3) with a root volume of 7.57 cm^3. The control treatment (T_5) recorded the lowest (4.23 cm^3) root volume, which was on par with T_2 (5.00 cm^3) and T_4 (5.57 cm^3).

4.2.2.3.1.7 Number of fruits per plant

The number of fruits per plant in *A.paniculata* at harvest as influenced by physical seed treatments are presented in Table 56. There was no significant difference in the number of fruits per plant. There was no fruit set in the plants raised from sulphuric acid treated seeds and untreated seeds.

4.2.2.3.1.8 Fruit weight (Fresh and dry) (g plant^{-1})

There was no significant difference in both fresh and dry weight of fruits at harvest. There was no fruit formation in T_4 and control plants.

4.2.2.3.1.9 Seed yield (g plant^{-1})

The various treatments did not show no significant difference in the seed yield (g plant^{-1}).

4.2.2.3.1.10 Thousand (1000) seed weight (g)

The thousand (1000) seed weight did not vary significantly among the physical treatments (T_1, T_2, T_3) that gave fruits. Treatments T_4 and T_5 did not set fruits.

4.2.2.3.2 Effect of hormonal seed priming on yield parameters in transplanted *A.paniculata*

Table 57 depicts the effect of hormonal seed priming treatments on yield parameters *viz.*, shoot weight, root weight, whole plant weight, root length, root diameter and root volume of *A.paniculata* plants at harvest (110 DAS). The yield parameters with respect to fruits and seeds *viz.*, number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are presented in Table 58.

4.2.2.3.2.1 Shoot fresh weight (g plant^{-1})

The data in Table 57 confirmed hormonal seed priming treatments significantly influenced shoot weight. T_1 showed significantly higher shoot weight (fresh-46.60 g plant^{-1}; dry-21.57 g plant^{-1}) which were on par with T_2. The minimum shoot fresh weight was recorded in T_9 (fresh -29.77 g plant^{-1}) which was on par with T_3, T_4, T_5, T_6, T_7 and T_8. The minimum shoot dry weight (9.93 g plant-1) was recorded in T_4, which was on par with T_3, T_5, T_6, T_7, T_8 and T_9.

4.2.2.3.2.2 Root weight (fresh and dry) (g plant^{-1})

The root weight varied significantly among the treatments. The root weight was found to be significantly higher in T_1 (fresh-10.03 g plant^{-1}; dry-2.02 g plant^{-1}). T_9 was

recorded the lowest (fresh-3.10 g plant^{-1}; dry-0.45 g plant^{-1}) root weight, to which the fresh weight was on par with T_3, T_5, T_7 and T_8.

4.2.2.3.2.3 Whole Plant biomass (fresh and dry) (g plant^{-1})

The whole plant biomass varied significantly among the treatments. The highest whole plant biomass (Fresh -56.63 g plant^{-1}; dry-23.60 g plant^{-1} was obtained in plants raised from T_1. The fresh weight of T_1 was observed to be on par with that of T_2. The minimum shoot fresh weight (32.87 g plant^{-1}) was observed in T_9 while lowest dry weight (11.01 g plant^{-1}) was observed in T_4. Both these treatments were on par with all other treatments except T_1 and T_2.

4.2.2.3.2.4 Root length (cm)

There was significant variation in root length among the treatments. The highest value for root length was noticed in treatment T_1 (44.57 cm) and the control treatment (T_9) recorded least value (16.37 cm). However, this was found to be on par with T_6 (22.87 cm).

4.2.2.3.2.5 Root diameter (cm)

From the table 57, it is clear that hormonal seed priming treatments had significant effect on root diameter. GA_3 @1500µM (T_1) showed maximum root diameter (3.73 cm) which was on par comparable with T_4 (3.17 cm). The control treatment (T_9) recorded the lowest value (2.37cm) which was on par with all the other treatments T_3, T_5, T_6, T_7 and T_8.

4.2.2.3.2.6 Root volume (cm^3)

The root volume varied significantly in *A.paniculata* among the different hormonal seed pretreatments. *A.paniculata* plants raised from GA_3@1500 µM (T_1) primed seeds produced higher root volume (8.60 cm^3). The plants raised from BA @ 100 µM (T_5) recorded the lowest (3.20 cm^3) root volume. This was found to be on par with T_2, T_3, T_6, T_7 and T_8.

4.2.2.3.2.7 Number of fruits per plant

At harvest, the treatment with GA_3@1500µM (T_1) recorded higher number of fruits per plant (21.67) and T_5 held the minimum value (3.67) for number of fruits. No fruit formation was observed in any other treatments except T_1, T_2 and T_5 until harvest.

4.2.2.3.2.8 Fruit weight (Fresh and dry) (g plant^{-1})

The observations recorded significant variation in the case of fruit fresh weight, while the dry weight did not show any variation. GA_3@1500µM (T_1) recorded maximum (1.16 g plant^{-1}) fruit fresh weight and the lowest value was observed in T_5 (0.17 g plant^{-1}). All the other treatments except T_1, T_2 and T_5 reported did not set fruit until harvest.

4.2.2.3.2.9 Seed yield (g plant^{-1})

The seed yield (g plant^{-1}) did not show any significant variation among the hormonal seed priming treatments.

4.2.2.3.2.10 Thousand (1000) seed weight (g)

The data in Table 58 confirmed that hormonal seed priming treatments significantly influenced thousand (1000) seed weight with respect to those treatments (T_1, T_2 and T_5) that set fruits. T_2 recorded the highest value (1.64 g) and T_5 recorded the lowest value which was on par with T_1.

4.2.2.3.3 Effect of Biostimulant Seed Priming on Yield Parameters in Transplanted *A.paniculata*

The effect of biostimulant seed priming treatments on yield parameters *viz.,* shoot weight, root weight, whole plant weight, root length, root diameter and root volume of *A.paniculata* plants at harvest (110 DAS) is presented in table 59. The yield parameters with respect to fruits and seeds *viz.*, number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are depicted in Table 60.

4.2.2.3.3.1 Shoot weight (fresh and dry) (g plant^{-1})

The maximum shoot weight (fresh-33.70 g plant^{-1}; dry-12.27 g plant^{-1}) was recorded in treatment T_5 at harvest and was comparable with the T_1, T_2 and the control (T_7). T_6 showed the least shoot fresh weight (fresh-22.30 g plant^{-1}; dry 6.03 g plant^{-1}) among the treatments, which was on par with T_2, T_3 and T_4.

4.2.2.3.3.2 Root weight (fresh and dry) (g plant^{-1})

The effect of various biostimulant seed pretreatments on root fresh weight of *A.paniculata* plants at harvest is presented in the table 59.The data confirmed the profound influence of biostimulant treatments on root fresh weight.

T_5 recorded the highest root weight (fresh- 5.27 g plant^{-1}; dry- 0.93 g plant^{-1}) and was on par with T_3 both on fresh and dry weight basis. T_2 recorded the lowest root weight (fresh - 2.60 g plant^{-1}, dry- 0.41 g plant^{-1}) which was on par with the treatments T_4, T_6 and T_7.

4.2.2.3.3.3 Whole plant weight (fresh and dry) (g plant^{-1})

The data about whole plant weight the profound influence of biostimulant treatments on whole plant biomass. The maximum whole plant weight (fresh-38.97 g plant^{-1}; dry-13.14 g plant^{-1}) was recorded in treatment T_5 and was comparable with the T_1 and the control treatment (T_7). T_6 showed the least shoot fresh weight (fresh-25.00 g plant^{-1}; dry 6.45 g plant^{-1}) among the treatments, which was on par with T_2, T_3 and T_4 and T_7.

4.2.2.3.3.4 Root length (cm)

The various biostimulant priming treatments showed a significant difference in the root length. T_5 recorded the maximum value (35.43 cm) and found to be on par with treatments T_3 (29.73 cm) and T_6 (27.17 cm). Minimum root length was recorded in control treatment, T_7 (16.37 cm) and was found to be on par with T_1 and T_2.

4.2.2.3.3.5 Root diameter (cm)

Plants raised from PG @ 1µM (T_5) primed seeds recorded maximum root diameter (3.07 cm) which was on par with T_1 and T_6. The least value was given by SA @1500µM

treated seeds (T_3) which gave a root diameter of 2.30 cm, which was found to be on par with treatments T_1, T_2, T_4 and T_7.

4.2.2.3.3.6 Root volume (cm^3)

The root volume (6.00 cm^3) was observed to be significantly higher in T_5. This was observed to be on par with T_4 with a root volume of 4.67 cm^3. The lowest root volume recorded in T_6 (3.27cm^3) which was on par with all the treatments except T_4 and T_5.

4.2.2.3.3.7 Number of fruits per plant

At harvest, no significant difference was observed in number of fruits per plant among the biostimulant priming treatments. Plants from other treatments showed no sign of fruiting till harvest.

4.2.2.3.3.8 Fruit weight (Fresh and dry) (g $plant^{-1}$)

The fruit weight both on fresh and dry weight basis showed a significant variation among the biostimulant seed priming treatments tried. T_5 recorded the highest value (fresh-0.34 g $plant^{-1}$, dry-0.30 g $plant^{-1}$) and was on par with treatment T_6. T_2 recorded the lowest value (fresh-0.092 g $plant^{-1}$, dry-0.08 g $plant^{-1}$).

4.2.2.3.3.9 Seed yield (g $plant^{-1}$)

The data in table 60 showed that biostimulant treatments have significant influence of on seed yield. T_6 recorded the highest value (0.024 g $plant^{-1}$) which was on par with treatment T_5. The lowest value was recorded in T_2 (0.001 g $plant^{-1}$).

4.2.2.3.3.10 Thousand (1000) seed weight (g)

Significant variation was noticed among the treatments (T_1, T_5, T_6) for thousand (1000) seed weight in *A. paniculata* plants that fruited. T_1 recorded the highest value (1.67g) and lowest value was observed in T_5. Both treatments were on par with T_6.

4.2.2.3.4 Effect of Seed Biopriming on Yield Parameters in Transplanted *A. paniculata*

The response of *A.paniculata* plants at harvest (110 DAS) on yield parameters *viz.*, shoot weight, root weight, whole plant weight, root length, root diameter and root volume

due to seed bio priming treatments is presented in Table 31. The yield parameters with respect to fruits and seeds *viz.*, number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are illustrated in Table 32.

4.2.2.3.4.1 Shoot weight (fresh and dry) (g plant^{-1})

The shoot weight varied significantly among the treatments with maximum value (fresh-46.30 g plant^{-1}; dry 15.5 g plant^{-1}) obtained in plants from seeds subjected to priming with *B. velezensis* (T_3). This was found to be on par with that of *P. fluorescens* (T_4). The least shoot weight (fresh- 27.57 g plant^{-1}; 7.83 g plant^{-1}) was observed in treatment T_2 (*B. amyloliquefaciens*) This was on par with treatments T_1 (*B. pumilus*) and T_5 (Control treatment).

4.2.2.3.4.2 Root weight (fresh and dry) (g plant^{-1})

The root yield varied significantly among the treatments with respect to fresh weight only.

Maximum (7.67 g plant^{-1}) root fresh weight was obtained from the plants raised from seeds primed with *B. velezensis* (T_3) and the mean value recorded were. The least root fresh weight (2.73g plant^{-1}) was observed in treatments. T_1 and T_5 (Control).

4.2.2.3.4.3 Whole plant biomass (fresh and dry) (g plant^{-1})

The whole plant biomass varied significantly among the treatments with maximum value (fresh-53.97 g plant^{-1}; dry 24.73 g plant^{-1}) obtained in plants from seeds subjected to priming with *B. velezensis* (T_3) and T_2 (*B. amyloliquefaciens*) respectively. The least shoot weight (fresh- 30.83 g plant^{-1}; dry-10.86 g plant^{-1}***)*** was observed in treatment T_2 (*B. amyloliquefaciens*) and T_1 (*B. pumilus*) respectively. This was found to be on par with all treatments except T_3 under fresh conditions and T_2 under dry conditions.

4.2.2.3.4.4 Root length (cm)

The data (Table 61) indicated that there was significant variation among the treatments with respect to the root length.

The root length (46.23 cm) was found to be higher T_3. The control treatment (T_5) was recorded the lowest root length with a mean value of 16.37±1.23cm, which was observed to be on par with T_4.

4.2.2.3.4.5 Root diameter (cm)

Significant variation was observed in terms of root diameter among the treatments of which B. *velezensis* (T_3) showed maximum root diameter (3.67 cm). T_2 and T_5 recorded the lowest value (2.37 cm) which was on par with T_1 and T_4.

4.2.2.3.4.6 Root volume (cm^3)

A significantly higher root volume was observed in treatment T_3 (8.00 cm^3). The control treatment (T_7) recorded the lowest root volume (4.23 cm^3), which was found to be on par with all the other treatments except T_3.

4.2.2.3.4.7 Number of fruits per plant

From the data (Table 62), it is clear that biopriming had no significant effect on number of fruits. The control treatment did not show fruit formation.

4.2.2.3.4.8 Fruit weight (Fresh and dry) (g $plant^{-1}$)

The biopriming treatments had significant effect on fresh fruit weight, whereas no variation was seen in dry weight. T_3 showed the highest fruit weight (fresh -0.19 g $plant^{-1}$) was on par with T_1. The lowest value (fresh-0.02 g $plant^{-1}$) was recorded in T_4. The control treatment did not set fruit.

4.2.2.3.4.9 Seed yield (g $plant^{-1}$)

The seed yield varied significantly among the treatments among the biopriming treatments tried. T_3 showed the highest value (0.057 g $plant^{-1}$). The lowest value (0.002 g $plant^{-1}$) was recorded in T_2 and was on par with T_4. The control treatment did not set fruit.

4.2.2.3.4.10 Thousand (1000) seed weight (g)

The thousand (1000) seed weight did not vary significantly among the treatments (T_1, T_2, T_3, T_4) that set fruits in which T_1 and T_4 showed the highest value (1.62g). This was on par with T_3. The lowest value (1.50 g) was recorded in T_2.

4.2.2.3.5 Effect of Various Seed Pretreatments on Yield Parameters in Transplanted *A. paniculata*

The effect of various seed priming treatments on yield parameters *viz.*, shoot weight, root weight, whole plant weight, root length, root diameter and root volume of *A.paniculata* plants at harvest (110 DAS) is presented in table 63. The yield parameters with respect to fruits and seeds *viz.*, number of fruits per plants, fruit weight per plant, seed yield per plant and thousand (1000) seed weight are depicted in Table 64.

4.2.2.3.5.1 Shoot weight (fresh and dry) (g plant^{-1})

The highest shoot fresh weight (52.47g plant^{-1}) was observed in T_3 and was found to be on par with, T_1, T_5, T_6 and T_{21}. Shoot dry weight (21.57 g plant) was the highest for T_5 and was on par with T_3. The lowest (fresh-22.30 g plant^{-1}; dry -6.03 g plant^{-1}) shoot weight was recorded in T_{18} and were observed to be on par with T_4, T_9, T_{10}, T_{14}, T_{15}, T_{16}, T_{19}, T_{20} and T_{23}.

4.2.2.3.5.2 Root weight (fresh and dry) (g plant^{-1})

The root weight (fresh-10.03 g plant^{-1}; dry-2.02 g plant^{-1}) of *A. paniculata* found to be higher in T_5. The lowest value for root weight (fresh- 2.60 g plant^{-1}; 0.41 g plant$^{-1)}$ was observed in $T_{14}$and were on par with T_2, T_{16}, T_{18}, T_{19}, T_{20} and T_{23}.

4.2.2.3.5.3 Whole plant biomass (fresh and dry) (g plant^{-1})

Significant difference was observed in whole plant biomass among the treatments. The highest fresh whole plant biomass (59.60 g plant^{-1}) was observed in T_3 and was found to be on par with, T_1, T_5, T_6 and T_{21}. Whole plant biomass under dry conditions (23.59 g plant) was the highest for T_{18} and was on par with T_3. T_4, T_{13}, T_{14}, T_{15}, T_{16}, T_{19}, T_{20} and T_{23}. The

lowest (fresh-25.00 g plant^{-1}; dry -6.03 g plant^{-1}) whole plant biomass was recorded in T_{18} and were observed to be on par with T_{14}, T_{15}, T_{16}, T_{19}, T_{20} and T_{23}.

4.2.2.3.5.4 Root length (cm)

The data confirmed the profound influence of various seed treatments on root length. T_{21} recorded the highest value (46.23 cm) and was on par with T_3 and T_5. T_{23} recorded the lowest root length with a value of 16.37 cm and was found to be on par with T_{10}, T_{13}, T_{14} and T_{22}.

4.2.2.3.5.5 Root diameter (cm)

Significant difference was observed in root diameter among the treatments. T_5 recorded the highest root diameter (3.73 cm) which was statistically on par with T_1, T_3 and T_{21}.T_{15} recorded the lowest root diameter with a mean value of 2.30 cm and this was found to be on par with T_2, T_4, T_{10}, T_{13}, T_{14}, T_{16}, T_{18}, T_{20}, T_{22} and T_{23}.

4.2.2.3.5.6 Root volume (cm^3)

There was significant difference in root volume, among the treatments. Out of all the treatments, T_1 recorded the highest root volume of 9.17 cm^3 which was found on par with T_3, T_5 and T_{21}. The least root volume was noticed in T_9 (3.20 cm^3) and was on par with T_6, T_7, T_8, T_{10}, T_{12}, T_{13}, T_{14}, T_{15}, T_{18}, T_{19}, T_{20}, T_{22} and T_{23}.

4.2.2.3.5.7 Number of fruits per plant

At harvest, there was significant variation in number of fruits (plant^{-1}) among the treatments. Plants from seeds primed with GA @1500 µM (T_5) recorded maximum number of fruits per plant (21.67). T_{20} gave the least value (2.00) which was on par with T_2, T_9, T_{13}, T_{14}, T_{17}, T_{18}, T_{19} and T_{22}.

4.2.2.3.5.8 Fruit weight (fresh and dry) (g plant^{-1})

There was a significant difference found in the fresh weight and dry weight of *A.paniculata* fruits in response to various seed treatments at harvest. At harvest, T_5 recorded significantly higher value for fruit weight(fresh-1.16 g plant^{-1}; dry -0.127 g plant^{-1}) among the treatments and was on par with T_3. The lowest weight for fruits (fresh- 0.02 g plant^{-1}; dry-

0.006 g plant^{-1}) was recorded in T_{22} and found to be on par with $T_{2,}$ T_9, $T_{13,}$ $T_{14,}$ $T_{18,}$ T_{19} and T_{21}.

4.2.2.3.5.9 Seed yield (g plant^{-1})

The seed yield (g plant^{-1}) of *A.paniculata* found to be the highest (0.057 g plant$^{-1)}$ .The lowest value (0.001 g plant^{-1}) for seed yield was observed in T_{14} which was on par with T_{20} and $T_{22.}$ Among the treatments $T_{4,}$ T_7, T_8, T_{10}, T_{11}, T_{12}, $T_{15,}$ T_{16} and T_{23} gave no fruits.

4.2.2.3.5.10 Thousand (1000) seed weight (g)

There was a significant variation among the treatments, with respect to thethousand (1000) seed weight. The highest (1.67 g) thousand (1000) seed weight as recorded in T_2 and T_{13}. This was found to be on par with T_{17}, T_{18}, $T_{19,}$ T_{21} and T_{22}. The lowest (1.50 g) thousand (1000) seed weight was recorded in $T_{20.}$ and was on par with T_1, T_3, T_5 and $T_{9.}$

4.2.3 INCIDENCE OF PESTS AND DISEASES

No pests and diseases were observed at all stages of plant growth during the course of the study.

Table 5. Effect of physical treatments on seed germination and seedling parameters of *Withania somnifera.*

T. No.	Physical treatment	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI
T_1	SC	58.00±1.75^{b}	57.00±1.44^{b}	2.97±0.10^{b}	10.00±1.00	8.03±0.02^{a}	3.30±1.99^{b}	2.73±1.45	11.33±1.82^{ab}	6.58±1.05^{b}
T_2	WS	84.00±1.52^{a}	83.67±1.42^{a}	4.87±0.06^{a}	8.67±0.57	9.23±0.09^{a}	4.07±0.06^{a}	2.3±0.04	13.30±0.01^{a}	11.16±0.25^{a}
T_3	HW	76.67±1.93^{a}	76.67±1.93^{a}	3.97±0.25^{a}	10.67±1.15	9.67±0.14^{a}	4.73±1.21^{a}	2.13±0.22	14.40±0.79^{a}	11.00±0.29^{a}
T_4	CSA	46.00±1.41^{c}	42.67±0.82^{b}	2.20±0.01^{b}	11.00±1.00	7.00±0.84^{b}	5.20±0.81^{a}	1.37±0.00	12.20±3.27^{a}	5.58±0.31^{b}
T_5	Control	51.33±2.28^{bc}	50.67±2.16^{b}	2.40±0.13^{b}	10.67±1.15	4.70±0.02^{b}	1.87±0.14^{b}	2.60±0.52	6.57±0.01^{b}	3.36±0.29^{b}
SE m (±)		3.451	4.216	0.273	0.816	0.417	0.750	0.547	0.887	0.541
C.D. (0.05)		11.016	25.129	1.628	NS	2.491	1.47	NS	5.29	3.226

T. No–Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; Gn- germination;S- Survival; GI-Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index; Each figure represents mean (±SD) of three replications

Table 6. Effect of hormonal priming on seed germination and seedling parameters of *Withania somnifera.*

T. No.	Hormones	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI
T_1	GA_3 @1500µM	82.00±1.52^{a}	82.00±1.52^{a}	4.87±0.20	8.33±0.57^{b}	9.50±0.39^{a}	4.90±0.12^{a}	1.97±0.04	14.40±0.39^{a}	11.80±1.11^{a}
T_2	GA_3 @3000µM	79.33±1.55^{a}	79.00±1.44^{a}	4.63±0.06	8.00±0.00^{b}	9.33±0.36^{a}	3.43±1.20^{ab}	2.97±1.42	12.77±1.14^{a}	10.10±0.97^{a}
T_3	IAA @ 0.1µM	57.33±1.70^{bc}	57.33±1.70^{b}	3.57±0.10	7.33±0.57^{b}	8.63±0.12^{a}	3.17±0.74^{ab}	2.9±0.81	10.90±3.25^{b}	6.30±2.17^{b}
T_4	IAA @ 1µM	58.00±1.75^{bc}	57.67±1.72^{b}	3.57±0.12	8.00±0.00^{b}	7.03±0.32^{b}	3.23±0.14^{ab}	2.2±0.21	10.27±0.12^{b}	5.97±0.60^{bc}
T_5	BA @ 100µM	63.33±0.82^{b}	43.33±4.43^{c}	4.47±0.01	7.00±0.00^{b}	8.67±0.12^{a}	3.03±1.21^{bb}	3.07±0.94	11.70±1.33^{a}	7.43±0.34^{b}
T_6	BA @ 300µM	60.00±2.04^{bc}	60.00±2.04^{b}	3.77±0.25	8.00±0.00^{b}	7.53±0.17^{b}	3.27±0.22^{ab}	2.33±0.14	10.80±0.37^{b}	6.50±1.11^{b}
T_7	TDZ @ 200µM	61.33±1.55^{bc}	61.33±1.55^{b}	3.70±0.16	8.00±0.00^{b}	7.97±0.44^{b}	2.40±0.09^{b}	3.33±0.30	10.37±0.41^{b}	6.37±0.69^{b}
T_8	TDZ @ 400µM	60.00±2.15^{bc}	60.00±2.15^{b}	3.57±0.16	8.33±0.57^{b}	7.67±0.22^{b}	4.57±0.14^{a}	1.67±0.00	10.73±3.12^{b}	6.50±3.16^{b}
T_9	Control	51.33±2.28^{c}	50.67±2.16^{bc}	2.40±0.13	10.67±1.15^{a}	4.70±0.02^{c}	1.87±0.14^{b}	2.60±0.52	6.57±0.01^{c}	3.36±0.29^{c}
SE m (±)		3.348	3.330	0.657	0.415	0.419	0.546	0.571	0.867	0.880
C.D. (0.05)		10.025	13.25	NS	1.339	1.349	1.758	NS	2.793	2.833

T. No – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; Gn- germination; S- Survival; GI- Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index; Each figure represents mean (±SD) of three replications.

Table 7. Effect of biostimulant priming on seed germination and seedling parameters of *Withania somnifera.*

T. No.	Biostimulant	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI
T_1	CH @ 5gL^{-1}	32.67±2.43^{c}	32.33±2.45^{b}	1.83±0.37	9.00±0.00^{a}	7.10±0.28^{a}	3.10±0.07	2.30±0.12	10.20±0.09^{ab}	3.30±1.33^{b}
T_2	CH @ 10 gL^{-1}	32.67±2.01^{c}	32.67±2.01^{b}	1.80±0.16	9.00±0.00^{a}	6.83±0.42^{a}	3.20±0.28	1.97±0.02	10.03±1.34^{a}	3.27±0.24^{b}
T_3	SA @ 1500µM	36.67±2.28^{c}	35.67±2.08^{b}	2.03±0.36	9.00±1.00^{a}	7.47±0.09^{a}	3.17±1.10	2.53±0.60	10.63±1.82^{a}	3.93±1.42^{b}
T_4	SA @ 3000µM	39.33±1.88^{c}	39.33±1.88^{a}	2.37±0.04	7.67±0.57^{b}	7.13±0.12^{a}	2.87±0.72	2.60±0.52	9.33±4.33^{a}	3.60±0.12^{b}
T_5	PG @ 1µM	62.00±1.52^{a}	61.33±1.55^{a}	4.47±0.16	6.67±0.57^{b}	7.80±0.21^{a}	2.73±1.70	3.33±2.40	10.53±0.85^{ab}	6.57±1.00^{a}
T_6	PG @ 10µM	64.00±2.47^{a}	64.00±2.47^{a}	4.77±0.37	6.67±0.57^{b}	7.53±1.08^{a}	3.03±0.44	2.53±0.26	10.57±2.29^{ab}	6.67±0.14^{a}
T_7	Control	51.33±2.28^{b}	50.67±2.16^{ab}	2.40±0.13	10.67±1.15^{a}	4.70±0.02^{b}	1.87±0.14	2.60±0.52	6.57±0.01^{b}	3.36±0.29^{b}
SE m (±)		4.794	6.517	1.08	0.563	0.480	0.652	0.651	1.012	0.659
C.D. (0.05)		14.683	26.069	NS	2.253	1.921	NS	NS	4.047	2.636

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol; Gn- germination; S- Survival; GI- Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index; Each figure represents mean (±SD) of three replications.

Table 8. Effect of biopriming on seed germination and seedling parameters of *Withania somnifera.*

T. No.	Microbes	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI
T_1	*BP*	60.00±2.54	60.00±2.54	3.87±0.76	7.33±0.57^{a}	7.77±1.12^{ab}	3.70±0.76	2.27±0.80	11.47±0.26	6.90±2.47^{a}
T_2	*Bam*	53.33±2.19	52.67±2.16	3.57±0.25	7.67±1.15^{a}	7.37±0.52^{ab}	3.20±1.21	2.47±0.54	10.57±3.16	5.53±0.02^{ab}
T_3	*BV*	57.33±2.16	56.67±2.19	3.67±0.06	8.33±0.57^{a}	7.87±0.26^{ab}	3.20±0.19	2.47±0.09	10.17±5.24	5.83±3.69^{ab}
T_4	*PF*	56.67±2.19	57.33±2.16	3.80±0.37	7.33±0.57^{a}	8.10±0.04^{a00}	3.40±1.17	2.50±0.49	11.50±1.51	6.47±0.14^{a}
T_5	Control	51.33±2.28	50.67±2.16	2.40±0.13	10.67±1.15^{a}	4.70±0.02^{b}	1.87±0.14	2.60±0.52	6.57±0.01	3.36±0.29^{b}
SEm(±)		5.224	7.205	0.613	0.699	0.537	0.680	0.572	1.166	0.940
C.D. (0.05)		NS	NS	NS	NS	3.198	NS	NS	NS	2.60

T. No. – Treatment Number; *BP- Bacillus pumilus; Bacillus Amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis;* SA-Salicylic acid; , PG-Phloroglucinol; Gn- germination; S- Survival; GI- Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index; Each figure represents mean (±SD) of three replications.

Table 9. Effect of various pretreatments on seed germination and seedling parameters of *Withania somnifera.*

Treatment	Pretreatment	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI
T_1	SC	58.00±1.75^{b}	57.00±1.44^{b}	2.97±0.10^{c}	10.00±1.00^{a}	8.03±0.02^{b}	3.30±1.99^{b}	2.73±1.45	11.33±1.82^{b}	6.58±1.05^{c}
T_2	WS	84.00±1.52^{a}	83.67±1.42^{a}	4.87±0.06^{a}	8.67±0.57^{b}	9.23±0.09^{a}	4.07±0.06^{a}	2.3±0.04	13.30±0.01^{a}	11.16±0.25^{a}
T_3	HW	76.67±1.93^{a}	76.67±1.93^{a}	3.97±0.25^{b}	10.67±1.15^{a}	9.67±0.14^{a}	4.73±1.21^{a}	2.13±0.22	14.40±0.79^{a}	11.00±0.29^{a}
T_4	CSA	46.00±1.41^{c}	42.67±0.82^{c}	2.20±0.01^{d}	11.00±1.00^{a}	7.00±0.84^{c}	5.20±0.81^{a}	1.37±0.00	12.20±3.27^{b}	5.58±0.31^{d}
T_5	GA_3 @1500µM	82.00±1.52^{a}	82.00±1.52^{a}	4.87±0.20^{a}	8.33±0.57^{b}	9.50±0.39^{a}	4.90±0.12^{a}	1.97±0.04	14.40±0.39^{a}	11.80±1.11^{a}
T_6	GA_3 @3000µM	79.33±1.55^{a}	79.00±1.44^{a}	4.63±0.06^{a}	8.00±0.00^{b}	9.33±0.36^{a}	3.43±1.20^{b}	2.97±1.42	12.77±1.14^{a}	10.10±0.97^{b}
T_7	IAA @ 0.1µM	57.33±1.70^{b}	57.33±1.70^{b}	3.57±0.10^{b}	7.33±0.57^{c}	8.63±0.12^{a}	3.17±0.74^{bc}	2.9±0.81	10.90±3.25^{b}	6.30±2.17^{c}
T_8	IAA @ 1µM	58.00±1.75^{b}	57.67±1.72^{b}	3.57±0.12^{b}	8.00±0.00^{b}	7.03±0.32^{c}	3.23±0.14^{b}	2.2±0.21	10.27±0.12^{b}	5.97±0.60^{c}
T_9	BA @ 100µM	63.33±0.82^{b}	43.33±4.43^{c}	4.47±0.01^{a}	7.00±0.00^{c}	8.67±0.12^{b}	3.03±1.21^{b}	3.07±0.94	11.70±1.33^{b}	7.43±0.34^{c}
T_{10}	BA @ 300µM	60.00±2.04^{b}	60.00±2.04^{b}	3.77±0.25^{b}	8.00±0.00^{b}	7.53±0.17^{c}	3.27±0.22^{b}	2.33±0.14	10.80±0.37^{b}	6.50±1.11^{c}
T_{11}	TDZ @ 200µM	61.33±1.55^{b}	61.33±1.55^{b}	3.70±0.16^{b}	8.00±0.00^{b}	7.97±0.44^{b}	2.40±0.09^{bc}	3.33±0.30	10.37±0.41^{b}	6.37±0.69^{c}
T_{12}	TDZ @ 400µM	60.00±2.15^{b}	60.00±2.15^{b}	3.57±0.16^{b}	8.33±0.57^{b}	7.67±0.22^{c}	4.57±0.14^{a}	1.67±0.00	10.73±3.12^{b}	6.50±3.16^{c}
T_{13}	CH @ 5gL^{-1}	32.67±2.43^{c}	32.33±2.45^{c}	1.83±0.37^{d}	9.00±0.00^{b}	7.10±0.28^{c}	3.10±0.07^{bc}	2.30±0.12	10.20±0.09^{b}	3.30±1.33^{e}
T_{14}	CH @ 10 gL^{-1}	32.67±2.01^{c}	32.67±2.01^{c}	1.80±0.16^{d}	9.00±0.00^{b}	6.83±0.42^{c}	3.20±0.28^{b}	1.97±0.02	10.03±1.34^{c}	3.27±0.24^{e}
T_{15}	SA @ 1500µM	36.67±2.28^{c}	35.67±2.08^{c}	2.03±0.36^{d}	9.00±1.00^{b}	7.47±0.09^{c}	3.17±1.10^{bc}	2.53±0.60	10.63±1.82^{b}	3.93±1.42^{e}
T_{16}	SA @ 3000µM	39.33±1.88^{c}	39.33±1.88^{c}	2.37±0.04^{cd}	7.67±0.57^{c}	7.13±0.12c	2.87±0.72^{bc}	2.60±0.52	9.33±4.33^{c}	3.60±0.12^{e}
T_{17}	PG @ 1µM	62.00±1.52^{b}	61.33±1.55^{b}	4.47±0.16^{a}	6.67±0.57^{c}	7.80±0.21^{b}	2.73±1.70^{bc}	3.33±2.40	10.53±0.85^{b}	6.57±1.00^{c}
T_{18}	PG @ 10µM	64.00±2.47^{b}	64.00±2.47^{b}	4.77±0.37^{a}	6.67±0.57^{c}	7.53±1.08^{c}	3.03±0.44^{bc}	2.53±0.26	10.57±2.29^{b}	6.67±0.14^{c}
T_{19}	*BP*	60.00±2.54^{b}	60.00±2.54^{b}	3.87±0.76^{b}	7.33±0.57^{c}	7.77±1.12^{b}	3.70±0.76^{b}	2.27±0.80	11.47±0.26^{b}	6.90±2.47^{c}
T_{20}	*BA*	53.33±2.19^{b}	52.67±2.16^{b}	3.57±0.25^{b}	7.67±1.15^{c}	7.37±0.52^{c}	3.20±1.21^{b}	2.47±0.54	10.57±3.16^{b}	5.53±0.02^{d}
T_{21}	*BV*	57.33±2.16^{b}	56.67±2.19^{b}	3.67±0.06^{b}	8.33±0.57^{b}	7.87±0.26^{b}	3.20±0.19^{b}	2.47±0.09	10.17±5.24^{c}	5.83±3.69^{c}
T_{22}	*PF*	56.67±2.19^{b}	57.33±2.16^{b}	3.80±0.37^{b}	7.33±0.57^{c}	8.10±0.04^{b}	3.40±1.17^{b}	2.50±0.49	11.50±1.51^{b}	6.47±0.14^{c}
T_{23}	Control	51.33±2.28^{c}	50.67±2.16^{b}	2.40±0.13^{cd}	10.67±1.15^{a}	4.70±0.02^{d}	1.87±0.14^{c}	2.60±0.52	6.57±0.01^{d}	3.36±0.29^{e}
SE m (±)		4.046	5.664	0.198	0.547	0.470	0.676	0.589	1.035	0.816
C.D. (0.05)		11.554	16.175	0.706	1.062	0.913	1.311	NS	2.008	1.582

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine;TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; PG- Phloroglucinol; *BP- Bacillus pumilus; Bacillus Amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensi;* Gn- germination; S- Survival; GI- Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index. Each figure represents mean (±SD) of three replications.

Table 10. Effect of physical seed treatments on plant height and number of branches in transplanted *Withania somnifera.*

T. No.	Physical treatment	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90DAS	Harvest	30 DAS	60 DAS	90DAS	Harvest
T_1	SC	8.03±0.02[a]	12.47±1.96[a]	16.53±0.14[b]	46.83±1.87[b]	-	2(0.60±0.00)	2(0.60±0.00)	3.00±0.00[bc]
T_2	WS	9.23±0.09[a]	16.57±0.47[a]	19.27±0.30[a]	60.80±2.88[a]	-	2(0.60±0.00)	2(0.60±0.00)	5.00±1.71[a]
T_3	HW	9.67±0.14[a]	14.67±0.29[a]	18.60±0.20[a]	57.90±3.74[a]	-	2(0.60±0.00)	2(0.60±0.00)	3.33±0.57[b]
T_4	CSA	7.00±0.84[b]	8.167±1.62[b]	14.17±0.30[c]	33.07±1.40[c]	-	0(0.30±0.00)	0(0.30±0.00)	2.00±0.00[bc]
T_5	Control	4.70±0.02[b]	6.03±0.32[b]	13.00±0.20[c]	35.07±0.83[c]	-	0(0.30±0.00)	0(0.30±0.00)	1.67±0.57[c]
SE m (±)		0.417	0.957	0.196	1.940	-	-	-	0.494
C.D. (0.05)		2.491	5.70	1.171	11.616	-	NS	NS	1.578

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; DAS- Days after sowing. Each figure represents mean (±SD) of three replications

Table 11. Effect of physical seed treatments on collar girth and number of flowers in transplanted *Withania somnifera.*

T. No.	Physical Treatment	Collar girth (cm)				Number of Flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	SC	0.06±0.16	0.20±0.00	0.20±0.00	0.27±0.18[b]	-	-	-	41.67±1.29[a]
T_2	WS	0.09±0.00	0.20±0.00	0.20±0.00	0.47±0.26[a]	-	-	-	31.33±1.55[b]
T_3	HW	0.09±0.00	0.20±0.00	0.20±0.00	0.50±0.39[a]	-	-	-	4.00±0.76[c]
T_4	CSA	0.06±0.16	0.10±0.00	0.20±0.00	0.23±0.18[b]	-	-	-	3.00±0.76[c]
T_5	Control	0.09±0.00	0.09±0.00	0.13±0.00	0.20±0.39[b]	-	-	-	3.00±0.76[c]
SE m (±)		0.017	0.001	-	0.045	-	-	-	1.491
C.D. (0.05)		NS	NS	NS	0.143	-	-	-	4.758

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 12. Effect of hormonal seed priming on plant height and number of branches in transplanted *Withania somnifera.*

T. No.	Hormones	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	GA_3 @ 1500µM	9.50±0.39[a]	16.27±1.07[a]	20.70±0.46[a]	55.57±7.74[a]	-	0.00±0.00	2.00±0.00	3.00±0.00[b]
T_2	GA_3 @ 3000µM	9.33±0.36[a]	13.43±0.45[b]	18.40±0.20[b]	54.30±3.76[a]	-	0.00±0.00	2.00±0.00	3.67±0.57[a]
T_3	IAA @ 0.1µM	8.63±0.12[a]	8.93±0.75[c]	14.30±0.30[e]	35.20±3.04[b]	-	0.00±0.00	0.00±0.00	2.00±0.00[c]
T_4	IAA @ 1µM	7.03±0.32[b]	9.13±1.33[c]	14.30±0.26[e]	33.53±2.74[b]	-	0.00±0.00	0.00±0.00	2.00±0.00[c]
T_5	BA @ 100µM	8.67±0.12[a]	11.00±0.70[c]	18.20±0.26[b]	50.50±3.40[a]	-	2.00±0.00	2.00±0.00	3.00±0.00[b]
T_6	BA @ 300µM	7.53±0.17[b]	12.37±0.22[b]	16.07±0.14[c]	42.00±1.65[b]	-	2.00±0.00	2.00±0.00	3.00±0.00[b]
T_7	TDZ @ 200µM	7.97±0.44[b]	10.07±1.18[c]	14.63±0.14[d]	37.73±5.33[b]	-	0.00±0.00	2.00±0.00	3.00±0.00[b]
T_8	TDZ @ 400µM	7.67±0.22[b]	11.87±0.95[b]	15.30±0.26[d]	41.63±0.66[b]	-	0.00±0.00	2.00±0.00	3.00±0.00[b]
T_9	Control	4.70±0.02[c]	6.03±0.32[d]	13.00±0.20[f]	35.07±0.83[b]	-	0.00±0.00	2.00±0.00	1.67±0.57[c]
SE m (±)		0.419	0.701	0.217	3.158	-	-	-	0.157
C.D. (0.05)		1.349	2.257	0.699	10.168	-	NS	NS	0.470

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; DAS- Days after sowing. Each figure represents mean (±SD) of three replications

Table 13. Effect of hormonal seed priming on collar girth and number of flowers in transplanted *Withania somnifera.*

T. No.	Hormones	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	GA_3 @ 1500µM	0.06±0.16	0.20±0.00	0.20±0.00	0.23±0.18	-	-	-	13.33±1.15[a]
T_2	GA_3 @ 3000µM	0.09±0.00	0.20±0.00	0.20±0.00	0.30±0.00	-	-	-	12.33±1.36[a]
T_3	IAA @ 0.1µM	0.09±0.00	0.10±0.00	0.17±0.18	0.23±0.18	-	-	-	6.67±0.82[b]
T_4	IAA @ 1µM	0.09±0.00	0.09±0.05	0.20±0.00	0.27±0.26	-	-	-	11.67±0.82[a]
T_5	BA @ 100µM	0.09±0.00	0.20±0.00	0.20±0.00	0.23±0.18	-	-	-	3.00±0.00[b]
T_6	BA @ 300µM	0.06±0.16	0.20±0.00	0.20±0.18	0.20±0.00	-	-	-	3.33±0.58[b]
T_7	TDZ @ 200µM	0.09±0.00	0.09±0.05	0.17±0.00	0.30±0.00	-	-	-	3.00±0.58[b]
T_8	TDZ @ 400µM	0.09±0.00	0.20±0.00	0.20±0.00	0.23±0.18	-	-	-	3.33±0.58[b]
T_9	Control	0.09±0.00	0.09±0.00	0.13±0.00	0.20±0.39	-	-	-	3.00±0.76[b]
SE m (±)		0.013	0.002	0.019	0.065		-	-	1.310
C.D. (0.05)		NS	NS	NS	NS		-	-	3.922

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 14. Effect of biostimulant seed priming on plant height and number of branches in transplanted *Withania somnifera.*

T. No.	Biostimulants	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	CH @ 5gL^{-1}	7.10±0.28^{a}	8.23±0.64^{b}	9.67±0.14^{f}	27.27±2.04^{c}	-	0.00±0.00	0.00±0.00	2.00±0.00^{c}
T_2	CH @ 10 gL^{-1}	6.83±0.42^{a}	7.20±0.70^{b}	12.30±0.46^{d}	34.63±1.90^{b}	-	0.00±0.00	0.00±0.00	2.67±0.57^{b}
T_3	SA @ 1500µM	7.47±0.09^{a}	8.20±0.30^{b}	13.27±0.35^{c}	37.37±2.60^{b}	-	0.00±0.00	0.00±0.00	3.00±0.00^{b}
T_4	SA @ 3000µM	7.13±0.12^{a}	8.13±0.40^{bc}	11.43±0.50^{e}	30.43±0.64^{c}	-	0.00±0.00	0.00±0.00	2.00±0.00^{c}
T_5	PG @ 1Mm	7.80±0.21^{a}	11.17±1.32^{a}	16.10±0.10^{b}	42.80±1.18^{a}	-	2.00±0.00	2.00±0.00	4.67±0.57^{a}
T_6	PG @ 10µM	7.53±1.08^{a}	11.30±0.17^{a}	17.40±0.53^{a}	46.37±2.75^{a}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_7	Control	4.70±0.02^{b}	6.03±0.32^{c}	13.00±0.20^{c}	35.07±0.83^{b}	-	0.00±0.00	0.00±0.00	1.67±0.57^{c}
SE m (±)		0.480	0.537	0.089	1.532	-	-	-	0.218
C.D. (0.05)		1.921	2.14	0.358	6.128	-	NS	NS	0.668

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 15. Effect of biostimulants priming seed primimg on collar girth and number of flowers in transplanted *Withania somnifera.*

T. No.	Biostimulants	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	CH @ 5gL^{-1}	0.04±0.16	0.09±0.00^{c}	0.10±0.00^{b}	0.20±0.00^{b}	-	-	-	30.00±1.00^{a}
T_2	CH @ 10 gL^{-1}	0.09±0.00	0.09±0.00^{c}	0.20±0.00^{a}	0.27±0.18^{b}	-	-	-	10.33±1.21^{c}
T_3	SA @ 1500µM	0.09±0.00	0.10±0.00^{b}	0.20±0.00^{a}	0.37±0.18^{a}	-	-	-	15.00±1.44^{b}
T_4	SA @ 3000µM	0.06±0.16	0.09±0.00^{c}	0.20±0.00^{a}	0.30±0.00^{a}	-	-	-	4.333±0.58^{ef}
T_5	PG @ 1µM	0.06±0.16	0.20±0.00^{a}	0.20±0.00^{a}	0.20±0.00^{b}	-	-	-	3.00±0.00^{f}
T_6	PG @ 10µM	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.20±0.00^{b}	-	-	-	8.00±3.00^{d}
T_7	Control	0.09±0.00	0.09±0.00^{c}	0.20±0.00^{a}	0.20±0.39^{b}	-	-	-	3.00±0.76^{f}
SE m (±)		0.018	0.001	0.013	0.025	-	-	-	0.735
C.D. (0.05)		NS	0.004	0.039	0.077	-	-	-	2.250

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 16. Effect of biopriming of seeds on plant height and number of branches in transplanted *Withania somnifera.*

T. No.	Microbes	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	*Bacillus pumilus (BP)*	7.77±1.12^{ab}	11.13±0.72^{a}	17.93±0.45^{a}	47.63±2.10^{a}	-	2.00±0.00	2.00±0.00	3.00±0.00^{a}
T_2	*Bacillus amyloliquefaciens(BA)*	7.37±0.52^{ab}	8.30±0.61^{b}	13.40±0.50^{bc}	36.80±2.23^{ab}	-	0.00±0.00	0.00±0.00	3.67±0.57^{a}
T_3	*Bacillus velezensis (BV)*	7.87±0.26^{ab}	9.70±0.10^{b}	14.53±0.14^{bc}	35.17±4.40^{b}	-	0.00±0.00	0.00±0.00	3.00±0.00^{a}
T_4	*Pseudomonas fluorescens (PF)*	8.10±0.04^{a}	12.27±0.24^{a}	14.97±0.14^{b}	41.83±0.90^{ab}	-	2.00±0.00	2.00±0.00	2.00±0.00^{bc}
T_5	Control	4.70±0.02^{b}	6.03±0.32^{c}	13.00±0.20^{c}	35.07±0.83^{b}	-	0.00±0.00	0.00±0.00	1.67±0.57^{c}
SE m (±)		0.537	0.377	0.268	2.010	-	-	-	0.211
C.D. (0.05)		3.198	2.25	1.599	11.984	-	NS	NS	0.673

T. No. – Treatment Number; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 17. Effect of bioprimimg of seeds on collar girth and number of flowers in transplanted *Withania somnifera.*

T. No.	Biopriming	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	*Bacillus pumilus (BP)*	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.27±0.18^{b}	-	-	-	3.33±0.58^{c}
T_2	*Bacillus amyloliquefaciens (BA)*	0.06±0.16	0.09±0.00^{b}	0.10±0.00^{b}	0.23±0.18^{b}	-	-	-	41.67±1.29^{a}
T_3	*Bacillus velezensis (BV)*	0.06±0.16	0.09±0.00^{b}	0.10±0.00^{b}	0.27±0.18^{b}	-	-	-	31.33±1.55^{b}
T_4	*Pseudomonas fluorescens (PF)*	0.06±0.16	0.17±0.17^{a}	0.20±0.18^{a}	0.47±0.26^{a}	-	-	-	4.00±0.76^{c}
T_5	Control	0.09±0.00	0.09±0.05^{b}	0.13±0.00^{b}	0.20±0.39^{c}	-	-	-	3.00±0.76^{c}
SE m (±)		0.021	0.015	0.015	0.021	-	-	-	1.647
C.D. (0.05)		NS	0.048	0.048	0.067	-	-	-	5.255

T. No. – Treatment Number; DAS- Days after sowing. Each figure represents mean (±SD) of three replications

Table 18. Effect of various seed pretreatments on plant height and number of branches in transplanted *Withania somnifera.*

T. No.	Pretreatment	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	SC	8.03±0.02^{b}	12.47±1.96^{c}	16.53±0.14^{f}	46.83±1.87^{c}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_2	WS	9.23±0.09^{a}	16.57±0.47^{a}	19.27±0.30^{b}	60.80±2.88^{a}	-	2.00±0.00	2.00±0.00	5.00±1.71^{a}
T_3	HW	9.67±0.14^{a}	14.67±0.29^{b}	18.60±0.20^{c}	57.90±3.74^{a}	-	2.00±0.00	2.00±0.00	3.33±0.57^{b}
T_4	CSA	7.00±0.84^{c}	8.17±1.62^{e}	14.17±0.30^{h}	33.07±1.40^{e}	-	0.00±0.00	0.00±0.00	2.00±0.00^{c}
T_5	GA_3 @1500µM	9.50±0.39^{a}	16.27±1.07^{a}	20.70±0.46^{a}	55.57±7.74^{b}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_6	GA_3 @3000µM	9.33±0.36^{a}	13.43±0.45^{b}	18.40±0.20^{c}	54.30±3.76^{b}	-	2.00±0.00	2.00±0.00	3.67±0.57^{b}
T_7	IAA @ 0.1µM	8.63±0.12^{b}	8.93±0.75^{e}	14.30±0.30^{h}	35.20±3.04^{e}	-	0.00±0.00	0.00±0.00	2.00±0.00^{c}
T_8	IAA @ 1µM	7.03±0.32^{c}	9.13±1.33^{e}	14.30±0.26^{h}	33.53±2.74^{e}	-	0.00±0.00	0.00±0.00	2.00±0.00^{c}
T_9	BA @ 100µM	8.67±0.12^{b}	11.00±0.70^{d}	18.20±0.26^{c}	50.50±3.40^{c}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_{10}	BA @ 300µM	7.53±0.17^{c}	12.37±0.22^{c}	16.07±0.14^{f}	42.00±1.65^{c}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_{11}	TDZ @ 200µM	7.97±0.44^{b}	10.07±1.18^{d}	14.63±0.14^{h}	37.73±5.33^{d}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_{12}	TDZ @ 400µM	7.67±0.22^{c}	11.87±0.95^{c}	15.30±0.26^{g}	41.63±0.66^{d}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_{13}	CH @ 5gL^{-1}	7.10±0.28^{c}	8.23±0.64^{e}	9.67±0.14^{l}	27.27±2.04^{f}		0.00±0.00	0.00±0.00	2.00±0.00^{c}
T_{14}	CH @ 10 gL^{-1}	6.83±0.42^{c}	7.20±0.70^{f}	12.30±0.46^{j}	34.63±1.90^{e}	-	0.00±0.00	0.00±0.00	2.67±0.57^{c}
T_{15}	SA @ 1500µM	7.47±0.09^{c}	8.20±0.3^{e}	13.27±0.35^{i}	37.37±2.60^{d}	-	0.00±0.00	0.00±0.00	3.00±0.00^{b}
T_{16}	SA @ 3000µM	7.13±0.12^{c}	8.13±0.40^{e}	11.43±0.50^{k}	30.43±0.64^{f}	-	0.00±0.00	0.00±0.00	2.00±0.00^{c}
T_{17}	PG @ 1µM	7.80±0.21^{b}	11.17±1.32^{c}	16.10±0.10^{f}	42.80±1.18^{c}	-	2.00±0.00	2.00±0.00	4.67±0.57^{e}
T_{18}	PG @ 10µM	7.53±1.08^{c}	11.30±0.17^{c}	17.40±0.53^{e}	46.37±2.75^{c}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_{19}	*Bacillus pumilus (BP)*	7.77±1.12^{b}	11.13±0.72^{c}	17.93±0.45^{d}	47.63±2.10^{c}	-	2.00±0.00	2.00±0.00	3.00±0.00^{b}
T_{20}	*Bacillus amyloliquefaciens (BA)*	7.37±0.52^{c}	8.30±0.61^{e}	13.40±0.50^{i}	36.80±2.23^{e}	-	0.00±0.00	0.00±0.00	3.67±0.57^{b}
T_{21}	*Bacillus velezensis (BV)*	7.87±0.26^{b}	9.70±0.10^{d}	14.53±0.14^{h}	35.17±4.40^{e}	-	0.00±0.00	0.00±0.00	3.00±0.00^{b}
T_{22}	*Pseudomonas fluorescens (PF)*	8.10±0.04^{b}	12.27±0.24^{c}	14.97±0.14^{g}	41.83±0.90^{d}	-	2.00±0.00	2.00±0.00	2.00±0.00^{c}
T_{23}	Control	4.70±0.02^{d}	6.03±0.32^{f}	13.00±0.20^{i}	35.07±0.83^{e}	-	0.00±0.00	0.00±0.00	1.67±0.57^{c}
SE m (±)		0.470	0.708	0.257	2.50	-	-	-	0.269
C.D. (0.05)		0.913	1.373	0.499	4.854	-	NS	NS	0.769

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; , PG- Phloroglucinol; DAS- Days after sowing; Each figure represents mean (±SD) of three replications.

Table 19. Effect of various of seed treatments on collar girth and number of flowers in transplanted *Withania somnifera.*

T. No.	Pretreatment	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	SC	0.06±0.16	0.20±0.00^{a}	0.20±0.00^{a}	0.27±0.18^{b}	-	-	-	41.67±1.29^{a}
T_2	WS	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.47±0.26^{a}	-	-	-	31.33±1.55^{b}
T_3	HW	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.50±0.39^{a}	-	-	-	4.00±0.7^{e}
T_4	CSA	0.06±0.16	0.10±0.00^{c}	0.20±0.00^{a}	0.23±0.18^{b}	-	-	-	3.00±0.76^{e}
T_5	GA_3 @1500Mm	0.06±0.16	0.20±0.00^{a}	0.20±0.00^{a}	0.23±0.18^{b}	-	-	-	13.33±1.15^{c}
T_6	GA_3 @3000Mm	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.30±0.00^{b}	-	-	-	12.33±1.36^{c}
T_7	IAA @ 0.1µM	0.09±0.00	0.10±0.00^{c}	0.17±0.18^{b}	0.23±0.18^{b}	-	-	-	6.67±0.82^{e}
T_8	IAA @ 1Mm	0.09±0.00	0.09±0.05^{c}	0.20±0.00^{a}	0.27±0.26^{b}	-	-	-	11.67±0.82^{d}
T_9	BA @ 100Mm	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.23±0.18^{b}	-	-	-	3.00±0.00^{e}
T_{10}	BA @ 300µM	0.06±0.16	0.20±0.00^{a}	0.17±0.18^{b}	0.20±0.00^{b}	-	-	-	3.33±0.58^{e}
T_{11}	TDZ @ 200µM	0.09±0.00	0.09±0.05^{c}	0.20±0.00^{a}	0.30±0.00^{b}	-	-	-	3.00±0.58^{e}
T_{12}	TDZ @ 400Mm	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.23±0.18^{b}	-	-	-	3.33±0.58^{e}
T_{13}	CH @ $5gL^{-1}$	0.04±0.16	0.09±0.00^{c}	0.10±0.00^{d}	0.20±0.00^{b}	-	-	-	30.00±1.00^{b}
T_{14}	CH @ 10 gL^{-1}	0.09±0.00	0.09±0.00^{c}	0.20±0.00^{a}	0.27±0.18^{b}	-	-	-	10.33±1.21^{e}
T_{15}	SA @ 1500µM	0.09±0.00	0.10±0.00^{c}	0.20±0.00^{a}	0.37±0.18^{a}	-	-	-	15.00±1.44^{c}
T_{16}	SA @ 3000µM	0.06±0.16	0.09±0.00^{c}	0.20±0.00^{a}	0.30±0.00^{b}	-	-	-	4.33±0.58^{e}
T_{17}	PG @ 1µM	0.06±0.16	0.20±0.00^{a}	0.20±0.00^{a}	0.20±0.00^{b}	-	-	-	3.00±0.00^{e}
T_{18}	PG @ 10µM	0.09±0.00	0.20±0.00^{a}	0.20±0.00^{a}	0.20±0.00^{b}	-	-	-	8.00±3.00^{d}
T_{19}	*Bacillus pumilus (BP)*	0.09±0.00	0.20±0.00^{a}	0.10±0.00^{d}	0.27±0.18^{b}	-	-	-	3.33±0.58^{f}
T_{20}	*Bacillus amyloliquefaciens (BA)*	0.06±0.16	0.09±0.00^{c}	0.10±0.00^{d}	0.23±0.18^{b}	-	-	-	41.67±1.29^{a}
T_{21}	*Bacillus velezensis (BV)*	0.06±0.16	0.09±0.00^{c}	0.20±0.00^{a}	0.27±0.18^{b}	-	-	-	31.33±1.55^{b}
T_{22}	*Pseudomonas fluorescens (PF)*	0.06±0.16	0.17±0.17^{b}	0.20±0.18^{a}	0.47±0.26^{a}	-	-	-	4.00±0.76^{f}
T_{23}	Control	0.09±0.00	0.09±0.05^{c}	0.13±0.00^{c}	0.20±0.39^{b}	-	-	-	3.00±0.76^{f}
	SE m (±)	0.18	0.007	0.034	0.047	-	-	-	1.376
	C.D. (0.05)	NS	0.020	0.012	0.135	-	-	-	3.930

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing; Each figure represents mean (±SD) of three replications.

Table 20. Effect of physical seed pretreatments on phenological parameters in transplanted *Withania somnifera.*

T. No.	Physical treatment	Days to flower initiation (Days)	Days to fruit set (Days) (Log transformed values)
T_1	SC	93.00±0.50^c	24.33±0.58
T_2	WS	92.33±0.33^c	25.67±0.58
T_3	HW	92.67±0.3^c	25.33±0.58
T_4	CSA	99.33±0.33^b	0.00±0.00
T_5	Control	101.33±0.67^a	0.00±0.00
SE m (±)		0.471	0.333
C.D. (0.05)		1.505	NS

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid.
Each figure represents mean (±SD) of three replications

Table 21. Effect of hormonal seed priming on phenological parameters in transplanted *Withania somnifera.*

T. No.	Hormones	Days to flower initiation (Days)	Days to fruit set (Days) (Log transformed values)
T_1	GA_3 @ 1500µM	92.33±0.33^d	25.33±0.82
T_2	GA_3 @ 3000µM	92.67±0.33^d	25.00±0.00
T_3	IAA @ 0.1µM	96.33±0.88^c	0.00±0.00
T_4	IAA @ 1µM	95.00±0.58^c	0.00±0.00
T_5	BA @ 100µM	93.33±0.33^d	26.00±0.00
T_6	BA @ 300µM	95.67±0.33^c	0.00±0.00
T_7	TDZ @ 200µM	99.00±0.58^b	0.00±0.00
T_8	TDZ @ 400µM	96.33±0.33^c	0.00±0.00
T_9	Control	101.33±0.67^a	0.00±0.00
SE m (±)		0.521	0.385
C.D. (0.05)		1.560	NS

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron;
Each figure represents mean (±SD) of three replications.

Table 22. Effect of biostimulant seed priming on phenological parameters in transplanted *Withania somnifera.*

Treatment	Biostimulants	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	CH @ 5gL^{-1}	101.00±0.58^{a}	0.00±0.00
T_2	CH @ 10gL^{-1}	100.67±0.67^{a}	0.00±0.00
T_3	SA @ 1500Mm	101.00±0.58^{a}	0.00±0.00
T_4	SA @ 3000Mm	101.67±0.33^{a}	24.67±0.58
T_5	PG @ 1µM	93.67±0.33^{b}	24.33±0.58
T_6	PG @ 10µM	92.67±0.33^{b}	0.00±0.00
T_7	Control	101.33±0.67^{a}	0.00±0.00
SE m (±)		0.519	0.333
C.D. (0.05)		1.591	NS

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol. Each figure represents mean (±SD) of three replications

Table 23. Effect of bioprimimg of seeds on phenological parameters in transplanted *Withania somnifera.*

T. No.	Microbes	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	*Bacillus pumilus (BP)*	92.33±0.33^{c}	26.67±0.58
T_2	*Bacillus amyloliquefaciens(BA)*	95.67±0.33^{b}	26.33±0.58
T_3	*Bacillus velezensis (BV*	95.67±0.33^{b}	26.33±0.58
T_4	*Pseudomonas fluorescens (PF)*	94.67±0.33^{b}	26.00±0.00
T_5	Control	101.33±0.67^{a}	0.00±0.00
SE m (±)		0.422	0.289
C.D. (0.05)		1.346	NS

Each figure represents mean (±SD) of three replications

Table 24. Effect of seed pretreatments on phenological parameters in transplanted *Withania somnifera.*

Treatment	Pretreatment	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	Scarification	93.00±0.58^{e}	24.33±0.58^{c}
T_2	Water soaking	92.33±0.33^{e}	25.67±0.58^{b}
T_3	Hot water	92.67±0.33^{e}	25.33±0.58^{b}
T_4	Conc.H_2SO_4	99.33±0.33^{b}	0.00±0.00
T_5	GA_3 @ 1500Mm	92.33±0.33^{e}	25.33±0.82^{b}
T_6	GA_3 @ 3000µM	92.67±0.33^{e}	25.00±0.00^{bc}
T_7	IAA @ 0.1µM	96.33±0.88^{c}	0.00±0.00
T_8	IAA @ 1µM	95.00±0.58^{c}	0.00±0.00
T_9	BA @ 100µM	93.33±0.33^{e}	26.00±0.00^{a}
T_{10}	BA @ 300µM	95.67±0.33^{c}	0.00±0.00
T_{11}	TDZ @ 200µM	99.00±0.58^{b}	0.00±0.00
T_{12}	TDZ @ 400µM	96.33±0.33^{c}	0.00±0.00
T_{13}	CH @ 5gL^{-1}	101.00±0.58^{a}	0.00±0.00
T_{14}	CH @ 10 gL^{-1}	100.67±0.67^{a}	0.00±0.00
T_{15}	SA @ 1500µM	101.00±0.58^{a}	0.00±0.00
T_{16}	SA @ 3000µM	101.67±0.33^{a}	0.00±0.00
T_{17}	PG @ 1µM	93.67±0.33^{d}	24.67±0.58^{c}
T_{18}	PG @ 10µM	92.67±0.33^{e}	24.33±0.58^{c}
T_{19}	*Bacillus pumilus (BP)*	92.33±0.33^{e}	26.67±0.58^{a}
T_{20}	*Bacillus amyloliquefaciens(BA)*	95.67±0.33^{c}	26.33±0.58^{a}
T_{21}	*Bacillus velezensis(BV)*	95.67±0.33^{c}	26.33±0.58^{a}
T_{22}	*Pseudomonas fluorescens (PF)*	94.67±0.33^{d}	26.00±0.00^{a}
T_{23}	Control	101.33±0.67^{a}	0.00±0.00
SE m (±)		0.466	0.333
C.D. (0.05)		1.332	0.979

T. No. – Treatment Number; SC- Scarification; WS- Water soaking; HW- Hot water; CSA- Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA- Benzyl Adenine; TDZ- Thidiazuron; CH- Chitosan; SA- Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing; Each figure represents mean (±SD) of three replications

Table 25. Effect of physical seed pretreatments on yield parameters in transplanted *Withania somnifera at harvest*

T. No.	Microbes	SW (g plant^{-1})		RW (g plant^{-1})		Harvest Index		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Shoot	Root			
T_1	SC	21.67±0.72^c	4.09±0.16^c	4.18±0.07^b	0.58±0.01^b	0.88±0.00^b	0.125±0.004^a	15.83±0.47^b	0.40±0.00^c	4.30±0.12^c
T_2	WS	37.61±0.22^a	7.17±0.03^a	5.46±0.21^a	0.77±0.03^a	0.90±0.00^a	0.097±0.003^b	7.87±0.47^c	1.00±0.06^a	7.40±0.27^a
T_3	HW	28.63±0.50^b	5.45±0.18^b	5.60±0.21^a	0.79±0.04^a	0.87±0.01^b	0.127±0.007^a	28.63±2.09^a	0.53±0.03^b	5.10±0.15^b
T_4	CSA	17.20±0.17^d	3.17±0.15^d	2.62±0.19^d	0.37±0.03^d	0.89±0.00^a	0.104±0.004^b	14.03±0.45^b	0.20±0.00^d	2.61±0.07^d
T_5	Control	16.67±0.23^d	3.14±0.07^d	3.20±0.15^c	0.46±0.02^c	0.87±0.00^b	0.128±0.003^a	7.87±0.47^c	0.20±0.00^d	2.63±0.32^d
SE m (±)		0.426	0.129	0.174	0.028	0.005	0.005	1.265	0.030	0.426
C.D. (0.05)		1.359	0.413	0.555	0.089	0.015	0.015	4.038	0.095	1.359

T. No. – Treatment Number; SC- Scarification; WS- Water soaking; HW- Hot water; CSA- Concentrated Sulphuric Acid; SW- Shoot weight; RW- Root weight; RL- Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications

Table 26. Effect of physical seed pretreatments on yield parameters in transplanted *Withania somnifera* at harvest

T. No.	Physical treatment	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight(g)
			Fresh weight	Dry weight		
T_1	SC	2.67±0.58^c	2.74±0.59^c	0.45±0.14^c	0.056±0.03^b	2.560±0.00
T_2	WS	12.33±1.21^a	12.56±1.26^a	1.87±0.50^a	0.057±0.04^b	2.620±0.00
T_3	HW	6.33±0.58^b	6.39±0.55^b	1.05±0.15^b	0.072±0.06^a	2.600±0.00
T_4	CSA	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.000
T_5	Control	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	2.560±0.000
SE m (±)		0.805	0.952	0.146	0.003	0.000
C.D. (0.05)		3.246	3.359	0.515	0.009	NS

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; Each figure represents mean (±SD) of three replications.

Table 27. Effect of hormonal seed priming on yield parameters in transplanted *Withania somnifera at harvest*

T. No.	Hormones	SW (g plant^{-1})		RW (g plant^{-1})		Harvest Index		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Shoot	Root			
T_1	GA_3@1500µM	27.73±0.33^a	5.09±0.05^a	5.60±0.06^a	0.79±0.02^a	0.87±0.00^b	0.135±0.002^a	9.30±0.35^b	1.10±0.06^a	9.15±0.14a
T_2	GA_3@3000µM	27.77±0.80^a	5.17±0.19^a	4.50±0.15^b	0.63±0.02^b	0.89±0.01^a	0.108±0.005^c	9.40±0.15^b	0.60±0.06^b	4.35±0.09b
T_3	IAA@0.1µM	17.03±0.15^d	3.29±0.05^{de}	3.29±0.11^c	0.46±0.02^c	0.88±0.00^a	0.122±0.003^b	14.63±0.18^a	0.30±0.00^c	3.03±0.14d
T_4	IAA@1Mm	19.13±0.34^c	3.50±0.11^d	3.27±0.14^c	0.46±0.02^c	0.89±0.00^a	0.115±0.001^{bc}	11.20±0.81^b	0.20±0.00^c	3.70±0.12c
T_5	BA@100µM	23.80±0.53^b	4.22±0.10^b	4.35±0.17^b	0.62±0.02^b	0.87±0.01^b	0.128±0.005^a	10.33±0.03^b	0.63±0.13^b	5.42±0.16b
T_6	BA@300µM	20.33±0.27^c	3.86±0.02^c	3.47±0.18^c	0.49±0.02^c	0.89±0.00^a	0.112±0.004^{bc}	12.80±1.06^a	0.33±0.03^c	4.10±0.12b
T_7	TDZ@200µM	18.13±0.33^d	3.46±0.08^{de}	3.57±0.13^c	0.50±0.02^c	0.87±0.00^b	0.126±0.003^a	4.03±0.24^d	0.37±0.03^c	3.83±0.09c
T_8	TDZ@400 µM	20.33±0.38^c	3.71±0.19^c	3.55±0.13^c	0.49±0.02^c	0.88±0.01^a	0.119±0.008^{bc}	6.60±0.40^{cd}	0.33±0.03^c	4.30±0.15b
T_9	Control	16.67±0.23^e	3.14±0.07^e	3.20±0.15^c	0.46±0.02^c	0.87±0.00^b	0.128±0.003^a	7.87±0.47^c	0.20±0.00^c	2.63±0.32d
SEm(±)		0.415	0.113	0.141	0.020	0.004	0.004	0.903	0.056	0.415
C.D. (0.05)		1.242	0.337	0.421	0.060	0.013	0.011	2.703	0.166	1.242

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ- Thidiazuron; SW-Shoot weight; RW-Root weight; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications

Table 28. Effect of hormonal seed priming on yield parameters in transplanted *Withania somnifera* at harvest

T. No.	Hormones	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight (g)
			Fresh weight	Dry weight		
T_1	GA_3@1500µM	9.00±0.76^a	9.49±0.81^a	1.36±0.29^a	0.057±0.06	2.620±0.17
T_2	GA_3@3000µM	4.33±0.58^b	4..43±0.62^b	0.68±0.27^b	0.056±0.05	2.503±0.19
T_3	IAA@0.1µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_4	IAA@1µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_5	BA@100µM	4.33±0.058^b	4.61±0.61^b	0.64±0.23^b	0.062±0.06	2.560±0.20
T_6	BA@300µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_7	TDZ@200µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_8	TDZ@400µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_9	Control	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
SE m (±)		0.430	0.490	0.073	0.004	0.036
C.D. (0.05)		1.518	1.729	0.258	NS	NS

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; Each figure represents mean (±SD) of three replications.

Table 29. Effect of biostimulant seed priming on yield parameters in transplante0d *Withania somnifera at harvest*

T. No.	Biostimulants	SW (g plant^{-1})		RW (g plant^{-1})		Harvest Index		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Shoot	Root			
T_1	CH @ 5gL^{-1}	13.80±0.36^{d}	2.69±0.02^{f}	2.60±0.06^{c}	0.37±0.01^{c}	0.88±0.00^{ab}	0.120±0.002^{ab}	9.30±0.32^{c}	0.20±0.00^{c}	1.77±0.19^{d}
T_2	CH @ 10gL^{-1}	16.23±0.18^{c}	3.03±0.07^{e}	3.46±0.07^{b}	0.48±0.01^{b}	0.86±0.00^{b}	0.136±0.004^{a}	4.37±0.39^{d}	0.20±0.00^{c}	2.23±0.17^{cd}
T_3	SA @ 1500µM	18.37±0.19^{b}	3.42±0.06^{c}	3.59±0.07^{b}	0.51±0.01^{b}	0.87±0.00^{b}	0.130±0.002^{a}	11.40±0.58^{b}	0.20±0.00^{c}	3.50±0.06^{b}
T_4	SA @ 3000µM	15.07±0.39^{d}	2.88±0.13^{d}	2.53±0.19^{c}	0.36±0.02^{c}	0.89±0.01^{a}	0.111±0.010^{b}	12.53±0.15^{b}	0.20±0.00^{c}	1.27±0.23^{d}
T_5	PG @ 1µM	20.13±0.26^{a}	3.80±0.11^{b}	2.97±0.49^{bc}	0.41±0.07^{c}	0.90±0.02^{a}	0.097±0.017^{b}	14.27±0.29^{a}	0.40±0.00^{b}	4.13±0.15^{a}
T_6	PG @ 10µM	21.40±0.95^{a}	3.96±0.18^{a}	4.36±0.13^{a}	0.64±0.02^{a}	0.86±0.01^{b}	0.140±0.007^{a}	8.90±0.31^{c}	0.57±0.03^{a}	3.60±0.12^{a}
T_7	Control	16.67±0.23^{c}	3.14±0.07^{d}	3.20±0.15^{bc}	0.46±0.02^{b}	0.87±0.00^{b}	0.128±0.003^{a}	7.87±0.47^{c}	0.20±0.00^{c}	2.63±0.32^{c}
SEm(±)		0.444	0.312	0.219	0.031	0.008	0.008	0.481	0.013	0.444
C.D. (0.05)		1.361	0.102	0.669	0.096	0.025	0.025	1.474	0.039	1.361

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol. SW-Shoot weight; RW-Root weight; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications

Table 30. Effect of biostimulant seed priming on yield parameters in transplanted *Withania somnifera* at harvest

T. No.	Biostimulants	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight (g)
			Fresh weight	Dry weight		
T_1	CH @ 5gL^{-1}	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_2	CH @ 10gL^{-1}	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_3	SA @ 1500µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_4	SA @ 3000µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_5	PG @ 1µM	2.33±0.58	2.48±0.57	0.33±0.21	0.069±0.06^{a}	2.640±0.19
T_6	PG @ 10µM	1.67±0.58	1.74±0.58	0.26±0.22	0.057±0.00^{b}	2.543±0.15
T_7	Control	0.00±0.00	0.00±0.00)	0.00±0.00	0.000±0.00	0.000±0.00
SE m (±)		0.333	0.330	0.047	0.002	0.031
C.D. (0.05)		NS	NS	NS	0.010	NS

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol. Each figure represents mean (±SD) of three replications

Table 31. Effect of seed biopriming on yield parameters in transplanted *Withania somnifera at harvest*

T. No.	Microbes	SW (g plant^{-1})		RW (g plant^{-1})		Harvest Index		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Shoot	Root			
T_1	*BP*	23.07±0.49^a	4.39±0.15^a	4.43±0.14^a	0.63±0.03^a	0.88±0.00^a	0.125±0.004^b	9.27±0.23^c	0.50±0.00^a	4.47±0.13^a
T_2	*Bam*	17.27±0.35^c	3.08±0.06^c	3.70±0.06^b	0.54±0.01^b	0.85±0.00^b	0.150±0.001^a	11.40±0.17^b	0.23±0.03^c	2.97±0.09^c
T_3	*BV*	16.47±0.44^c	2.99±0.05^c	3.27±0.12^b	0.45±0.01^c	0.87±0.01^a	0.130±0.005^b	8.17±0.89^c	0.23±0.03^c	3.07±0.07^c
T_4	*PF*	19.93±0.29^b	3.78±0.02^b	3.62±0.27^b	0.51±0.04^c	0.88±0.01^a	0.119±0.008^b	15.83±0.47^a	0.33±0.03^b	3.77±0.15^b
T_5	Control	16.67±0.23^c	3.14±0.07^c	3.20±0.15^b	0.46±0.02^c	0.87±0.00^a	0.128±0.003^b	7.87±0.47^c	0.20±0.00^c	2.63±0.32^c
SE m (±)		0.373	0.080	0.162	0.024	0.005	0.005	0.459	0.026	0.373
C.D. (0.05)		1.190	0.256	0.516	0.077	0.015	0.015	1.465	0.082	1.190

T. No. – Treatment Number; *BP- Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.* SW-Shoot weight; RW-Root weight; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications

Table 32. Effect of seed biopriming on yield parameters in transplanted *Withania somnifera* at harvest

T. No.	Microbes	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight (g)
			Fresh weight	Dry weight		
T_1	*BP*	3.67±0.82	3.84±0.84	0.41±0.29	0.065±0.03^a	2.627±0.11
T_2	*Bam*	3.00±0.76	2.89±0.74	0.33±0.20	0.060±0.05^a	2.677±0.25
T_3	*BV*	2.67±0.58	2.60±0.57	0.49±0.23	0.027±0.10^b	2.530±0.14
T_4	*PF*	3.33±0.58	3.25±0.62	0.00±0.00	0.062±0.00^a	2.553±0.22
T_5	Control	0.00±0.00	0.00±0.00	0.41±0.29	0.000±0.00	0.000±0.00
SE m (±)		0.500	0.513	0.068	0.006	0.041
C.D. (0.05)		NS	NS	NS	0.021	NS

T. No. – Treatment Number; *BP- Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.*
The data represents the mean of three replications

Table 33. Effect of seed pretreatments on yield parameters in transplanted *Withania somnifera* at harvest

T. No.	Pretreatments	SW (g plant^{-1})		RW (g plant^{-1})		Harvest Index		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Shoot	Root			
T_1	SC	21.67±0.72^{d}	4.09±0.16^{d}	4.18±0.07^{b}	0.58±0.01^{b}	0.88±0.00^{b}	0.125±0.004^{b}	15.83±0.47^{b}	0.40±0.00^{c}	4.30±0.12^{d}
T_2	WS	37.61±0.22^{a}	7.17±0.03^{a}	5.46±0.21^{a}	0.77±0.03^{a}	0.90±0.00^{a}	0.097±0.003^{c}	7.87±0.47^{e}	1.00±0.06^{a}	7.40±0.27^{b}
T_3	HW	28.63±0.50^{b}	5.45±0.18^{b}	5.60±0.21^{a}	0.79±0.04^{a}	0.87±0.01^{b}	0.127±0.007^{b}	28.63±2.09^{a}	0.53±0.03^{b}	5.10±0.15^{c}
T_4	CSA	17.20±0.17^{f}	3.17±0.15^{g}	2.62±0.19^{d}	0.37±0.03^{e}	0.89±0.00^{a}	0.104±0.004^{c}	14.03±0.45^{b}	0.20±0.00^{d}	2.61±0.07^{g}
T_5	GA_3 @1500µM	27.73±0.33^{b}	5.09±0.05^{c}	5.60±0.06^{a}	0.79±0.02^{a}	0.87±0.00^{b}	0.135±0.002^{a}	9.30±0.35^{d}	1.10±0.06^{a}	9.15±0.14^{a}
T_6	GA_3 @3000µM	27.77±0.80^{b}	5.17±0.19^{b}	4.50±0.15^{b}	0.63±0.02^{b}	0.89±0.01^{a}	0.108±0.005^{c}	9.40±0.15^{d}	0.60±0.06^{b}	4.35±0.09^{d}
T_7	IAA @ 0.1µM	17.03±0.15^{g}	3.29±0.05^{f}	3.29±0.11^{c}	0.46±0.02^{d}	0.88±0.00^{b}	0.122±0.003^{b}	14.63±0.18^{b}	0.30±0.00^{c}	3.03±0.14^{f}
T_8	IAA @ 1µM	19.13±0.34^{e}	3.50±0.11^{f}	3.27±0.14^{c}	0.46±0.02^{d}	0.89±0.00^{a}	0.115±0.001^{b}	11.20±0.81^{c}	0.20±0.00^{d}	3.70±0.12^{e}
T_9	BA @ 100µM	23.80±0.53^{c}	4.22±0.10^{d}	4.35±0.17^{b}	0.62±0.02^{b}	0.87±0.01^{b}	0.128±0.005^{b}	10.33±0.03^{d}	0.63±0.13^{b}	5.42±0.16^{c}
T_{10}	BA @ 300µM	20.33±0.27^{e}	3.86±0.02^{e}	3.47±0.18^{c}	0.49±0.02^{c}	0.89±0.00^{a}	0.112±0.004^{c}	12.80±1.06^{c}	0.33±0.03^{c}	4.10±0.12^{d}
T_{11}	TDZ @ 200µM	18.13±0.33^{f}	3.46±0.08^{f}	3.57±0.13^{c}	0.50±0.02^{c}	0.87±0.00^{b}	0.126±0.003^{b}	4.03±0.24^{g}	0.37±0.03^{c}	3.83±0.09^{e}
T_{12}	TDZ @ 400µM	20.33±0.38^{e}	3.71±0.19^{e}	3.55±0.13^{c}	0.49±0.02^{c}	0.88±0.01^{b}	0.119±0.008^{b}	6.60±0.40^{f}	0.33±0.03^{c}	4.30±0.15^{d}
T_{13}	CH @ 5gL^{-1}	13.80±0.36^{i}	2.69±0.02^{h}	2.60±0.06^{d}	0.37±0.01^{e}	0.88±0.00^{b}	0.120±0.002^{b}	9.30±0.32^{d}	0.20±0.00^{d}	1.77±0.19^{g}
T_{14}	CH @ 10 gL^{-1}	16.23±0.18^{g}	3.03±0.07^{g}	3.46±0.07^{c}	0.48±0.01^{c}	0.86±0.00^{c}	0.136±0.004^{a}	4.37±0.39^{g}	0.20±0.00^{d}	2.23±0.17^{g}
T_{15}	SA @ 1500µM	18.37±0.19^{f}	3.42±0.06^{f}	3.59±0.07^{c}	0.51±0.01^{c}	0.87±0.00^{b}	0.130±0.002^{b}	11.40±0.58^{c}	0.20±0.00^{d}	3.50±0.06^{d}
T_{16}	SA @ 3000µM	15.07±0.39^{h}	2.88±0.13^{gh}	2.53±0.19^{d}	0.36±0.02^{e}	0.89±0.01^{a}	0.111±0.010^{c}	12.53±0.15^{c}	0.20±0.00^{d}	1.27±0.23^{h}
T_{17}	PG @ 1µM	20.13±0.26^{e}	3.80±0.11^{e}	2.97±0.49^{d}	0.41±0.07^{de}	0.90±0.02^{a}	0.097±0.017^{c}	14.27±0.29^{b}	0.40±0.00^{c}	4.13±0.15^{d}
T_{18}	PG @ 10µM	21.40±0.95^{d}	3.96±0.18^{e}	4.36±0.13^{b}	0.64±0.02^{b}	0.86±0.01^{c}	0.140±0.007^{a}	8.90±0.31^{d}	0.57±0.03^{b}	3.60±0.12^{e}
T_{19}	*BP*	23.07±0.49^{c}	4.39±0.15^{d}	4.43±0.14^{b}	0.63±0.03^{b}	0.88±0.00^{b}	0.125±0.004^{b}	9.27±0.23^{d}	0.50±0.00^{c}	4.47±0.13^{d}
T_{20}	*BA*	17.27±0.35^{f}	3.08±0.06^{g}	3.70±0.06^{c}	0.54±0.01^{c}	0.85±0.00^{c}	0.150±0.001^{a}	11.40±0.17^{c}	0.23±0.03^{d}	2.97±0.09^{f}
T_{21}	*BV*	16.47±0.44^{g}	2.99±0.05^{gh}	3.27±0.12^{c}	0.45±0.01^{d}	0.87±0.01^{b}	0.130±0.005^{b}	8.17±0.89^{d}	0.23±0.03^{d}	3.07±0.07^{f}
T_{22}	*PF*	19.93±0.29^{e}	3.78±0.02^{e}	3.62±0.27^{c}	0.51±0.04^{c}	0.88±0.01^{b}	0.119±0.008^{b}	15.83±0.47^{b}	0.33±0.03^{c}	3.77±0.15^{f}
T_{23}	Control	16.67±0.23^{g}	3.14±0.07^{g}	3.20±0.15^{c}	0.46±0.02^{d}	0.87±0.00^{b}	0.128±0.003^{b}	7.87±0.47^{e}	0.20±0.00^{d}	2.63±0.32^{f}
	SE m (±)	0.436	0.112	0.177	0.026	0.006	0.006	0.825	0.040	0.154
	C.D. (0.05)	1.245	0.320	0.507	0.074	0.017	0.017	2.355	0.114	0.441

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; , PG- Phloroglucinol; *BP- Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.* SW-Shoot weight; RW-Root weight; HI-Harvest Index; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications

Table 34. Effect of seed pretreatments on yield parameters in transplanted *Withania somnifera* at harvest

T. No.	Treatments	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight (g)
			Fresh weight	Dry weight		
T_1	SC	2.67±0.58^{e}	2.74±0.59^{e}	0.45±0.14^{f}	0.056±0.03^{f}	2.560±0.00^{e}
T_2	WS	12.33±1.21^{a}	12.56±1.26^{a}	1.87±0.50^{a}	0.057±0.04^{e}	2.620±0.00^{c}
T_3	HW	6.33±0.58^{c}	6.39±0.55^{c}	1.05±0.15^{c}	0.072±0.06^{a}	2.600±0.00^{d}
T_4	CSA	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_5	GA_3 @1500µM	9.00±0.76^{b}	9.49±0.81^{b}	1.36±0.29^{b}	0.057±0.06^{e}	2.620±0.17^{c}
T_6	GA_3 @3000µM	4.33±0.58^{d}	4..43±0.62^{d}	0.68±0.27^{d}	0.056±0.05^{f}	2.503±0.19^{i}
T_7	IAA @ 0.1µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_8	IAA @ 1µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_9	BA @ 100µM	4.33±0.58^{d}	4.61±0.61^{c}	0.64±0.23^{d}	0.062±0.06^{d}	2.560±0.20^{e}
T_{10}	BA @ 300µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_{11}	TDZ @ 200µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_{12}	TDZ @ 400µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_{13}	CH @ 5gL^{-1}	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_{14}	CH @ 10 gL^{-1}	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_{15}	SA @ 1500µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_{16}	SA @ 3000µM	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
T_{17}	PG @ 1µM	2.33±0.58^{e}	2.48±0.57^{e}	0.33±0.21	0.069±0.06^{b}	2.640±0.19^{b}
T_{18}	PG @ 10µM	1.67±0.58^{e}	1.74±0.58^{e}	0.26±0.22^{i}	0.057±0.00^{e}	2.543±0.15^{g}
T_{19}	*BP*	3.67±0.82^{d}	3.84±0.84^{d}	0.55±0.29^{e}	0.065±0.03^{c}	2.627±0.11^{b}
T_{20}	*BA*	3.00±0.76^{e}	2.89±0.74^{e}	0.41±0.29^{g}	0.060±0.05^{d}	2.677±0.25^{a}
T_{21}	*BV*	2.67±0.58^{e}	2.60±0.57^{e}	0.33±0.20^{h}	0.027±0.35^{g}	2.530±0.14^{h}
T_{22}	*PF*	3.33±0.58^{e}	3.25±0.62^{e}	0.49±0.23^{f}	0.062±0.03^{d}	2.553±0.22^{f}
T_{23}	Control	0.00±0.00	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00
SE m (±)		0.627	0.627	0.012	0.001	0.002
C.D. (0.05)		1.840	1.840	0.035	0.002	0.006

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; , PG- Phloroglucinol; *BP- Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.* The data represents the mean of three replications

Table 35. Effect of physical treatments on seed germination and seedling parameters of *Andrographis paniculata.*

T. No.	Physical treatment	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI (cm)
T_1	SC	84.00±1.75^{a}	82.00±1.07^{a}	11.73±1.84^{a}	4.00±0.00^{b}	9.83±0.51^{a}	3.67±0.83^{b}	2.91±0.81	13.50±0.66^{b}	11.34±0.61^{b}
T_2	WS	79.33±2.01^{a}	78.66±2.01^{a}	16.20±0.591^{a}	3.00±0.00^{c}	5.57±0.67^{b}	3.50±0.50^{b}	1.63±0.50	9.07±0.54^{c}	7.16±0.48^{c}
T_3	HW	84.67±1.88^{a}	83.33±3.52^{a}	15.77±1.50^{a}	3.33±0.57^{c}	10.67±0.28^{a}	5.27±0.71^{a}	2.05±0.42	15.93±0.76^{a}	13.38±0.70^{a}
T_4	CSA	53.33±2.19^{b}	52.66±1.88^{b}	12.58±1.27^{a}	2.00±0.00^{d}	5.90±0.84^{b}	2.43±0.52^{b}	2.44±0.47	8.33±0.94^{c}	4.42±0.69^{d}
T_5	Control	46.67±0.82^{b}	46.66±0.81^{b}	4.78±0.40^{b}	5.00±0.00^{a}	3.13±0.52^{c}	2.67±0.42^{b}	1.19±0.33	5.80±0.62^{d}	2.67±0.41^{e}
SE m (±)		3.515	3.515	1.945	0.149	0.410	0.425	0.559	0.340	0.369
C.D. (0.05)		11.219	11.219	6.209	0.476	1.309	1.357	NS	1.085	1.179

T. No–Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; Gn- germination; S- Survival; GI-Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI-Allometric Index; Each figure represents mean (±SD) of three replications.

Table 36. Effect of hormonal priming on seed germination and seedling parameters of *Andrographis paniculata.*

T. No.	Hormones	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI (cm)
T_1	GA_3 @ 1500Mm	82.00±1.86^{a}	82.00±1.86^{a}	7.79±0.78^{a}	5.00±0.76^{b}	11.57±0.80	4.80±0.62	2.41±0.44	16.37±0.93^{a}	13.42±0.84^{a}
T_2	GA_3 @ 3000µM	69.33±1.88^{b}	65.33±1.15^{b}	7.54±0.78^{a}	5.67±0.57^{a}	5.93±0.54^{b}	5.67±1.37	1.28±0.59	11.60±1.31^{b}	8.00±1.09^{b}
T_3	IAA @ 0.1µM	64.67±2.28^{b}	62.66±5.69^{b}	9.42±1.31^{a}	4.00±0.76^{bc}	4.33±0.54^{c}	3.10±0.75	1.45±0.40	7.43±0.93^{e}	4.76±0.74^{c}
T_4	IAA @ 1Mm	72.00±1.52^{a}	70.67±2.39^{a}	6.48±0.81^{b}	6.00±0.76^{a}	5.00±0.32^{b}	3.33±0.57	1.53±0.44	8.37±0.49^{d}	6.00±0.41^{c}
T_5	BA @ 100Mm	65.33±2.60^{b}	64.00±2.54^{b}	7.49±0.90^{a}	4.33±0.81^{bc}	5.33±0.47^{b}	3.43±0.54	1.64±0.42	8.77±0.70^{d}	5.69±0.57^{c}
T_6	BA @ 300µM	70.67±1.88^{a}	68.00±2.31^{b}	5.82±0.50^{b}	6.67±0.57^{a}	5.90±0.57^{b}	3.40±0.24	1.73±0.28	9.30±0.60^{c}	6.51±0.50^{b}
T_7	TDZ @ 200Mm	68.67±1.33^{b}	68.66±1.52^{b}	9.47±0.86^{a}	3.67±0.57^{bc}	5.97±0.45^{b}	3.53±0.44	1.69±0.36	9.50±0.35^{c}	6.46±0.28^{b}
T_8	TDZ @ 400Mm	62.00±2.24^{b}	61.33±2.39^{b}	9.21±1.07^{a}	3.33±0.57^{c}	5.80±0.50^{b}	3.07±0.17	1.87±0.26	8.87±0.52^{d}	5.49±0.41^{c}
T_9	Control	46.67±0.82^{c}	46.66±0.81^{c}	4.78±0.40^{b}	5.00±0.00^{b}	3.13±0.52^{d}	2.67±0.42	1.19±0.33	5.80±0.62^{f}	2.67±0.41^{d}
SE m (±)		4.000	4.000	0.872	0.458	0.320	0.689	0.751	0.181	0.523
C.D. (0.05)		11.977	11.977	2.612	1.372	0.957	NS	NS	0.541	1.565

T. No – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; Gn- germination; S- Survival; GI-Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI-Allometric Index; Each figure represents mean (±SD) of three replications.

Table 37. Effect of biostimulant priming on seed germination and seedling parameters of *Andrographis paniculata.*

T. No.	Biostimulant	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI (cm)
T_1	CH@5gL^{-1}	41.33±1.55^{b}	41.33±1.55^{b}	5.36±0.82	4.33±0.82^{b}	4.93±0.35^{b}	3.30±0.50	1.51±0.14	8.23±0.36	3.38±0.24^{cd}
T_2	CH@10 gL^{-1}	45.33±1.63^{b}	45.33±1.63^{b}	5.64±0.64	4.33±0.82^{b}	5.20±0.56^{a}	3.27±0.03	1.59±0.28	8.47±0.59	3.81±0.40^{c}
T_3	SA@1500µM	42.00±2.15^{b}	42.00±2.15^{b}	5.24±0.67	4.00±0.00^{b}	6.00±0.82^{a}	3.70±0.85	1.71±0.52	9.70±1.14	4.07±0.74^{c}
T_4	SA@3000µM	43.33±1.55^{b}	43.33±2.40^{b}	3.84±0.52	6.67±0.94^{a}	5.00±0.54^{b}	2.93±0.48	1.74±0.48	7.93±0.48	3.41±0.32^{cd}
T_5	PG@1µM	66.67±1.71^{a}	64.66±1.15^{a}	6.17±0.42	6.00±0.76^{a}	5.47±0.47^{a}	3.67±0.57	1.50±0.26	9.13±0.73	6.03±0.59^{a}
T_6	PG@10µM	49.33±2.41^{b}	49.33±1.55^{b}	5.28±0.87	6.00±0.00^{a}	6.20±0.62^{a}	4.03±0.84	1.68±0.58	10.23±0.72	5.01±0.51^{b}
T_7	Control	46.67±0.82^{b}	46.66±0.81^{b}	4.78±0.40	5.00±0.00^{b}	3.13±0.52^{c}	2.67±0.42	1.19±0.33	5.80±0.62	2.67±0.41^{d}
SE m (±)		3.436	3.295	0.470	0.535	0.359	0.450	0.611	0.202	3.436
C.D. (0.05)		10.525	10.091	NS	1.637	1.098	NS	NS	NS	10.525

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol; Gn- germination; S- Survival; GI- Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index; Each figure represents mean (±SD) of three replications.

Table 38. Effect of biopriming on seed germination and seedling parameters of *Andrographis paniculata.*

T. No.	Microbes	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI (cm)
T_1	*BP*	66.00±2.15^{b}	66.00±2.15^{b}	5.69±0.76^{b}	6.67±0.57^{a}	6.93±0.35^{b}	3.93±0.41^{a}	1.77±0.03^{b}	10.87±0.42^{a}	7.17±0.35^{b}
T_2	*Bam*	60.67±1.33^{b}	60.66±1.76^{b}	5.41±0.52^{b}	5.33±0.57^{b}	4.67±0.65^{c}	2.77±0.66^{b}	1.74±0.46^{b}	7.43±0.90^{b}	4.46±0.70^{c}
T_3	*BV*	82.67±1.55^{a}	82.67±1.55^{a}	6.68±0.42^{a}	6.33±0.57^{a}	8.97±0.51^{a}	2.37±0.26^{b}	3.79±0.24^{a}	11.33±0.57^{a}	9.29±0.51^{a}
T_4	*PF*	66.00±2.03^{b}	66.00±1.33^{b}	5.03±0.22^{b}	6.67±0.57^{a}	2.77±0.52^{d}	2.43±0.45^{b}	1.18±0.46^{b}	5.20±0.35^{d}	3.43±0.28^{d}
T_5	Control	46.67±0.82^{c}	46.66±0.81^{c}	4.78±0.40^{b}	5.00±0.00^{b}	3.13±0.52^{d}	2.67±0.42^{b}	1.19±0.33^{b}	5.80±0.62^{c}	2.67±0.41^{d}
SEm(±)		3.098	3.098	0.308	0.298	0.285	0.242	3.960	0.148	0.266
C.D. (0.05)		9.889	9.889	0.983	0.952	0.909	0.772	1.640	0.473	0.848

T. No. – Treatment Number; *BP- Bacillus pumilus; Bacillus Amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis;* SA-Salicylic acid; , PG- Phloroglucinol; Gn- germination; S- Survival; GI- Germination Index; MGT- Mean Germination Time; SL- shoot length; RL- Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index; Each figure represents mean (±SD) of three replication

Table 39. Effect of various pretreatments on seed germination and seedling parameters of *Andrographis paniculata.*

Treatment	Pretreatment	Gn (%)	S (%)	GI	MGT (Days)	SL (cm)	RL (cm)	AI	Sdl L (cm)	SVI (cm)
T_1	SC	84.00±1.75^{a}	82.00±1.07^{a}	11.73±1.84^{b}	4.00±0.00^{c}	9.83±0.51^{b}	3.67±0.83^{b}	2.91±0.80^{a}	13.50±0.66^{b}	11.34±0.61^{b}
T_2	WS	79.33±2.01^{a}	78.66±2.01^{a}	16.20±0.59^{a}	3.00±0.00^{c}	5.57±0.67^{e}	3.50±0.50^{b}	1.63±0.50^{b}	9.07±0.54^{d}	7.16±0.48^{d}
T_3	HW	84.67±1.88^{a}	83.33±3.52^{a}	15.77±1.50^{a}	3.33±0.57^{c}	10.67±0.28^{a}	5.27±0.71^{a}	2.05±0.42^{a}	15.93±0.76^{a}	13.38±0.70^{a}
T_4	CSA	53.33±2.19^{d}	52.66±1.88^{c}	12.58±1.27^{b}	2.00±0.00^{d}	5.90±0.84^{d}	2.43±0.52^{b}	2.44±0.47^{a}	8.33±0.94^{e}	4.42±0.69^{f}
T_5	GA_3 @1500µM	82.00±1.86^{a}	82.00±1.86^{a}	7.79±0.78^{c}	5.00±0.76^{b}	11.57±0.80^{a}	4.80±0.62^{a}	2.41±0.44^{a}	16.37±0.93^{a}	13.42±0.84^{a}
T_6	GA_3 @3000µM	69.33±1.88^{b}	65.33±1.15^{b}	7.54±0.78^{c}	5.67±0.57^{a}	5.93±0.54^{c}	5.67±1.37^{a}	1.28±0.59^{b}	11.60±1.31^{b}	8.00±1.09^{d}
T_7	IAA @ 0.1µM	64.67±2.28^{b}	62.66±5.69^{b}	9.42±1.31^{c}	4.00±0.76^{c}	4.33±0.54^{f}	3.10±0.75^{b}	1.45±0.40^{b}	7.43±0.93^{f}	4.76±0.74^{f}
T_8	IAA @ 1µM	72.00±1.52^{b}	70.67±2.39^{b}	6.48±0.81^{cd}	6.00±0.76^{a}	5.00±0.32^{e}	3.33±0.57^{b}	1.53±0.44^{b}	8.37±0.49^{e}	6.00±0.41^{e}
T_9	BA @ 100µM	65.33±2.60^{b}	64.00±2.54^{b}	7.49±0.90^{c}	4.33±0.81^{b}	5.33±0.47^{e}	3.43±0.54^{b}	1.64±0.42^{b}	8.77±0.70^{e}	5.69±0.57^{e}
T_{10}	BA @ 300µM	70.67±1.88^{b}	68.00±2.31^{b}	5.82±0.50^{d}	6.67±0.57^{a}	5.90±0.57^{d}	3.40±0.24^{b}	1.73±0.28^{b}	9.30±0.60^{d}	6.51±0.50^{e}
T_{11}	TDZ @ 200µM	68.67±1.33^{b}	68.66±1.52^{b}	9.47±0.86^{b}	3.67±0.57^{c}	5.97±0.45^{c}	3.53±0.44^{b}	1.69±0.36^{b}	9.50±0.35^{d}	6.46±0.28^{e}
T_{12}	TDZ @ 400µM	62.00±2.24^{b}	61.33±2.39^{b}	9.21±1.07^{c}	3.33±0.57^{c}	5.80±0.50^{e}	3.07±0.17^{b}	1.87±0.26^{b}	8.87±0.52^{e}	5.49±0.41^{e}
T_{13}	CH @ 5gL^{-1}	41.33±1.55^{d}	41.33±1.55^{d}	5.36±0.82^{d}	4.33±0.82^{b}	4.93±0.35^{e}	3.30±0.50^{b}	1.51±0.14^{b}	8.23±0.36^{e}	3.38±0.24^{fg}
T_{14}	CH @ 10 gL^{-1}	45.33±1.63^{d}	45.33±1.63^{cd}	5.64±0.64^{d}	4.33±0.82^{b}	5.20±0.56^{e}	3.27±0.03^{b}	1.59±0.28^{b}	8.47±0.59^{e}	3.81±0.40^{g}
T_{15}	SA @ 1500µM	42.00±2.15^{d}	42.00±2.15^{dd}	5.24±0.67^{d}	4.00±0.00^{c}	6.00±0.82^{c}	3.70±0.85^{b}	1.71±0.52^{b}	9.70±1.14^{d}	4.07±0.74^{f}
T_{16}	SA @ 3000µM	43.33±1.55^{d}	43.33±2.40^{cd}	3.84±0.52^{d}	6.67±0.94^{a}	5.00±0.54^{e}	2.93±0.48^{b}	1.74±0.48^{b}	7.93±0.48^{f}	3.41±0.32^{g}
T_{17}	PG @ 1µM	49.33±2.41^{c}	49.33±1.55^{cd}	5.28±0.87^{d}	6.00±0.00^{a}	6.20±0.62^{c}	4.03±0.84^{b}	1.68±0.58^{b}	10.23±0.72^{c}	5.01±0.51^{f}
T_{18}	PG @ 10µM	66.67±1.71^{b}	64.66±1.15^{b}	6.17±0.42^{d}	6.00±0.76^{a}	5.47±0.47^{e}	3.67±0.57^{b}	1.50±0.26^{b}	9.13±0.73^{d}	6.03±0.59^{e}
T_{19}	*BP*	66.00±2.15^{b}	66.00±2.15^{b}	5.69±0.76^{d}	6.67±0.57^{a}	6.93±0.35^{c}	3.93±0.41^{b}	1.77±0.03^{b}	10.87±0.42^{c}	7.17±0.35^{d}
T_{20}	*BA*	60.67±1.33^{c}	60.66±1.76^{b}	5.41±0.52^{d}	5.33±0.57^{b}	4.67±0.65^{f}	2.77±0.66^{b}	1.74±0.46^{b}	7.43±0.90^{f}	4.46±0.70^{f}
T_{21}	*BV*	82.67±1.55^{a}	82.66±1.55^{a}	6.68±0.42^{c}	6.33±0.57^{a}	8.97±0.51^{b}	2.37±0.26^{b}	3.79±0.24^{a}	11.33±0.57^{b}	9.29±0.51^{c}
T_{22}	*PF*	66.00±2.03^{b}	66.00±1.33^{b}	5.03±0.22^{d}	6.67±0.57^{a}	2.77±0.52^{g}	2.43±0.45^{b}	1.18±0.46^{b}	5.20±0.35^{g}	3.43±0.28^{g}
T_{23}	Control	46.67±0.82^{d}	46.66±0.81^{cd}	4.78±0.40^{c}	5.00±0.00^{b}	3.13±0.52^{g}	2.67±0.42^{b}	1.19±0.33^{b}	5.80±0.62^{g}	2.67±0.41^{g}
SE m (±)		3.817	3.654	1.098	0.440	0.352	0.543	0.652	0.231	0.415
C.D. (0.05)		10.901	10.436	3.135	1.255	1.004	1.551	1.861	0.661	1.186

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; , PG- Phloroglucinol; *BP- Bacillus pumilus; Bacillus Amyloliquefaciens; PF-Pseudomonas fluorescens*; *BV-Bacillus velezensi;* Gn- germination; S- Survival; GI- Germination Index; MGT- Mean Germination Time; SL- shoot length; RL-Root length; Sdl L- Seedling Length; SVI- Seedling Vigour Index; AI- Allometric Index. Each figure represents mean (±SD) of three replications.

Table 40. Effect of physical seed treatments on plant height and number of branches in transplanted *Andrographis paniculata.*

T. No.	Physical treatment	Plant height (cm)				Number of branches(plant^{-1})			
		30 DAS	60 DAS	90DAS	Harvest	30 DAS	60 DAS	90DAS	Harvest
T_1	SC	9.83±0.71^a	26.63±1.18^a	48.27±1.27^a	57.87±1.34^a	-	7.33±1.33^a	22.00±2.00^a	22.00±2.00^a
T_2	WS	5.57±0.82^b	24.67±1.11^a	46.47±1.58^a	49.40±1.00^b	-	5.33±0.94^a	22.00±1.44^a	22.00±1.44^a
T_3	HW	10.67±0.17^a	25.90±1.07^a	44.00±1.34^a	55.77±1.12^a	-	7.67±0.82^a	21.67±1.09^a	21.67±1.09^a
T_4	CSA	5.90±0.92^b	17.87±1.31^b	32.47±1.13^b	36.93±1.06^c	-	3.33±1.09^b	14.00±0.76^b	14.00±0.76^b
T_5	Control	3.13±0.72^c	14.77±0.81^b	34.33±0.90^b	36.10±1.22^c	-	1.33±0.94^b	13.67±0.57^b	13.67±0.57^b
SE m (±)		0.410	1.848	2.305	2.003	-	1.145	2.124	0.410
C.D. (0.05)		1.309	5.900	7.357	6.394	-	3.655	6.779	1.309

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; DAS- Days after sowing.
Each figure represents mean (±SD) of three replications

Table 41. Effect of physical seed treatments on collar girth and number of flowers in transplanted *Andrographis paniculata.*

T. No.	Physical treatment	Collar girth (cm)				Number of Flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	SC	0.10±0.00^b	0.97±0.30	1.40±0.32^a	1.40±0.32^a	-	-	4.00±1.19	19.33±1.42^a
T_2	WS	0.09±0.03^b	0.67±0.17	1.40±0.24^a	1.40±0.24^a	-	-	2.00±0.00	7.00±1.90^b
T_3	HW	0.13±0.14^a	0.90±0.24	1.83±0.52^a	1.83±0.52^a	-	-	9.33±1.47	27.33±2.09^a
T_4	CSA	0.09±0.05^b	0.60±0.35	1.00±0.32^b	1.00±0.32^b	-	-	2.00±0.00	3.00±0.76^b
T_5	Control	0.10±0.00^b	0.73±0.17	0.87±0.17^b	0.87±0.17^b	-	-	2.00±0.00	2.00±1.08^b
SE m (±)		0.008	0.073	0.138	0.138	-	-	2.271	2.753
C.D. (0.05)		0.025	NS	0.441	0.441	-	-	NS	8.786

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 42. Effect of hormonal seed priming on plant height and number of branches in transplanted *Andrographis paniculata.*

T. No.	Hormones	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	GA_3 @ 1500µM	11.57±0.89^{a}	26.63±1.13^{a}	49.97±1.19^{a}	56.80±1.07^{a}	-	8.00±0.00^{a}	20.00±1.08^{a}	20.00±1.08^{a}
T_2	GA_3 @ 3000µM	5.93±0.73^{b}	26.57±1.12^{a}	47.73±1.27^{a}	52.27±1.20^{a}	-	5.33±1.15^{b}	19.33±1.65^{a}	19.33±1.65^{a}
T_3	IAA @ 0.1µM	4.33±0.73^{c}	18.57±0.97^{bc}	42.50±1.09^{b}	45.40±1.13^{b}	-	5.33±0.82^{b}	19.33±1.71^{a}	19.33±1.71^{a}
T_4	IAA @ 1µM	5.00±0.57^{c}	20.63±1.11^{b}	45.43±1.12^{a}	48.93±1.45^{a}	-	4.67±0.57^{b}	19.00±1.79^{a}	19.00±1.79^{a}
T_5	BA @ 100µM	5.33±0.69^{b}	23.85±1.00^{a}	44.33±1.31^{a}	46.40±1.41^{b}	-	4.00±1.08^{b}	16.33±1.09^{b}	16.33±1.09^{b}
T_6	BA @ 300µM	5.90±0.75^{b}	23.93±1.03^{a}	35.57±1.22^{cc}	40.47±0.94^{b}	-	4.33±0.57^{b}	14.67±1.15^{b}	14.67±1.15^{b}
T_7	TDZ @ 200µM	5.97±0.67^{b}	21.97±1.22^{b}	39.53±1.16^{bc}	41.90±1.27^{bc}	-	4.00±0.76^{b}	15.33±0.82^{b}	15.33±0.82^{b}
T_8	TDZ @ 400µM	5.80±0.71^{b}	23.43±0.84^{a}	37.93±1.32^{bc}	42.87±1.32^{bc}	-	5.33±0.82^{b}	15.33±1.15^{b}	15.33±1.15^{b}
T_9	Control	3.13±0.72^{d}	14.77±0.80^{c}	34.33±0.90^{c}	36.10±1.22^{c}	-	1.33±0.94^{c}	13.67±0.57^{b}	13.67±0.57^{b}
SE m (±)		0.320	1.331	2.156	2.701	-	0.770	1.296	1.296
C.D. (0.05)		0.957	3.986	6.456	8.087	-	2.305	3.88	3.88

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; DAS- Days after sowing. Each figure represents mean (±SD) of three replications

Table 43. Effect of hormonal seed priming on collar girth and number of flowers in transplanted *Andrographis paniculata.*

T. No.	Hormones	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	GA_3 @ 1500µM	0.10±0.00	1.10±0.24^{a}	1.90±0.52^{a}	1.90±0.52^{a}	-	-	11.33±1.37^{a}	21.33±1.92^{a}
T_2	GA_3 @ 3000µM	0.10±0.00	0.77±0.30^{b}	1.47±0.44^{a}	1.47±0.44^{a}	-	-	6.00±1.23^{b}	12.67±2.77^{a}
T_3	IAA @ 0.1µM	0.10±0.00	0.77±0.35^{b}	1.13±0.49^{b}	1.13±0.49^{b}	-	-	2.00±0.00^{b}	4.00±1.08^{bc}
T_4	IAA @ 1µM	0.10±0.00	0.80±0.24^{b}	0.87±0.17^{b}	0.87±0.17^{b}	-	-	3.33±1.07^{b}	5.00±1.24^{bc}
T_5	BA @ 100µM	0.10±0.00	0.63±0.30^{b}	1.13±0.35^{b}	1.13±0.35^{b}	-	-	2.00±0.00^{b}	12.00±1.08^{b}
T_6	BA @ 300µM	0.10±0.00	0.73±0.17^{b}	1.30±0.46^{b}	1.30±0.46^{b}	-	-	2.00±0.00^{b}	4.67±1.29^{bc}
T_7	TDZ @ 200µM	0.10±0.00	0.73±0.17^{b}	1.17±0.52^{b}	1.17±0.52^{b}	-	-	3.33±1.07^{b}	10.00±1.08^{bc}
T_8	TDZ @ 400µM	0.10±0.00	0.83±0.30^{b}	1.13±0.49^{b}	1.13±0.49^{b}	-	-	2.00±0.00^{b}	5.33±1.15^{bc}
T_9	Control	0.10±0.00	0.73±0.17^{b}	0.87±0.17^{b}	0.87±0.17^{b}	-	-	2.00±0.00^{b}	2.00±1.08^{c}
SE m (±)		-	0.073	0.198	0.198	-	-	1.540	3.069
C.D. (0.05)		NS	0.218	0.591	0.591	-	-	4.610	9.190

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 44. Effect of biostimulant seed priming on plant height and number of branches in transplanted *Andrographis paniculata.*

T. No.	Biostimulants	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	CH @ 5gL^{-1}	4.93±0.59^{b}	18.93±1.25^{a}	35.47±0.91^{b}	37.87±1.02^{b}	-	6.00±0.00^{a}	14.00±1.08^{b}	14.00±1.08^{b}
T_2	CH @ 10 gL^{-1}	5.20±0.75^{a}	18.23±0.90^{a}	31.47±0.98^{b}	35.57±1.22^{b}	-	5.33±0.82^{a}	14.33±0.57^{b}	14.33±0.57^{b}
T_3	SA @ 1500µM	6.00±0.90^{a}	19.27±0.94^{a}	32.97±0.86^{b}	36.57±1.30^{b}	-	5.00±0.76^{a}	15.00±0.76^{b}	15.00±0.76^{b}
T_4	SA @ 3000µM	5.00±0.73^{b}	16.07±1.00^{b}	30.60±0.59^{b}	35.73±1.19^{b}	-	6.00±0.76^{a}	13.67±0.94^{b}	13.67±0.94^{b}
T_5	PG @ 1µM	6.20±0.79^{a}	20.80±0.90^{a}	42.30±0.00^{a}	48.57±1.15^{a}	-	5.33±0.57^{a}	16.00±1.08^{ab}	16.00±1.08^{ab}
T_6	PG @ 10µM	5.47±0.69^{a}	19.77±1.05^{a}	35.67±1.42^{b}	38.63±1.35^{b}	-	4.67±0.57^{a}	18.00±1.08^{a}	18.00±1.08^{a}
T_7	Control	3.13±0.72^{c}	14.77±0.80^{b}	34.33±0.90^{b}	36.10±1.22^{b}	-	1.33±0.94^{b}	13.67±0.57^{b}	13.67±0.57^{b}
SE m (±)		0.359	0.925	1.973	2.089	-	0.549	0.845	0.845
C.D. (0.05)		1.098	2.833	6.043	6.398	-	1.682	2.588	2.588

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 45. Effect of biostimulants priming seed primimg on collar girth and number of flowers in transplanted *Andrographis paniculata.*

T. No.	Biostimulants	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	CH @ 5gL^{-1}	0.10±0.00^{a}	0.87±0.07^{a}	0.97±0.30^{b}	1.20±0.32^{a}	-	-	2.00±0.00	12.00±1.08
T_2	CH @ 10 gL^{-1}	0.10±0.00^{a}	0.87±0.26^{a}	1.00±0.32^{ab}	1.00±0.32^{ab}	-	-	2.00±0.00	5.33±0.94
T_3	SA @ 1500µM	0.09±0.05^{b}	0.63±0.17^{b}	0.93±0.17^{b}	0.93±0.17^{b}	-	-	2.00±0.00	7.00±1.00
T_4	SA @ 3000µM	0.09±0.05^{b}	0.70±0.24^{b}	0.93±0.17^{b}	0.93±0.17^{b}	-	-	2.00±0.00	3.33±0.82
T_5	PG @ 1µM	0.09±0.05^{b}	0.70±0.24^{b}	1.20±0.32^{a}	1.20±0.17^{a}	-	-	4.00±1.41	13.00±2.56
T_6	PG @ 10µM	0.09±0.05^{b}	0.70±0.24^{b}	0.83±0.17^{b}	0.83±0.30^{b}	-	-	4.67±1.28	11.00±1.00
T_7	Control	0.10±0.00^{a}	0.73±0.17^{a}	0.87±0.17^{b}	0.87±0.17^{b}	-	-	2.00±0.00	2.00±1.08
SE m (±)		0.003	0.050	0.068	0.068	-	-	1.260	2.643
C.D. (0.05)		0.008	0.154	0.208	0.208	-	-	NS	NS

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 46. Effect of biopriming of seeds on plant height and number of branches in transplanted *Andrographis paniculata.*

T. No.	Microbes	Plant height (cm)				Number of branches(plant^{-1})			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	*Bacillus pumilus (BP)*	6.93±0.59^{a}	20.13±0.55^{b}	33.90±1.35^{b}	38.83±1.34^{b}	-	5.33±0.82^{a}	14.00±0.76^{c}	14.00±0.76^{c}
T_2	*Bacillus amyloliquefaciens(BA)*	4.67±0.81^{c}	19.97±1.10^{b}	38.00±1.19^{b}	40.47±0.94^{b}	-	4.00±0.76^{b}	15.33±0.82^{b}	15.33±0.82^{b}
T_3	*Bacillus velezensis (BV)*	8.97±0.71^{b}	27.90±0.98^{a}	48.90±1.18^{a}	55.77±1.31^{a}	-	6.33±0.82^{a}	19.33±0.82^{a}	19.33±0.82^{a}
T_4	*Pseudomonas fluorescens (PF)*	2.77±0.72^{d}	20.97±1.00^{b}	41.13±1.37^{b}	41.67±1.12^{b}	-	5.00±0.76^{a}	16.00±0.00^{b}	16.00±0.00^{b}
T_5	Control	3.13±0.72^{d}	14.77±0.80^{c}	34.33±0.90^{b}	36.10±1.22^{b}	-	1.33±0.94^{c}	13.67±0.57^{c}	13.67±0.57^{c}
SE m (±)		0.285	0.947	2.540	2.312	-	0.683	0.516	0.516
C.D. (0.05)		0.909	3.024	8.108	7.380	-	2.180	1.648	1.648

T. No. – Treatment Number; DAS- Days after sowing. Each figure represents mean (±SD) of three replications.

Table 47. Effect of bioprimimg of seeds on collar girth and number of flowers in transplanted *Andrographis paniculata.*

T. No.	Biopriming	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	*Bacillus pumilus (BP)*	0.10±0.00^{a}	0.83±0.17^{b}	0.90±0.24^{b}	0.90±0.24^{b}	-	-	2.00±0.00^{b}	10.33±1.33^{b}
T_2	*Bacillus amyloliquefaciens (BA)*	0.09±0.05^{b}	0.73±0.17^{b}	0.97±0.35^{b}	0.97±0.35^{b}	-	-	2.00±0.00^{b}	6.33±1.20^{bc}
T_3	*Bacillus velezensis (BV)*	0.09±0.00^{b}	1.07±0.30^{a}	1.50±0.24^{a}	1.50±0.24^{a}	-	-	5.33±1.15^{a}	22.67±1.88^{a}
T_4	*Pseudomonas fluorescens (PF)*	0.09±0.05^{b}	0.83±0.17^{b}	0.97±0.17^{b}	0.97±0.17^{b}	-	-	2.00±0.00^{b}	9.33±1.15^{b}
T_5	Control	0.10±0.00^{a}	0.73±0.17^{b}	0.87±0.17^{b}	0.87±0.17^{b}	-	-	2.00±0.00^{b}	2.00±1.08^{c}
SE m (±)		0.002	0.049	0.068	0.068	-	-	2.518	2.039
C.D. (0.05)		0.007	0.158	0.218	0.218	-	-	0.789	6.507

T. No. – Treatment Number; DAS- Days after sowing. Each figure represents mean (±SD) of three replications

Table 48. Effect of various seed pretreatments on plant height and number of branches in transplanted *Andrographis paniculata*.

T. No.	Pretreatment	Plant height (cm)				Number of branches			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	SC	9.83±0.71^{b}	26.63±1.18^{a}	48.27±1.27^{a}	57.87±1.34^{a}	-	7.33±1.33^{a}	22.00±2.01^{a}	22.00±2.01^{a}
T_2	WS	5.57±0.82^{d}	24.67±1.11^{a}	33.13±1.95^{b}	49.40±1.00^{b}	-	5.33±0.94^{b}	22.00±1.44^{a}	22.00±1.44^{a}
T_3	HW	10.67±0.17^{a}	25.90±1.07^{a}	44.00±1.34^{a}	55.77±1.12^{a}	-	7.67±0.82^{a}	21.67±1.09^{a}	21.67±1.09^{a}
T_4	CSA	5.90±0.92^{d}	17.87±1.31^{c}	32.47±1.13^{b}	36.93±1.06^{c}	-	3.33±1.09^{b}	14.00±0.76^{b}	14.00±0.76^{b}
T_5	GA_3 @1500µM	11.57±0.89^{a}	26.63±1.13^{a}	49.97±1.19^{a}	56.80±1.07^{a}	-	8.00±0.00^{a}	20.00±1.08^{a}	20.00±1.08^{a}
T_6	GA_3 @3000µM	5.93±0.73^{c}	26.57±1.12^{a}	47.73±1.27^{a}	52.27±1.20^{a}	-	5.33±1.15^{b}	19.33±1.65^{a}	19.33±1.65^{a}
T_7	IAA @ 0.1µM	4.33±0.73^{e}	18.57±0.97^{bc}	42.50±1.09^{a}	45.40±1.13^{b}	-	5.33±0.82^{b}	19.33±1.71^{a}	19.33±1.71^{a}
T_8	IAA @ 1µM	5.00±0.57^{d}	20.63±1.11^{b}	45.43±1.12^{a}	48.93±1.45^{b}	-	4.67±0.57^{b}	19.00±1.79^{a}	19.00±1.79^{a}
T_9	BA @ 100µM	5.33±0.69^{d}	23.85±1.00^{a}	44.33±1.31^{a}	46.40±1.41^{b}	-	4.00±1.08^{b}	16.33±1.09^{b}	16.33±1.09^{b}
T_{10}	BA @ 300µM	5.90±0.75^{d}	23.93±1.03^{a}	35.57±1.22^{b}	40.47±0.94^{c}	-	4.33±0.57^{b}	14.67±1.15^{b}	14.67±1.15^{b}
T_{11}	TDZ @ 200µM	5.97±0.67^{c}	21.97±1.22^{b}	39.53±1.16^{b}	41.90±1.27^{c}	-	4.00±0.76^{b}	15.33±0.82^{b}	15.33±0.82^{b}
T_{12}	TDZ @ 400µM	5.80±0.71^{d}	23.43±0.84^{a}	37.93±1.32^{b}	42.87±1.32^{b}	-	5.33±0.82^{b}	15.33±1.15^{b}	15.33±1.15^{b}
T_{13}	CH @ 5gL^{-1}	4.93±0.59^{d}	18.93±1.25^{b}	35.47±0.91^{b}	37.87±1.02^{c}	-	6.00±0.00^{a}	14.00±1.08^{b}	14.00±1.08^{b}
T_{14}	CH @ 10 gL^{-1}	5.20±0.75^{d}	18.23±0.90^{bc}	31.47±0.98^{b}	35.57±1.22^{c}	-	5.33±0.82^{b}	14.33±0.57^{b}	14.33±0.57^{b}
T_{15}	SA @ 1500µM	6.00±0.90^{c}	19.27±0.94^{b}	32.97±0.86^{b}	36.57±1.30^{c}	-	5.00±0.76^{b}	15.00±0.76^{b}	15.00±0.76^{b}
T_{16}	SA @ 3000µM	5.00±0.73^{d}	16.07±1.00^{c}	30.60±0.59^{b}	35.73±1.19^{c}	-	6.00±0.76^{a}	13.67±0.94^{b}	13.67±0.94^{b}
T_{17}	PG @ 1µM	6.20±0.79^{c}	20.80±0.90^{b}	42.30±0.00^{a}	48.57±1.15^{b}	-	5.33±0.57^{b}	16.00±1.08^{b}	16.00±1.08^{b}
T_{18}	PG @ 10µM	5.47±0.69^{d}	19.77±1.05^{b}	35.67±1.42^{b}	38.63±1.35^{c}	-	4.67±0.57^{b}	18.00±1.08^{ab}	18.00±1.08^{ab}
T_{19}	*Bacillus pumilus (BP)*	6.93±0.59^{c}	20.13±0.55^{b}	33.90±1.35^{b}	38.83±1.34^{c}	-	5.33±0.82^{b}	14.00±0.76^{b}	14.00±0.76^{b}
T_{20}	*Bacillus amyloliquefaciens (BA)*	4.67±0.81^{e}	19.97±1.10^{b}	38.00±1.19^{b}	40.47±0.94^{c}	-	4.00±0.76^{b}	15.33±0.82^{b}	15.33±0.82^{b}
T_{21}	*Bacillus velezensis (BV)*	8.97±0.71^{b}	27.90±0.98^{a}	48.90±1.18^{a}	55.77±1.31^{a}	-	6.33±0.82^{a}	19.33±0.82^{a}	19.33±0.82^{a}
T_{22}	*Pseudomonas fluorescens (PF)*	2.77±0.72^{f}	20.97±1.00^{b}	41.13±1.37^{a}	41.67±1.12^{c}	-	5.00±0.76^{b}	16.00±0.00^{b}	16.00±0.00^{b}
T_{23}	Control	3.13±0.72^{f}	14.77±0.80^{c}	34.33±0.90^{b}	36.10±1.22^{c}	-	1.33±0.94^{c}	13.67±0.57^{b}	13.67±0.57^{b}
SE m (±)		0.352	1.366	3.649	2.366	-	0.780	1.637	1.637
C.D. (0.05)		1.004	3.902	10.421	6.757	-	2.228	4.676	4.676

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing;Each figure represents mean (±SD) of three replications

Table 49. Effect of various of seed treatments on collar girth and number of flowers in transplanted *Andrographis paniculata*.

T. No.	Pretreatment	Collar girth (cm)				Number of flowers			
		30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1	SC	0.10 ± 0.00^{b}	0.97 ± 0.30^{a}	1.40 ± 0.32^{b}	1.40 ± 0.32^{b}	-	-	4.00 ± 1.19^{d}	19.33 ± 1.42^{a}
T_2	WS	0.09 ± 0.03^{b}	0.67 ± 0.17^{c}	1.40 ± 0.24^{b}	1.40 ± 0.24^{b}	-	-	2.00 ± 0.00^{e}	7.00 ± 1.90^{bc}
T_3	HW	0.13 ± 0.14^{a}	0.90 ± 0.24^{b}	1.83 ± 0.52^{a}	1.83 ± 0.52^{a}	-	-	9.33 ± 1.47^{b}	27.33 ± 2.09^{a}
T_4	CSA	0.09 ± 0.03^{b}	0.60 ± 0.35^{c}	1.00 ± 0.32^{c}	1.00 ± 0.32^{c}	-	-	2.00 ± 0.00^{e}	3.00 ± 0.76^{c}
T_5	GA_3 @1500Mm	0.10 ± 0.00^{b}	1.10 ± 0.24^{a}	1.90 ± 0.52^{a}	1.90 ± 0.52^{a}	-	-	11.33 ± 1.37^{a}	21.33 ± 1.92^{a}
T_6	GA_3 @3000Mm	0.10 ± 0.00^{b}	0.77 ± 0.30^{bc}	1.47 ± 0.44^{b}	1.47 ± 0.44^{b}	-	-	6.00 ± 1.23^{c}	12.67 ± 2.77^{b}
T_7	IAA @ 0.1µM	0.10 ± 0.00^{b}	0.77 ± 0.35^{bc}	1.13 ± 0.49^{bc}	1.13 ± 0.49^{bc}	-	-	2.00 ± 0.00^{e}	4.00 ± 1.08^{c}
T_8	IAA @ 1Mm	0.10 ± 0.00^{b}	0.80 ± 0.24^{b}	0.87 ± 0.17^{c}	0.87 ± 0.17^{c}	-	-	3.33 ± 1.07^{d}	5.00 ± 1.24^{bc}
T_9	BA @ 100Mm	0.10 ± 0.00^{b}	0.63 ± 0.30^{c}	1.13 ± 0.35^{bc}	1.13 ± 0.35^{bc}	-	-	2.00 ± 0.00^{e}	12.00 ± 1.08^{b}
T_{10}	BA @ 300µM	0.10 ± 0.00^{b}	0.73 ± 0.17^{bc}	1.30 ± 0.46^{b}	1.30 ± 0.46^{b}	-	-	2.00 ± 0.00^{e}	4.67 ± 1.29^{c}
T_{11}	TDZ @ 200µM	0.10 ± 0.00^{b}	0.73 ± 0.17^{bc}	1.17 ± 0.52^{bc}	1.17 ± 0.52^{bc}	-	-	3.33 ± 1.07^{d}	10.00 ± 1.08^{b}
T_{12}	TDZ @ 400Mm	0.10 ± 0.00^{b}	0.83 ± 0.30^{b}	1.13 ± 0.49^{bc}	1.13 ± 0.49^{bc}	-	-	2.00 ± 0.00^{e}	5.33 ± 1.15^{bc}
T_{13}	CH @ $5gL^{-1}$	0.10 ± 0.00^{b}	0.87 ± 0.07^{b}	0.97 ± 0.30^{c}	0.97 ± 0.30^{c}	-	-	2.00 ± 0.00^{e}	12.00 ± 1.08^{b}
T_{14}	CH @ 10 gL^{-1}	0.10 ± 0.00^{b}	0.87 ± 0.26^{b}	1.00 ± 0.32^{c}	1.00 ± 0.32^{c}	-	-	2.00 ± 0.00^{e}	5.33 ± 0.94^{bc}
T_{15}	SA @ 1500µM	0.09 ± 0.03^{b}	0.63 ± 0.17^{c}	0.93 ± 0.17^{c}	0.93 ± 0.17^{c}	-	-	2.00 ± 0.00^{e}	7.00 ± 1.00^{bc}
T_{16}	SA @ 3000µM	0.09 ± 0.03^{b}	0.70 ± 0.24^{c}	0.93 ± 0.17^{c}	0.93 ± 0.17^{c}	-	-	2.00 ± 0.00^{e}	3.33 ± 0.82^{c}
T_{17}	PG @ 1µM	0.09 ± 0.03^{b}	0.70 ± 0.24^{c}	1.20 ± 0.32^{bc}	1.20 ± 0.32^{bc}	-	-	4.00 ± 1.41^{d}	13.00 ± 2.56^{b}
T_{18}	PG @ 10µM	0.09 ± 0.03^{b}	0.70 ± 0.24^{c}	0.83 ± 0.17^{c}	0.83 ± 0.17^{c}	-	-	4.67 ± 1.28^{c}	11.00 ± 1.00^{b}
T_{19}	*Bacillus pumilus (BP)*	0.10 ± 0.00^{b}	0.83 ± 0.17^{b}	0.90 ± 0.24^{c}	0.90 ± 0.24^{c}	-	-	2.00 ± 0.00^{e}	10.33 ± 1.33^{b}
T_{20}	*Bacillus amyloliquefaciens (BA)*	0.09 ± 0.03^{b}	0.73 ± 0.17^{bc}	0.97 ± 0.35^{c}	0.97 ± 0.35^{c}	-	-	2.00 ± 0.00^{e}	6.33 ± 1.20^{bc}
T_{21}	*Bacillus velezensis (BV)*	0.09 ± 0.03^{b}	1.07 ± 0.30^{a}	1.50 ± 0.24^{a}	1.50 ± 0.24^{a}	-	-	5.33 ± 1.15^{c}	22.67 ± 1.88^{a}
T_{22}	*Pseudomonas fluorescens (PF)*	0.09 ± 0.03^{b}	0.83 ± 0.17^{b}	0.97 ± 0.17^{c}	0.97 ± 0.17^{c}	-	-	2.00 ± 0.00^{e}	9.33 ± 1.15^{bc}
T_{23}	Control	0.10 ± 0.00^{b}	0.73 ± 0.17^{bc}	0.87 ± 0.17^{c}	0.87 ± 0.017^{c}	-	-	2.00 ± 0.00^{e}	2.00 ± 1.08^{c}
	SE m (±)	0.004	0.066	0.147	0.147	-	-	4.664	2.862
	C.D. (0.05)	0.012	0.188	0.419	0.419	-	-	1.633	8.172

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; PG- Phloroglucinol; DAS- Days after sowing; Each figure represents mean (±SD) of three replications

Table 50. Effect of physical seed pretreatments on phenological parameters in transplanted *Andrographis paniculata.*

T. No.	Physical treatment	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	SC	89.33±1.09	17.67±0.58 [b]
T_2	WS	66.33±5.76	15.00±0.00 [b]
T_3	HW	89.33±2.24	22.67±1.36 [a]
T_4	CSA	110.67±1.15	0.00±0.00
T_5	Control	64.67±5.69	0.00±0.00
SE m (±)		20.864	0.016
C.D. (0.05)		NS	0.050

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid. Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 51. Effect of hormonal seed priming on phenological parameters in transplanted *Andrographis paniculata.*

T. No.	Hormones	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	GA_3 @ 1500µM	84.00±1.41	23.00±0.10
T_2	GA_3 @ 3000µM	90.67±1.61	24.00±0.10
T_3	IAA @ 0.1µM	94.00±1.07	0.00±0.00
T_4	IAA @ 1µM	94.00±1.73	0.00±0.00
T_5	BA @ 100µM	94.33±0.93	21.00±0.24
T_6	BA @ 300µM	96.67±0.93	0.00±0.00
T_7	TDZ @ 200µM	96.00±2.03	0.00±0.00
T_8	TDZ @ 400µM	98.33±1.78	0.00±0.00
T_9	Control	64.67±5.69	0.00±0.00
SE m (±)		11.035	-
C.D. (0.05)		NS	NS

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 52. Effect of biostimulant seed priming on phenological parameters in transplanted *Andrographis paniculata.*

Treatment	Biostimulants	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	CH @ 5gL^{-1}	101.67±2.24	23.00±0.10
T_2	CH @ 10gL^{-1}	107.0± 1.41	16.00±1.24
T_3	SA @ 1500µM	103.0± 1.75	0.00±0.00
T_4	SA @ 3000µM	99.67±1.09	0.00±0.00
T_5	PG @ 1µM	60.00±5.48	22.33±1.20
T_6	PG @ 10µM	91.00±1.70	19.33±2.06
T_7	Control	64.67±5.69	0.00±0.00
SE m (±)		16.892	2.375
C.D. (0.05)		NS	NS

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol. Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 53. Effect of bioprimimg of seeds on phenological parameters in transplanted *Andrographis paniculata.*

T. No.	Microbes	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	*Bacillus pumilus (BP)*	94.67±1.63	19.33±1.36
T_2	*Bacillus amyloliquefaciens(BA)*	99.00±1.44	18.67±1.55
T_3	*Bacillus velezensis (BV*	89.67±1.48	19.33±1.09
T_4	*Pseudomonas fluorescens (PF)*	102.67±1.55	21.67±1.09
T_5	Control	64.67±5.69	0.00±0.00
SE m (±)		14.614	1.740
C.D. (0.05)		NS	NS

Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 54. Effect of seed pretreatments on phenological parameters in transplanted *Andrographis paniculata.*

Treatment	Pretreatment	Days to flower initiation (Days)	Days to fruit set (Days)
T_1	Scarification	89.33±1.09	17.67±0.58[b]
T_2	Water soaking	66.33±5.76	15.00±0.00[b]
T_3	Hot water	89.33±2.24	22.67±1.36[a]
T_4	Conc.H_2SO_4	110.67±1.15	0.00±0.00
T_5	GA_3 @ 1500µM	84.00±1.41	23.00±0.10[a]
T_6	GA_3 @ 3000µM	90.67±1.61	24.00±0.10[a]
T_7	IAA @ 0.1µM	94.00±1.07	0.00±0.00
T_8	IAA @ 1µM	94.00±1.73	0.00±0.00
T_9	BA @ 100µM	94.33±0.93	21.00±0.24[a]
T_{10}	BA @ 300µM	96.67±0.93	0.00±0.00
T_{11}	TDZ @ 200µM	96.00±2.03	0.00±0.00
T_{12}	TDZ @ 400µM	98.33±1.78	0.00±0.00
T_{13}	CH @ 5gL^{-1}	101.67±2.24	23.00±0.10[a]
T_{14}	CH @ 10 gL^{-1}	107.0± 1.41	16.00±1.24[b]
T_{15}	SA @ 1500µM	103.0± 1.75	0.00±0.00
T_{16}	SA @ 3000µM	99.67±1.09	0.00±0.00
T_{17}	PG @ 1µM	60.00±5.48	22.33±1.20[a]
T_{18}	PG @ 10µM	91.00±1.70	19.33±2.06[a]
T_{19}	*Bacillus pumilus (BP)*	94.67±1.63	19.33±1.36[a]
T_{20}	*Bacillus amyloliquefaciens (BA)*	99.00±1.44	18.67±1.55[b]
T_{21}	*Bacillus velezensis (BV)*	89.67±1.48	19.33±1.09[a]
T_{22}	*Pseudomonas fluorescens (PF)*	102.67±1.55	21.67±1.09[a]
T_{23}	Control	64.67±5.69	0.00±0.00
SE m (±)		11.796	1.652
C.D. (0.05)		NS	4.811

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; , PG- Phloroglucinol; DAS- Days after sowing; Each figure represents mean (±SD) of three replications.Treatments that set fruits only are subjected to statistical analysis.

Table 55. Effect of physical seed pretreatments on yield parameters in transplanted *Andrographis paniculata at harvest*

T. No.	Microbes	SW (g plant^{-1})		RW (g plant^{-1})		Whole plant biomass (g plant^{-1})		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Fresh weight	Dry weight			
T_1	SC	45.27±0.96^a	13.97±0.98^b	7.77±0.90^a	1.42±0.14^a	53.03±1.25^a	15.39±1.75^b	33.27±1.72^a	3.70±0.24^a	9.17±1.01^a
T_2	WS	31.67±1.26^b	12.23±0.92^b	3.93±0.70^b	0.56±0.12^c	35.60±1.42^b	12.79±1.65^b	37.77±1.13^a	2.47±0.35^b	5.00±0.63^b
T_3	HW	52.47±2.87^a	20.77±1.66^a	7.13±0.70^a	1.13±0.28^b	59.60±2.95^a	21.90±0.14^a	40.23±2.07^a	3.30±0.52^a	7.57±0.96^a
T_4	CSA	28.63±1.97^b	11.00±1.19^b	4.50±0.77^b	0.96±0.35^b	33.13±3.62^b	11.96±0.57^b	26.20±1.60^b	2.57±0.41^b	5.57±0.77^b
T_5	Control	29.77±1.09^b	10.63±1.22^b	3.10±0.83^b	0.45±0.41^c	32.87±1.26^b	11.08±1.22^b	16.37±1.23^c	2.37±0.39^b	4.23±0.64^b
SE m (±)		4.191	1.635	0.582	0.088	4.591	2.562	2.743	0.165	0.722
C.D. (0.05)		13.377	5.218	1.857	0.281	14.655	5.274	8.754	0.528	2.305

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; SW-Shoot weight; RW-Root weight; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications.

Table 56. Effect of physical seed pretreatments on yield parameters in transplanted *Andrographis paniculata* at harvest

T. No.	Physical treatment	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight(g)
			Fresh weight	Dry weight		
T_1	SC	8.67±1.21	0.42±0.26	0.042±0.11	0.020±0.04	1.57±0.32
T_2	WS	6.00±0.00	0.29±0.00	0.032±0.00	0.029±0.00	1.67±0.11
T_3	HW	15.33±1.94	1.07±0.59	0.075±0.15	0.019±0.05	1.56±0.13
T_4	CSA	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_5	Control	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
SE m (±)		2.325	2.325	0.210	0.014	0.006
C.D. (0.05)		NS	NS	NS	NS	NS

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 57. Effect of hormonal seed priming on yield parameters in transplanted *Andrographis paniculata at harvest*

T. No.	Hormones	SW (g plant^{-1})		RW (g plant^{-1})		Whole plant biomass (g plant^{-1})		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Fresh weight	Dry weight			
T_1	GA_3@1500µM	46.60±2.44^a	21.57±1.58^a	10.03±1.25^a	2.02±0.08^a	56.63±2.63^a	23.60±1.87^a	44.57±1.52^a	3.73±0.42^a	8.60±0.65^a
T_2	GA_3@3000µM	43.30±1.46^a	16.17±1.22^a	5.83±0.91^b	0.98±0.05^b	49.13±1.15^a	17.15±1.20^b	33.40±2.01^b	3.03±0.39^b	4.83±0.82^b
T_3	IAA@0.1µM	36.77±1.68^{ab}	13.83±1.37^b	4.40±1.12^c	0.91±0.08^c	41.17±2.00^b	14.74±1.39^b	27.40±1.14^b	2.90±0.35^{bc}	4.90±0.46^b
T_4	IAA@1Mm	32.07±1.83^b	9.93±1.30^b	6.10±1.11^b	1.08±0.05^b	38.17±1.45^b	11.01±1.25^b	34.60±1.58^b	3.17±0.62^a	4.30±0.66^{bc}
T_5	BA@100Mm	32.23±2.19^b	11.37±1.01^b	5.10±0.78^{bc}	0.92±0.08	37.33±2.32^b	11.65±1.87^b	32.87±1.80^b	2.83±0.45^{bc}	3.20±0.75^c
T_6	BA@300Mm	32.67±2.41^b	10.73±1.86^b	7.17±0.67^b	1.13±0.48^b	39.83±2.42^b	12.50±1.05^b	22.87±1.34^c	2.77±0.39^{bc}	4.50±0.68^b
T_7	TDZ@200µM	35.83±1.13^{ab}	12.13±0.96^b	4.03±0.35^c	0.98±0.05^b	39.87±1.15^b	13.10±0.88^b	26.30±1.62^b	2.93±0.36^{bc}	5.13±0.35^b
T_8	TDZ@400µM	36.57±1.49^{ab}	13.70±1.12^b	3.87±0.54^b	0.65±0.11^d	40.43±1.40^b	14.35±1.12^b	32.97±2.19^b	2.90±0.41^{bc}	4.90±0.50^b
T_9	Control	29.77±1.09^b	10.63±1.22^b	3.10±0.83^c	0.45±0.41^d	32.87±1.26^b	11.08±1.22^b	16.37±1.23^c	2.37±0.39^c	4.23±0.64^{bc}
SE m (±)		3.0707	2.073	0.889	0.062	3.973	2.059	2.874	0.196	0.430
C.D. (0.05)		11.098	6.207	2.661	0.184	11.896	6.164	8.606	0.586	1.287

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ- Thidiazuron; SW-Shoot weight; RW-Root weight; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications.

Table 58. Effect of hormonal seed priming on yield parameters in transplanted *Andrographis paniculata* at harvest

T. No.	Hormones	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight(g)
			Fresh weight	Dry weight		
T_1	GA_3@1500µM	21.67±1.63^a	1.16±0.33^a	0.127±0.16^a	0.015±0.00	1.52±0.13^b
T_2	GA_3@3000µM	12.00±0.00^b	0.59±0.00^b	0.076±0.00^b	0.010±0.00	1.64±0.00^a
T_3	IAA@0.1µM	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_4	IAA@1Mm	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_5	BA@100µM	3.67±0.58^c	0.17±0.13^c	0.014±0.03^c	0.013±0.07	1.51±0.11^b
T_6	BA@300µM	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_7	TDZ@200µM	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_8	TDZ@400µM	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_9	Control	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
SE m (±)		1.552	0.062	0.015	0.003	0.013
C.D. (0.05)		5.474	0.219	0.052	NS	0.045

T. No. – Treatment Number; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 59. Effect of biostimulant seed priming on yield parameters in transplanted *Andrographis paniculata at harvest*

T. No.	Biostimulants	SW (g plant^{-1})		RW (g plant^{-1})		Whole plant biomass (g plant^{-1})		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Fresh weight	Dry weight			
T_1	CH @ 5gL^{-1}	30.73±1.45^a	12.17±1.73^a	3.40±0.46^b	0.68±0.08^b	34.13±1.43^a	12.95±1.22^a	24.37±1.28^{bc}	2.63±0.41^a	4.57±0.42^b
T_2	CH @ 10gL^{-1}	27.77±1.51^{ab}	7.77±0.88^{ab}	2.60±0.71^b	0.41±0.08^c	30.37±1.56^b	8.18±0.88^b	22.23±1.59^{bc}	2.60±0.35^b	3.67±0.69^b
T_3	SA @ 1500µM	26.10±0.71^b	6.73±0.75^b	3.63±0.98^{ab}	0.81±0.08^a	29.73±0.98^b	7.55±0.77^b	29.73±1.28^a	2.30±0.24^b	3.97±0.69^b
T_4	SA @ 3000µM	24.03±1.25^b	6.47±0.62^b	3.53±0.30^b	0.54±0.08^{bc}	27.57±1.28^b	7.01±0.61^b	26.27±2.24^b	2.50±0.24^b	4.67±0.35^a
T_5	PG @ 1µM	33.70±2.12^a	12.27±1.26^a	5.27±0.83^a	0.93±0.08^a	38.97±2.28^a	13.14±1.25^a	35.43±1.26^a	3.07±0.36^a	6.00±0.85^a
T_6	PG @ 10µM	22.30±1.32^b	6.03±0.96^b	2.70±0.57^b	0.42±0.08^c	25.00±1.43^b	6.45±0.97^b	27.17±1.77^a	2.80±0.50^a	3.27±0.64^b
T_7	Control	29.77±1.09^a	10.63±1.22^a	3.10±0.83^b	0.45±0.41^c	32.87±1.26^{ab}	11.08±1.22^{ab}	16.37±1.23^c	2.37±0.39^b	4.23±0.64^b
SEm(±)		1.969	1.491	0.535	0.070	2.604	1.651	2.716	0.146	0.441
C.D. (0.05)		6.029	4.565	1.638	0.214	7.974	4.755	8.319	0.448	1.350

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol. SW-Shoot weight; RW-Root weight; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications.

Table 60. Effect of biostimulant seed priming on yield parameters in transplanted *Andrographis paniculata* at harvest

T. No.	Biostimulants	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight(g)
			Fresh weight	Dry weight		
T_1	CH @ 5gL^{-1}	5.00±0.00	0.250±0.00^a	0.020±0.00	0.012±0.00^b	1.67±0.00^a
T_2	CH @ 10gL^{-1}	2.00±0.00	0.092±0.10^b	0.008±0.00	0.001±0.00^c	1.60±0.00^b
T_3	SA @ 1500µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.000
T_4	SA @ 3000µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.000
T_5	PG @ 1µM	6.00±0.00	0.340±0.18^a	0.030±0.00	0.022±0.04^a	1.59±0.08^b
T_6	PG @ 10µM	4.67±1.15	0.220±0.25^a	0.024±0.25	0.024±0.03^a	1.63±0.18^{ab}
T_7	Control	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
SE m (±)		0.667	0.036	0.032	0.001	0.016
C.D. (0.05)		NS	0.119	NS	0.003	0.053

T. No. – Treatment Number; CH- Chitosan; SA-Salicylic acid; PG- Phloroglucinol. Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 61. Effect of seed biopriming on yield parameters in transplanted *Andrographis paniculata at harvest*

T. No.	Microbes	SW (g plant^{-1})		RW (g plant^{-1})		Whole plant biomass (g plant^{-1})		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Fresh weight	Dry weight			

T_1	*BP*	31.50±2.61^{b}	10.40±1.26^{b}	2.73±0.83^{b}	0.46±0.08	34.23±2.66^{b}	10.86±1.27^{b}	25.27±1.74^{b}	2.83±0.48^{b}	4.43±0.82^{b}
T_2	*Bam*	27.57±0.75^{b}	7.83±0.64^{b}	3.27±0.42^{b}	0.58±0.08	30.83±0.74^{b}	8.41±0.69^{b}	25.57±1.36^{b}	2.37±0.17^{b}	4.33±0.45^{b}
T_3	*BV*	46.30±2.00^{a}	15.50±1.46^{a}	7.67±0.80^{a}	1.37±0.37	53.97±2.05^{a}	16.87±1.45^{a}	46.23±1.85^{a}	3.67±0.57^{a}	8.00±1.13^{a}
T_4	*PF*	35.37±1.95^{ab}	11.53±1.31^{ab}	3.60±1.05^{b}	0.64±0.05	38.97±2.06^{b}	12.12±0.95^{b}	23.73±0.93^{bc}	2.80±0.35^{b}	4.50±0.90^{b}
T_5	Control	29.77±1.09^{b}	10.63±1.22^{b}	3.10±0.83^{b}	0.45±0.41	32.87±1.26^{b}	11.08±1.22^{b}	16.37±1.23^{c}	2.37±0.39^{b}	4.23±0.64^{b}
SE m (±)		3.960	1.490	0.682	0.078	4.207	2.529	2.345	0.199	0.767
C.D. (0.05)		12.640	4.755	2.177	NS	13.427	5.078	7.486	0.635	2.447

T. No. – Treatment Number; *BP- Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.* SW-Shoot weight; RW-Root weight; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications

Table 62. Effect of seed biopriming on yield parameters in transplanted *Andrographis paniculata* at harvest

T. No.	Microbes	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight(g)
			Fresh weight	Dry weight		
T_1	*BP*	3.00±0.00	0.18±0.13^{a}	0.204±0.31	0.008±0.00^{b}	1.62±0.15^{a}
T_2	*Bam*	2.00±0.00	0.10±0.00^{b}	0.010±0.00	0.002±0.00^{c}	1.50±0.00^{b}
T_3	*BV*	14.00±2.36	0.19±0.17^{a}	0.060±0.06	0.057±0.03^{a}	1.61±0.19^{a}
T_4	*PF*	4.00±0.76	0.02±0.50^{c}	0.006±0.04	0.004±0.00^{c}	1.62±0.16^{a}
T_5	Control	0.00±0.00	0.00±0.00	0.000±0.00	0.000±0.00	0.00±0.00
SE m (±)		2.799	0.017	0.048	0.000	0.026
C.D. (0.05)		NS	0.055	NS	0.002	0.084

T. No. – Treatment Number; *BP- Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.*
The data represents the mean of three replications. Treatments that set fruits only are subjected to statistical analysis.

Table 63. Effect of seed pretreatments on yield parameters in transplanted *Andrographis paniculata* at harvest

T. No.	Pretreatments	SW (g plant^{-1})		RW (g plant^{-1})		Whole plant biomass (g plant^{-1})		RL (cm)	RD (cm)	RV (cm^3)
		Fresh weight	Dry weight	Fresh weight	Dry weight	Fresh weight	Dry weight			
T_1	SC	45.27±0.96^{a}	13.97±0.98^{b}	7.77±0.90^{b}	1.42±0.14^{b}	53.03±1.25^{a}	15.39±1.75^{bb}	33.27±1.72^{b}	3.70±0.24^{a}	9.17±1.01^{a}
T_2	WS	31.67±1.26^{bc}	12.23±0.92^{b}	3.93±0.70^{cd}	0.56±0.12^{ef}	35.60±1.42^{bc}	12.79±1.65^{b}	37.77±1.13^{b}	2.47±0.35^{d}	5.00±0.63^{b}

T_3	HW	52.47±2.87^{a}	20.77±1.66^{b}	7.13±0.70^{b}	1.13±0.28^{c}	59.60±2.95^{a}	21.90±0.14^{a}	40.23±2.07^{a}	3.30±0.52^{a}	7.57±0.96^{a}
T_4	CSA	28.63±1.97^{bc}	11.00±1.19^{c}	4.50±0.77^{cd}	0.96±0.35^{c}	33.13 ±3.62^{bc}	11.96±0.57^{b}	26.20±1.60^{c}	2.57±0.41^{d}	5.57±0.77^{b}
T_5	GA_3 @1500µM	46.60±2.44^{a}	21.57±1.58^{a}	10.03±1.25^{a}	2.02±0.45^{a}	56.63±2.63^{a}	23.59±0.50^{a}	44.57±1.52^{a}	3.73±0.42^{a}	8.60±0.65^{a}
T_6	GA_3 @3000µM	43.30±1.46^{a}	12.13±0.96^{b}	5.83±0.91^{b}	0.98±0.25^{c}	49.13±1.15^{a}	13.11±1.12^{b}	33.40±2.01^{b}	3.03±0.39^{c}	4.83±0.82^{bc}
T_7	IAA @ 0.1µM	36.77±1.68^{b}	13.83±1.37^{b}	4.40±1.12^{cd}	0.91±0.21^{d}	41.17±2.00^{b}	14.74±1.92^{b}	27.40±1.14^{c}	2.90±0.35^{c}	4.90±0.46^{bc}
T_8	IAA @ 1µM	32.07±1.83^{bc}	13.70±1.12^{b}	6.10±1.11^{b}	1.08±0.35^{c}	38.17±1.45^{b}	14.78±1.56^{b}	34.60±1.58^{b}	3.17±0.62^{c}	4.30±0.66^{bc}
T_9	BA @ 100µM	32.23±2.19^{bc}	9.93±1.30^{c}	5.10±0.78^{c}	0.92±0.25^{d}	37.33±2.32^{b}	10.85±1.78^{c}	32.87±1.80^{b}	2.83±0.45^{c}	3.20±0.75^{c}
T_{10}	BA @ 300µM	32.67±2.41^{bc}	10.73±1.86^{c}	7.17±0.67^{b}	1.13±0.29^{c}	39.83±2.42^{b}	11.86±1.15^{b}	22.87±1.34^{cd}	2.77±0.39^{cd}	4.50±0.68^{bc}
T_{11}	TDZ @ 200µM	35.83±1.13^{b}	11.37±1.01^{b}	4.03±0.35^{cd}	0.98±0.39^{b}	39.87±1.15^{b}	12.35±1.78^{b}	26.30±1.62^{c}	2.93±0.36^{c}	5.13±0.35^{b}
T_{12}	TDZ @ 400µM	36.57±1.49^{b}	16.17±1.22^{b}	3.87±0.54^{cd}	0.65±0.08^{e}	40.43±1.40^{b}	16.82±0.56^{b}	32.97±2.19^{b}	2.90±0.41^{c}	4.90±0.50^{bc}
T_{13}	CH @ 5gL^{-1}	30.73±1.45^{bc}	12.27±1.26^{b}	3.40±0.46^{cd}	0.68±0.32^{e}	34.13±1.43^{bc}	12.95±0.75^{b}	24.37±1.28^{cd}	2.63±0.41^{d}	4.57±0.42^{bc}
T_{14}	CH @ 10 gL^{-1}	27.77±1.51^{bc}	7.77±0.88^{c}	2.60±0.71^{d}	0.41±0.17^{f}	30.37±1.56^{bc}	8.18±1.36^{c}	22.23±1.59^{cd}	2.60±0.35^{d}	3.67±0.69^{c}
T_{15}	SA @ 1500µM	26.10±0.71^{bc}	6.73±0.75^{c}	3.63±0.98^{cd}	0.93±0.29^{c}	29.73±0.98^{bc}	7.66±0.99^{c}	29.73±1.28^{b}	2.30±0.24^{d}	3.97±0.69^{c}
T_{16}	SA @ 3000µM	24.03±1.25^{c}	6.47±0.62^{c}	3.53±0.30^{cd}	0.54±0.13^{ef}	27.57±1.28^{c}	7.01±0.66^{c}	26.27±2.24^{c}	2.50±0.24^{d}	4.67±0.35^{bc}
T_{17}	PG @ 1µM	33.70±2.12^{b}	12.17±1.73^{b}	5.27±0.83^{c}	0.81±0.21^{d}	38.97±2.28^{b}	12.98±1.17^{b}	35.43±1.26^{b}	3.07±0.36^{c}	6.00±0.85^{b}
T_{18}	PG @ 10µM	22.30±1.32^{c}	6.03±0.96^{c}	2.70±0.57^{d}	0.42±0.13^{f}	25.00±1.43^{c}	6.45±0.41^{c}	27.17±1.77^{c}	2.80±0.50^{cd}	3.27±0.64^{c}
T_{19}	*BP*	31.50±2.61^{bc}	10.40±1.26^{c}	2.73±0.83^{d}	0.46±0.12^{f}	34.23±2.66^{bc}	10.86±0.78^{c}	25.27±1.74^{c}	2.83±0.48^{c}	4.43±0.82^{bc}
T_{20}	*BA*	27.57±0.75^{bc}	7.83±0.64^{c}	3.27±0.42^{c}	0.58±0.32^{ef}	30.83±0.74^{bc}	8.41±1.13^{c}	25.57±1.36^{c}	2.37±0.17^{d}	4.33±0.45^{bc}
T_{21}	*BV*	46.30±2.00^{a}	15.50±1.46^{b}	7.67±0.80^{b}	1.37±0.17^{b}	53.97±2.05^{a}	16.87±0.65^{b}	46.23±1.85^{a}	3.67±0.57^{a}	8.00±1.13^{a}
T_{22}	*PF*	35.37±1.95^{b}	11.53±1.31^{b}	3.60±1.05^{cd}	0.64±0.13^{e}	38.97±2.06^{b}	12.17±0.75^{b}	23.73±0.93^{b}	2.80±0.35^{c}	4.50±0.90^{bc}
T_{23}	Control	29.77±1.09^{bc}	10.63±1.22^{c}	3.10±0.83^{d}	0.45±0.20^{f}	32.87±1.26^{bc}	11.08±0.57^{c}	16.37±1.23^{d}	2.37±0.39^{d}	4.23±0.64^{bc}
	SE m (±)	3.746	1.786	0.748	0.070	4.023	1.765	2.830	0.182	0.602
	C.D. (0.05)	10.698	5.102	2.135	0.199	11.488	5.040	8.081	0.521	1.721

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA-Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; PG- Phloroglucinol; *BP- Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.* SW-Shoot weight; RW-Root weight; HI-Harvest Index; RL-Root length; RD-Root diameter; RV-Root volume. Each figure represents mean (±SD) of three replications. Treatments that set fruits only are subjected to statistical analysis.

T. No.	Treatments	No of fruits (No plant^{-1})	Fruit weight (g plant^{-1})		Seed yield (g plant^{-1})	thousand (1000) seed weight (g)
			Fresh weight	Dry weight		
T_1	SC	8.67±1.21^{c}	0.420±0.26^{b}	0.042±0.11^{ab}	0.020±0.04^{c}	1.57±0.32^{b}
T_2	WS	6.00±0.00^{cd}	0.290±0.00^{bc}	0.032±0.00^{b}	0.029±0.00^{b}	1.67±0.11^{a}

T_3	HW	15.33±1.94^{b}	1.070±0.59^{a}	0.075±0.15^{ab}	0.019±0.05^{c}	1.56±0.13^{b}
T_4	CSA	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_5	GA_3 @1500µM	21.67±1.63^{a}	1.160±0.33^{a}	0.127±0.16^{a}	0.015±0.00^{d}	1.52±0.13^{b}
T_6	GA_3 @3000µM	12.00±0.00^{b}	0.590±0.00^{b}	0.076±0.00^{ab}	0.010±0.00^{d}	1.64±0.00^{a}
T_7	IAA @ 0.1µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_8	IAA @ 1µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_9	BA @ 100µM	3.67±0.58^{cd}	0.170±0.13^{c}	0.014±0.03^{b}	0.013±0.07^{d}	1.51±0.11^{b}
T_{10}	BA @ 300µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_{11}	TDZ @ 200µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_{12}	TDZ @ 400µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
T_{13}	CH @ 5gL^{-1}	5.00±0.00^{cd}	0.250±0.00^{c}	0.020±0.00^{b}	0.012±0.00^{d}	1.67±0.00^{a}
T_{14}	CH @ 10 gL^{-1}	4.00±0.00^{cd}	0.092±0.10^{c}	0.008±0.00^{b}	0.001±0.00^{f}	0.00±0.000
T_{15}	SA @ 1500µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.000
T_{16}	SA @ 3000µM	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.000
T_{17}	PG @ 1µM	6.00±0.00^{cd}	0.340±0.18^{b}	0.030±0.00^{b}	0.022±0.04^{c}	1.59±0.08^{ab}
T_{18}	PG @ 10µM	4.67±1.15^{cd}	0.220±0.25^{c}	0.024±0.25^{b}	0.024±0.03^{b}	1.63±0.18^{a}
T_{19}	*BP*	3.00±0.00^{cd}	0.180±0.13^{c}	0.004±0.31^{b}	0.008±0.00^{e}	1.62±0.15^{a}
T_{20}	*BA*	2.00±0.00^{d}	0.100±0.00^{c}	0.010±0.00^{b}	0.002±0.00^{f}	1.50±0.00^{b}
T_{21}	*BV*	14.00±2.36^{b}	0.190±0.17^{c}	0.060±0.06^{ab}	0.057±0.03^{a}	1.61±0.19^{a}
T_{22}	*PF*	4.00±0.76^{cd}	0.020±0.50^{c}	0.006±0.04^{b}	0.004±0.00^{ef}	1.62±0.16^{a}
T_{23}	Control	0.00±0.00	0.000±0.00	0.000±0.00	0.000±0.00	0.00±0.00
SE m (±)		2.010	0.104	0.032	0.002	0.033
C.D. (0.05)		5.852	0.302	0.094	0.005	0.096

Table 64. Effect of seed pretreatments on yield parameters in transplanted *Andrographis paniculata* at harvest

T. No. – Treatment Number; SC-Scarification; WS-Water soaking; HW-Hot water; CSA-Concentrated Sulphuric Acid; GA- Gibberellic acid; IAA- Indole Acetic Acid; BA-Benzyl Adenine; TDZ-Thidiazuron; CH-Chitosan; SA-Salicylic acid; PG- Phloroglucinol; *BP-Bacillus pumilus; Bacillus amyloliquefaciens; PF- Pseudomonas fluorescens*; *BV-Bacillus velezensis.* The data represents the mean of three replications. Treatments that set fruits only are subjected to statistical analysis.

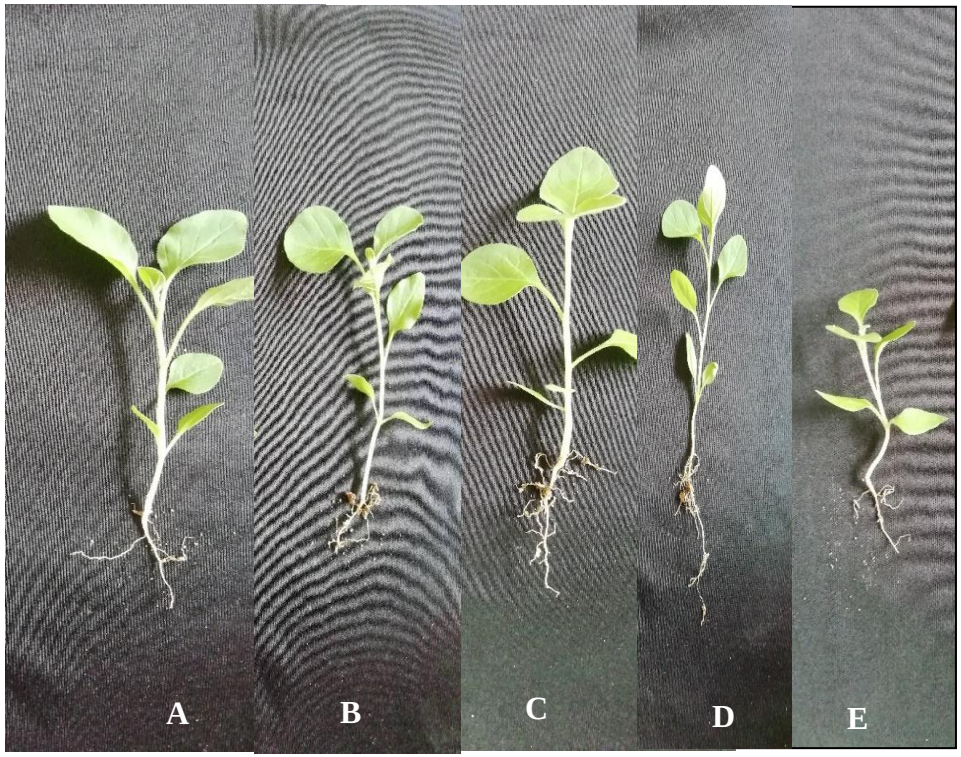

Plate 1. Effect of physical seed pretreatments on *W. somnifera* seedlings (30 DAS): (A) Scarification (using sand paper), (B) Water soaking (overnight), (C)Hotwater treatment (65^{o}C for 10 min), (D) Concentrated sulphuric acid (1 min), (E) Control

Plate 2. Effect of hormonal seed priming on *W. somnifera* seedlings (30 DAS): (A) GA_3 @ 1500 µM, (B) GA_3 @ 3000 µM, (C) IAA @ 0.1 µM, (D) IAA @ 1 µM, (E) BA @ 100 µM, (F) BA @ 300 µM,(G) TDZ @ 200 µM, (H) TDZ @ 400 µM, (I) Control

Plate 3. Effect of biostimulant seed priming on *W. somnifera* seedlings (30 DAS):(A) Chitosan @ 5g L^{-1}, (B) Chitosan @ 10 gL^{-1}, (C) Salicylic acid @ 1500 µM, (D) Salicylic acid @ 3000 µM, (E) Phloroglucinol @ 1 µM, (F) Phloroglucinol @ 10 µM, (G) Control

Plate 4. Effect of seed biopriming on *W. somnifera* seedlings (30 DAS): (A) *Bacillus pumilus*VLY17, (B) *Bacillus amyloliquefaciens*VLY24, (C) *Pseudomonas fluorescens*PN026R, (D) *Bacillus velezensis*

PCSE10, (E) Control

Plate 5. Effect of seed pretreatments at flowering (90 DAS) in *W. somnifera*: (A)GA_3@1500 µM, (B)Hot water treatment, (C) Water soaking

Plate 6. Effect of physical seed pretreatments on shoot biomass at harvest (120 DAS) in *W. somnifera*: (A) Scarification (using sand paper), (B) Water soaking (overnight), (C) Hotwater treatment (65^{o}C for 10 min), (D) Concentrated sulphuric acid (1 min), (E) Control

Plate 7. Effect of hormonal seed priming treatments on shoot biomass at harvest (120 DAS) in *W. somnifera*: (A) GA_3 @ 1500 µM, (B) GA_3 @ 3000 µM, (C) IAA @ 0.1 µM, (D) IAA @ 1 µM, (E) BA @ 100 µM, (F) BA @ 300 µM, (G) TDZ @ 200 µM, (H) TDZ @ 400 µM, (I) Control

Plate 8. Effect of biostimulant seed priming on shoot biomass at harvest (120 DAS) in *W. somnifera*: (A) Chitosan @ 5g L^{-1}, (B) Chitosan @10 gL^{-1}, (C) Salicylic acid @ 1500 µM, (D) Salicylic acid @ 3000 µM, (E) Phloroglucinol @ 1 µM, (F) Phloroglucinol @ 10 µM, (G) Control

A B C D E

Plate 9. Effect of seed biopriming on shoot biomass at harvest (120 DAS) in *W.somnifera*: (A) *Bacillus pumilus*VLY17, (B) *Bacillus amyloliquefaciens*VLY24, (C)*Pseudomonas fluorescens*PN026R, (D) *Bacillus velezensis*PCSE10, (E) Control

Plate 10. Pests observed during the study in *Withania somnifera*: Hairy caterpillar- *Pericallia ricini*

Plate 11. Effect of physical seed pretreatments treatments on *A.paniculata* seedlings (30 DAS): (A) Scarification (using sand paper), (B) Water soaking (overnight), (C) Hotwater treatment (65^{o}C for 10 min), (D) Concentrated sulphuric acid (1 min), (E) Control

Plate 12. Effect of hormonal seed priming on *A. paniculata* seedlings (30 DAS): (A) GA_3 @ 1500 µM, (B) GA_3 @ 3000 µM,

(C) IAA @ 0.1 µM, (D)IAA @ 1 µM, (E) BA @ 100 µM, (F) BA @ 300 µM, (G) TDZ @ 200 µM, (H) TDZ @ 400 µM, (I) Control

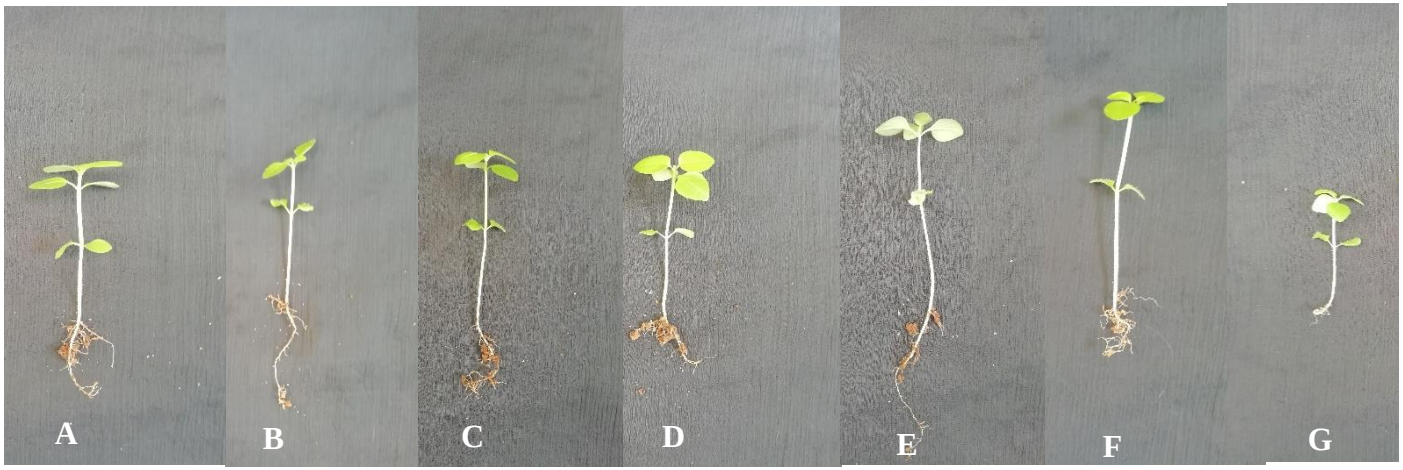

Plate 13.Effect of biostimulant seed priming on *A. paniculata seedlings* (30 DAS):(A)Chitosan@5gL^{1}, (B) Chitosan@ 10 gL^{-1}, (C) Salicylic acid @ 1500 µM, (D) Salicylic acid @ 3000 µM, (E) Phloroglucinol @ 1 µM, (F) Phloroglucinol @ 10 µM, (G) Control

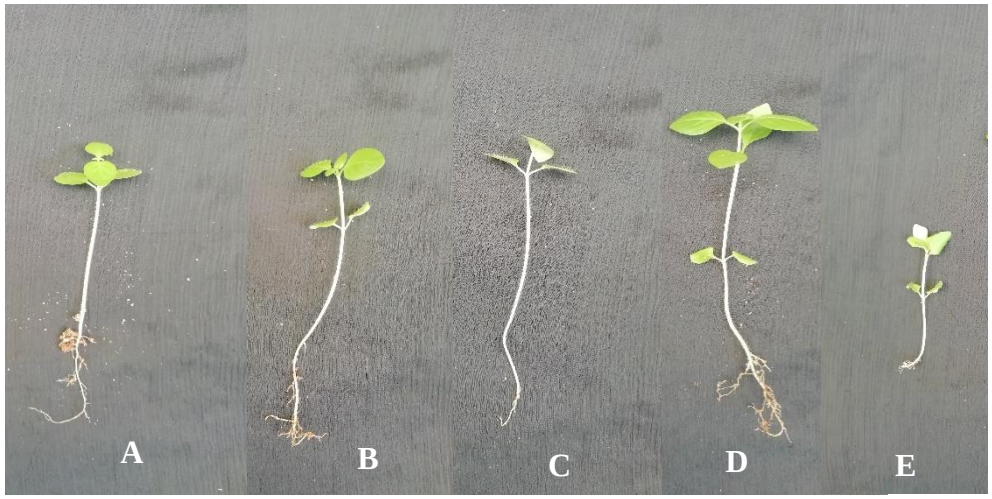

Plate 14. Effect of seed biopriming on *A.paniculata* seedlings (30 DAS): (A) *Bacillus pumilus*VLY17, (B) *Bacillus amyloliquefaciens*VLY24, (C) *Pseudomonas fluorescens*PN026R, (D) *Bacillus velezensis* PCSE10, (E) Control

Plate 15. Effect of physical seed pretreatments on shoot biomass at harvest (110 DAS) in *A. paniculata*: (A) Scarification (using sand paper), (B) Water soaking (overnight), (C) Hotwater treatment (65^{o}C for 10 min), (D) Concentrated sulphuric acid (1 min), (E) Control

Plate 16. Effect of hormonal seed priming on shoot biomass at harvest (110 DAS) in *A. paniculata*: (A) GA_3 @ 1500 µM, (B) GA_3 @ 3000 µM, (C)IAA @ 0.1 µM, (D) IAA @ 1 µM, (E) BA @ 100 µM, (F) BA @ 300 µM, (G) TDZ @ 200 µM, (H) TDZ @ 400 µM, (I) Control

Plate 17. Effect of biostimulant seed priming on shoot biomass at harvest (110 DAS) *in A. paniculata*: (A) Chitosan @ 5g L^{-1},(B)Chitosan @ 10 gL^{-1}, (C) Salicylic acid @ 1500 µM, (D) Salicylic acid @ 3000 µM, (E) Phloroglucinol@ 1 µM, (F) Phloroglucinol @ 10 µM, (G) Control

Plate 18. Effect of seed biopriming on shoot biomass at harvest (110 DAS) in *A. paniculata*: (A) *Bacillus pumilus* VLY17, (B) *Bacillus amyloliquefaciens* VLY24, (C) *Pseudomonas fluorescens*PN026R, (D) *Bacillus velezensis*PCSE10, (E) Control

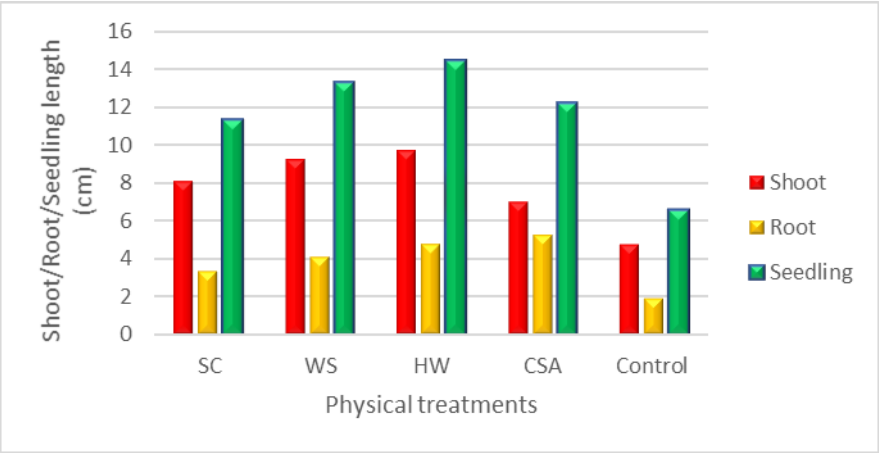

Fig 1. Effect of physical seed pretreatments on shoot, root and seedling length in *W.somnifera*

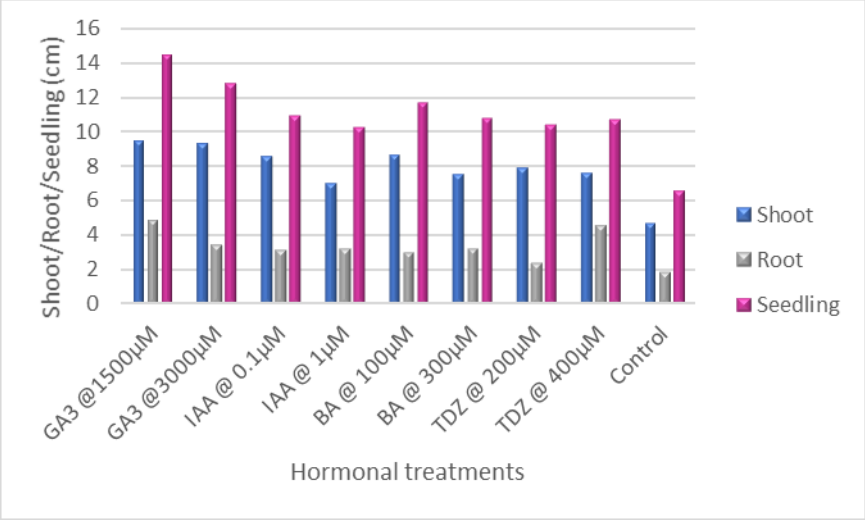

Fig 2. Effect of hormonal seed priming on shoot, root and seedling length in *length in W.somnifera*

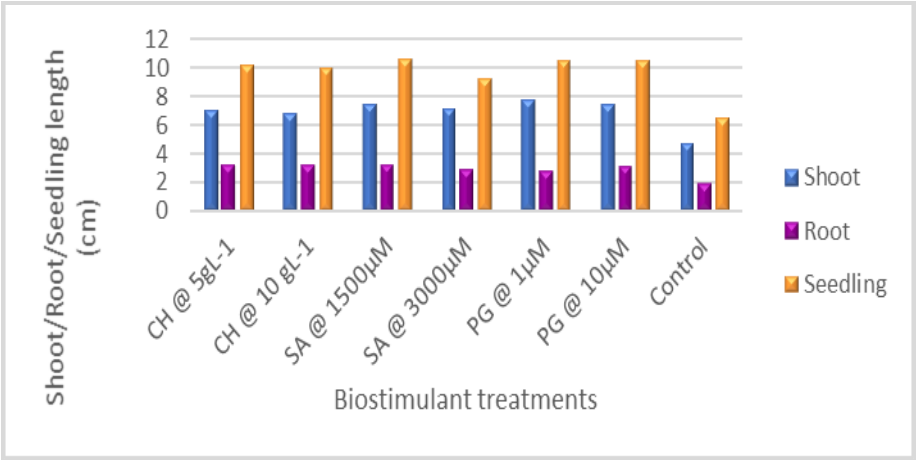

Fig 3. Effect of biostimulant seed priming on shoot, root and seedling length in length in *W.somnifera*

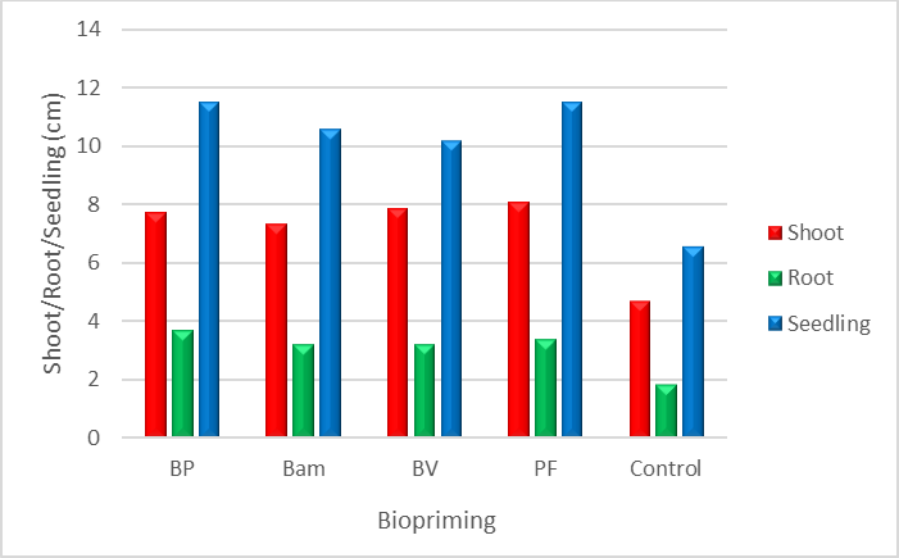

Fig 4. Effect of seed biopriming on shoot, root and seedling length in *length in W.somnifera*

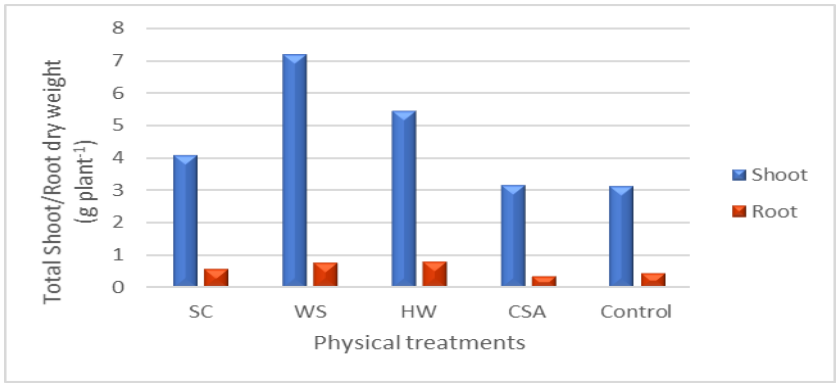

Fig 5. Effect of physical seed treatments on total shoot and root dry *weight in W.somnifera*

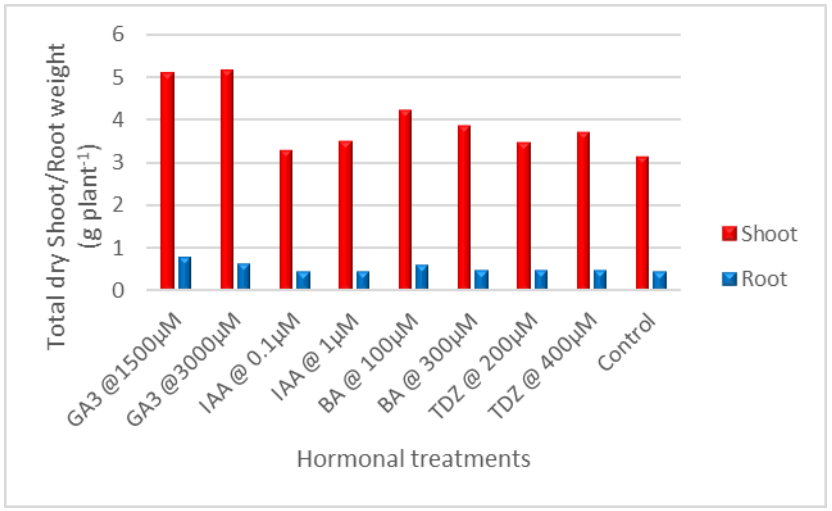

Fig 6. Effect of hormonal seed priming on total shoot and root dry weight

In ***W.somnifera***

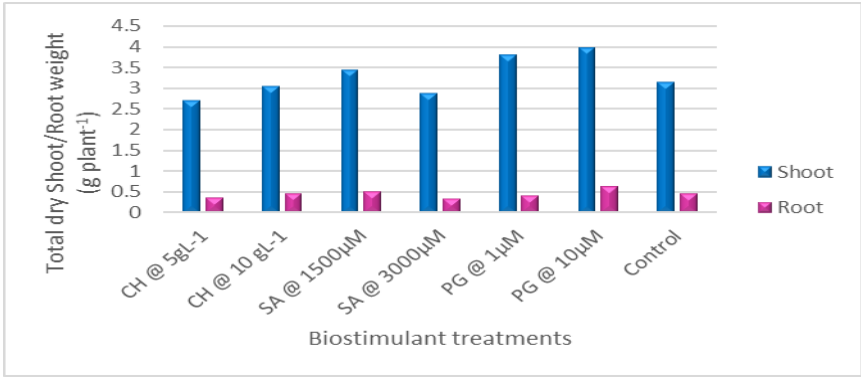

Fig 7. Effect of biostimulant seed priming on total shoot and root dry weight in *W.somnifera*

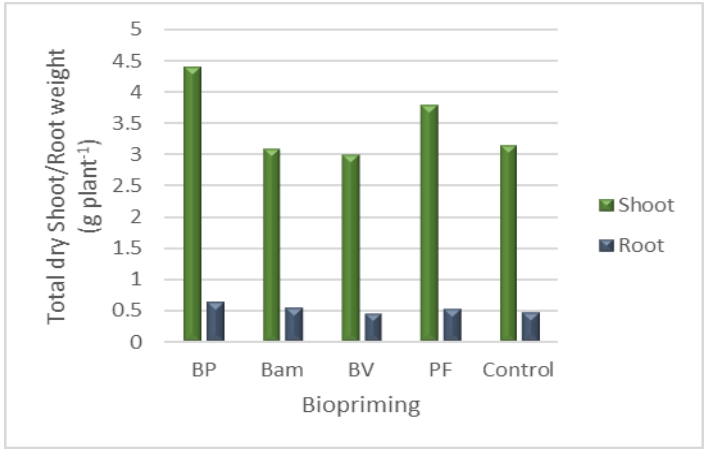

Fig 8. Effect of seed biopriming on total shoot and root in *W.somnifera* weight in *W.somnifera*

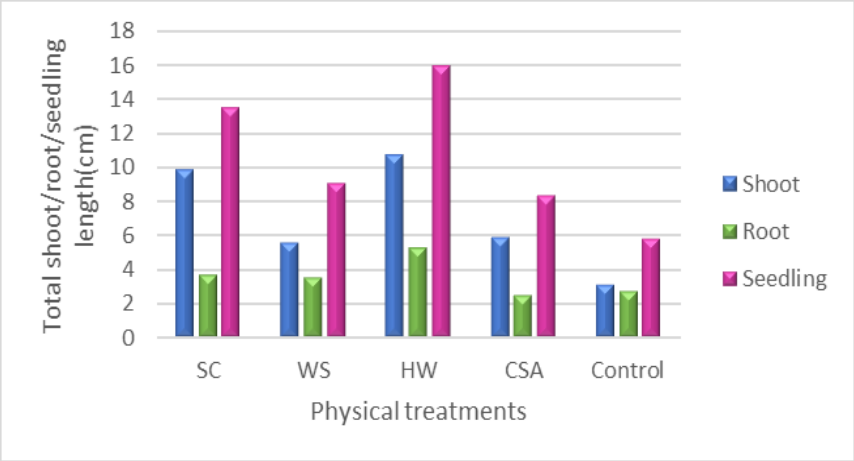

Fig 9. Effect of physical seed treatments on shoot, root and seedling length in *A.paniculata*

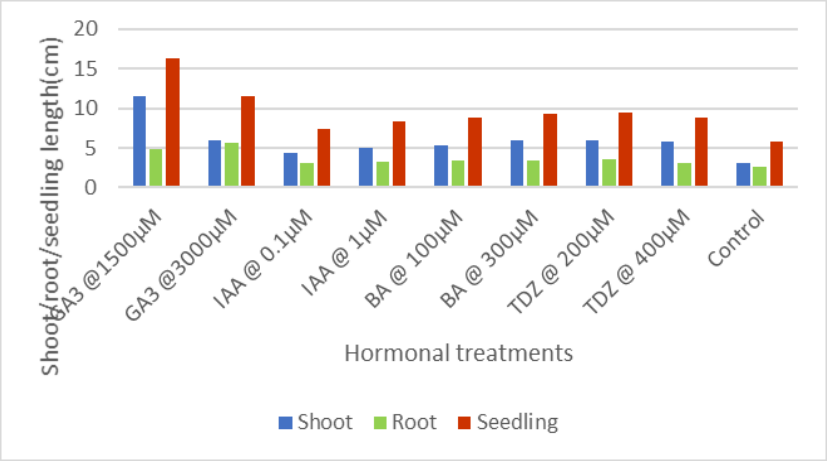

Fig 10. Effect of hormonal seed priming on shoot, root and seedling length in *A.paniculata*

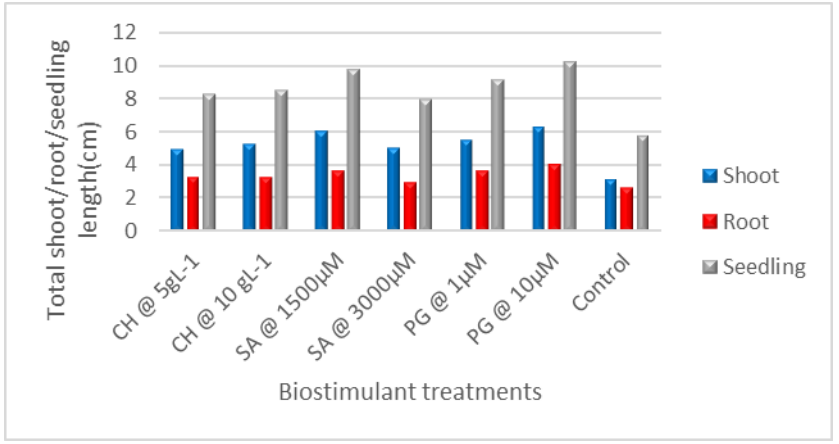

Fig 11. Effect of biostimulant seed priming on shoot, root and seedling length in *A. paniculata*

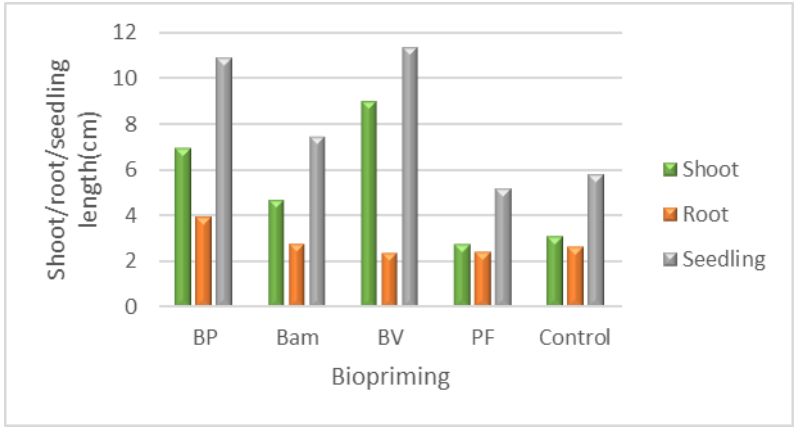

Fig 12. Effect of seed biopriming on shoot, root and seedling length in *A. paniculata*

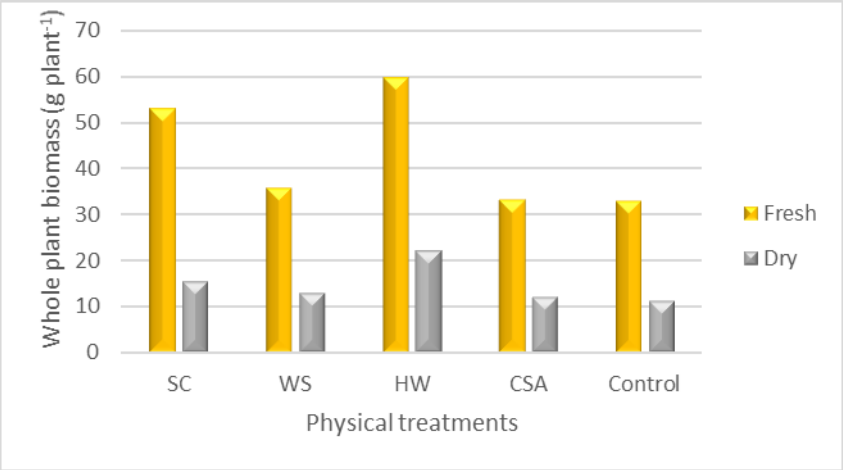

Fig 13. Effect of physical seed treatments on whole plant biomass in *A. paniculata*

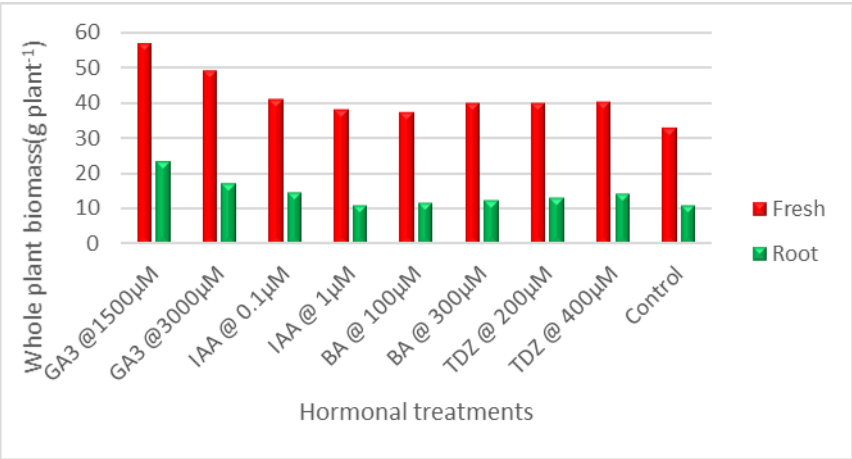

Fig 14. Effect of hormonal seed priming on whole plant biomass in *A.paniculata*

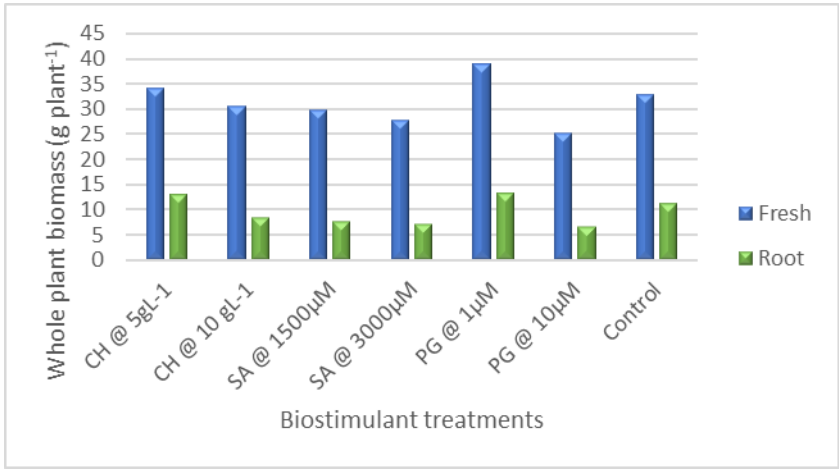

Fig 15. Effect of biostimulant seed priming on whole plant biomass in *A. paniculata*

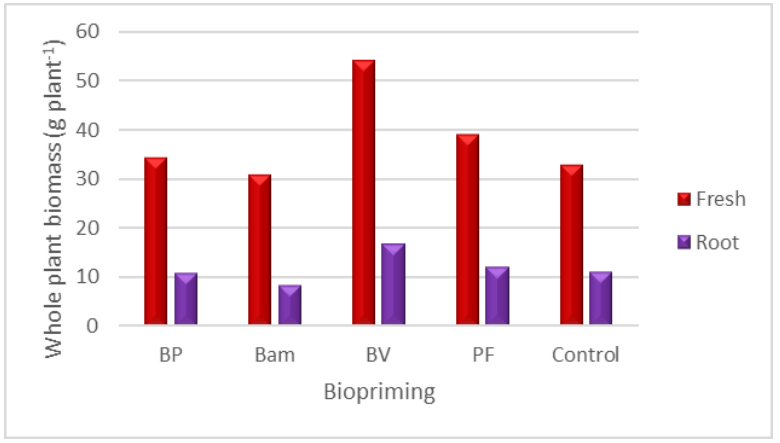

Fig 16. Effect of seed biopriming on whole plant biomass in *A. paniculata*

DISCUSSION

5. DISCUSSION

The study entitled "Germination and plant growth responses in Ashwagandha (*Withania somnifera* (L.) Dunal) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees) to seed pretreatments" was carried out at the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during 2018-2020. The results of study are discussed in this chapter.

The seeds of two medicinal plants *W.somnifera* and *A.paniculata* were subjected to different pretreatments, to study their effect on germination, growth and yield.The responses of the two crops towards various pretreatments are discussed here.

5.1 *WITHANIA SOMNIFERA*

5.1.1 Effect of physical pretreatments of seeds on enhancing germination, plant growth and yield in *W. somnifera.*

The results of this study indicated that among the physical treatments seeds subjected to water soaking (T_2) exhibited germination (84.00 per cent), and seedling vigor index (11.16). The positive effect of this treatment in germination and seedling parameters are also reflected in morphological, phenological and yield parameters such as plant height (60.80 cm), number of branches (5.00), days to flower initiation (92.33), shoot weight (fresh -37.61 g plant^{-1}; dry-7.17 g plant^{-1}), root diameter (1.00 cm), root volume (7.40 cm^3), number of fruits per plant (12.33) and fruit weight (fresh-12.56 plant^{-1}; dry-1.87g plant^{-1}). In consensus with our study, Sabongari and Aliero (2004) demonstrated that a higher germination per cent, seedling length, stem girth and dry matter was obtained in water soaking treatment for 24 h in *Lycopersicum esculentum* over the control treatment.

The seeds subjected to hot water treatment (T_3) recorded the highest values for seedling length (14.40 cm) and collar girth (0.50 cm). This treatment also demonstrated higher values for root weight (fresh-5.60 g plant^{-1}; dry-0.79 g plant^{-1}), root length (28.63 cm) and seed yield (0.072 g plant^{-1}). Singh *et al.,* (2018) reported that seed treatment with hot water @ 50-52 °C for 30 min had a positive effect on total emergence, seedling height,

seedling dry weight and seed vigour index of bell pepper (*Capsicum annuum*) in comparison to the control treatment under nursery conditions.

Treatment with concentrated sulphuric acid (T_4) recorded the lowest values in most of the parameters right from the germination till the harvest. This treatment recorded the lowest germination (46.00 per cent), plant height (33.07 cm), collar girth (0.23), root weight (fresh-2.62 g plant^{-1}, dry-0.37 g plant^{-1}), root diameter (0.20 cm), root volume(2.61cm^3). *W. somnifera* seeds subjected to concentrated sulphuric acid did not even set fruits. In consensus with our finding, Aduradola and Adejomo (2005) reported that concentrated H_2SO_4 inhibited germination and reduced germination per cent in seeds of *Erythronphleum suaveolens*, which could be due to the probable damage of the embryo on acid exposure.

5.1.2 Effect of hormonal pretreatments of seeds on enhancing germination, plant growth and yield in *W. somnifera.*

The highest germination (82.00per cent), seedling length (14.40 cm), seedling vigor index (11.80), plant height(55.57 cm), number of flowers (13.33), minimum days to flowering (92.33), highest root weight (fresh-5.60 g plant^{-1}; dry-0.79 g plant^{-1}), root diameter (1.10 cm), root volume (9.15 cm^3), number of fruits per plant (9.00) and fruit weight (fresh-9.49 g plant^{-1}: dry-1.36 g plant^{-1}) was recorded in the treatment with GA_3 @ 1500µM (T_1). All of these parameters except root weight root diameter, number of fruits per plant and plant height was on par with GA_3 @ 3000µM (T_2) which produced maximum number of branches (3.67) and shoot weight (fresh-27.77 g plant^{-1}; dry-5.17 g plant^{-1}) which were on par with T_1. This indicates that both the concentrations of GA_3 applied enhanced the germination, plant growth and yield. Similar effects of overnight priming of GA_3 @ 50 ppm was observed in speed of germination (2.47), germination per cent (54.67), seedling length (19.61 cm) and vigour index (1072.31) of *Rauvolfia serpentina* seeds. The highest seed germination and seedling establishment obtained while treating seeds with GA_3 might be due to the metabolic reactions induced by it in the seeds (Mohammad *et al*., 2010).

Seed priming with IAA @ 0.1 and 1 µM, BA @ 300 µM and TDZ @ 200 and 400 µM were found to inhibit germination and the germination per cent was on par with that of control treatment. Findings of El-Mergawi and El-Wahed (2020) suggested that while

presoaking seeds in IAA solutions suppressed the growth of 5 days old seedlings. This inhibitory effect was again confirmed in a study by Emem *et al.* (2017) wherein the mean percentage germination and seedling vigour of *Cucumis melo* was significantly higher in the control than in IAA @ 100-500 ppm. The inhibitory effect of TDZ has been reported in *Arachis hypogea* (Singh *et al*., 2008) and that of BA @60 ppm for 48 h were reported in *Nigella sativa* L. (El-Ghamery and Mousa, 2017)

All the treatments except priming with GA_3, did not keep the consistency in performance, shown in germination, in the subsequent stages plant growth and yield.

5.1.3 Effect of biostimulant pretreatments of seeds on enhancing germination, plant growth and yield in *W. somnifera.*

The highest germination (64.00 per cent), seedling vigor index (6.67cm) and plant height (46.37 cm), minimum days to fruit set (92.67), shoot weight (fresh-21.40 g plant^{-1}; dry-3.96 g plant^{-1}), root weight (fresh- 4.36 g plant^{-1}; dry- 0.64 g plant^{-1}) and root diameter (0.57 cm) were recorded in treatment PG @ 10 µM (T_6) and was on par with PG @ 1 µM (T_5)which recorded significantly superior number of branches (4.67), root length (14.27 cm), root volume (4.13 cm^3), seed yield (0.069 g plant^{-1}). In line with this finding, positive effect of seed priming with PG supported maximum seed germination and seedling growth in *Ceratotheca triloba* plants was reported by Masonda *et al.* (2018). Also, Rengaswamy *et al.* (2014) observed that maize seeds primed with PG @ 10^{-7} M, recorded significantly higher shoot and root lengths in the seedlings compared to control treatments.

The lowest germination and seedling vigour index were observed in chitosan primed seeds. This is in agreement with the results given by Guan *et al.* (2009) that seed priming with chitosan had no significant effect on final germination percentage of maize.

Seedlings obtained from SA @ 1500 µM primed seeds (T_3) recorded the highest seedling length (10.63 cm), inspite of low germination. However, Moghaddam *et al.* (2018) explained that the seeds of fenugreek primed with SA @ 2800 µM increased the germination from 41 to 100 per cent.

5.1.4 Effect of biopriming pretreatments of seeds on enhancing germination, plant growth and yield in *W. somnifera.*

There was no significant difference in germination, survival per cent, GI, MGT, seedling root length, allometric index, seedling length. However, biopriming treatments has significant influence on seedling shoot length and seedling vigour index. The shoot length was observed to be the highest in plants obtained from *P. fluorescens*, while the highest seedling vigour index was observed in *B. pumilus* but was on par with all biopriming treatments except control.

B. *pumilus* (T_1) gave the highest value (6.90) for seedling vigor index, plant height of 47.63 cm, collar girth (0.20 cm), lowest (92.33) number of days to flower initiation, root weight (fresh-4.43 g plant^{-1}; dry-0.63 g plant^{-1}), shoot weight (fresh-23.07 g plant^{-1}; dry 4.39 g plant^{-1}) and seed yield (0.065 g plant^{-1}). This positive effect of *B. pumilus* with respect to growth parameters in terms of plant height and root fresh weight was observed in red pepper plug seedlings (Joo *et al.* 2004), of root length in wheat (Hafeez *et al.* 2006), of number of roots, root length and number of nodes in rice plants (Liu *et al.*, 2020).

Seeds primed with *Bacillus amyloliquefaciens* recorded the lowest seedling vigor index (4.46) and collar girth (0.10 cm) but significantly higher number of branches (3.67) and number of flowers (41.67). Idriss *et al*. (2002) opined that *B. amyloliquefaciens* treatment @ 10^9 cfu mL^{-1} enhanced plant growth in maize.

The root length (15.83 cm) was found to be higher in plants obtained from the seeds primed with *P. fluorescens* (T_4). In line with this result, Karthikeyan *et al.* (2009) demonstrated that *P. fluorescens* @ 10^7cfu mL^{-1} primed *Catharanthus roseus* seeds recorded higher root length in *C. rosea*.

In spite of having a better seedling vigour index, *B. velezensis* (T_3) recorded minimum root weight (fresh-3.27 g plant^{-1}: dry-0.45 g plant^{-1}), shoot weight (fresh-16.47 g plant^{-1}; dry-2.99 g plant^{-1}) and seed yield (0.027 g plant^{-1}). This indicates that a better seedling vigour need not always reflect in the yield of the crop.

All the biopriming treatments were observed to give a higher seedling vigour index over the control treatment. According to Satya *et al*., (2016), seed treatments with beneficial bacteria results in its attachment and survival on the seed surface. After seed treatment, cells of bacteria move from the endothelium of the seed to the emerging radicle, and multiply. Bacteria colonize only a small proportion of the root surface, largely the junctions between epidermal cells and the regions surrounding emerging lateral roots

5.1.5 Effect of various seed pretreatments of seeds on enhancing germination, plant growth and yield in *W. somnifera.*

The seeds subjected to water soaking (T_2) recorded significantly higher germination, plant height, number of branches, lowest number of days to flower initiation, shoot weight, number of fruits per plant and fruit weight. The highest germination of water soaked seeds could have been due to the softening of seed coat, removal of inhibitors, reducing the time required to reach optimum moisture level with constant supply of oxygen, increasing the level of intermediate metabolites associated with germination which in turn improved the morphological and yield parameters (Duffus, 1985; Hartman *et al*., 2007; Raza *et al*., 2013).

The seed germination and seedling parameters recorded in hot water treated seeds were found to be on par with that of water soaked seeds in W. *somnifera*. According to Tomer and Maguire (1989), the higher seedling length, collar girth and root length recorded by plants from hot water treated seeds might be due to breaking or cracking of the hard seed coat, which enhanced germination and subsequently the plant growth.

GA_3 @1500 µM primed seeds (T_5) recorded the highest seedling vigour index seedling length, lowest number of days to flower initiation, root diameter, root volume and root weight. Cleland (1999) suggested that the superior performance by GA_3 can be either due to the induction of enzymes like proteases during the germination or induction of the aleurone cells to produce α-amylase which is the precursor of soluble sugars from starch causing activation of cell division in the intercalary meristem.

The seed with CH @ 5g L^{-1} and CH @10 gL^{-1} recorded lower germination, seedling vigour index, plant growth and yield. This indicated that the chitosan priming was inhibitory to the germination and plant growth responses at these levels of chitosan tried. In contrast to

this, Mahdavi and Rahimi (2013) observed significant improvement in germination and seedling vigour index in CH @ 2g L^{-1} primed ajowan seeds. This positive effect on yield and yield components was also confirmed by Janmohammadi *et al*. (2014) in plants raised from CH @ 0.5 g L^{-1} primed lentil seeds. Hameed *et al.* 2013, observed that seed priming with chitosan enhanced proteases activity and soluble proteins. The activity of proteases might sustain the respiratory requirements of the vigorously growing seedling and enhance nitrogen metabolism in primed seeds. In the present study, the inhibitory effect on germination, plant growth and yield were observed in *W. somnifera* might be due to exposure to seeds to higher concentration of chitosan.

SA @ 3000 µM (T_{16}) also recorded lower germination and seedling vigour index. This finding is justified by Emem *et al.* (2017), who observed lower germination and seedling vigour in SA primed seeds of *Cucumis melo*.

5.2 *ANDROGRAPHIS PANICULATA*

5.2.1 Effect of physical pretreatments of seeds on enhancing germination, plant growth and yield in A. paniculata

Hot water treatment, Sand paper scarification and water soaking of seeds resulted in higher germination, seedling length, seedling vigor index, collar girth, number of flowers, and yield. The pronounced effect of hot water treatment had been proved in increasing the seedling length of the medicinal plant *Bunium persicum* at 80°C for 20 min (Bhardwaj *et al.,* 2016) and plant height, branch number, fruit weight and minimum days to flowering of *Capsicum frutescens* plants at 35˚C for 2 min (Normasari *et al.,* 2016). A supportive study in seeds of *Medicago* and *Trifolium* species when scarified using sandpaper showed an enhancement in germination from 18 to 97 per cent and 40 to 95 per cent, respectively in these species (Uzun and Aydin, 2004). The positive results of water soaking were also proved by Mirmazloum *et al.* (2020) in *Carum carvi* seeds in which hydropriming for 12 h enhanced the germination per cent, germination rate and shoot length compared to the control treatment.

The lowest values in terms of germination, seedling parameters, plant growth and yield were recorded in sulphuric acid treated seeds and control treatment. Hence, it can be

inferred that, water soaking, hot water treatment and sand paper scarification was effective in enhancing the said parameters.

5.2.2 Effect of hormonal pretreatments of seeds on enhancing germination, plant growth and yield in *A. paniculata*

The higher germination, seedling length, seedling vigor index, plant height, number of branches, collar girth, number of flowers, whole plant biomass were recorded in the treatment with GA_3 @ 1500 µM (T_1) The findings of our study is comparable with that done by Mohammad *et al*. (2010) in which *Calendula officinalis* and *Foeniculum vulgare* seeds primed with GA_3 @ 20 mg L^{-1} for 24 h at 25°C induced metabolic reactions in seeds and thus improved seed germination and seedling establishment. However, in the present study, it was observed that higher concentration of GA_3 and TDZ, lower concentration of BA and IAA, recorded lower germination per cent, but significantly higher than the control. The improved effect of these hormones on germination has been confirmed by various researchers. According to Kaur and Setia (2012), IAA @ 5 µg ml^{-1} primed *A. paniculata* seeds improved germination, root length, shoot length and seedling vigour index over the control. Tomato seeds primed for 24h with BA @ 100 ppm were observed to give better germination percent, germination index, seedling growth over non-primed seeds (Nawaz et al., 2012). TDZ @ 6.3 µM in *Bunium percicum* improved germination (Emamipoor and Maziah, 2014)

5.2.3 Effect of biostimulant seed priming on germination and seedling parameters in *A. paniculata*

The seeds primed with PG @ 1 g L^{-1} and 10 g L^{-1}, recorded higher germination, seedling growth, seedling vigour index, plant growth and yield in *A. paniculata*. In accordance with our investigation, Masondo *et al.* (2018) reported that PG @ 1 µM improved germination, root length, shoot length and seedling vigour index in *Ceratotheca triloba*.

The lower germination and seedling parameters were observed in chitosan and SA primed seeds. The chitosan at lower concentration (CH @ 5 gL^{-1}) recorded significantly higher whole plant biomass over the control. However, chitosan at higher concentration (CH @ 10 gL^{-1}) recorded very low biomass on par with that of the control. Janmohammadi *et al*. (2014) opined that the lentil seeds when treated with chitosan 0.5 g L^{-1} for 1 h gave better

results in yield and yield components. Plants raised from SA @ 1500 and 3000 µM primed seeds recorded lower plant biomass, which was on par with the control. In contrast to our study, seeds primed with SA @ 50 ppm was observed to improve germination, and seedling parameters in spring wheat (Afzal *et al.,* 2006). Vincent and Plasencia (2011) reported that exogenous application of SA influences plant biological processes of germination, plant growth and development. The effect of SA is in a concentration-dependent manner, being stimulated at lower dose of SA and inhibited at higher dose. SA regulates cellular redox status, accumulating ROS. Lower SA concentration results in the accumulation of low-level ROS that serve as secondary signals to stimulate biological processes. On the contrary, higher of concentration of exogenous SA activate the accumulation of high levels ROS, which can cause oxidative stress and cell death. So, it can be inferred that poor performance of SA on germination and plant growth might be due to its higher concentration applied in the study.

5.2.4 Effect of biopriming pretreatments of seeds on enhancing germination, plant growth and yield in *A. paniculata*

A significantly higher germination, seedling parameters, plant growth and yield was observed in *B. velenzenis* primed seeds and in plants obtained from them. The growth promoting effect of *B. velezensis* seed priming was demonstrated in plants *viz.*, carrot, cucumber, chilli and tomato by Meng *et al.* (2016).

The germination per cent and seedling vigour index were observed to be significantly higher in the treatments with *B.pumilus* and B. amyloliquifaciens. However, there two treatments recorded lower plant biomass yield, and was observed to on par with the control. In contrast to this, better performance, in terms of germination, plant growth and yield due to seed priming with *B. amylolquifaciens* and *B. pumilus* has been reported in wheat (Hafeez *et al*., 2006; Rahman *et al*., 2018). The present study again confirms the fact the better seedling vigour index need not always reflect on the yield.

5.2.5 Effect of various pretreatments of seeds on enhancing germination, plant growth and yield in *A. paniculata*

The GA_3 @ 1500 µM primed and hot water treated seeds recorded higher germination, seedling length and seedling vigour index. The same treatments recorded higher whole plant biomass. The chitosan primed seeds recorded and SA @ 3000 µM recorded lower value in terms of germination, seedling vigour index and whole plant biomass and these parameters were found to be in par with the control treatment. This indicated the inhibitory effect of chitosan and SA on seed germination and plant growth responses which might be due to the higher concentration to which the seeds are exposed to. The growth promotion effect of lower concentrations of salicylic acid and chitosan has been demonstrated by Afzal *et al.* (2006) and Janmohammadi *et al.* (2014), respectively.

B. velezensis primed seeds exhibited higher germination and whole plant biomass on par with GA_3 @ 1500 µM, but a significantly lower seedling vigour index compared to that of GA_3 @ 1500 µM which recorded the highest value. It also recorded higher root length, root diameter, root volume and root biomass. The growth promoting effect of *B. velezensis* has been elucidated by Wang *et al.* (2020).

According to Hwangbo *et al.* (2016), *B. velezensis* is a phosphate-solubilizing bacterium that promote plant growth. Talboys *et al*. (2014) reported that in *Triticum aestivum*, auxin secretion by *B. velezensis* increased the exudation of organic carbon and promoted growth of roots. This is also reported to enhance plant growth by uptake of nutrient and secretion of secondary metabolites to promote the development of plant root system (Kim *et al*., 2017).

In the present investigation, it was observed that most of the seed pretreatments, that exhibited better seedling vigour index showed better performance, which respect to morphological and yield parameters. However, a few treatments demonstrated a contradictory effect. Among the various seed pretreatments tried, *W. somnifera* seeds exposed to water soaking, hot water and GA3@1500 µM, and *A. paniculata* seeds exposed to hot water treatment and GA3 @1500 µM recorded superior performance with respect to seed germination, seedling vigour, plant growth and yield.

Future line of work

- The seed priming experiments have to be carried out at our field conditions to study its efficiency in acclimatization and survival.

- Attempts should be made to study and investigate the effect of each of these seed priming agents in improving the crop quality in terms of production of secondary metabolites both in *W.somnifera* and *A.paniculata*

- The effect of different modes of application *viz.*, foliar spray, combined application of seed priming and foliar spray at different concentrations and pretreatment time have to be studied.

SUMMARY

6. SUMMARY

The present investigation entitled “Germination and plant growth responses in Ashwagandha (*Withania somnifera* (L.) Dunal) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees) to seed pretreatments” was conducted in the Department of Plantation Crops and Spices, College of Agriculture, Vellayani during 2018-2020 with the objective to standardize pretreatment of seeds for enhanced germination and plant growth in *W. somnifera* and *A. paniculata.*

The seeds of *W. somnifera* and *A. paniculata* used for the study were sourced from Anand Agricultural University, Gujarat, India. The study was carried out in two phases: Phase 1- Pretreatment of seeds for enhanced germination; Phase 2- Evaluation of transplanted seedlings obtained from pretreated seeds for enhanced plant growth. The seeds of *W. somnifera* and *A. paniculata* were subjected to various pretreatments *viz.*, physical treatment, hormonal priming, biostimulant priming and biopriming (using microbes). The seeds kept for germination without any pretreatment were taken as the control.

In the first phase of the study in *W. somnifera*, seeds subjected to water soaking recorded higher germination (84.00 per cent), seedling length (13.30 cm), survival percentage (83.67 per cent), germination index (4.87) and seedling vigour index (11.16) which were on par with that of hot water treatment. The physical treatments did not have any influence on mean germination time and allometric index. Among the hormonal priming treatments, seeds exposed to GA_3 @1500 µM recorded the highest germination (82.00 per cent), survival percentage (82 per cent), seedling length (14.40 cm) and seedling vigour index (11.80) which were found to be on par with GA_3 @3000 µM. Mean germination time and allometric index was not observed to have a significant variation on physical seed pretreatments. In biostimulant seed priming, PG @ 10µM primed seeds recorded higher germination (64.00 per cent), survival percentage (64.00 per cent), mean germination time (6.67 days), seedling length (10.57cm) and seedling vigour index (6.67) and were found to be on par with those of PG @ 1µM primed seeds. The biostimulant priming did not influence germination index and allometric index. The biopriming treatments had no significant effect

on germination, survival percentage, germination index, mean germination time, allometric index and seedling length. However, significantly higher seedling vigour index was observed in all the biopriming treatments over the control treatment. Among all the pretreatments tried, water soaking treatment, hot water treatment, GA_3 @ 1500µM was recorded significantly higher germination, survival percentage, germination index, allometric index, seedling length and seedling vigour index. Lower mean germination time was observed in seeds with PG @ 1µM and PG @ 10µM treatments, also various treatments tried had no influence on allometric index.

In the second phase of the study, the 30 day old seedlings of *W. somnifera* raised from pretreated seeds and untreated (control) seeds were transplanted and evaluated for plant growth and yield (shoot and root biomass), at harvest (120 DAS). Among the physical treatments, *W. somnifera* plants derived from water soaked seeds were observed to give higher plant height (60.80cm), number of branches (5.00), collar girth (0.47 cm), minimum days to flowering (92.33 days), shoot biomass (fresh-37.61 g $plant^{-1}$; dry -7.17 g $plant^{-1}$), root biomass (fresh-5.60 g $plant^{-1}$; dry-0.79 g $plant^{-1}$), shoot harvest index (0.90), root diameter (1.00cm), root volume (37.61cm^3), number of fruits (12.33) and fruit weight (fresh-12.56g; dry-1.87g). Except for the number of branches, days to flowering, shoot harvest index, shoot biomass, root diameter and root volume, these were observed to be on par in plants from hot water treated seeds which recorded highest root length (28.63cm) and seed yield (0.072 g $plant^{-1}$). Scarified seeds gave the maximum number of flowers at harvest (41.67). Days to fruitset and thousand (1000) seed weight did not show any variation due to physical treatments. Among the hormonal priming treatments, plants from GA_3 @ 1500 µM primed seeds recorded higher plant height (55.57cm), number of flowers (13.33), minimum days to flowering (92.33 days), shoot (fresh-27.73 g $plant^{-1}$; dry-5.09 g $plant^{-1}$) and root (fresh-5.60 g $plant^{-1}$; dry-0.79 g $plant^{-1}$) biomass, root harvest index (0.135), root diameter (1.1 cm), number of fruits (9.00) and fruit weight (fresh-9.49 g $plant^{-1}$;dry-1.36 g $plant^{-1}$). The plant height, number of flowers, days to flowering, root volume and shoot biomass were found to be on par with that of GA_3 @ 3000 µM which recorded the highest shoot harvest index (0.89) and root volume (27.77cm^3). Highest root length (14.63 cm) was observed in IAA @ 0.1 µM on par with BA @ 300 µM. In biostimulant priming, plants generated from PG @ 10 µM treated seeds gave the highest plant height (46.37 cm), minimum days for flowering (92.67),

shoot (fresh-21.40 g plant^{-1}; dry-3.96 g plant^{-1}) and root (fresh-4.36 g plant^{-1}; dry-0.64 g plant^{-1}) biomass, root harvest index (0.140) and root diameter (0.57cm). The plant height, days to flowering and shoot biomass were observed to be on par with that of PG @ 1µM which recorded highest value in number of branches (4.67), shoot harvest index (0.90), root length (14.27cm), root volume (20.13cm^3) and seed yield (0.069g plant^{-1}). However, the highest collar girth (0.37) and number of flowers (30.00) were recorded in plants raised from SA @ 1500 µM and CH@ 5 g L^{-1} primed seeds. The biostimulant treatments had no significant influence on days to fruit set, number of fruits, fruit weight and thousand (1000) seed weight. Among the biopriming treatments, plants derived from the seeds treated with *B. pumilis*, recorded higher plant height (47.63 cm), number of branches (3.00), minimum days to flowering (92.33), shoot (fresh-23.07 g plant^{-1}; dry-4.39 g plant^{-1}) and root (fresh-4.43 g plant^{-1}; 0.63 g plant^{-1}) biomass, shoot harvest index (0.88), root diameter (0.5cm), root volume (23.07 cm) and seed yield (0.065 g plant^{-1}). The plant height, shoot weight, shoot harvest index and seed yield was on par with that of *P. fluorescens* and the plants from the same treatment recorded the highest collar girth (0.47cm). The highest number of flowers (41.67) and root harvest index (0.150) was observed in *B.amyloliquefaciens.* The days to fruit set, number of fruits, fruit weight and thousand (1000) seed weight were not significantly influenced by biopriming treatments. Among the various pretreatments tried, plants raised from water soaked seeds gave better performance with respect to plant height, number of branches, collar girth, minimum days for flowering, shoot harvest index, shoot biomass, number of fruits and fruit weight. The plants from hot water treated seeds gave the highest root biomass, root length and seed yield, which was observed to be on par with that in plants from water soaked seeds. The plants raised from seeds treated with GA_3 @1500µM gave highest root diameter and root volume, where as better performance with respect to number of flowers and days to fruit set were exhibited by scarified seeds and thousand (1000) seed weight by *B.amyloliquefaciens* treatment .

In the first phase of the study in *A. paniculata*, seeds when exposed to physical treatments, higher germination (84.67 per cent), survival percentage (83.33 per cent), seedling length (15.93 cm) and seedling vigour index (13.38) were recorded in hot water treatment followed by scarification and water soaking treatment in which the latter recorded highest germination index (16.20). The sulphuric acid treatment showed lowest mean

germination time (2.00 days). The allometric index was not significantly influenced by physical treatments. Among the hormonal priming treatments, GA_3 @1500µM primed seeds recorded the highest germination (82.00 per cent), survival percentage (82.00 per cent), seedling length (16.37 cm) and seedling vigour index (13.42). The highest germination index (9.47) and lowest mean germination time (3.33 days) were found in TDZ@ 200 µM and TDZ@ 400 µM respectively and this was on par with each other. The allometric index had no significant effect on hormonal priming. With respect to biostimulant seed priming, seeds treated with PG @ 1µM recorded higher germination (66.67 per cent), survival percentage (64.66 per cent) and seedling vigour index (6.03), while seedling length, germination index and allometric index did not show any variation among the biostimulant treatments. Among the biopriming treatments, seeds primed with *B. velezensis* recorded the highest germination (82.67 per cent), survival percentage (82.66), germination index (6.68), allometric index (3.79), seedling length (11.33 cm) and seedling vigour index (9.29). In *A. paniculata*, among all the pretreatments tried hot water treated as well as GA_3 @ 1500 µM primed seeds recorded higher germination, survival percentage, germination index, seedling length and seedling vigour index. The mean germination time were the highest in BA@ 300 µM, SA@3000 µM, *B.pumilis* and *P. fluorescens* and allometric index in *B.velezensis.*

In the second phase of the study in *A. paniculata*, the 30 day old seedlings from pretreated seeds and untreated (control) seeds were transplanted and evaluated for plant growth and yield (whole plant biomass) at harvest (110 DAS). Among the physical treatments, *A.paniculata plants* derived from hot water treated seeds recorded higher plant height (55.77 cm), number of branches (21.67), collar girth (1.83 cm), number of flowers (27.33), root length (40.23 cm) and whole plant biomass (fresh-59.60 g $plant^{-1}$; dry-21.90 g $plant^{-1}$) at harvest. These were on par with those of scarified seeds which recorded highest root diameter (3.70cm) and root volume (9.17cm^3). Days to fruit set was minimum in the plants from water soaked seeds. The physical treatments had no significant on parameters *viz*., days to flowering, number of flowers, fruit weight, seed yield and thousand (1000) seed weight. In hormonal priming, the highest plant height (56.80 cm), number of branches (20.00), collar girth (1.90 cm), number of flowers (21.33), root length (44.57cm), root diameter (3.73cm), root volume (8.60cm^3), whole plant biomass (fresh-56.63 g $plant^{-1}$ and dry-23.60 g $plant^{-1}$), number of fruits (21.67),fruit weight (fresh-1.16 g $plant^{-1}$;dry-0.127 g

plant^{-1}) were observed in plants raised from seeds primed with GA_3 @1500µM. The thousand (1000) seed weight was highest (1.64g) in GA_3 @3000µM. Days to flowering, days to fruit set and seed yield did not show any significant difference with hormonal priming. Among the biostimulant priming, higher plant height (48.57 cm), number of branches (16.00), collar girth (1.20 cm), whole plant biomass (fresh-38.97g plant^{-1} and dry-13.14g plant^{-1}), root length (35.43cm), root diameter (3.07cm), root volume (6.00 cm^3) and fresh fruit weight (0.34 g plant^{-1}) were observed in plants raised from PG @1 µM primed seeds. The seed yield (0.024 g plant^{-1}) and thousand (1000) seed weight (1.67g) were found to be the highest in PG @10 µM and CH @5 GL^{-1} respectively. There was no significant difference among the biostimulant treatments on number of flowers, days to flowering, days to fruit set, number of fruits and dry fruit weight. On evaluation of plants derived from bioprimed seeds, those from *B. velezensis* primed seeds recorded the highest plant height (55.77 cm), number of branches (19.33), collar girth (1.50 cm), number of flowers (22.67), whole plant biomass (fresh-53.97 g plant^{-1}; dry16.87 g plant^{-1}), root length (46.23cm), root diameter (3.67cm), root volume (8.00cm^3), fresh fruit set (0.19 g plant^{-1}), seed yield (0.057 g plant^{-1}), thousand (1000) seed weight (1.62 g plant^{-1}). The biopriming treatments did not have any significant difference with respect to days to flowering, days to fruit set, number of fruits and dry fruit weight. Among all the seed pretreatments tried, plants generated from hot water treated and GA_3@1500µM primed seeds recorded higher plant height, number of branches, collar girth, number of flowers, whole plant biomass, root diameter, root volume, number of fruits and fruit weight. The water soaking treatment was found to have minimum days to fruit set and highest thousand (1000) seed weight whereas, treatment with *B. velezensis* recorded highest root length and seed yield. There was no significant difference in days to flowering among the various treatments.

Among the various seed pretreatments tried, *W. somnifera* seeds exposed to water soaking, hot water and GA_3@1500µM and *A. paniculata* seeds exposed to hot water treatment and GA_3@1500µM recorded superior performance with respect to seed germination, seedling vigour, plant growth and yield.

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GERMINATION AND PLANT GROWTH RESPONSES IN ASHWAGANDHA (*WITHANIA SOMNIFERA* (L.) DUNAL) AND KIRIYATHU (*ANDROGRAPHIS PANICULATA* (BURM.F.) NEES) TO SEED PRETREATMENTS

By

NAMITHA NADESH

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ABSTRACT

Germination and plant growth responses in Ashwagandha (*Withania somnifera* (L.) Dunal) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees) to seed pretreatments.

The present investigation entitled "Germination and plant growth responses in Ashwagandha (*Withania somnifera* (L.) Dunal) and Kiriyathu (*Andrographis paniculata* (Burm.f.) Nees) to seed pretreatments" was conducted in the Department of Plantation Crops and Spices, College of Agriculture, Vellayani during 2018-2020 with the objective to standardize pretreatment of seeds for enhanced germination and plant growth in *W. somnifera* and *A. paniculata.*

The seeds of *W. somnifera* and *A. paniculata* used for the study were sourced from Anand Agricultural University, Gujarat, India. The study was carried out in two phases: Phase 1- Pretreatment of seeds for enhanced germination; Phase 2- Evaluation of transplanted seedlings obtained from pretreated seeds for enhanced plant growth. The seeds of *W. somnifera* and *A. paniculata* were subjected to various pretreatments *viz.*, physical treatment, hormonal priming, biostimulant priming and biopriming (using microbes). The seeds kept for germination without any pretreatment were taken as the control.

In the first phase of the study in *W. somnifera*, seeds subjected to water soaking recorded higher germination (84.00 per cent), seedling length (13.30 cm) and seedling vigour index (11.16) which were on par with that of hot water treatment. Among the hormonal priming treatments, seeds exposed to GA_3 @1500 µM recorded the highest germination (82.00 per cent), seedling length (14.40 cm) and seedling vigour index (11.80) which were found to be on par with GA_3 @1500 µM. In biostimulant seed priming, PG @ 10µM primed seeds recorded higher germination (64.00 per cent), seedling length (10.57cm) and seedling vigour index (6.67) and were found to be on par with those of PG @ 1µM primed seeds. The biopriming treatments had no significant effect on germination and seedling length. However, significantly higher seedling vigour index was observed in all the biopriming treatments over the control treatment. Among all the pretreatments tried, water soaking treatment, hot water treatment, GA_3 @ 1500µM was recorded significantly higher germination, seedling length and seedling vigour index.

In the second phase of the study, the 30 day old seedlings of *W. somnifera* raised from pretreated seeds and untreated (control) seeds were transplanted and evaluated for plant growth and yield (shoot and root biomass), at harvest (120 DAS). Among the physical treatments, *W. somnifera* plants derived from water soaked seeds were observed to give higher plant height (60.80cm), number of branches (5.00), collar girth (0.47 cm), shoot biomass (fresh-37.61 g plant^{-1}; dry -7.17 g plant^{-1}) and root biomass (fresh-5.60 g plant^{-1}; dry-0.79 g plant^{-1}). These were observed to be on par in plants from hot water treated seeds, except for the number of branches and shoot biomass. Among the hormonal priming treatments, plants from GA_3 @ 1500 µM primed seeds recorded higher plant height (55.57cm), shoot (fresh-27.73 g plant^{-1}; dry-5.09 g plant^{-1}) and root (fresh-5.60 g plant^{-1}; dry-0.79 g plant^{-1}) biomass. The plant height and shoot biomass were found to be on par with that of GA_3 @ 1500 µM. In biostimulant priming, plants generated from PG @ 10 µM treated seeds gave the highest plant height (46.37 cm), shoot (fresh-21.40 g plant^{-1}; dry-3.96 g plant^{-1}) and root (fresh-4.36 g plant^{-1}; dry-0.64 g plant^{-1}) biomass. The plant height and shoot biomass were observed to be on par with that of PG @ 1µM. However, the highest number of branches and collar girth were recorded in plants raised from PG @ 1µM and SA @ 1500 µM primed seeds. Among the biopriming treatments, plants derived from the seeds treated with *B. pumilis*, recorded higher plant height (47.63 cm), number of branches (3.00), shoot (fresh-23.07 g plant^{-1}; dry-4.39 g plant^{-1}) and root (fresh-4.43 g plant^{-1}; 0.63 g plant^{-1}) biomass. The plant height and shoot weight was on par with that of *P. fluorescens* and the plants from the same treatment recorded the highest collar girth. Among the various pretreatments tried, plants raised from water soaked seeds gave better performance with respect to plant height, number of branches, collar girth and shoot biomass. The plants from hot water treated and GA_3 @ 1500µM primed seeds gave the highest root biomass, which was observed to be on par with that in plants from water soaked seeds.

In the first phase of the study in *A. paniculata*, seeds when exposed to physical treatments, higher germination (84.67 per cent), seedling length (15.93 cm) and seedling vigour index (13.38) were recorded in hot water treatment followed by scarification. Among the hormonal priming treatments, GA_3 @1500µM primed seeds recorded the highest germination (82.00 per cent), seedling length (16.37 cm) and seedling vigour index (13.42). With respect to biostimulant seed priming, seeds treated with PG @ 1µM recorded higher

germination (66.67 per cent) and seedling vigour index (6.03), while seedling length did not show any variation among the biostimulant treatments. Among the biopriming treatments, seeds primed with *B. velezensis* recorded the highest germination (82.67 per cent), seedling length (11.33 cm) and seedling vigour index (9.29). In *A. paniculata,* among all the pretreatments tried hot water treated as well as GA_3 @ 1500 µM primed seeds recorded higher germination, seedling length and seedling vigour index.

In the second phase of the study in *A. paniculata,* the 30 day old seedlings from pretreated seeds and untreated (control) seeds were transplanted and evaluated for plant growth and yield (whole plant biomass) at harvest (110 DAS). Among the physical treatments, *A.paniculata plants* derived from hot water treated seeds recorded higher plant height (55.77 cm), number of branches (21.67), collar girth (1.83 cm) and whole plant biomass (fresh-59.60 g plant^{-1}; dry-21.90 g plant^{-1}) at harvest. These were on par with those of scarified seeds. In hormonal priming, the highest plant height (56.80 cm), number of branches (20.00), collar girth (1.90 cm) and whole plant biomass (fresh-56.63 g plant^{-1} and dry-23.60 g plant^{-1}) were observed in plants raised from seeds primed with GA_3 @1500µM. Among the biostimulant priming, higher plant height (48.57 cm), number of branches (16.00), collar girth (1.20 cm) and whole plant biomass (fresh-38.97g plant^{-1} and dry-13.14g plant^{-1}) were observed in plants raised from PG @1 µM primed seeds. On evaluation of plants derived from bioprimed seeds, those from *B. velezensis* primed seeds recorded the highest plant height (55.77 cm), number of branches (19.33), collar girth (1.50 cm) and whole plant biomass (fresh-53.97 g plant^{-1}; dry16.87 g plant^{-1}). Among all the seed pretreatments tried, plants generated from hot water treated and GA_3@1500µM primed seeds recorded higher plant height, number of branches, collar girth and whole plant biomass.

Among the various seed pretreatments tried, *W. somnifera* seeds exposed to water soaking, hot water and GA_3@1500µM and *A. paniculata* seeds exposed to hot water treatment and GA_3@1500µM recorded superior performance with respect to seed germination, seedling vigour, plant growth and yield.