Enhancing morpho-physiological vigour of sesame seedlings for improving productivity and weed competitiveness

By

SREEPRIYA S

(2015-11-060)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Enhancing morpho-physiological vigour of sesame seedlings for improving productivity and weed competitiveness"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 23-08-2017

Sreepriya S.

(2015-11-060)

CERTIFICATE

Certified that this thesis entitled **"Enhancing morpho-physiological vigour of sesame seedlings for improving productivity and weed competitiveness"** is a bonafide record of research work done independently by **Ms. Sreepriya S (2015-11-060)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associate ship or fellowship to her.

Vellanikkara

Date: 23-08-2017

Dr. T. Girija
Major Advisor
Professor and Head
Department of Plant Physiology
Kerala Agricultural University
Thrissur, Kerala

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. **Sreepriya S (2015-11-060)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Plant Physiology**, agree that the thesis entitled **"Enhancing morpho-physiological vigour of sesame seedlings for improving productivity and weed competitiveness"** may be submitted by **Ms. Sreepriya S (2015-11-060)**, in partial fulfillment of the requirement for the degree.

Dr. T. Girija
Professor and Head
Department of Plant Physiology
College of Horticulture
Vellanikkara

Dr. Bindu M. R
Professor
Department of Plant breeding
ORARS
Kayamkulam

Dr. Meera V Menon
Professor
Department of Agronomy
College of Horticullture
Vellanikkara

Dr. Dijee Bastian
Professor
Plant breeding and genetics
Department of Seed science and Technology
College of Horticulture
Vellanikkara

23/8/17

EXTERNAL EXAMINER

(Dr. P. Jeyakumar)

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Abbreviations

DAS	Days after sowing
WAE	Week after emergence
%	Per cent
CGR	Crop growth rate
RGR	Relative growth rate
NAR	Net assimilation rate
LAI	Leaf area index
NRase	Nitrate reductase enzyme activity
IAA	Indole acetic acid
GA	Gibberellic acid
PGPR Mix I	Plant Growth Promoting Rhizobacteria Mix 1
Kg ha^{-1}	Kilogram per hectare
RWC	Relative water content
WCE	Weed control efficiency
Tank mix (TM)	Mixture of $MnSO_4$, Borax and GA

Introduction

1. INTRODUCTION

Sesame is one of the oldest oil seed crops cultivated in India. Globally, India is the largest producer, consumer and exporter of sesame. As per the Solvent Extractors Association of India (SEAI), the area under sesame crop was 19.81 lakh hectares with a production of 8.87 lakh tonnes during 2015-16. Sesame seed has high oil content compared to other oilseeds, the content ranging from 37 to 52 per cent. Due to the presence of compounds sesamoline and sesamine, sesame oil is resistant to rancidity. Hence sesame is known as the 'queen of oilseeds' (Namiki, 1995). The oil is rich in protein (22 per cent) and its seed meal contains 42 per cent protein (Nagendra *et al.*, 2012). The seeds are a rich source of food, nutrition, edible oil and bio-medicine. The crop is heat tolerant but sensitive to water logging. In Kerala, sesame is usually grown in summer rice fallows due to its short duration and low water requirement.

Weed infestation is a major biotic stress affecting the yield of sesame as its seedling growth is slow during the first four weeks, making it a poor competitor at the early stages of crop growth (Nazir, 1994; Bennett *et al.*, 2003). Yield loss as high as 81 per cent was reported in the crop due to weed infestation (Shaalan *et al.*, 2014). Insufficient weed control at early crop periods mainly at the critical period of crop weed competition, leads to yield reduction (Weaver *et al.*, 1992). Upadhyay (1985) suggested that suppression of weed growth at crop establishment stage is important as early growth of sesame is slow.

One approach to weed management in sesame could be seed priming (Vafaei *et al.*, 2013). Seed priming is a pre-sowing strategy for improving seedling establishment by modulating pre-germination metabolic activity prior to emergence of the radicle. This technique generally enhances germination rate and plant performance (Bradford, 1986). Proper seed priming treatments with micronutrients, plant growth regulators and biofertilizers can improve early seedling vigour and establishment. Various seed priming techniques have been developed which include hydro priming, hormonal priming, nutri priming and priming with Plant growth promoting rhizobacteria (PGPR). Hydro-priming enhances seed germination and seedling emergence under both saline and non-saline conditions. According to Mazid (2014) presowing seed priming with Gibberellic acid (GA) alters the vegetative growth pattern through the synthesis of important cell metabolites that affect the metabolism and physiology of plants. Manganese (Mn) is an important micronutrient that plays a vital role in photosynthesis and nitrogen metabolism (Stout and Arnon, 1939). Boron is associated with cell division, flowering, fruiting, carbohydrate and nitrogen metabolism, calcium utilization, disease resistance and water relations (Sprague, 1951). Plant growth promoting rhizobacteria (PGPR) are bacteria that colonize in plant roots and encourage plant growth by a wide variety of mechanisms such as phosphate solubilization, phytohormone production and antifungal activity (Ibiene *et al.*, 2012).

Currently there are no recommended herbicides for weed management in sesame. Hence integrated weed management techniques have to be adopted. Utilizing priming agents for improving early vigour of seedlings is an accepted concept. Such an improvement in seedling vigour can be instrumental in suppressing weed growth. This has to be further validated in the field. In this context, the experiment has been envisaged with the following objectives:

1. To assess the effect of priming agents on germination, growth and vigour index of sesame varieties.
2. To identify the most suitable priming agents for improving vigour and productivity of sesame.
3. To select the variety which gives maximum response to seed priming.
4. To evaluate the effect of early vigour on weed competition.

Review of Literature

2. REVIEW OF LITERATURE

Weed infestation is a major factor that affects the yield of sesame. The slow initial growth of sesame during the first four weeks is the main reason that makes them poor competitors to the quick growing weeds. In order to improve the seedling vigour, seed priming with different treatments can be practiced. The effect of seed priming treatments on morphological, physiological, biochemical and yield attributes of sesame plant and its influence on weed suppression has been reviewed.

2.1. SEED PRIMING

Seed priming is a technique which involves imbibition of water by the seeds and drying thereafter to start the early events in germination up to radicle emergence (Varier *et al.*, 2010). The main seed priming techniques includes hydro priming, halo priming, osmo priming and hormonal priming (Singh *et al.*, 2015). The principle of seed priming is based on the fact that the seed is hydrated to a moisture level sufficient to initiate the early events of germination but not the radicle emergence (Moradi and Younesi, 2009).

2.1.1. Hydro priming

Thornton *et al.* (1993) reported that the damaged DNA during ageing is repaired by aerated hydration of seeds. On the basis of the study in priming of tomato, Ozbingol *et al.* (1999) opined that seed priming enhances DNA replication thus allowing the cell to pass from G1 to G2 phase of cell cycle rapidly. Western analysis revealed that a cytoskeleton protein, β tubulin, involved in cortical microtubule formation is found to increase during aerated hydro priming (Powell *et al.* 2000). Benamar *et al.* (2003) on the basis of cytochrome c permeation assay reported that 12 hour of hydro priming improves the mitochondrial outer membrane integrity. An experiment conducted to investigate the effect of pre-sowing hydro priming of mung bean seed (*Vigna* *radiata* (L.) Wilczek) on the severity of incidence of mung bean yellow mosaic virus reported that only 14 per cent of the primed plants showed lethal symptoms where as 70 per cent of the non-primed plants showed lethal symptoms (Rashid *et al.*, 2004). Shinde (2008) noticed the induction of RNA synthesis in primed cotton seeds. Hydro priming is a simple, low cost low risk approach which involves continuous or successive addition of limited amount of water to the seed. It enhances germination, seedling emergence and also helps in enzyme activity for rapid germination (Singh *et al.*, 2015).

2.1.2. Nutri priming

Availability of micro nutrients limits the yield as they are involved in key physiological process like photosynthesis and respiration (Marschner, 1995). Nutri priming improves the nutrient content in the crop and also enriches the seeds of the crop with the specific treated nutrient. Nutri priming is an effective and easy alternative for micronutrient application (Savithri *et al.*, 1998). Research evidences suggest that pre sowing seed treatment with micro nutrients is beneficial. The technique of nutrient seed priming involves soaking of seeds in a specific concentration of nutrient solution in order to increase the nutrient content and also for increased seed quality for better germination and seedling establishment (Imran *et al.*, 2013). Both macro and micro nutrients play an important role in plant growth and productivity. Micro nutrients such as Zn, Mn, B and Mo are important as they are involved in important functions such as membrane stabilization, free radical detoxification, as co factors in enzymes, and also take part in different physiological process during germination and early seedling establishment (Rakshit *et al.*, 2013).

2.1.2.1. *Seed priming with Boron*

Sprague (1951) reported that the micro nutrient boron is associated with cell division, flowering and fruiting, carbohydrate and nitrogen metabolism, calcium utilization, disease resistance, water relations, and act as a catalyst for certain reactions. Reproductive stage of plant is more sensitive to boron deficiency than vegetative stage (Dell and Huang, 1997). Boron deficiency down regulates several enzymes for cell wall loosening to facilitate cell elongation (Cosgrove, 1999). Brown *et al.* (2002) observed that in the absence of boron, pollen tubes may burst, which may possibly be due to the primary boron functions in the cell wall structure of the pollen tubes. Culturing of tobacco BY-2 (*Nicotiana tabacum* L. cv 'Bright Yellow 2') cells in lower boron concentration reported the up regulation of several genes involved in the rescue system of oxidative damage (Kabayashi *et al.*, 2004). In a study on pea (*Pisum sativum* L.), Kumar *et al.* (2008) reported increased plant height, fruiting and pod yield when seeds were primed in 0.5 per cent boron solution with a concomitant reduction in days to 50 per cent flowering. The different physiological process in the life cycle of plants like cell wall development, carbohydrate and RNA metabolism are regulated by boron (Herrera-Rodriguez *et al.*, 2010). Concentration of priming solution is the most critical factor while seed priming with boron. In rice lower concentration of boron (0.001 per cent) is reported to increase the germination and seedling growth whereas higher concentration (0.5 per cent) caused toxic effects (Rehman *et al.*, 2012). A comparative study of soil, foliar and seed priming application of boron in rice conducted by Rehman *et al.* (2014) revealed seed priming and foliar spray reduced panicle sterility, improved kernel quality, growth and yield. They also opined that seed priming is the most economical treatment to achieve higher yield.

In oats (*Avena sativa* L.), seed priming with 0.02 per cent boric acid improved the panicle length and grain weight which in turn resulted in 8.52 per cent yield increase over control although its effect on tillering was negligible (Saric and Saciragic, 1969).

2.1.2.2. *Priming with Manganese sulphate ($MnSO_4$)*

Manganese is an important trace element which plays a vital role in photosynthesis and nitrogen metabolism (Stout and Arnon, 1939). Priming wheat seeds in 0.2 per cent $MnSO_4$ solution for 12 hour significantly improved growth, grain yield and grain Manganese contents

(Khalid and Malik, 1982). Manganese content was higher in the wheat seeds, where the mother plant was sown after seed priming with Manganese (Marcar and Graham, 1986). Mirshekari *et al.* (2012) reported that priming of marigold with one per cent $MnSO_4$ for 12hour improved the flower yield by 30.67 per cent.

2.1.3. Hormonal priming

2.1.3.1. *Priming with gibberellic acid (GA)*

GA stimulates hydrolytic enzymes that are needed for the degradation of the cells surrounding the radicle and thus speeds germination by promoting seedling elongation of cereal seeds (Rood *et al.*, 1990). The plant hormone GA is known to affect many physiological processes in plants like germination, leaf expansion, photosynthesis, nitrogen fixation, water and mineral uptake, phloem loading, assimilate translocation and harvest index (Gana, 2010). Presowing seed priming with GA is able to alter the vegetative growth pattern thorough the synthesis of important cell metabolites that affect the metabolism and physiology of plants (Mazid, 2014)

2.1.3.2. *Priming with Indole acetic acid (IAA)*

IAA is an important plant hormone that controls vascular tissue development, cell elongation and apical dominance (Wang *et al.*, 2001). Seed priming in cotton with IAA 200ppm had resulted in improved salinity stress tolerance mainly through maintenance of higher chlorophyll content, proline content, nitrate reductase activity, potassium, calcium, K/Na ratio and reduced sodium content in leaf (Babu, 2006).

2.1.4. Priming with Biofertilizer

Cakmakci *et al.* (2007) reported that inoculation of plants with Azospirillum improved total plant biomass, plant height, leaf size, leaf area index and root length of cereals. Plant growth promoting rhizobacteria (PGPR) are a group of bacteria that actively colonize in plant roots and increase plant growth and yield (Heidari *et al.*, 2011).

2.2. EFFECT OF SEED PRIMING

2.2.1. Effect of different seed priming on germination characteristics

2.2.1.1. Germination per cent

Nethaji (2006) reported that hydropriming of mustard seeds improved the germination percentage and seedling vigour. Hydro priming in bhindi and bittergourd improved the germination percentage, vigour and storability of seeds (Nirmala, 2006).

12 hour soaking of soyabean cv conquista in 5mM $MnSO_4$ and 0.5 mM boric acid solution at 20ºC resulted in significant increase in germination percentage and micro nutrient content in seeds under low temperature stress. (Imran *et al.*, 2008). Among the micronutrients $ZnSO_4$, $FeSO_4$, $CuSO_4$, $MnSO_4$ and borax used for pelleting, the maximum germination percentage was obtained from seeds pelleted with $MnSO_4$@ 300mg/kg of seeds (Suma *et al.*, 2014).

Presoaking with gibberellic acid increased the rate and the final germination percentage of osmotically stressed flax and sesame seeds, while those of stressed onion seeds were slightly retarded (Heikal *et al.* 1982). Baily (2004) suggested that the decrease in germination percentage in aged seeds is due to reduction in α- amylase enzyme. Seed invigoration of sesame cultivar CO1 with different concentrations of GA_3, IAA and NAA revealed that GA_3 @ 100 ppm resulted in higher germination followed by IAA @100 ppm. While seed priming with NAA had deleterious effects at all concentrations. Moreover, the study reported that hydro priming the sesame cultivar CO1 had improved the germination by 2 per cent (Suma *et al.*, 2006). Tabatabaei (2013) reported that priming of sesame seeds after accelerated ageing with 50ppm GA_3 had improved the germination of aged seeds. Significant improvement in germination per cent was observed in sesame seeds treated with 200 ppm GA (Mura *et al.*, 2015). Priming of sesame variety TMV-1 with 2.0 mg/l IAA and 2.0 mg/l GA_3 resulted in two and four per cent increase in germination per cent over control respectively (Subash *et al.,* 2015).

Suma *et al.* (2014) reported that pelleting of sesame seeds of variety CO1 with Azospirillum and Phosphobacteria improved the germination by 6 per cent and 4 per cent respectively over control (80 per cent). Even after four months of storage, the germination per cent was higher (6 per cent and 1 per cent respectively) than control. Moreover the germination after four month of storage was improved by 6 per cent and 1 per cent over control. In an experiment conducted to evaluate the effect of GA_3, IAA and Azospirillum on germination of sesame variety TMV-7 revealed that presowing treatments had significantly improved the germination by 14, 13 and 18 per cent respectively over control (Subash and Rafath, 2016).

2.2.1.2. Shoot and root length

Study by Shabbir *et al.* (2014) opined that hydro priming of sesame seeds improved the shoot and root length of seedlings significantly when compared to control.

Seed pelleting with Azospirillum and phosphobacteria in sesame variety CO1 had improved the root length to 11.53 cm and 11.0 cm respectively over control (8.1 cm). Shoot length also showed a positive response of 7.6 cm and 7.5 cm over control (5.6 cm) (Suma *et al.,* 2014). Presowing treatments 2.0mg/l GA and 2.0mg/l IAA had improved the root length (6.81cm and 5.20cm) of sesame variety TMV-1 over control (4.65cm) (Subash *et al.*, 2015). The root and shoot length of sesame variety TMV-7 had significantly improved by seed priming with IAA (2.0mg/l), GA_3 (2.0mg/l) and Azospirillum, of which the maximum root length of 7.23cm and shoot length of 10.11cm was obtained with Azospirillum treatment, whereas the untreated seeds had only 4.28 and 5.21 cm root and shoot length respectively (Subash and Rafath, 2016).

2.2.1.3. *Vigour index*

Munawar *et al.* (2013) reported that soaking of carrot seeds in water (1006) and 1.5 per cent Mn (1448) improved the vigour index than unprimed seeds (730).

Mura *et al.* (2015) reported that sesame seed treatment with 200ppm GA recorded significantly higher vigour index.

An experiment done in seed pelleting of sesame cv CO1 with Azospirillum and Phosphobacteria showed an improvement in vigour index from 1120 (control) to 1643 and 1554 respectively (Suma *et al.*, 2014).

2.2.1.4. *Speed of germination*

Priming of *Solanum lycocarpum* seeds with water for 15 days at 15ºC resulted in fastest and uniform germination and suggested that the priming effect is due to the mechanical weakening of the endosperm and development of endo-ß-mannanase activity (Anese *et al.* (2011). Vafaei *et al.* (2013) reported that hydropriming of sesame seeds shortened the days to emergence by about 2.5 days. A study conducted by Shabbir *et al.* (2014) reported that hydro priming of sesame seeds for a period of 8 hrs prior to sowing had significantly decreased the time to start emergence and mean emergence time The study also revealed the positive impact of hydro priming on final emergence percentage, energy of emergence and emergence index.

The mean time required for germination of aged seeds of sorghum was reported to have decreased due to pretreatment of aged seeds with 50 ppm GA_3 (Azadi *et al.*, 2013).

2.2.2. Effect of seed priming on growth parameters

2.2.2.1. *Leaf area*

Ogbuehi *et al.* (2013) reported that the mean leaf area of bambara groundnut was significantly improved at 2, 4, 6, 8 and 10 weeks after planting with 24 hour hydro priming ($15cm^2$, $64cm^2$, $73cm^2$, $126cm^2$ and $130cm^2$ respectively).

2.2.2.2. *Crop growth rate (CGR)*

Rehman *et al.* (2011) reported that on hydro priming of rice (*Oryza sativa* L) cv. super basmati seeds for 12 hours recorded the highest crop growth rate of $4.16gm^{-2}d^{-1}$ at 82 days after sowing, while the control recorded $3.55gm^{-2}d^{-1}$. Crop growth rate of sesame plants raised from seeds primed with GA_3 @200ppm for 18 hours were the highest when compared with other priming treatments and untreated control (Mura *et al.*, 2015).

2.2.2.3. *Relative growth rate (RGR)*

Offiong (2010) compared the RGR of *Tectona grandis* (Linn. F) seeds soaked in running water, stagnant water and control. Results showed that RGR of seeds soaked in running water was 11.72g/month. While that of seeds soaked in stagnant water was1.58g/month and that in control was only 1.92g/month.

2.2.2.4. *Net assimilation rate (NAR)*

Ogbuehi *et al.* (2013) reported that 12 hour soaking of Bambara groundnut (*Vigna subterranea* (L.) Verdc) seeds in water had resulted in highest NAR of $0.0088mgcm^{-2}day^{-1}$ where as the unprimed plants have a NAR of only $0.0047\ mgcm^{-2}day^{-1}$ at 10 weeks after planting.

2.2.2.5. *Leaf area index (LAI)*

Ogbuechi *et al.* (2013) reported that the LAI was not significantly affected by the hydro priming periods.

An experiment conducted by Mura *et al.* (2015) reported that the 200ppm GA treated sesame seeds had significantly higher leaf area index during 30, 45, 60 and 90 DAS than with the KH_2PO_4 treated seeds.

2.2.3. Effect of seed priming on physiological and biochemical observations

2.2.3.1. *Chlorophyll content*

In an experiment conducted on *Sesame indicum* cv. Rama reported that seed priming with 200 ppm GA recorded the highest chlorophyll a, chlorophyll b and total chlorophyll content followed by 100 ppm GA and 200 ppm NaH_2PO_4.Where as the unprimed seed showed the lowest values of chlorophyll content. (Mura *et al.*, 2015).

Study on seed priming in broccoli seedlings by Memon *et al.* (2013) revealed that water priming improved the chlorophyll content to 3.6 mg ml^{-1} and priming with 0.01 per cent boric acid solution to 4.13mg ml^{-1} whereas, the unprimed seeds recorded a chlorophyll content of 2.99 mg ml^{-1}.

2.2.3.2. *Nitrate reductase enzyme activity*

Babu (2006) observed that in cotton under salinity the nitrate reductase activity increased when seeds were primed with 1AA @ 200ppm (181.38 n moles NO_2^- g^{-1} fresh weight) and GA @ 10ppm (175.76 n moles NO_2^- g^{-1} fresh weight) where as the control showed the lowest value (167.16 n moles NO_2^- g^{-1} fresh weight) at 45 DAS.

2.2.3.3. *Soluble protein content*

Smith (1991) observed 115 per cent increase in soluble protein content when seeds of chillies (*Capsicum annuum* L. cv. Keystone Resistance Giant 3) were primed with -0.91Mpa NaCl.

2.2.3.4. *Relative water content (RWC)*

Mahootchi and Golezani (2013) reported that hydro priming of chick pea plants from high vigour seed lot under different irrigation treatments had higher relative water content, compared with those from low vigour seed lots. The shoot and root relative water content in sunflower at different salinity levels (64.38per cent at 0.1 per cent NaCl) were improved by hydro priming (95.83 per cent) (Pahoja *et al.*, 2013).

Shariatmadari *et al.* (2017) reported that GA priming of chickpea seeds for 18 hrs improved the RWC to 13 per cent, 27 per cent and 55 per cent under drought stress levels of 70, 50 and 30 per cent field capacity, respectively.

2.2.3.5. *Photosynthetic rate and Stomatal conductance*

Shah (2007) reported that priming of black cumin seeds (*Nigella sativa* L.) with 10^{-5}M GA solution improved the photosynthetic rate (14.17mmol CO_2 $m^{-2}s^{-1}$) and stomatal conductance (0.382mol $m^{-2}s^{-1}$) over control (10.95 and 0.30 respectively).

2.2.4. Effect of seed priming on yield and yield attributes

2.2.4.1. *Number of branches per plant*

Gnyandev *et al.* (2009) observed that the number of branches increased when the seeds of chick pea varieties A-1 and KAV-2 were primed with boron (1g/kg seeds) (23.07) and phosphorus solubilizing bacteria (20g/kg seeds) (25.60), whereas the number of branches in control was 21.07.

2.2.4.2. *Number of capsules per plant*

An experiment conducted with the sesame cv.TMV3 by Thiruppathi *et al.* (2001) showed that the seed inoculation of azospirillum had significantly improved the number of capsules per plant. Also, the combined application of seed inoculation of azospirillum along with soil and foliar application of $ZnSO_4$@5Kg/ha and $ZnSO_4$ @ 5per cent respectively had improved the number of capsules per plant. In an experiment conducted to partially replace the chemical fertilizers by bio-organic fertilizers, two sesame varieties (Giza 32 and shandawel 3) El-Habbasha *et al.* (2007) reported that 75 per cent chemical fertilizers + 25per cent organic + biofertilizers recorded the highest values of capsules per plant followed by 50per cent chemical fertilizers+50 per cent organic +biofertilizers.

2.2.4.3. ***Number of seeds per capsule***

The highest number of seeds per capsule was observed in *Sesame indicum* cv Rama when seeds were primed with GA_3@ 200ppm where as the dry sown seeds produced least number of seeds per capsule (Mura *et al.*, 2015).

Seed inoculation of sesame cv.TMV3 with azospirillum had significantly improved the number of seeds per capsule. Also, the combined application of seed inoculation with azospirillum along with soil and foliar application of $ZnSO_4$@5Kg/ha and $ZnSO_4$ @ 5per cent respectively had improved the number of seeds per capsule (Thiruppathi *et al.*, 2001).

2.2.4.4. ***1000 seed weight***

The 1000 seed weight in *Sesame indicum* cv Rama showed highest value with the seed treatment of GA_3@200ppm where as the dry sown seeds produced least number of seeds per capsule (Mura *et al.*, 2015).

2.2.4.5. ***Dry matter***

Rashid *et al.* (2004) reported that pre sowing hydro priming of Mungbean (*Vigna radiata* (L.) Wilczek) seeds for 8 hour produced 80 per cent more biomass (3.3t/ha) than unprimed seeds (1.9t/ha). Vafaei *et al.* (2013) reported that hydro priming of sesame seeds improved the plant dry weight from 5529 to 5910 kg per ha. According to Shabbir *et al.* (2014) hydro priming of sesame seeds for 8 hour prior to sowing have improved the dry weight of the plant.

Sesame seed treatment with 200ppm GA resulted in significantly higher dry matter accumulation where as the dry seed recorded lower values in 30, 45, 60 and 90 days after sowing (Mura *et al.*, 2015).

2.2.4.6. *Yield*

Rashid *et al.* (2004) reported that pre sowing hydro priming of mung bean (*Vigna radiata* (L.) Wilczek) seeds produced 415 per cent more grain yield (0.36 versus 0.07 t /ha) than did non-primed crops. An experiment conducted by Vafaei *et al.* (2013) reported that proper combination of pre and post emergence herbicides along with seed hydro priming is effective in weed control in Sesame which gives seed yield comparable to that of full season weed-free condition. Sharma *et al.* (2014) reported that, hydro priming of okra seeds for 12 hour increased the fruit yield up to 55 per cent compared to control.

Seed priming in Oats with 0.02per cent H_3BO_3 had no significant effect on germination but an increase in panicle length and grain weight was observed which contributed to an 8.42 per cent increase in grain yield (Saric and Saciragic, 1969). Seed priming with 0.2 per cent $MnSO_4$ for 12 hour increased grain yield in wheat (Khalid and Malik, 1982). Nazir *et al.* (2000) reported 12.79 per cent increase in grain yield in wheat when seed priming was done with 0.1 M $MnSO_4$ for 12hours.

Seed invigoration of *Sesame indicum* cv Rama with 200 and 100ppm GA_3 recorded the highest seed yield as compared to NaH_2PO_4 treated and dry sown crops (Mura *et al*, 2015).

In an experiment to partially replace the chemical fertilizers by bio-organic fertilizers of two sesame varieties (Giza 32 and Shandawel 3) it was observed that 75per cent chemical fertilizers + 25per cent organic + biofertilizers recorded the highest seed yield /fad (El-Habbasha *et al.*, 2007).

2.3. WEED FLORA IN SESAME FIELD

The two year pooled data on weed flora of sesame in north western Ethiopia reported that the relative density of natural broad leaved weeds was 89 per cent and that of grassy weeds was 11per cent. *Ocimum basilicum* (L) and *Corchorus orinocensis* (L.) contributed 36 per cent of the total weed population

(Amare *et al*., 2009). An experiment conducted by Ijilal *et al.* (2011) reported that the main weed flora present in summer sesame field of University of Agriculture, Faisalabad were *Trianthema portulocastrum, Echinocloa colona, Cyperus rotundus and Cynodon dactylon.* Duary and Hazra (2013) reported that the grassy weed *Digitaria sanguinalis* (66.7 per cent) followed by the broad leaved weeds *Spilanthes acmella* (15.5%) were the most predominant weeds among the total weeds. Other grassy weeds were, *Echinochloa colona, Eleusine indica and Dactyloctenium aegyptium.* Broad leaved weeds include *Trianthema portulacastrum, Tephrosia purpurea* and *Ageratum conyzoides.* An experiment conducted by Shaalan *et al.* (2014) in sesame cv shandawil 1 field identified *Xanthium strumariam* (74.5 per cent), *Portulaca oleraceae* (6.4per cent), *Echinochloa colona* (5.8 per cent), *Setaria viridis* (5.3 per cent) *Chenopodium murale* (3.1per cent), *Amaranthus viridis* (2.6 per cent) and *Euphorbia geniculata* (2.3per cent) as the main weed flora.

2.4. CRITICAL PERIOD OF CROP WEED COMPETITION IN SESAME

Singh *et al.* (1993) reported that the critical period of crop weed competition in pigeon pea+sesame intercropping was from 15 to 45 days after sowing. The critical period of weed competition in sesame was reported to be 60 days after emergence in Sausa and 30-35days after emergence in Monteiro, Brazil (Beltro *et al*., 1997). Weed infestation was reported to be very harmful in sesame crop within 30 to 45 DAS in India (Venkatakrishnan and Gnanmurthy., 1998). According to Amare *et al.* (2009) the critical period of weed competition in sesame is between 10 and 30 DAE. Ijilal *et al.* (2011) reported that weed competition of 6WAE significantly reduced the yield and yield decline starts weedy condition 3WAE in sesame. Duary and Hazra (2013) reported that the critical period of crop weed competition in sesame was between 15 and 45 DAS. Tyagi *et al.* (2013) reported that critical period of weed control for sesame at Tikamgarh district of Madhya Pradesh was found to be about 15 to 45 DAS. The critical period of weed competition in sesame was found to be 15-70 DAS in the season of 2011 and 18-41 DAS with acceptable yield loss of 5 per cent in 2012 in sesame cv shandiwal 1(Shaalan *et al.*, 2014).

2.5. EFFECT OF WEEDS ON PLANTS

2.5.1 Effect of weeds on growth parameters

2.5.1.1 Plant height

Amare (2011) reported a reduction in plant height with the weed competition period. Ijilal *et al.* (2011) reported that in sesame the weed competition beyond 4WAE suppressed the crop growth which was reflected in the form of reduced plant height. The maximum height of 125.4cm was obtained from weed free plot which was significantly on par with 3 and 4 weeks of weed competition whereas unweeded control produced the shortest plants of 117.1cm. Shaalan *et al.* (2014) reported that the weedy condition affect sesame plant height. A weedy condition of 42 days after emergence onwards significantly reduced the plant height and weed free period of 14 days after emergence produced shorter plants, increasing weed free period thereafter increased the plant height in two growing seasons.

2.5.1.2. *Dry matter accumulation*

An experiment with treatments comprised of quantitative series of both increasing duration of weediness (weedy up to 10, 20, 30, 40, 50, 60 and 70 days) and weed free period (weed free upto10, 20, 30, 40, 50, 60 and 70 days) in sesame showed that in early competition the highest plant dry matter of 3375 kg ha^{-1} was obtained from weedy up to 10DAE and decreased successively with increase in weedy period to about 805 kg ha^{-1}. Similarly, in late competition the highest dry matter of 3682 kg ha^{-1} was obtained from weed free up to 70DAE and deceased steadily up to about 885 kg ha^{-1} in weed free up to 10 DAE (Amare *et al.*, 2009). Ijilal *et al.* (2011) reported that in sesame the highest dry matter was produced from full season weed free plot (2944 kg ha^{-1}) which was statistically on par with weedy condition up to 3WAE and a progressive decrease was reported from weeding after 4,5,6, and 7 WAE. The lowest plant dry matter was obtained (2547 kg ha^{-1}) from full season weedy plots. Shaalan *et al.* (2014) reported that the biological yield in sesame cv Shandiwal 1 reduced from 4.82 t/ha in complete weed free condition to 1.39 , 1.58, 1.92,1.98, 2.33,3.77 in weedy up to 84, 70,56, 42,28, 14 days and to 4.74, 4.58, 449, 4.43, 4.26 and 2.27 in weed free up to 84, 70, 56, 42, 28, 14 days.

2.5.1.3. *Leaf area*

Munene *et al.* (2008) reported a reduction in flag leaf area in rice (*Oryza sativa*) with the competition of wild rice (*Oryza punctata*) in Kenya. Hakkim *et al.* (2013) reported that the leaf area of rice reduced from 907cm^2 per hill (weed-free check) to 643cm^2 per hill (weedy-check).

2.5.1.4. *Crop growth rate (CGR)*

Amini *et al.* (2013) reported that the CGR of common jack bean was reduced with weed infestation. Chikoye *et al.* (1995) found that the white bean CGR was reduced in competition with common ragweed (*Ambrosia artemisiifolia* L.). CGR of the weedy corn declined by about 10 and 40 per cent at 60 and 80 DAE (Ghanizadeh *et al.*, 2014).

2.5.1.5. *Relative growth rate (RGR)*

Amini and Fateh (2011) observed that RGR of red kidneybean cultivars indicated a high correlation with competitiveness of red kidneybean against redroot pigweed (*Amaranthus retroflexus*). Ghanizadeh *et al.* (2014) reported that the CGR is higher for weed free plots of corn whereas the unweeded plots recorded lower values

2.5.1.6. *Net assimilation rate (NAR)*

Dunan and Zimdahl (1991) reported that relative growth rate (RGR) and net assimilation rate (NAR) was not correlated with the competitive ability of barley against wild oat (*Avena fatua* L.)

2.5.1.7. *Leaf area index (LAI)*

El Naim and Eldouma (2011) reported that weed competition reduced the LAI in peanut (*Arachis hypogaea* L). Amini *et al.* (2013) reported that the LAI of common jack bean was reduced with infestation of common ragweed (*Ambrosia artemisiifolia* L.) and also the date of peak LAI was affected. Ghanizadeh *et al.* (2014) reported that interference of weeds resulted in 46 per cent decrease in the LAI of corn at 80 DAE.

2.5.2 Effect of seed priming on yield and yield attributes

2.5.2.1 *Number of branches per plant*

El Naim and Eldouma (2011) reported that the weed competition reduced the number of branches in peanut (*Arachis hypogaea* L). Shehzad *et al.* (2011) reported that in garden cress (*Lepidium sativum* L.) a weed competition period of 60 days after emergence reduced the number of branches from 16.25 (weed free) to 13.25.

2.5.2.2 *Number of capsules per plant*

El-Serogy (1992) reported that a reduction in number of capsules with an increase in weedy duration in sesame. Ijilal *et al.* (2011) reported that there is a strong significant negative relationship (R^2=0.948) between the number of capsules per plant and duration of weed competition in sesame. The highest number of capsules per plant was produced by weed free plots which were on par with the plot which was weed free 3 weeks after emergence. According to Duary and Hazra (2013) the highest number of capsules per plant was produced when weed free condition was maintained throughout the growth period. Moreover there is no significant difference in the number of capsules produced from weed free plot, weedy up to 15 DAS, weed free up to 45DAS and weed free up to 60 DAS. The number of capsules per plant reduced from 66.2 in complete weed free plot to 19.0 , 21.5, 29.8, 30.5, 36.5 in complete weedy, weedy up to 84, weed free upto14, weedy up to 70 and 56 respectively (Shaalan *et al.*, 2014).

2.5.2.3 ***Number of seeds per capsules***

Ijilal *et al.* (2011) reported that there was a strong significant negative relationship (R^2=0.966) between number of seeds per capsule and duration of weed competition in sesame. The highest number of seeds per capsule was produced by weed free plots which were at par with the plot which was weed free after 3 week after emergence. The least was obtained from full season weed competition (38.97 seeds per capsule). According to Duary and Hazra (2013) the lowest number of seeds per capsules was produced from weedy check which was statistically on par with weedy up to 45 DAS, weedy up to 60 DAS and weed free up to 15DAS.

2.5.2.4 ***Test weight***

The regression analysis of 1000 seed weight with weed competition duration revealed that the highest seed weight was obtained from complete weed free plot (3.92g) and least in complete full season weedy plot in sesame (3.16g) (Ijilal *et al.*, 2011). Duary and Hazra (2013) reported that there was no significant difference in test weight of sesame seeds with weedy and weed free periods. Shaalan *et al.* (2014) reported that 1000 seed weight in sesame cv shandiwal 1 decreased with increase in weedy period. The maximum seed weight (6.31g) was obtained from full season weed free treatment, followed by weedy treatment of 14 DAE (5.37g).

2..5.2.5 ***Seed yield***

Amare *et al.* (2009) reported that an yield loss of 82.1, 81.2, 81.1, 80.6, 76.7, 65.80 per cent in seed yield occurred in weedy up to 70, 60, 50, 40, weed free up to 10 and weedy up to 30 DAE in sesame. According to the experiment conducted by Ijilal *et al.* (2011) to determine the critical period of crop weed competition in sesame, it was seen that a change from full season weed free to weedy condition in sesame resulted in a reduction of 12.4 per cent seed yield. The highest seed yield (363 kg ha^{-1}) was obtained from full season weed free condition which was comparable with the seed yield from 3, 4, and 5 weeks weedy conditions. In sesame variety Rama, an investigation on determination of crop weed competition reported that the plot which was weed free up to 60 DAS followed by weed free up to 45 DAS showed highest seed yield on the basis of percentage of weed free check (Duary and Hazra, 2013). According to Shaalan *et al.* (2014) a reduction of 79 per cent and 81 per cent in grain yield was reported in all season weedy compared to all season weed free plot during first and second season respectively in sesame.

2.6. EFFECT OF EARLY SEEDLING VIGOUR ON WEED SUPPRESSION

Wortmann (1993) reported that in bean (*Phaseolus vulgaris* L.) the ability to suppress weeds was found to be related to leaf size, leaf area index, and plant growth rate. Leaf size and leaf area index accounted for 73 per cent of the variation among genotypes for weed biomass at the time of bean harvest. Dias *et al.* (2011) reported that soybean plants which developed from seeds with high and intermediate vigour showed the best results for competition against weeds by reducing weed dry mass accumulation. Plants which developed from high vigour seeds gave the best results for grain yield for both weeded and unweeded treatments.

Experiment conducted by Vafaei *et al.* (2013) showed that a proper combination of pre- and post-emergence herbicides along with seed priming could be used to control the weeds in sesame and to obtain a seed yield comparable with weed-free conditions.

Materials and Methods

3. MATERIALS AND METHODS

The aim of the present study was to understand the effect of seed priming on germination, vigour and productivity of sesame and the influence of early vigour on improving weed competitiveness of sesame. A laboratory study and thereafter a field study was conducted to identify the most promising priming agent and to identify the varieties that showed maximum response to priming. A brief account of the materials used and methodology adopted in this study are given below.

3.1. EXPERIMENT 1(LABORATORY STUDY)

3.1.1. Location

The laboratory study was conducted at the Department of Plant Physiology, College of Horticulture, Vellanikkara.

3.1.2 Time of study

The laboratory study was carried out from 15-07-2016 to 3-10-2016.

3.1.3 Varieties

Seeds of five varieties of sesame *viz*. Kayamkulam-1, Thilak, Thilathara, Thilarani and Surya released from the Kerala Agricultural University were selected for the laboratory study.

3.1.4. Experimental details

Total treatments- 10

T_1: IAA at 100 ppm

T_2: GA_3 at 100 ppm

T_3: Phosphobacteria @ 50g/kg of seed

T_4: Azospirillum @ 50 g/kg seed

T_5: PGPR Mix I @ 50g/kg seed

PGPR mix 1 is a compatible consortium of Plant Growth Promoting Rhizobacteria, is expected to reduce the fertilizer requirement by enhancing soil nutrient availability, released by College of Agriculture, Vellayani; Kerala Agricultural University.

T_6: Borax, 0.1 per cent

T_7: $MnSO_4$, 0.3 per cent

T_8: Tank mix of GA_3, $MnSO_4$ and Borax (Tank mix)

T_9: Water priming

T_{10}: Control

- Design: CRD
- Number of replications: 100 seeds in four replications

3.1.5. Seed treatment method

T_1, T_2, T_6, T_7, T_8 and T_9 –50 g sesame seeds of the five varieties were soaked in one litre of each of the priming solutions for 8h and were dried back to 8 per cent moisture content.

T_3, T_4 and T_5- sesame seeds were moistened by sprinkling water and mixed with culture @ 50g /kg seed in a plastic tray, dried in shade for 30 min and were sown immediately.

3.1.6. Morphological observations

3.1.6.1. ***Germination per cent***

The germination test was conducted as per the procedure outlined in the ISTA rules (1999). Four replications of hundred seeds each were sown in seed germination crepe paper (Basis Weight: Std. 100/150 gsm and Sheet Size: Std. 16"*18"/Custom). After the test period of seven days the seedlings were counted and the mean values were expressed as percentage of the total number of seeds placed for germination.

3.1.6.2. *Shoot length (cm)*

At the time of germination count, the length between collar and the tip of the primary shoot of thirty random seedlings was measured as the shoot length and the mean value was expressed in centimetres.

3.1.6.3. *Root length (cm)*

The seedlings of which the shoot length was measured was used to measure the root length. The root lengths of seedlings were measured as the length between the collar and the tip of the primary root and the mean length was expressed in centimetres.

3.1.6.4. *Vigour index*

Vigour index-I was computed in the present experiment by using the procedure of Abdul-Baki and Anderson (1973).

Vigour index-I = Germination (%) × Total seedling length (cm)

3.1.6.5. *Speed of germination*

Four replicates of twenty seeds were used to test the speed of germination of the ten different treatments. The seeds with radicle protrusion were counted every day from the day of sowing up to 7 days. The speed of germination was calculated using the following formula given by Maguire (1962). The results were expressed in number.

Speed of germination = $X_1/Y_1 + X_2\text{-}X_1/Y_2 + \ldots\ldots + Xn - Xn\text{-}1/ Yn$

X_1- Number of seeds germinated at first count

X_2- Number of seeds germinated at second count

Plate 1. Germination studies in Laboratory

Xn- Number of seeds germinated at n th day

Y_1- Number of days from sowing to first count

Y_2- Number of days from sowing to second count

Yn- Number of days from sowing to nth count

3.2. EXPERIMENT II (FIELD STUDY)

The field study on enhancing the morphophysiological vigour of sesame seedlings for improving productivity and weed competitiveness was conducted at ORARS, Kayamkulam. The materials and methodology adopted in the field study are briefly described below.

3.2.1. Location

The experiment was carried out at Onattukara Regional Agricultural Research Station, Kayamkulam.

3.2.2. Variety used

The sesame variety used for the field study was Thilak (ACV3) released from Kerala Agricultural University (1993). Thilak is a pureline selection from Malappuram local suited for summer rice fallows of Onattukara.

3.2.3. Season

The crop period was from February 2017 to April 2017.

3.2.4. Treatments

The experiment was laid out in spilt plot design with 2 main plots and 6 sub plots treatments. The two main plots comprised of hand weeded and unweeded treatments. The sub plots consisted of five seed priming treatments *viz.* Water, Gibberellic acid, Borax, $MnSO_4$ and Tank mix (Mixture of GA, $MnSO_4$ and borax) and untreated control. 250 g seeds were soaked for 8 hrs and after shade drying, the seeds were sown in the field.

3.2.5. Field operations

The details of various field operations from land preparation to harvesting are given below.

3.2.5.1. *Land preparation, sowing and fertilizer application*

Before starting the experiment, soil sample was collected from the experimental site and analyzed for the basic properties like pH, EC, macro and micro nutrients (Table.1). The experimental area was ploughed twice to a fine tilth. The plot size was $2m^2$ (2m×1m) with a spacing of 60 cm between plots. Fertilizers were applied as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2016). N: P: K @ 30:15:30 Kg ha^{-1} was applied as basal dose at the time of sowing. After the fertilizer application seeds were dibbled at a spacing of 15 cm ×20 cm. The priming treatment was given one day before sowing. Thinning was done 15 days after sowing. 2 per cent foliar spray of urea was given after thinning.

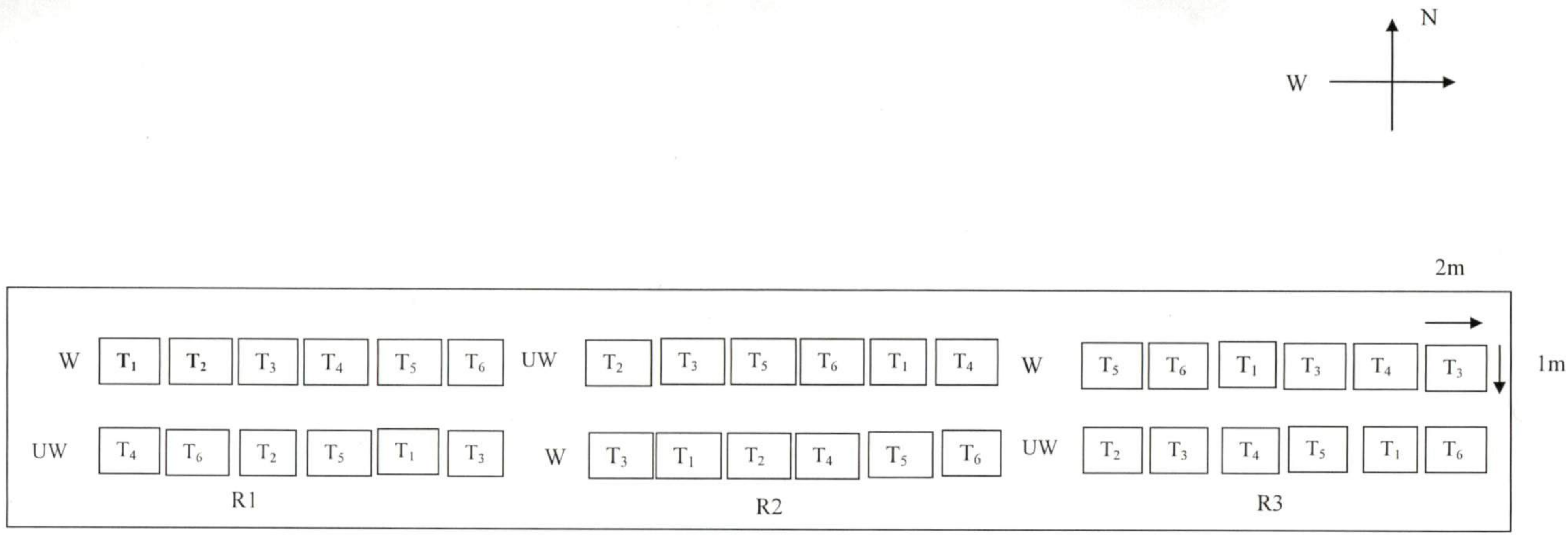

Fig. 1. Layout of the experiment

Main plots (2) -

W- Weeded

UW- Unweeded

Subplots (6) -

T_1- Control (unprimed)
T_2-Water
T_3-GA
T_4-Borax
T_5-$MnSO_4$
T_6- Tank mix (Mixture of $MnSO_4$, Borax and GA)

Plate 2. Sowing, thinning and intercultivation of sesame

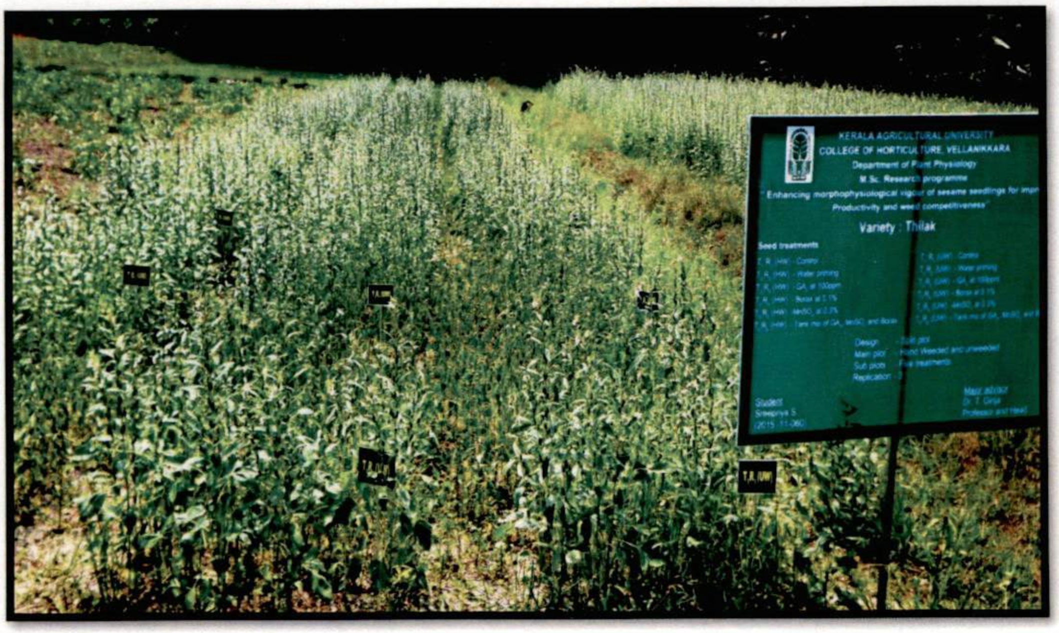

Plate 3. General view of experimental plot

Table. 1 Methods used for soil analysis

Parameters	Methods		References
	Extraction	Estimation	
pH	Soil water suspension of 1:2.5 ratio	Potentiometric method using pH meter	Jackson (1958)
Electrical conductivity	Soil water suspension of 1:2.5 ratio	Conductivity meter	Jackson (1958)
Organic carbon	Wet digestion method		Walkley and Black (1934)
Available nitrogen	Alkaline permanganate method		Subbiah and Asija (1956)
Available phosphorous	Bray-1 extract	Spectrophotometer (Model: Lambda 25)	Bray and Kurtz (1945)
Available potassium	Neutral normal ammonium acetate	Flame photometer (Model: CL 308)	Jackson (1958)
Available calcium and magnesium	Neutral normal ammonium acetate	Atomic Absorption Spectrophotometer	Jackson (1958)
Available sulphur	0.15% $CaCl_2$	Turbidimetrically by $BaCl_2$ using spectrophotometer	Williams and Steinbergs (1959)
Available Iron, manganese, zinc and copper	Extraction using 0.1M HCl	Atomic Absorption Spectrophotometer	Sims and Johnson, (1991)
Available boron	Hot water extraction	Colorimetrically by Azomethane-H using spectrophotometer	Berger and Truog (1939)

3.2.5.2. *Harvesting*

The crop was harvested by pulling out the plants when the capsules turned yellowish. The root portion was cut and the plants were stacked in bundles for four days. The defoliated plants were then sun dried till the capsules shattered. The seeds were cleaned, dried and yield was expressed in kg/ha.

3.2.6. Morphological observations

3.2.6.1. *Plant height*

Four plants were selected randomly from each plot and tagged. The height of selected plants were measured at 20, 40, 60 days after sowing and at the time of harvest. The height was measured from the base to the tip of the stem and expressed in centimeters.

3.2.6.2. *Days to branching*

The time taken for branching was counted from the date of sowing and expressed as days to branching.

3.2.6.3. *Days to first flowering*

The days from sowing to the emergence of first flower was counted from each plot.

3.2.6.4. *Days to 50 per cent flowering*

The number of days taken for 50 per cent flowering in each plot were recorded.

3.2.6.5. *Days to maturity*

Yellowing and defoliation occurs in sesame prior to harvest. In this stage, plants were considered as mature and the number of days taken in each plot were counted.

Plate 4. Harvesting

Plate 5. Sun drying sesame plants after harvest

3.2.6.6. *Total leaf area*

The leaf area was estimated on weight basis. The total leaf area was calculated by the formula given below and expressed in cm^2.

$L_2 = (L_1/W_1) \text{ X } W_2$

L_1 – single leaf area $\quad$ W_1 = weight of single leaf

L_2 = whole leaf area $\quad$ W_2= weight of all leaves

3.2.7. Growth indices

3.2.7.1. *Crop growth rate ($g\ m^{-2}\ d^{-1}$)*

Crop growth rate (CGR) is the rate of dry matter production per unit ground area per unit time. CGR was calculated by adapting the formula suggested by Watson (1952) and expressed as $g\ m^{-2}\ d^{-1}$.

$$CGR = \frac{(W_2-W_1)}{(T_2-T_1)} \text{ X } \frac{1}{A}$$

Where,

W_1 and W_2 = Dry weights of plants at time intervals T_1 and T_2 respectively.

A = Unit land area occupied by the plant (cm^2)

3.2.7.2. *Relative growth rate ($g\ g^{-1}\ d^{-1}$)*

Relative growth rate (RGR) is the rate of increase in the dry weight per unit weight already present per unit time. It was calculated by using the formula of Blackman (1919) and expressed as $g\ g^{-1}\ d^{-1}$.

$$RGR = \frac{(\log_e W_2 - \log_e W_1)}{T_2-T_1}$$

Where,

W_1 and W_2 = Dry weights of plants at time intervals T_1 and T_2 respectively.

3.2.7.3. ***Net assimilation rate (mg cm^{-2} d^{-1})***

Net assimilation rate (NAR) is the rate of dry weight increase per unit leaf area per unit time, which was calculated by the formula given by Gregory (1926) and expressed as mg cm^{-2} d^{-1}.

$$NAR = \frac{(W_2 - W_1)}{(T_2 - T_1)} \times \frac{(\log_e L_2 - \log_e L_1)}{(L_2 - L_1)}$$

Where,

L_1 and W_1 = Leaf area (cm^2) and dry weight of the plant (g) at time T_1

L_2 and W_2 = Leaf area (cm^2) and dry weight of the plant (g) at time T_2.

3.2.7.4. ***Leaf area index***

The leaf area index was calculated using the formula given by Williams (1946).

LAI = Total leaf area of the plant/ Ground area occupied by the plant

3.2.8. Physiological observations

3.2.8.1. ***Photosynthetic rate***

Photosynthetic rate was measured by using the instrument infrared gas analyzer (Model LI-6400 of Licor Inc. Lincoln, Nebraska, USA) at vegetative and reproductive stages of the plant and the readings were taken from 8 to 10 am and expressed as μ mol CO_2 m^{-2} s^{-1}.

3.2.8.2. *Stomatal conductance*

Stomatal conductance was measured by using the instrument infrared gas analyzer (Model LI-6400 of Licor Inc. Lincoln, Nebraska, USA) at vegetative and reproductive stages of the plant and the readings were taken from 8 to 10 am and expressed as mol $m^{-2}s^{-1}$.

3.2.8.3. *Transpiration rate*

Transpiration rate was measured by using the instrument infrared gas analyzer (Model LI-6400 of Licor Inc. Lincoln, Nebraska, USA) at vegetative and reproductive stages of the plant and the readings were taken from 8 to 10 am and expressed as m mol H_2O $m^{-2}s^{-1}$.

3.2.9. Biochemical observations

3.2.9.1. *Chlorophyll content*

Chlorophyll a, chlorophyll b and total chlorophyll were estimated by the method suggested by Hiscox and Israelstam (1979). The chlorophyll content was estimated in spectrophotometer (Model-4001/4 Thermo Spectonic, Thermo Electron Corporation, USA) at two wavelengths i.e., 663 nm and 645 nm and expressed as m g g^{-1} fresh weight of plant tissue. The calculation was done by using the following formulae.

Chlorophyll 'a' = [(12.7 x A663) – (2.69 x A645)] x V/1000 x W

Chlorophyll 'b'= [(22.9 x A645) – (4.68 x A663)] x V/1000 x W

Total chlorophyll = [(20.2 x A645) + (8.02 x A663)] x V/1000 x W

Where,

A = Absorption at given wavelength

V = Total volume of sample in extraction medium

W = Weight of sample

3.2.9.2. *Nitrate reductase activity*

To estimate nitrate reductase enzyme activity in the leaf, the method suggested by Hageman and Flesher (1960) was followed. The nitrite formed was estimated by the method described by Nicholas *et al.* (1976), by measuring the absorbance of pink colour at 540 nm using spectrophotometer and expressed in μ moles of NO_2^- formed g^{-1} fresh weight hr^{-1}.

3.2.9.3. *IAA content*

IAA oxidase activity was estimated by the method suggested by Parthasaradhy *et al.* (1970) with slight modification, using Garden Weber reagent. Two hundred and fifty milligram plant sample was homogenized in a mortar and pestle using phosphate buffer and centrifuged. Extract was collected and volume made up to 25ml. Ice-cold phosphate buffer and auxin were added to 1ml sample extract taken from 25ml. The absorbance was read at 520 nm and the enzyme activity was expressed as μg of unoxidised auxin g^{-1} h^{-1}.

3.2.9.4. *Total soluble protein*

Total soluble protein content in the leaf was estimated by the method suggested by Lowry *et al.* (1951). 500 mg of leaf sample was macerated with 10ml phosphate buffer solution. After centrifugation for 10 minutes at 3000rpm the volume of supernatant was made up to 25ml. 5ml of ACT (alkaline copper tartarate) and 0.5ml of Folin-Ciocalteau reagent were added to 1ml of supernatant. After 30 minutes absorbance of the blue colour at 660nm was measured in a spectrophotometer and expressed as mg g^{-1}.

3.2.9.5. *GA content*

The method for the extraction, purification and estimation of endogenous plant hormone gibberellic acid (GA) was modified from that described by Sundberg (1990) and Kojima (1995). One gram of plant sample was homogenized in a mortar and pestle with methanol (ice cold) and kept at 4 ºC in dark for four hours. The homogenate was centrifuged, filtered and the solid residue was further extracted twice with the same solvent.

All the methanolic extracts were combined and concentrated to a water residue in vacuum at 50°C for one hour. The volume was adjusted to 10 ml with phosphate buffer and partitioned in a separating funnel with 10 ml diethyl ether by stirring for 3 minutes. The ether phase was discarded and the aqueous phase was adjusted to pH 2.7 with 0.4 M HCl. The partitioned aqueous extract was collected twice with 0.4M $NaHCO_3$. This was then partitioned with 10 ml ethyl acetate. The aqueous phase was decanted and stored at 4°C after adding 2 ml of methanol. This was used for gibberellin estimation by adding zinc acetate (2ml), potassium ferrocyanide (2ml). It was then centrifuged. The supernatant collected was kept at 20°C for 75 minutes after adding 30 per cent HCl. The absorbance was read at 254 nm using a UV- VIS spectro photometer. GA content was calculated and expressed in $\mu g\ g^{-1}$.

3.2.9.6. *Relative water content (RWC)*

Relative water content was calculated by the formula given by Weatherly and Barrs (1962) and expressed in per cent.

$$RWC = \frac{FW-DW}{TW-DW} \times 100$$

Where,

FW= Fresh weight of leaf discs (g)

TW= Turgid weight of leaf discs (g)

DW= Dry weight of leaf discs (g)

3.2.10. Yield attributes and yield

3.2.10.1. *Number of branches per plant*

The number of branches per plant of selected plants in each plot was counted at the time of harvest.

3.2.10.2. *Number of capsules per plant*

The number of capsules of selected plants in each plot was counted at the time of harvest.

3.2.10.3. *Number of seeds per pod*

At the time of harvest the number of seeds in each capsule was counted from ten pods of each plot and the mean was estimated for each variety.

3.2.10.4. *Thousand seed weight*

One thousand seeds were counted from pods of selected plants in each replication and their weight was recorded in grams.

3.2.10.5. *Yield per plant*

The harvested seeds from plants of each plot were weighed separately and the mean was expressed as grams per plant.

3.2.10.6. *Yield per hectare*

The yield obtained from each plot was estimated and expressed as kg per hectare.

3.2.11. Estimation on weed competitiveness

3.2.11.1. *Weed count*

Weeds present in one square metre area of each plot were counted at 10 DAS and at the time of harvest.

3.2.11.2. ***Weed dry weight***

Dry weight of weeds present in one square metre area of each unweeded treatment was measured at 10 DAS and at the time of harvest.

3.2.11.3. ***Weed control efficiency***

The weed control efficiency of the different priming treatments over control was calculated in the unweeded treatment using the following formula:

$$WCE = (x-y/x) \times 100$$

(Gupta, 2010)

x- Dry weight of weeds in unweeded plots

y- Dry weight of weeds in plots where priming treatment was given

3.3. STATISTICAL ANALYSIS

Statistical analysis was done using OPSTAT developed by CCS HAU, Hisar. Pair wise comparisons of the treatments were done using critical difference. For the laboratory study the ten priming treatments were categorized to four groups based on similarity as follows:

1. Plant growth regulators (IAA, GA)
2. Biofertilizers (Phosphobacteria, Azospirillum and PGPR Mix I)
3. Nutrients ($MnSO_4$, Borax)
4. Water, tank mix of $MnSO_4$, borax and GA

The data of laboratory study was analyzed in two factorial CRD with variety and treatment as the two factors.

The field study was analyzed in split plot design. The main plot and subplot treatments are given in Table 2.

Table. 2 Main plot and subplot treatments

Main plot treatments	Sub plot treatments (Seed priming)
Weeded	Control
	Water
	GA
	Borax
	$MnSO_4$
	Tank mix (Mixture of $MnSO_4$, Borax and GA)
Unweeded	Control
	Water
	GA
	Borax
	$MnSO_4$
	Tank mix (Mixture of $MnSO_4$, Borax and GA)

Results

4. RESULTS

4.1. RESULTS OF LABORATORY STUDY

A laboratory experiment was conducted to study the effect of various priming agents on germination per cent, shoot length, root length, vigour index and speed of germination of five sesame varieties. The results of the laboratory study conducted are detailed below.

4.1.1. Effect of seed priming treatments on germination per cent of sesame varieties

4.1.1.1. *Plant growth regulators (IAA and GA)*

Germination per cent of sesame varieties on priming with plant growth regulators are given in the Table 3. Hormonal priming significantly improved the germination per cent in all the varieties over control. The highest germination per cent was recorded in Thilak with GA treatment (96.85 per cent) which was statistically on par with IAA Priming (94 per cent) in the same variety. The lowest germination of 35.85 per cent was recorded with the unprimed seeds of the variety Thilatara. Comparison of hormonal priming agents irrespective of the varieties showed that both priming agents were statistically on par. Comparison of varieties irrespective of the treatment showed that highest germination per cent was for Kayamkulam-1(91.80 per cent) which was statistically on par with Thilak (91.67 per cent), followed by Surya (86.66 per cent). The variety Thilarani recorded higher germination percent (60.00 per cent) than the variety Thilatara (41.93 per cent) which recorded the lowest mean germination per cent.

Table. 3. Effect of plant growth regulators (IAA, GA) on germination per cent of sesame varieties

Treatments	Varieties					
	Surya	**Thilak**	**Kayamkulam-I**	**Thilarani**	**Thilathara**	**Mean**
Control	80.82[b]	84.17[b]	86.67[b]	53.32[b]	35.85[c]	68.17[b]
IAA	91.60[a]	94.00[a]	94.57[a]	55.02[b]	48.30[a]	76.71[a]
GA	87.50[ab]	96.85[a]	94.17[a]	71.65[a]	41.65[b]	78.36[a]
Mean	86.66[b]	91.67[a]	91.80[a]	60.00[c]	41.93[d]	
CD (0.05)	8.43	6.60	3.64	11.01	4.45	

CD (0.05) (Treatment means) - 2.737
CD (0.05) (Varietal means) - 3.534

4.1.1.2. *Biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I)*

Germination per cent of sesame varieties primed with different biofertilizers are given in the Table 4. Biofertilizer priming significantly improved germination in the varieties Surya, Thilarani and Thilatara. Among them, in the variety Surya, highest germination was observed with PGPR mix 1 (89.17 per cent) followed by priming with Phosphobacteria (82 per cent) in the same variety. The latter was statistically on par with Azospirillum priming in Surya. Comparison of biofertilizer priming irrespective of varieties showed that highest germination percent was recorded for PGPR mix 1 (73.45 per cent) which was statistically on par with Azospirillum (73.13 per cent) treatment. The latter was on par with priming with Phosphobacteria (70.98 per cent). Comparison of varieties irrespective of treatments showed that highest germination was recorded for Kayamkulam I (88.43per cent) which was statistically on par with Thilak (86.00 per cent), followed by Surya (83.41 per cent) and Thilarani (60.76 per cent). Least germination was reported from Thilatara (38.55 per cent).

Table. 4. Effect of biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I) on Germination per cent of Sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	80.82[b]	84.17	86.67	53.32[b]	35.85[bc]	68.17[c]
Phosphobacteria	82.00[b]	88.75	91.07	62.25[a]	30.85[c]	70.98[b]
Azospirillum	81.65[b]	85.50	87.67	65.00[a]	45.82[a]	73.13[ab]
PGPR MIX 1	89.17[a]	85.57	88.32	62.25[a]	41.67[ab]	73.45[a]
Mean	83.41[b]	86[a]	88.43[a]	60.76[c]	38.55[d]	
CD (0.05)	3.613	NS	NS	6.548	6.166	

CD (0.05) (Treatment means) - 2.264
CD (0.05) (Varietal means) - 2.531

4.1.1.3. *Nutrients ($MnSO_4$, Borax)*

Germination per cent of sesame varieties the seeds of which were primed are given in the Table 5. Nutrient priming significantly improved the germination in all varieties. Highest germination percent of 95.85 per cent was observed for both MnSO4 and Borax in Kayamkulam 1. Comparison of varieties irrespective of nutrient priming showed that the highest germination percent was recorded from Kayamkulam 1(92.78 per cent) which was statistically on par with Thilak (90.47 per cent) followed by Surya (85.68 per cent), which recorded higher germination than Thilarani (56.8 per cent), while the lowest germination was recorded by Thilatara (47.50 per cent). Comparison of priming treatments irrespective of varieties showed that the priming with $MnSO_4$ recorded the highest germination per cent (79.70per cent) followed by Borax (76.08per cent) priming.

Table. 5. Effect of nutrients ($MnSO_4$, Borax) on germination per cent of Sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	80.82[b]	84.17[b]	86.67[b]	53.32[b]	35.85[b]	68.17[c]
$MnSO_4$	87.07[ab]	93.50[a]	95.85[a]	59.57[a]	62.50[a]	79.70[a]
Borax	89.15[a]	93.75[a]	95.82[a]	57.50[a]	44.17[b]	76.08[b]
Mean	85.68[b]	90.47[a]	92.78[a]	56.80[c]	47.50[d]	
CD (0.05)	6.29	1.69	8.08	4.293	13.10	

CD (0.05) (Treatment means) - 2.763
CD (0.05) (Varietal means) - 3.567

4.1.1.4. *Water and tank mix*

Germination per cent of sesame varieties primed with water and tank mix are given in Table 6. Priming with Tank mix priming and water priming significantly improved the germination per cent over control. The highest germination was recorded for priming with Tank mix in Thilak (92.9 per cent) which was statistically on par with water priming (92.5 per cent) in the same variety. Comparison of treatments irrespective of varieties showed that both priming methods were statistically on par. Comparison of varieties irrespective of treatments showed that the germination per cent was highest for Thilak (89.85 per cent) which was statistically on par with Kayamkulam I (88.16 per cent). The latter was statistically on par with Surya (85.55 per cent) followed by Thilarani (61.10 per cent) and lowest germination was observed in Thilatara (42.48 per cent).

Table. 6. Effect of water and tank mix on germination per cent of Sesame varieties

Treatments	Varieties					
	Surya	**Thilak**	**Kayamkulam-I**	**Thilarani**	**Thilathara**	**Mean**
Control	80.82[b]	84.17[b]	86.67[b]	53.32[b]	35.85[b]	68.17[b]
Tank mix	87.5[a]	92.90[a]	90.82[a]	68.32[a]	45.77[a]	77.06[a]
Water	88.32[a]	92.5[a]	86.97[b]	61.65[a]	45.82[a]	
Mean	85.55[b]	89.85[a]	88.16[ab]	61.10[c]	42.48[d]	
CD (0.05)	5.74	1.13	3.52	8.04	7.74	

CD (0.05) (Treatment means) - 2.184
CD (0.05) (Varietal means) - 2.819

4.1.2. Effect of seed priming treatments on shoot length of sesame varieties

4.1.2.1. *Plant growth regulators (IAA, GA)*

Effect of plant growth regulators on shoot length of sesame varieties are given in Table 7. Among the plant growth hormones, priming with GA significantly improved the shoot length in all the five sesame varieties whereas, IAA priming did not statistically improve the shoot length over control in any of the varieties. Among the varieties, Thilak showed highest shoot length of 7.25cm with GA priming followed by Kayamkulam I (6.90cm) and Surya (6.20cm). In the case of priming with GA, the lowest shoot length was observed in the variety Thilathara (3.82cm) which was significantly on par with that of the variety Thilarani (3.96cm). Interaction effect between hormonal treatment and varieties was also significant indicating that among the varieties Thilak had the maximum response to GA as compared to other treatment and varieties.

Table. 7. Effect of plant growth regulators (IAA, GA) on shoot length of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	5.27^{b}	5.55^{b}	5.67^{b}	3.82^{b}	3.70^{a}	4.81^{b}
IAA	5.25^{b}	5.52^{b}	5.57^{b}	3.87^{b}	3.52^{b}	4.75^{c}
GA	6.20^{a}	7.25^{a}	6.90^{a}	4.20^{a}	4.20^{a}	5.75^{a}
Mean	5.57^{b}	6.10^{a}	6.05^{a}	3.96^{c}	3.82^{c}	
CD (0.05)	0.336	0.357	0.643	0.299	0.522	

CD (0.05) (Treatment means) - 0.180
CD (0.05) (Varietal means) - 0.232

4.1.2.2. *Biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I)*

Effect of biofertilizers on shoot length of sesame varieties are given in Table 8. Among the biofertilizers the highest shoot length was observed in PGPR Mix-1 treatment in the variety Thilak (6.17cm) followed by Azospirillum treatment in the same variety. The lowest shoot length was recorded from Phosphobacteria in the variety Thilatara (3.37cm) which was inferior to control. Comparison of priming treatments irrespective of varieties showed that the treatment effect of PGPR mix 1 was statistically on par with Azospirillum treatment. Seed priming with Phosphobacteria was inferior to all other treatments including control which did not significantly improve the shoot length in any variety. Comparison of varieties irrespective of the treatments shows that the highest shoot length was recorded for Thilak (5.75 cm) which was statistically on par with Kayamkulam I (5.68 cm) followed by Surya (5.27 cm), Thiarani (4.39 cm) and Thilatara (3.58 cm).

Table. 8. Effect of biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I) on shoot length of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	5.27[a]	5.55[b]	5.65[a]	3.82[b]	3.75	4.81[b]
Phosphobacteria	5.15[a]	5.50[b]	5.55[a]	4.42[a]	3.37	4.8[b]
Azospirillum	5.42[a]	5.77[b]	5.75[a]	4.57[a]	3.72	5.05[a]
PGPR Mix I	5.25[a]	6.17[a]	5.75[a]	4.75[a]	3.50	5.08[a]
Mean	5.27[b]	5.75[a]	5.68[a]	4.39[c]	3.58[d]	
CD (0.05)	0.390	0.358	0.627	0.373	NS	

CD (0.05) (Treatment means) - 0.224
CD (0.05) (Varietal means) - 0.251

4.1.2.3. *Nutrients ($MnSO_4$, borax)*

Effect of nutrients on shoot length of sesame varieties are given in Table 9. Nutrient priming significantly improved the shoot length in all varieties except in Kayamkulam-1 and Thilathara. $MnSO_4$ treated seeds of variety Thilak showed significantly highest shoot length of 6.5 cm followed by borax priming in the same variety (6.25 cm). Lowest value of shoot length was recorded for Thilathara (3.60 cm) with borax priming. Comparison of nutrient priming methods irrespective of varieties showed that both the priming methods were statistically on par. Comparison of varieties irrespective of priming methods showed that the highest shoot length was recorded from Thilak (6.10 cm) which was statistically on par with Kayamkulam-1 (5.84 cm) The latter was on par with Surya (5.79 cm) followed by Thilarani (4.40 cm) and Thilatara (3.80 cm).

Table. 9. Effect of nutrients ($MnSO_4$, borax) on shoot length of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	5.27^{b}	5.55^{b}	5.67	3.82^{b}	3.75	4.81^{b}
$MnSO_4$	5.95^{a}	6.50^{a}	6.12	4.55^{a}	4.05	5.43^{a}
Borax	6.15^{a}	6.25^{a}	5.72	4.85^{a}	3.60	5.31^{a}
Mean	5.79^{b}	6.10^{a}	5.84^{ab}	4.40^{c}	3.80^{d}	
CD (0.05)	0.336	0.272	NS	0.357	NS	

CD (0.05) (Treatment mean) - 0.202
CD (0.05) (Varietal mean) - 0.261

4.1.2.4. *Water and tank mix*

Effect of water and tank mix priming on shoot length of sesame varieties are given in Table 10. Both water priming and priming with tank mix of $MnSO_4$, Borax and GA significantly improved the shoot length in all varieties except in Thilathara. Highest shoot length was obtained from priming with tank mix in the variety Thilak (6.67 cm) followed by the same treatment in Kayamkulam-1 and the least value of shoot length was recorded for the variety Thilathara (3.8cm) with tank mix priming. Water priming also improved the shoot length in all varieties compared to the control. In the case of water priming, highest shoot length was recorded for the variety Thilak (6.27 cm) followed by Kayamkulam I (6.00 cm) and Surya (6.00 cm). Comparison of both priming treatments water and tank mix showed that priming with tank mix was superior over water priming irrespective of varieties and both statistically superior over control. Comparison of varieties irrespective of the treatments showed that the highest shoot length was recorded from the variety Thilak (6.16 cm) which was statistically on par with Kayamkulam-1 (6.07 cm). The latter was statistically on par with Surya (5.87cm) followed by Thilarani (4.50 cm). Lowest value of shoot length was observed for Thilatara (3.87cm).

Table.10. Effect of water and tank mix on shoot length of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	5.27b	5.55c	5.67c	3.82b	3.70	4.81c
Tank mix	6.35a	6.67a	6.55a	4.8a	3.80	5.63a
Water	6.00a	6.27b	6.00bc	4.87a	4.10	5.45b
Mean	5.87b	6.16a	6.07ab	4.50c	3.87d	
CD (0.05)	0.419	0.294	0.485	0.299	NS	

CD (0.05) (Treatment means) - 0.175
CD (0.05) (Varietal means) - 0.226

4.1.3. Effect of priming treatments on root length of sesame varieties

4.1.3.1. *Plant growth regulators (IAA, GA)*

Effect of seed priming with plant growth regulators on root length of sesame varieties are given in the Table 11. There was no significant difference between the treatments in all varieties except Thilak. Among the treatments IAA showed significant improvement in root length (11.40 cm) over GA (10.60 cm) in Thilak. Comparison between hormonal seed priming agents irrespective of varieties showed that IAA recorded significantly higher root length. GA treatment was statistically on par with control.

Table. 11. Effect of plant growth regulators (IAA, GA) on root length of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	6.85	10.00	9.70	6.50	6.40	7.89c
IAA	7.12	11.40	11.60	6.80	6.60	8.70a
GA	6.50	10.60	10.50	5.60	6.60	7.96b
Mean	6.81b	10.67a	10.60a	6.31b	6.50b	
CD (0.05)	NS	0.958	NS	NS	NS	

CD (0.05) (Treatment mean) - 0.551
CD (0.05) (Varietal mean) - 0.711

4.1.3.2. *Biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I)*

Effect of seed priming with biofertilizers on root length of sesame varieties are given in the Table 12. In the varieties Thilarani and Thilatara biofertilizer priming significantly improved the root length. In both the varieties highest root length was observed in PGPR mix 1 treatment. But the highest root length was recorded for Thilak with Azospirillum treatment but the treatments were nonsignificant. The lowest root length was recorded from Thilatara with Azospirillum treatment (7.12cm) which was statistically on par with Phosphobacteria priming and control. Effects of seed priming with biofertilizers irrespective of the varieties showed that PGPR mix I priming gave the highest root length followed by Phosphobacteria and Azospirillum which were statistically on par. Comparison among varieties irrespective of the treatments showed that the highest root length was recorded for Thilak (10.50 cm) and Kayamkulam I(10.25cm). Lowest root length was observed for Surya (7.67 cm) which was statistically on par with Thilarani (7.78 cm) and Thilathara (7.88 cm).

Table. 12. Effect of biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I) on root length of sesame varieties.

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	6.85	10.00	9.70	6.52[c]	6.37[b]	7.89[c]
Phosphobacteria	8.40	10.50	10.82	7.75[bc]	7.50[b]	8.99[b]
Azospirillum	7.65	10.95	10.12	7.85[ab]	7.12[b]	8.74[b]
PGPR mix1	7.8	10.55	10.35	9.00[a]	10.55[a]	9.65[a]
Mean	7.67[b]	10.50[a]	10.25[a]	7.78[b]	7.88[b]	
CD (0.05)	NS	NS	NS	1.232	1.165	

CD (0.05) (Treatment means) - 0.468
CD (0.05) (Varietal means) - 0.524

4.1.3.3. *Nutrients ($MnSO_4$, borax)*

Effect of seed priming with nutrients on root length of sesame varieties are given in the Table 13. Nutri priming significantly improved the root length in the varieties Thilak, Thilarani and Thilathara. Highest root length was recorded for

$MnSO_4$ priming in the variety Thilak (11.7cm). The lowest root length was recorded from $MnSO_4$ treatment in the variety Thilathara (6.55cm). Comparison of nutrient priming irrespective of varieties showed that the highest root length was obtained for $MnSO_4$ treatment which was statistically on par with borax priming. Comparison of varieties irrespective of the treatments showed that the highest value of root length was observed in the variety Thilak (10.7 cm) followed by Kayamkulam 1 (9.79 cm). The root length for Thilathara (6.65 cm) was inferior to Thilarani (7.87 cm) and Surya (7.59 cm) which were statistically on par.

Table. 13. Effect of nutrients ($MnSO_4$, borax) on root length of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	6.85	10.00^{b}	9.70	6.52^{b}	6.37^{b}	7.89^{b}
$MnSO_4$	8.02	11.70^{a}	10.42	8.37^{a}	6.55^{b}	9.01^{a}
Borax	7.90	10.40^{b}	9.25	8.72^{a}	7.05^{a}	8.66^{a}
Mean	7.59^{c}	10.70^{a}	9.79^{b}	7.87^{c}	6.65^{d}	
CD (0.05)	NS	1.020	NS	1.11	0.485	

CD (0.05) (Treatment means) - 0.443
CD (0.05) (Varietal means) - 0.572

4.1.3.4. *Water and tank mix*

Effect of seed priming with water and tank mix on root length of sesame varieties are given in Table 14. Priming with tank mix and water showed significant improvement on the root length in the varieties Surya, Thilarani and Thilathara. Among them, highest root length was recorded for Thilathara with water priming (9.95 cm) followed by Surya (8.95 cm) for the same treatment. In Thilarani highest root length was observed in priming with tank mix (8.45cm) which was statistically on par with water priming (8.23cm). Comparison of two priming agents irrespective of varieties showed that highest root length was seen in water priming followed by priming with tank mix. Both treatments are significantly superior than control. Comparison of varieties irrespective of priming agents showed that the highest root length was observed in Kayamkulam

1 (9.87 cm) which was statistically on par with Thilak (9.71 cm), followed by Surya (8.19 cm) .The lowest root length was recorded for Thilarani (7.73cm) which was statistically on par with Thilathara (7.79 cm).

Table. 14. Effect of water priming and tank mix on root length of Sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	6.85^{b}	10.00	9.70	6.52^{b}	6.37^{c}	7.89^{c}
Tank mix	8.77^{a}	9.20	9.42	8.45^{a}	7.05^{b}	8.58^{b}
Water	8.95^{a}	9.95	10.50	8.23^{a}	9.95^{a}	9.51^{a}
Mean	8.19^{b}	9.71^{a}	9.87^{a}	7.73^{c}	7.79^{c}	
CD (0.05)	1.395	NS	NS	0.740	0.561	

CD (0.05) (Treatment means) - 0.508
CD (0.05) (Varietal means) - 0.393

4.1.4. Effect of priming treatments on vigour index

4.1.4.1. *Plant growth regulators (IAA, GA)*

Effect of plant growth regulators on vigour index of sesame varieties are given in Table 15. Hormonal priming improved the vigour index of all the varieties except Surya. Highest vigour index was observed in the variety Thilak with GA priming (1726.20) followed by the variety Kayamkulam I with the same treatment (1640.45). The latter was statistically on par with IAA priming in the same variety (1623.40). Among the hormonal priming treatments the lowest vigour index was recorded for Thilathara (451.25) with GA priming which was statistically similar to the IAA priming in the same variety (488.25). Comparison of hormonal priming agents irrespective of varieties showed that both priming treatments were statistically on par and also superior to the control. Comparison of varieties irrespective of treatments showed that highest vigour index was recorded for Thilak (1542.68) which was statistically on par with Kayamkulam I (1532.58) followed by Surya (1074.08), Thilarani (615.26) and the lowest vigour index for Thilathara (433.27).

Table. 15. Effect of plant growth regulators (IAA, GA) on vigour index of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	976.47	1307.87[c]	1333.90[b]	555.27[b]	360.32[b]	906.77[b]
IAA	1136.00	1593.97[b]	1623.40[a]	586.15[b]	488.25[a]	1085.55[a]
GA	1109.77	1726.20[a]	1640.45[a]	704.37[a]	451.25[a]	1126.41[a]
CD	NS	89.88	225.56	95.236	70.73	
Mean(0.05)	1074.08[b]	1542.68[a]	1532.58[a]	615.26[c]	433.27[d]	

CD (0.05) (Treatment means)- 57.310
CD (0.05) (Varietal means)- 73.987

4.1.4.2. *Biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I)*

Effect of biofertilizers on vigour index of sesame varieties are given in Table 16. Biofertilizer priming significantly improved the vigour index of the varieties Surya, Thilarani and Thilathara. The highest vigour index was recorded from the variety Kayamkulam I (1494.47) with the seed treatment of Phosphobacteria followed by PGPR mix-1 priming in Thilak (1432.05). The lowest vigour index was recorded from the variety Thilatara with priming of Phosphobacteria (332.85) which was lower than control (360.32). Comparison of priming agents irrespective of varieties showed that the highest vigour index was recorded for PGPR mix-1(1093.62) priming followed by Azospirillum (1038.63) and Phosphobacteria priming (1022.84), both were statistically on par. Comparison of varieties irrespective of priming agents showed that Kayamkulam-I (1410.91) recorded the highest vigour index and was statistically similar to Thilak (1397.15). The variety Surya (1079.50) recorded higher vigour index than Thilrani (746.06). The lowest vigour index was recorded for Thilathara (443.69).

Table. 16. Effect of biofertilizers (Phosphobacteria, azospirillum and PGPR mix I) on vigour index of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	976.47[b]	1307.87	1333.90	555.27[b]	360.32[cd]	906.77[c]
Phosphobacteria	1107.70[a]	1417.57	1494.47	761.62[a]	332.85[d]	1022.84[b]
Azospirillum	1068.77[ab]	1431.10	1389.85	807.27[a]	496.15[b]	1038.63[b]
PGPR mix 1	1165.07[a]	1432.05	1425.45	860.10[a]	585.45[a]	1093.62[a]
Mean	1079.50[b]	1397.15[a]	1410.91[a]	746.06[c]	443.69[d]	
CD (0.05)	110.66	NS	NS	133.33	59.585	

CD (0.05) (Treatment means) - 49.286
CD (0.05) (Varietal means) - 55.104

4.1.4.3. *Nutrients ($MnSO_4$, Borax)*

Effect of nutripriming on vigour index of sesame varieties are given in Table 17. Nutrient priming significantly improved vigour index in all the varieties over control. The highest vigour index was recorded for $MnSO_4$ primed seeds of Thilak (1700.70) followed by the same treatment in Kayamkulam-I (1587.37). The lowest vigour index was recorded for borax priming in Thilathara (447.05). Comparison of nutrients irrespective of varieties showed that priming with $MnSO_4$ (1183.97) was superior to borax priming (1095.19). Comparison of varieties irrespective of nutrients showed that the highest vigour index was observed in the variety Thilak (1522.25) followed by Kayamkulam 1 (1452.30), Surya (1148.60), Thilarani (700.48) and lowest for Thilathara (486.25).

Table. 17. Effect of nutrients ($MnSO_4$, borax) on vigour index of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	976.47^b	1307.87^c	1333.90^b	555.27^b	360.32^b	906.77^c
$MnSO_4$	1213.35^a	1700.70^a	1587.37^a	767.05^a	651.40^a	1183.97^a
Borax	1255.97^a	1558.17^b	1435.62^{ab}	779.12^a	447.05^b	1095.19^b
Mean	1148.60^c	1522.25^a	1452.30^b	700.48^d	486.25^e	
CD (0.05)	122.98	120.89	153.46	92.33	129.49	

CD (0.05) (Treatment mean) - 50.448
CD (0.05) (Varietal mean) - 65.128

4.1.4.4. *Water and tank mix*

Effect of priming with water and tank mix on vigour index of sesame varieties are given in Table 18. Priming with water and tank mix improved the vigour index of the sesame varieties Surya, Thilak, Thilarani and Thilathara. The highest vigour index was recorded for Thilak with water priming (1503.20) followed by priming with tank mix in the same variety (1477.55). The lowest vigour index was recorded for priming treatment with tank mix in Thilathara (495.20). Comparison of priming agents irrespective of the varieties showed that both priming treatments were statistically on par. Comparison of varieties irrespective of priming agents showed that the highest vigour index was observed for Thilak (1429.54) which was statistically on par with Kayamkulam-I (1408.04) followed by Surya (1206.78) and Thilarani (755.49). The lowest vigour index was recorded for Thilathara (500.27).

Table. 18. Effect of water and tank mix on vigour index of sesame seedlings

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	976.47[b]	1307.87[b]	1333.90	555.27[b]	360.32[c]	906.77[b]
Tank mix	1322.67[a]	1477.55[a]	1452.22	904.42[a]	495.20[b]	1130.41[a]
Water	1321.20[a]	1503.20[a]	1438.00	806.77[a]	645.30[a]	1142.89[a]
Mean	1206.78[b]	1429.54[a]	1408.04[a]	755.49[c]	500.27[d]	
CD (0.05)	151.487	78.564	NS	115.608	99.188	

CD (0.05) (Treatment means) - 46.812
CD (0.05) (Varietal means) - 60.434

4.1.5. Effect of priming treatments on speed of germination of sesame varieties

4.1.5.1. *Plant growth regulators (IAA, GA)*

Effect of priming with plant growth regulators on speed of germination of sesame varieties are given in Table 19. Hormonal priming have significantly improved the speed of germination in all varieties over control. The highest speed of germination was recorded in Thilak (90.00) with GA treatment followed by IAA priming (89.25) in the same variety which were statistically on par. The lowest speed of germination was recorded from Thilatara (27.50) with IAA priming. Comparison of priming agents irrespective of varieties showed that highest speed of germination was observed in GA priming (65.00). Comparison of varieties irrespective of priming treatments showed that highest speed of germination was recorded for Thilak (79.41) followed by Kayamkulam 1(69.58), Surya (53.41), Thilarani (37.00) and Thilathara (26.00).

Table. 19. Effect of plant growth regulators (IAA, GA) on speed of germination of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	34.00^{c}	59.00^{b}	45.00^{c}	26.00^{b}	16.75^{b}	36.15^{c}
IAA	57.50^{b}	89.25^{a}	76.25^{b}	40.00^{a}	27.50^{a}	58.10^{b}
GA	68.75^{a}	90.00^{a}	87.50^{a}	45.00^{a}	33.75^{a}	65.00^{a}
Mean	53.41^{c}	79.41^{a}	69.58^{b}	37.00^{d}	26.00^{e}	
CD (0.05)	8.967	6.321	7.515	8.31	6.735	

CD (0.05) (Treatment means) - 3.031
CD (0.05) (Varietal means) - 3.914

4.1.5.2. *Biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I)*

Effect of priming with biofertilizers on speed of germination of sesame varieties are given in Table 20. Speed of germination was significantly influenced by biofertilizer priming. The highest speed of germination was recorded for priming with Phosphobacteria in Thilak (85.50) followed by PGPR mix-1 (83.75) and Azospirillum (83.50) treatment in the same variety. Lowest speed of germination was shown by priming with Phosphobacteria in the variety Thilathara (24.00). Comparison of biofertilizers irrespective of varieties showed that all the three are statistically on par. Comparison of varieties irrespective of treatments showed that the highest speed of germination was recorded in Thilak (77.92) followed by Kayamkulam 1(72.90), Surya (53.46), Thilarani (31.51) and Thilathara (23.95).

Table. 20. Effect of Biofertilizers (Phosphobacteria, Azospirillum and PGPR mix I) on speed of germination of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	33.75[b]	58.93[b]	45.00[b]	25.82[b]	16.75[b]	36.15[b]
Phosphobacteria	57.62[a]	85.50[a]	82.87[a]	33.12[a]	24.00[ab]	56.62[a]
Azospirillum	60.00[a]	83.50[a]	81.25[a]	31.5[ab]	26.55[a]	56.56[a]
PGPR mix 1	62.50[a]	83.75[a]	82.50[a]	35.62[a]	28.75[a]	58.62[a]
Mean	53.46[c]	77.92[a]	72.90[b]	31.51[d]	23.95[e]	
CD (0.05)	5.204	3.024	7.986	3.529	8.689	

CD (0.05) (Treatment means) - 2.496
CD (0.05) (Varietal means) - 2.791

4.1.5.3. *Nutrients ($MnSO_4$, Borax)*

Effect of priming with nutrients on speed of germination of sesame varieties are given in Table 21. Nutripriming significantly improved the speed of germination in all varieties over control. The highest speed of germination was recorded in Thilak (93.75) followed by Kayamkulam 1(92.50) with $MnSO_4$ priming. The lowest speed of germination was recorded for Thilathara (30.75) with borax priming. Comparison of priming agents irrespective of varieties showed that highest speed of germination was shown by $MnSO_4$ priming (68.55). Comparison of varieties irrespective of priming treatments showed that highest speed of germination was recorded for Thilak (80.75) followed by Kayamkulam-1(75.00), Surya (58), Thilarani (38.25) and Thilathara (27.75).

Table. 21. Effect of nutrients ($MnSO_4$, Borax) on speed of germination of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	34.00^{b}	59.00^{c}	45.00^{b}	26.00^{b}	16.75^{b}	36.15^{c}
$MnSO_4$	73.25^{a}	93.75^{a}	92.50^{a}	47.50^{a}	35.75^{a}	68.55^{a}
Borax	67.50^{a}	89.50^{b}	87.50^{a}	41.25^{a}	30.75^{a}	63.30^{b}
Mean	58.25^{c}	80.75^{a}	75.00^{b}	38.25^{d}	27.75^{e}	
CD (0.05)	8.941	3.596	5.407	7.254	7.33	

CD (0.05) (Treatment mean) - 2.673
CD (0.05) (Varietal mean) - 3.451

4.1.5.4. *Water and tank mix*

Effect of priming with water and tank mix on speed of germination of sesame varieties are given in Table 22. Speed of germination was significantly influenced by priming with water and tank mix over control. The highest speed of germination was recorded for priming with tank mix in Thilak (90.00). Lowest speed of germination was shown by Thilathara (30.25) with water priming. Comparison of priming agents irrespective of varieties showed that both were statistically on par. Comparison of varieties irrespective of treatments showed that the highest speed of germination was recorded in Thilak (79.50) followed by Kayamkulam 1(73.91), Surya (57.41), Thilarani (37.58) and Thilathara (26.75).

Table. 22. Effect of water and tank mix on speed of germination of sesame varieties

Treatments	Varieties					
	Surya	Thilak	Kayamkulam-I	Thilarani	Thilathara	Mean
Control	34.00[b]	59.00[b]	45.00[b]	26.00[b]	16.75[b]	36.15[b]
Tank mix	69.50[a]	90.00[a]	89.50[a]	44.25[a]	33.25[a]	65.30[a]
Water	68.75[a]	89.50[a]	87.25[a]	42.50[a]	30.25[a]	63.65[a]
Mean	57.41[c]	79.50[a]	73.91 [b]	37.58[d]	26.75[e]	
CD (0.05)	10.877	2.73	4.683	9.225	7.229	

CD (0.05) (Treatment means) - 2.98
CD (0.05) (Varietal means) - 3.847

Comparison of effect of priming agents on varieties showed that the interaction effect was significant indicating that all the varieties did not respond to priming agents in similar manner. Among the varieties highest positive response was observed for Thilak and Kayamkulam 1. Hence the variety Thilak was selected for the field trial as it was the most popular variety among farmers.

Among the priming treatments the highest response was observed for GA, $MnSO_4$, borax and tank mix for most of the parameters studied. Hence these treatments along with water priming and control were chosen for the field experiment.

4.2. RESULTS OF FIELD STUDY

The present study aimed to enhance the morpho-physiological vigour of sesame variety, Thilak by seed priming with micronutrients and growth regulators, so as to improve productivity and weed competitiveness. The results of the study are detailed below.

4.2.1 Morphological and phenological observations

4.2.1.1. *Plant height*

Sesame seeds were subjected to priming with water, GA, borax, $MnSO_4$ and Tank mix (mixture of GA, $MnSO_4$ and borax). The height of seedlings were measured at 20, 40, 60 days after sowing and at harvest, and was compared in the weeded and unweeded plots (Table 23). Comparison of seedling height in the unweeded and weeded plots revealed that the plants in the weeded plot had significantly higher height compared to the unweeded plots in all the treatments throughout the growth period. At 20DAS among the treatments, highest plant height was recorded for GA (13.66 cm) priming which was statistically on par with $MnSO_4$ priming (13.16 cm) and the latter was statistically on par with Tank mix priming (12.83 cm). Priming with water (12 cm) and borax (11.66 cm) were statistically on par. The lowest plant height was recorded for control (10.16 cm). Height of GA treated plants was comparatively less and on par with that of control from 40 days after sowing to harvest. Priming with $MnSO_4$, Tank mix, Borax and water were statistically similar to each other and superior to GA priming. The response of all the priming treatments in weeded and unweeded plots were similar.

Table. 23. Effect of seed priming on plant height (cm) of sesame variety Thilak at different stages

Plant height (cm)						
	20DAS			40DAS		
Treatments	W	UW	Mean	W	UW	Mean
T1-Control	11.33	9.00	10.16^{d}	41.66	35.00	38.33^{b}
T2-Water	13.00	11.00	12.00^{c}	45.66	41.66	43.66^{a}
T3-GA	15.00	12.33	13.66^{a}	43.66	37.66	40.66^{ab}
T4-Borax	12.66	10.66	11.66^{c}	45.33	41.00	43.16^{a}
T5-$MnSO_4$	14.66	11.66	13.16^{ab}	46.66	42.00	44.33^{a}
T6-Tank mix	14.00	11.66	12.83^{b}	46.33	41.66	44.00^{a}
Mean	13.44^{a}	11.05^{b}		44.88^{a}	39.83^{b}	
CD (0.05)	0.257		0.633	3.225		2.66
	60DAS			Harvest		
Treatments	W	UW	Mean	W	UW	Mean
T1-Control	94.33	88.00	91.16^{b}	96.83	90.50	93.66^{b}
T2-Water	100.16	92.66	96.41^{a}	102.66	95.16	98.91^{a}
T3-GA	96.00	89.00	92.50^{b}	98.50	91.50	95.00^{b}
T4-Borax	100.66	93.33	97.00^{a}	103.16	95.83	99.50^{a}
T5-$MnSO_4$	102.33	94.33	98.33^{a}	104.83	96.83	100.83^{a}
T6-Tank mix	101.00	93.00	97.00^{a}	104.50	95.50	100.00^{a}
Mean	99.08^{a}	91.72^{b}		101.75^{a}	94.22^{b}	
CD (0.05)	6.105		2.654	5.533		2.809

4.2.1.2. Leaf area

Leaf area of selected plants were measured at 20, 40, 60 days after sowing and at harvest and was compared in the weeded and unweeded plots (Table 24). The result revealed that the plants in the weeded plot had significantly higher leaf area compared to the unweeded plots in all the treatments throughout the growth period. However the interaction effect was not significant. At 20 DAS highest leaf area was observed in $MnSO_4$ treatment (39.00 cm^2) followed by borax (37.66

cm^2), Tank mix (37.50 cm^2) and water priming (36.66 cm^2). All these were statistically on par. The lowest leaf area was recorded for control (30.00). At 40DAS highest leaf area was shown by priming with $MnSO_4$ (274.00 cm^2) followed by Tank mix (273.00 cm^2) and borax (265.00 cm^2) which were statistically on par. The latter was statistically on par with water priming (257.33 cm^2). The least leaf area was recorded for priming with GA (248.33 cm^2) which was statistically superior to control (233.83 cm^2). At 60 DAS the highest leaf area was shown by priming with $MnSO_4$ (650.58 cm^2). Priming with borax (633.33 cm^2), Tank mix (630.00 cm^2) and water priming (628.33 cm^2) were statistically on par and superior to priming with GA (594.16 cm^2). The lowest leaf area was recorded for control (575.00 cm^2). All the priming treatments responded similarly in weeded and unweeded plots. At the time of harvest the leaf area changed irrespective of treatments due to natural leaf fall.

Table. 24. Effect of seed priming on leaf area of sesame (cm^2) variety Thilak

Leaf area (cm^2)						
	20DAS			40DAS		
Treatments	**W**	**UW**	**Mean**	**W**	**UW**	**Mean**
T1-Control	33.00	27.00	30.00^{b}	252.66	215.00	233.83^{d}
T2-Water	40.00	33.33	36.66^{a}	274.66	240.00	257.33^{bc}
T3-GA	35.33	30.66	33.00^{a}	260.00	236.66	248.33^{c}
T4-Borax	41.33	34.00	37.66^{a}	283.33	246.00	265.00^{ab}
T5-$MnSO_4$	43.00	35.00	39.00^{a}	292.00	256.00	274.00^{a}
T6-Tank mix	41.66	33.33	37.50^{a}	290.33	255.66	273.00^{a}
Mean	39.05^{a}	32.22^{b}		275.50^{a}	241.66^{b}	
CD (0.05)	0.892		2.718	1.544		9.831
	60DAS			**Harvest**		
Treatments	**W**	**UW**	**Mean**	**W**	**UW**	**Mean**
Control	640.00	510.00	575.00^{d}	516.66	463.33	490.00
Water	696.66	560.00	628.33^{b}	533.33	480.00	506.66
GA	648.33	540.00	594.16^{c}	585.00	406.66	495.83
Borax	700.00	566.66	633.33^{b}	543.33	510.00	526.66
$MnSO_4$	721.16	580.00	650.58^{a}	509.66	480.00	494.83
Tank mix	696.66	563.33	630.00^{b}	503.33	500.00	501.66
Mean	683.80^{a}	556.66^{b}		531.88	473.33	
CD (0.05)	20.422		16.781	NS		NS

4.2.1.3. Days to branching

Effect of seed priming on days to branching are presented in Table 25. There was no significant difference in days taken for branching between weeded and unweeded plots. All seed priming treatments took less number of days for branching compared to control.

Table. 25. Effect of seed priming on days to branching of sesame variety Thilak

Days to branching			
Treatments	**W**	**UW**	**Mean**
T1-Control	24.33	24.00	24.16[a]
T2-Water	17.66	20.33	19.00[b]
T3-GA	18.66	20.66	19.66[b]
T4-Borax	17.66	20.66	19.16[b]
T5-$MnSO_4$	16.66	20.33	18.50[b]
T6-Tank mix	18.66	19.66	19.16[b]
Mean	18.944	20.944	
CD (0.05)	NS		1.696

4.2.1.4. Days to first flowering

Effect of priming treatments on days to first flowering are given in Table.26. Weeded plots took less number of days for first flowering compared to un-weeded plots. The least number of days for flowering was taken by GA (26 days) and Tank mix (26 days) treatments followed by $MnSO_4$ (27 days). Control (30 days) took more number of days to flower and was statistically similar to water (28 days) and borax (28 days) treatment.

Table. 26. Effect of seed priming on days to first flowering of sesame variety Thilak

Days to first flowering			
Treatments	**W**	**UW**	**Mean**
T1-Control	29.00	31.00	30.00[a]
T2-Water	27.00	30.00	28.50[ab]
T3-GA	24.00	28.33	26.167[c]
T4-Borax	27.00	30.00	28.50[ab]
T5-$MnSO_4$	26.00	29.00	27.50[bc]
T6-Tank mix	24.33	29.00	26.667[c]
Mean	26.222[b]	29.556[a]	
CD (0.05)	3.12		1.463

4.2.1.5. Days to 50 per cent flowering

Effect of seed priming treatments on days to 50 per cent flowering are given in Table 27. There was no significant difference in days to 50 per cent flowering between weeded and unweeded plots. While plants in the control took 40 days for 50 per cent flowering, the GA treated plants took only 35 days which shows a significant difference. Priming with water (38 days), borax (38 days), Tank mix (36 days) and MnO_4 (36 days) also took less number of days for 50 per cent flowering as compared to control.

Table. 27. Effect of seed priming on days to 50 per cent flowering of sesame variety Thilak

Days to 50 per cent flowering			
Treatments	W	UW	Mean
T1-Control	40	41	40.5[a]
T2-Water	38	39	38.5[b]
T3-GA	35	36	35.5[d]
T4-Borax	38	39	38.5[b]
T5-$MnSO_4$	36	37	36.5[c]
T6-Tank mix	36	37	36.5[c]
Mean	37.16	38.16	
CD (0.05)	NS		0.952

4.2.1.6. Days to maturity

There was no significant difference in days taken for maturity between the different treatments in both weeded and unweeded plots (Table 28).

Table. 28. Effect of seed priming on days to maturity of sesame variety Thilak

Days to maturity			
Treatments	W	UW	Mean
T1-Control	76.00	76.00	76.00
T2-Water	74.33	76.00	75.16
T3-GA	74.33	75.33	74.83
T4-Borax	73.66	76.33	75.00
T5-$MnSO_4$	75.00	75.00	75.00
T6-Tank mix	74.00	74.33	74.16
Mean	74.55	75.50	
CD	NS		NS

4.2.2. Physiological characters

4.2.2.1 *Crop growth rate (CGR)*

CGR was taken at the intervals of 20-40 days, 40-60 days, and 60 days-harvest (Table 29). Weeded plots recorded higher CGR throughout the growth period compared to unweeded plots. The treatment response in weeded and unweeded plots was the same. At 20-40 days interval highest CGR was recorded by priming with $MnSO_4$ (8.41) which was statistically on par with Tank mix (8.30 $gm^{-2}d^{-1}$). Priming with borax (7.83 $gm^{-2}d^{-1}$) and water (7.48 $gm^{-2}d^{-1}$) were statistically on par. The lowest value of CGR was recorded with GA priming (6.97 $gm^{-2}d^{-1}$) which was statistically similar to control (6.65 $gm^{-2}d^{-1}$). At 40-60 days, highest CGR was recorded for priming with $MnSO_4$ (17.20 $gm^{-2}d^{-1}$) followed by Tank mix (17.10 $gm^{-2}d^{-1}$) and borax (16.35 $gm^{-2}d^{-1}$) which were all statistically on par. The lowest value of CGR was recorded with GA priming (15.32 $gm^{-2}d^{-1}$) which was statistically similar to control (14.80 $gm^{-2}d^{-1}$) and water priming (15.80 $gm^{-2}d^{-1}$). At 60 days to harvest there was a reduction in CGR in all the treatments, however the difference between the treatments was non significant.

Table. 29. Effect of seed priming on crop growth rate ($gm^{-2}d^{-1}$) of sesame variety Thilak

Crop growth rate ($gm^{-2}d^{-1}$)									
	20-40DAS			40-60DAS			60DAS-Harvest		
Treatments	**W**	**UW**	**Mean**	**W**	**UW**	**Mean**	**W**	**UW**	**Mean**
T1-Control	7.24	6.07	6.65^{d}	16.93	12.66	14.80^{d}	2.16	3.72	2.94
T2-Water	7.97	6.99	7.48^{c}	17.50	14.10	15.80^{bc}	3.05	3.28	3.16
T3-GA	7.74	6.20	6.97^{d}	17.10	13.54	15.32^{cd}	3.33	1.05	2.19
T4-Borax	8.53	7.12	7.83^{bc}	18.13	14.57	16.35^{ab}	3.88	4.16	4.02
T5-$MnSO_4$	9.03	7.80	8.41^{a}	19.23	15.18	17.20^{a}	3.39	3.88	3.63
T6-Tank mix	8.91	7.7	8.30^{ab}	19.16	15.04	17.10^{a}	3.61	2.78	3.19
Mean	8.23^{a}	6.98^{b}		18.01^{a}	14.18^{b}		3.24	3.14	
CD (0.05)	1.145		0.501	0.636		1.612	NS		NS

4.2.2.2. *Relative growth rate (RGR)*

Effects of seed priming on relative growth rate of sesame are given in Table.30. RGR values were significantly higher in the weeded than the un-weeded plots throughout the experimental period. The priming treatments responded similarly in weeded and unweeded plots. At the interval of 20-40 days the highest RGR was recorded for $MnSO_4$ (0.04) and Tank mix (0.04 $gg^{-1}d^{-1}$) followed by borax (0.039 $gg^{-1}d^{-1}$) and water priming (0.038 $gg^{-1}d^{-1}$) which were statistically on par. The latter was statistically on par with GA priming (0.035). The lowest value of RGR was recorded with control (0.027 $gg^{-1}d^{-1}$). At the interval of 40-60 days the highest RGR was recorded by priming with $MnSO_4$ (0.022 $gg^{-1}d^{-1}$). Priming with Tank mix (0.021 $gg^{-1}d^{-1}$), borax (0.021 $gg^{-1}d^{-1}$) and water priming (0.021 $gg^{-1}d^{-1}$) were statistically on par and superior to GA priming (0.018 $gg^{-1}d^{-1}$). The lowest value of RGR was recorded with control (0.017 $gg^{-1}d^{-1}$). At the interval of 60 DAS-harvest there was reduction in RGR in all the treatments and difference between the treatments were non-significant.

Table. 30. Effect of seed priming on relative growth rate ($gg^{-1}d^{-1}$) of Sesame variety Thilak

Relative growth rate ($gg^{-1}d^{-1}$)									
	20-40DAS			40-60DAS			60DAS-Harvest		
Treatments	W	UW	Mean	W	UW	Mean	W	UW	Mean
T1-Control	0.031	0.024	0.027^{c}	0.020	0.013	0.017^{d}	0.006	0.006	0.006
T2-Water	0.039	0.036	0.038^{ab}	0.024	0.017	0.021^{b}	0.004	0.006	0.005
T3-GA	0.035	0.034	0.035^{b}	0.022	0.015	0.018^{c}	0.004	0.005	0.005
T4-Borax	0.040	0.037	0.039^{a}	0.024	0.018	0.021^{b}	0.004	0.006	0.005
T5-$MnSO_4$	0.040	0.039	0.040^{a}	0.025	0.018	0.022^{a}	0.004	0.005	0.005
T6-Tank mix	0.041	0.039	0.04^{a}	0.025	0.018	0.021^{b}	0.004	0.004	0.004
Mean	0.038^{a}	0.035^{b}		0.023^{a}	0.017^{b}		0.004	0.006	
CD (0.05)	0.002		0.004	0.001		0.001	NS		NS

4.2.2.3. *Net assimilation rate (NAR)*

Effects of seed priming on net assimilation rate of sesame are given in Table 31. Throughout the crop growth period weeded plots recorded significantly higher NAR than unweeded plots. The treatment effect was similar in the weeded and unweeded plots. At the interval of 20-40 days highest NAR was recorded by priming with $MnSO_4$ (2.320 mg cm^{-2} d^{-1}) followed by Tank mix (2.220 mg cm^{-2} d^{-1}) and borax (2.160 mg cm^{-2} d^{-1}) which were statistically on par. Priming with water (1.810 mg cm^{-2} d^{-1}) and GA (1.680 mg cm^{-2} d^{-1}) were statistically similar. The latter was statistically similar to control (1.45 mg cm^{-2} d^{-1}). At the interval of 40-60 days highest NAR was recorded by priming with $MnSO_4$ (1.090 mg cm^{-2} d^{-1}). Priming with borax (1.032 mg cm^{-2} d^{-1}), Tank mix (1.027 mg cm^{-2} d^{-1}) and water (1.003 mg cm^{-2} d^{-1}) were statistically on par. The lowest value of NAR was recorded with control (0.919 mg cm^{-2} d^{-1}) which was statistically on par with GA priming (0.957 mg cm^{-2} d^{-1}). At the interval of 60 DAS-harvest there was reduction in NAR in all the treatments and difference between the treatments were non-significant.

Table. 31. Effect of seed priming on net assimilation rate (mg cm^{-2} d^{-1}) of Sesame variety Thilak.

Net assimilation rate (mg cm^{-2} d^{-1})									
	20-40DAS			40-60DAS			60DAS-Harvest		
Treatments	W	UW	Mean	W	UW	Mean	W	UW	Mean
T1-Control	1.751	1.149	1.450^{c}	1.010	0.810	0.919^{c}	0.316	0.274	0.295
T2-Water	2.033	1.600	1.810^{b}	1.110	0.890	1.003^{b}	0.226	0.378	0.302
T3-GA	2.136	1.233	1.680^{bc}	1.080	0.820	0.957^{c}	0.253	0.266	0.260
T4-Borax	2.330	2.000	2.16^{a}	1.170	0.890	1.032^{b}	0.271	0.332	0.302
T5-MnSO$_4$	2.407	2.232	2.32^{a}	1.270	0.900	1.090^{a}	0.265	0.321	0.293
T6-Tank mix	2.376	2.081	2.22^{a}	1.140	0.900	1.027^{b}	0.256	0.243	0.249
Mean	2.172^{a}	1.716^{b}		1.135^{a}	0.872^{b}		0.265	0.302	
CD (0.05)	0.326		0.311	0.062		0.042	NS		NS

4.2.2.4. *Leaf area index*

Effects of seed priming on LAI are given in Table.32. Weeded plots recorded significantly higher LAI than unweeded plots throughout the crop growth period and the priming treatments similarly affected weeded and un-weeded plots. At 20DAS, highest LAI was recorded by priming with $MnSO_4$ (0.130) followed by Tank mix (0.125), borax (0.125) and water priming (0.122) which were statistically on par. The lowest LAI was recorded for GA priming (0.112) which was statistically superior to control. At 40 DAS highest LAI was recorded by priming with $MnSO_4$ (0.913) followed by Tank mix (0.910) and borax priming (0.883) which were statistically on par. The latter was statistically on par with water priming (0.855). The lowest value of LAI was recorded with control (0.780) which was statistically inferior to priming with GA (0.828). At 60 DAS highest LAI was recorded for $MnSO_4$ (2.168) treatment followed by the treatments borax (2.110), Tank mix (2.100) and water (2.093) which were statistically similar. The lowest LAI was recorded for control (1.950). At the time of harvest there was reduction in LAI in all the treatments and difference between the treatments were non-significant due to natural leaf fall at the time of harvest.

Table. 32. Effect of seed priming on LAI of sesame variety Thilak.

LAI						
	20DAS			40DAS		
Treatments	**W**	**UW**	**Mean**	**W**	**UW**	**Mean**
T1-Control	0.110	0.090	0.100^{c}	0.843	0.717	0.780^{d}
T2-Water	0.130	0.113	0.122^{a}	0.913	0.797	0.855^{bc}
T3-GA	0.120	0.103	0.112^{b}	0.867	0.790	0.828^{c}
T4-Borax	0.137	0.113	0.125^{a}	0.943	0.823	0.883^{ab}
T5-$MnSO_4$	0.143	0.117	0.130^{a}	0.973	0.853	0.913^{a}
T6-Tank mix	0.137	0.113	0.125^{a}	0.967	0.853	0.910^{a}
Mean	0.129^{a}	0.108^{b}		0.918^{a}	0.806^{b}	
CD (0.05)	0.003		0.01	0.001		0.034
	60DAS			Harvest		
Treatments	**W**	**UW**	**Mean**	**W**	**UW**	**Mean**
T1-Control	2.133	1.767	1.950^{b}	1.610	1.057	1.333
T2-Water	2.320	1.867	2.093^{a}	1.067	0.733	0.900
T3-GA	2.160	1.800	1.980^{b}	1.383	0.887	1.135
T4-Borax	2.333	1.887	2.110^{a}	0.810	1.000	0.905
T5-$MnSO_4$	2.403	1.933	2.168^{a}	0.443	1.367	0.905
T6-Tank mix	2.320	1.880	2.100^{a}	0.570	1.143	0.857
Mean	2.278^{a}	1.856^{b}		0.981	1.031	
CD (0.05)	0.076		0.096	NS		NS

4.2.2.5. *Photosynthetic rate*

Effects of seed priming on photosynthetic rate at vegetative and reproductive stages of sesame are given in Table 33. At vegetative stage highest photosynthetic rate was recorded for priming with borax (16.53 μ mole CO_2 m^{-2}

s^{-1}) which was statistically on par with $MnSO_4$ (16.26 µ mole CO_2 $m^{-2}s^{-1}$) priming. Priming with Tank mix (16.00 µ mole CO_2 $m^{-2}s^{-1}$) and water (15.96 µ mole CO_2 $m^{-2}s^{-1}$) were statistically on par. GA treatment (15.53 µ mole CO_2 $m^{-2}s^{-1}$) recorded the lowest photosynthetic rate at vegetative stage which was on par with control. At reproductive stage highest photosynthetic rate was recorded for $MnSO_4$ (18.10 µ mole CO_2 $m^{-2}s^{-1}$) followed by borax (17.50 µ mole CO_2 $m^{-2}s^{-1}$). Priming with water (17.06 µ mole CO_2 $m^{-2}s^{-1}$) and tank mix (17.00 µ mole CO_2 $m^{-2}s^{-1}$) were statistically on par. GA (16.70 µ mole CO_2 $m^{-2}s^{-1}$) recorded the lowest photosynthetic rate which was statistically on par with control.

Table. 33. Effect of seed priming on photosynthetic rate (µ mole CO_2 $m^{-2}s^{-1}$) at vegetative and reproductive stage of sesame variety Thilak.

Photosynthetic rate (µ mole CO_2 $m^{-2}s^{-1}$)		
Treatments	**Vegetative stage**	**Reproductive stage**
T1-Control	15.46[c]	16.70[d]
T2-Water	15.96[b]	17.06[c]
T3-GA	15.53[c]	16.70[d]
T4-Borax	16.53[a]	17.50[b]
T5-$MnSO_4$	16.26[ab]	18.10[a]
T6-Tank mix	16.00[b]	17.00[c]
CD (0.05)	0.374	0.211

4.2.2.6. *Transpiration rate*

Effect of seed priming on transpiration rate at vegetative and reproductive stages of sesame are given in Table 34. At vegetative stage transpiration rate was highest for priming with Borax (8.10 µmol H_2O $m^{-2}s^{-1}$) followed by $MnSO_4$ (7.69 µmol H_2O $m^{-2}s^{-1}$), Water priming (6.91 µmol H_2O $m^{-2}s^{-1}$), Tank mix (6.70 µmol H_2O $m^{-2}s^{-1}$) and GA priming (6.14 µmol H_2O $m^{-2}s^{-1}$). Control (5.68 µmol H_2O $m^{-2}s^{-1}$) recorded the lowest transpiration rate. At reproductive stage, highest transpiration rate was recorded for priming with Tank mix (8.41 µmol H_2O $m^{-2}s^{-1}$) followed by $MnSO_4$ (6.91 µmol H_2O $m^{-2}s^{-1}$), GA (6.86 µmol H_2O $m^{-2}s^{-1}$), borax

(6.50 μmol H_2O $m^{-2}s^{-1}$), water (5.67 μmol H_2O $m^{-2}s^{-1}$). Control (5.47 μmol H_2O $m^{-2}s^{-1}$) recorded the lowest transpiration rate.

Table. 34. Effect of seed priming on transpiration rate (μmol H_2O $m^{-2}s^{-1}$) at vegetative and reproductive stages of sesame variety Thilak

Transpiration rate (μmol H_2O $m^{-2}s^{-1}$)		
Treatments	**Vegetative stage**	**Reproductive stage**
T1-Control	5.68^{f}	5.47^{f}
T2-Water	6.91^{d}	5.67^{e}
T3-GA	6.14^{e}	6.86^{c}
T4-Borax	8.10^{a}	6.50^{d}
T5-$MnSO_4$	7.69^{b}	6.91^{b}
T6-Tank mix	6.70^{c}	8.41^{a}
CD (0.05)	0.022	0.029

4.2.2.7 *Stomatal conductance*

Effect of seed priming on stomatal conductance at vegetative and reproductive stages of sesame are given in Table 35. At vegetative stage stomatal conductance was highest for priming with Borax (0.614 mol $m^{-2}s^{-1}$) followed by $MnSO_4$ (0.581 mol $m^{-2}s^{-1}$), Tank mix (0.522 mol $m^{-2}s^{-1}$), Water (0.412 mol $m^{-2}s^{-1}$) and GA (0.368 mol $m^{-2}s^{-1}$). Control recorded the lowest stomatal conductance (0.306 mol $m^{-2}s^{-1}$). At reproductive stage, highest stomatal conductance was recorded for $MnSO_4$ (0.334 mol $m^{-2}s^{-1}$) followed by borax (0.294 mol $m^{-2}s^{-1}$), Tank mix (0.282 mol $m^{-2}s^{-1}$), GA (0.234 mol $m^{-2}s^{-1}$) and water priming (0.192 mol $m^{-2}s^{-1}$). Control recorded the lowest stomatal conductance (0.164 mol $m^{-2}s^{-1}$).

Table. 35. Effect of seed priming on stomatal conductance (mol $m^{-2}s^{-1}$) at vegetative and reproductive stages of sesame variety Thilak

Stomatal conductance (mol $m^{-2}s^{-1}$)		
Treatments	**Vegetative stage**	**Reproductive stage**
T1-Control	0.306^{f}	0.164^{f}
T2-Water	0.412^{d}	0.192^{e}
T3-GA	0.368^{e}	0.234^{d}
T4-Borax	0.614^{a}	0.294^{b}
T5-$MnSO_4$	0.581^{b}	0.334^{a}
T6-Tank mix	0.522^{c}	0.282^{c}
CD (0.05)	0.003	0.002

4.2.3. Biochemical observations

4.2.3.1. Chlorophyll content

Effect of seed priming on chlorophyll content at vegetative and reproductive stages of sesame are given in Table 36. At vegetative stage $MnSO_4$ (2.36 mg g^{-1}) priming showed highest chlorophyll a content followed by borax (2.21 mg g^{-1}) and water (1.66 mg g^{-1}). Tank mix (1.40 mg g^{-1}) and GA (1.35 mg g^{-1}) were statistically on par. The lowest value was recorded with control (1.29). The highest value for chlorophyll b was recorded for $MnSO_4$ (0.66 mg g^{-1}) followed by borax (0.57 mg g^{-1}) and Tank mix (0.49 mg g^{-1}). Water (0.48 mg g^{-1}) and GA (0.47 mg g^{-1}) priming were statistically on par. The lowest value of chlorophyll b was recorded for control (0.45). The highest value of total chlorophyll was shown by $MnSO_4$ (3.027) followed by borax (2.780 mg g^{-1}), water (2.143) and Tank mix (1.890 mg g^{-1}). GA (1.823 mg g^{-1}) was statistically on par with control (1.750 mg g^{-1}). At reproductive stage $MnSO_4$ (2.38 mg g^{-1}) showed highest chlorophyll a followed by borax (2.3 mg g^{-1}), GA (2.13 mg g^{-1}) and Tank mix (1.90 mg g^{-1}). Priming with water (1.72 mg g^{-1}) was statistically on par with control (1.49) which recorded the lowest value. The highest value for chlorophyll b was recorded for $MnSO_4$ (0.77 mg g^{-1}) followed by GA (0.68 mg g^{-1}) which were statistically on par. Priming with borax (0.61 mg g^{-1}), Tank mix

(0.58 mg g^{-1}) and water (0.56 mg g^{-1}) were statistically on par with control (0.54 mg g^{-1}). The highest value of total chlorophyll was shown by $MnSO_4$ (3.150 mg g^{-1}) priming followed by borax (2.907 mg g^{-1}) and GA (2.803 mg g^{-1}) which were statistically on par. Tank mix (2.480 mg g^{-1}) treatment was on par with GA. Water (2.273 mg g^{-1}) priming was statistically on par with control (2.037 mg g^{-1}).

Table. 36. Effect of seed priming on chlorophyll content (mg g^{-1} fresh wt) at vegetative and reproductive stages of sesame variety Thilak

Chlorophyll content (mg g^{-1} fresh wt) at vegetative stage			
Treatments	**Chlorophyll a**	**Chlorophyll b**	**Total chlorophyll**
T1-Control	1.29^{e}	0.45^{e}	1.750^{e}
T2-Water	1.66^{c}	0.48^{cd}	2.143^{c}
T3-GA	1.35^{d}	0.47^{d}	1.823^{de}
T4-Borax	2.21^{b}	0.57^{b}	2.780^{b}
T5-$MnSO_4$	2.36^{a}	0.66^{a}	3.027^{a}
T6-Tank mix	1.40^{d}	0.49^{c}	1.890^{d}
CD (0.05)	0.082	0.018	0.093
Chlorophyll content (mg g^{-1} fresh wt) at reproductive stage			
Treatments	**Chlorophyll a**	**Chlorophyll b**	**Total chlorophyll**
T1-Control	1.49^{d}	0.54^{c}	2.037^{d}
T2-Water	1.72^{cd}	0.56^{bc}	2.273^{cd}
T3-GA	2.13^{ab}	0.68^{ab}	2.803^{ab}
T4-Borax	2.3^{a}	0.61^{bc}	2.907^{a}
T5-$MnSO_4$	2.38^{a}	0.77^{a}	3.150^{a}
T6-Tank mix	1.90^{bc}	0.58^{bc}	2.480^{bc}
CD (0.05)	0.289	0.136	0.361

4.2.3.2. Nitrate reductase enzyme activity

Effects of seed priming on nitrate reductase enzyme activity at vegetative and reproductive stages of Sesame are given in Table 37. At vegetative stage highest nitrate reductase enzyme activity was observed in $MnSO_4$ (1568.33μ moles NO_2^- g^{-1} hr^{-1}). Treatments Tank mix (823.33 μ moles NO_2^- g^{-1} hr^{-1}) and GA (796.66 μ moles NO_2^- g^{-1} hr^{-1}) were statistically on par. Priming with water (656.66 μ moles NO_2^- g^{-1} hr^{-1}) and borax (673.33 μ moles NO_2^- g^{-1} hr^{-1}) were statistically similar and superior to control (611.66 μ moles NO_2^- g^{-1} hr^{-1}). At reproductive stage highest nitrate reductase activity was recorded for $MnSO_4$ (1790.00 μ moles NO_2^- g^{-1} hr^{-1}) followed by Borax (1528.33 μ moles NO_2^- g^{-1} hr^{-1}), Tank mix (883.33 μ moles NO_2^- g^{-1} hr^{-1}), GA (816.66 μ moles NO_2^- g^{-1} hr^{-1}) and water priming (488.33 μ moles NO_2^- g^{-1} hr^{-1}). Control recorded the lowest nitrate reductase enzyme activity (465.00 μ moles NO_2^- g^{-1} hr^{-1}).

Table. 37. Effect of seed priming on nitrate reductase enzyme activity (μ moles of NO_2^- formed g^{-1} fresh weight hr^{-1}) at vegetative and reproductive stages of sesame

Nitrate reductase enzyme activity (μ moles of NO_2^- formed g^{-1} fresh weight hr^{-1})		
Treatments	**Vegetative stage**	**Reproductive stage**
T1-Control	611.66^{d}	465.00^{f}
T2-Water	656.66^{c}	488.33^{e}
T3-GA	796.66^{b}	816.66^{d}
T4-Borax	673.33^{c}	1528.33^{b}
T5-$MnSO_4$	1568.33^{a}	1790.00^{a}
T6-Tank mix	823.33^{b}	883.33^{c}
CD (0.05)	34.31	19.156

4.2.3.3. IAA content

Effect of seed priming on IAA content at vegetative and reproductive stages of sesame are given in Table 38. At vegetative stage, the highest IAA activity was found in seeds primed with borax (1.025 mg of unoxidised auxin g^{-1} hr^{-1}) and tank mix (1.025 mg of unoxidised auxin g^{-1} hr^{-1}) followed by $MnSO_4$ (1.005 mg of unoxidised auxin g^{-1} hr^{-1}) and GA (1.000 mg of unoxidised auxin g^{-1} hr^{-1}) which were statistically on par. Priming with water (0.980 mg of unoxidised auxin g^{-1} hr^{-1}) was statistically superior to control (0.858 mg of unoxidised auxin g^{-1} hr^{-1}). At reproductive stage of the crop the highest IAA activity was found in seeds treated with borax (1.575 mg of unoxidised auxin g^{-1} hr^{-1}) followed by water (1.400 mg of unoxidised auxin g^{-1} hr^{-1}). Priming with tank mix (1.307 mg of unoxidised auxin g^{-1} hr^{-1}) and $MnSO_4$ (1.300 mg of unoxidised auxin g^{-1} hr^{-1}) were statistically similar and superior to GA (1.150 mg of unoxidised auxin g^{-1} hr^{-1}). Control recorded the lowest value of IAA (1.000 mg of unoxidised auxin g^{-1} hr^{-1}).

Table. 38. Effect of seed priming on IAA content (mg of unoxidised auxin g^{-1} hr^{-1}) at vegetative and reproductive stages of sesame variety Thilak

IAA content (mg of unoxidised auxin g^{-1} hr^{-1})		
Treatments	**Vegetative stage**	**Reproductive stage**
Control	0.858 ^{d}	1.000 ^{e}
Water priming	0.980 ^{c}	1.400 ^{b}
GA	1.000 ^{b}	1.150 ^{d}
Borax	1.025 ^{a}	1.575 ^{a}
$MnSO_4$	1.005 ^{b}	1.300 ^{c}
Tank mix	1.025 ^{a}	1.307 ^{c}
CD (0.05)	0.007	0.039

4.2.3.4. GA content

Effect of seed priming on GA content at vegetative and reproductive stages of Sesame are given in Table 39. At vegetative stage highest GA content was observed with GA (66.66 μgg^{-1}) followed by Tank mix (60.33 μgg^{-1}), Water (57.33 μg g^{-1}), $MnSO_4$ and Borax (51.83 μg g^{-1}). At reproductive stage, highest GA content was recorded with GA (139.50 μg g^{-1}) followed by water (118.33 μg g^{-1}), Tank mix (102.00 μg g^{-1}), Borax (76.66) and $MnSO_4$ (60.50 μg g^{-1}). The lowest GA content was observed for control both at vegetative (21.83 μg g^{-1}) and reproductive stages (50.33 μg g^{-1}) of the crop.

Table. 39. Effect of seed priming on GA content (μg g^{-1}) at vegetative and reproductive stages of sesame variety Thilak

	GA content (μgg^{-1})	
Treatments	**Vegetative stage**	**Reproductive stage**
T1-Control	21.83^{e}	50.33^{f}
T2-Water	57.33^{c}	118.33^{b}
T3-GA	66.66^{a}	139.50^{a}
T4-Borax	51.83^{d}	76.66^{d}
T5-$MnSO_4$	53.00^{d}	60.50^{e}
T6-Tank mix	60.33^{b}	102.00^{c}
CD (0.05)	3.777	7.924

4.2.3.5. Soluble protein content

Seed priming improved the soluble protein content of sesame plants. During vegetative and reproductive stage maximum soluble protein content was recorded in $MnSO_4$ (15.50 and 17.66 mg g^{-1}) primed seeds followed by borax (11.66 and 14.40 mg g^{-1}), Tank mix (11.00 and 15.50 mg g^{-1}), GA (10.33 and 12.00 mg g^{-1}). Control (6.00 and 10.66 mg g^{-1}) recorded the lowest value which was on par with water priming (6.08 and 10.83 mg g^{-1}) at vegetative and reproductive stages respectively (Table 40).

Table. 40. Effect of seed priming on soluble protein content (mg g $^{-1}$) at vegetative and reproductive stages of sesame variety Thilak

Soluble protein content (mg g $^{-1}$)		
Treatments	Vegetative stage	Reproductive stage
T1-Control	6.00^{e}	10.66^{e}
T2-Water	6.08^{e}	10.83^{e}
T3-GA	10.33^{d}	12.00^{d}
T4-Borax	11.66^{b}	14.40^{c}
T5-$MnSO_4$	15.50^{a}	17.66^{a}
T6-Tank mix	11.00^{c}	15.50^{b}
CD (0.05)	0.641	0.759

4.2.3.6. Relative water content (RWC)

Effect of seed priming on relative water content at vegetative and reproductive stages of sesame are given in Table 41. At vegetative stage, priming with $MnSO_4$ (67.02%) recorded highest RWC. GA (63.74%) and Tank mix (61.71%) treatments were statistically on par. Priming with water (54.67%) and control (53.6%) were statistically on par and inferior to borax priming (57.30%). At reproductive stage, highest RWC was recorded with Borax (84.00%), Control (82.08%) and water (81.41%), which were statistically on par. $MnSO_4$ (77.66%) recorded the lowest RWC which was statistically on par with GA (78.33%) and Tank mix (80.00%) treatments.

Table. 41. Effect of seed priming on relative water content (per cent) at vegetative and reproductive stages of sesame variety Thilak

Relative water content (per cent)		
Treatments	**Vegetative stage**	**Reproductive stage**
T1-Control	53.60^{d}	82.08^{ab}
T2-Water	54.67^{d}	81.41^{abc}
T3-GA	63.74^{b}	78.33^{cd}
T4-Borax	57.30^{c}	84.00^{a}
T5-$MnSO_4$	67.02^{a}	77.66^{d}
T6-Tank mix	61.71^{b}	80.00^{bcd}
CD (0.05)	2.199	3.451

4.2.4. Yield attributes and yield

4.2.4.1 *Number of branches per plant*

Effects of seed priming on number of branches per plant are given in Table 42. Weeded plots recorded significantly higher number of branches (4.94) than unweeded plots (3.66). Among the treatments highest number of branches were recorded for priming with $MnSO_4$ (5.00) followed by Tank mix (4.67) and water priming (4.67) which were statistically on par. The lowest number of branches was recorded for control (3.5) which was statistically on par with GA priming (3.83) and Borax (4.17)

Table. 42. Effect of seed priming on number of branches per plant of sesame variety Thilak

Number of branches per plant			
Treatments	W	UW	Mean
T1-Control	4.00	3.00	3.50^{c}
T2-Water	5.33	4.00	4.67^{ab}
T3-GA	4.00	3.67	3.83^{c}
T4-Borax	5.00	3.33	4.17^{bc}
T5-$MnSO_4$	6.00	4.00	5.00^{a}
T6-Tank mix	5.33	4.00	4.67^{ab}
Mean	4.94^{a}	3.66^{b}	
CD (0.05)	0.257		0.793

4.2.4.2. *Number of capsules per plant*

Effect of seed priming on number of capsules per plant was given in Table 43. The weeded plots showed significantly higher number of capsules per plant than un-weeded plots irrespective of priming treatments. Interaction effect was also significant indicating that in the treatments Borax, $MnSO_4$ and Tank mix, even under unweeded condition, the capsule number was on par with weeded condition and significantly higher than control, GA and water priming treatments.

Table. 43. Effect of seed priming on Number of capsules per plant of sesame variety Thilak

Number of capsules per plant			
Treatments	**W**	**UW**	**Mean**
T1-Control	42.66[a]	24.00[b]	33.33[c]
T2-W	44.66[a]	37.00[b]	40.83[ab]
T3-GA	45.33[a]	29.00[b]	37.16[bc]
T4-Borax	44.00[a]	38.00[a]	41.00[ab]
T5-$MnSO_4$	46.00[a]	39.66[a]	42.83[a]
T6-Tank mix	44.00[a]	37.00[a]	40.50[ab]
Mean	44.44[a]	34.11[b]	
CD (0.05)	5.141		4.598

CD for comparing weeded and unweeded plots – 7.404

CD for comparing treatments within main plot- 7.55

4.2.4.3. Number of seeds per capsule

Effect of seed priming on number of seeds per capsule are given in Table 44. Weeded plots (61.33) recorded significantly higher number of seeds per capsule than unweeded plots (52.88). Among the treatments highest number of seeds per capsule was recorded for $MnSO_4$ (60.66) and Tank mix (60.00) priming followed by borax (58.16) and water priming (57.66) which were statistically on par. Priming with GA recorded the lowest number of seeds (53.50) which was statistically on par with control (52.66).

Table. 44. Effect of seed priming on number of seeds per capsule of sesame variety Thilak

Number of seeds per capsule			
Treatments	W	UW	Mean
T1-Control	61.66	43.66	52.66[b]
T2-Water	62.00	53.33[b]	57.66[a]
T3-GA	54.00	53.0	53.50[b]
T4-Borax	62.00	54.33	58.16[a]
T5-$MnSO_4$	64.00	57.33	60.66[a]
T6-Tank mix	64.33	55.66	60.00[a]
Mean	61.33	52.88	
CD (0.05)	5.502		3.075

4.2.4.4. 1000 seed weight

Effect of seed priming on 1000 seed weight of sesame are given in Table 45. There was no significant difference in 1000 grain weight observed between weeded and unweeded plots and also between the priming treatments.

Table. 45. Effect of seed priming on 1000 seed weight (g) of sesame variety Thilak

1000 seed weight (g)			
Treatments	W	UW	Mean
T1-Control	2.733	2.733	2.733
T2-Water	2.713	2.757	2.735
T3-GA	2.877	2.73	2.803
T4-Borax	2.85	2.723	2.787
T5-$MnSO_4$	2.74	2.78	2.76
T6-Tank mix	2.70	2.847	2.773
Mean	2.769	2.762	
CD (0.05)	NS		NS

4.2.4.5. Yield per plant

Effect of seed priming on seed yield per plant are given in Table 46. Weeded and unweeded plots showed significant difference in yield per plant. Higher yield was recorded from weeded plots. Highest yield per plant was recorded for $MnSO_4$ priming (3.69 g) which was statistically on par with Tank mix priming (3.60 g). Priming with borax (3.35 g) and water (3.30 g) were statistically on par. The lowest yield was recorded for GA (2.61 g) which was superior to control (2.35 g).

Table. 46. Effect of seed priming on yield per plant (g) of sesame variety Thilak

Yield per plant (g)			
Treatments	**W**	**UW**	**Mean**
T1-Control	2.53	2.16	2.35^{e}
T2-Water	3.33	3.26	3.30^{c}
T3-GA	2.86	2.36	2.61^{d}
T4-Borax	3.43	3.26	3.35^{bc}
T5-$MnSO_4$	3.8	3.56	3.69^{a}
T6-Tank mix	3.66	3.53	3.60^{ab}
Mean	3.271^{a}	3.026^{b}	
CD (0.05)	0.235		0.258

4.2.4.6. Yield per hectare

Effect of seed priming on yield per hectare of sesame are given in Table 47. Weeded plots recorded highest yield per hectare than unweeded plots. Among the treatments highest yield per hectare was recorded from $MnSO_4$ (1230.12 kg ha^{-1}) which was statistically on par with Tank mix (1200.00 kg ha^{-1}). Priming with borax (1116.67 kg ha^{-1}) and water (1097.22 kg ha^{-1}) were statistically on par. GA treatment (869.07 kg ha^{-1}) recorded the lowest yield which was statistically superior to that of control (783.95 kg ha^{-1}).

Table. 47. Effect of seed priming on yield per hectare (kg ha^{-1}) of sesame variety Thilak

Yield per hectare (kg ha^{-1})			
Treatments	**W**	**UW**	**Mean**
T1-Control	842.69	725.21	783.95^{d}
T2-Water	1,105.56	1,089.89	1,097.22^{b}
T3-GA	954.58	784.56	869.07^{c}
T4-Borax	1,144.45	1,089.89	1,116.67^{b}
T5-$MnSO_4$	1,272.85	1,188.38	1,230.12^{a}
T6-Tank mix	1,222.22	1,177.78	1,200.00^{a}
Mean	1,090.23^{a}	1,008.79^{b}	
CD (0.05)	80.93		78.47

4.2.5. Estimation of weed competitiveness

4.2.5.1.1. *Species wise weed count*

The major weed flora found in the sesame field was *Melochia corchorifolia, Digitaria ciliaris, Echinochloa colona, Oryza sativa and Cleome viscosa.* At 10 DAS *Melochia chorchorifolia* were predominant, whereas at harvest, population of *Digitaria ciliaris* was high in all the treatment plots. The lowest weed count was recorded for *Cleome viscosa*. The different treatments did not have any influence on the weed floral composition (Table 48). However there was significant variation in the population of the weed species in the different treatments. For computation the weed species were classified as broad leaved species and grasses. Sedges were not observed in the field.

Table. 48. Species wise weed count at 10 DAS and harvest

Species wise weed count							
10 DAS							
Weed species	**Control**	**Water**	**GA**	**Borax**	**$MnSO_4$**	**Tank mix**	**CD (0.05)**
Melochia corchorifolia	33.33^{a} (5.67)	36.33^{a} (6.019)	36.33^{a} (6.01)	30.66^{a} (5.32)	40.66^{a} (6.44)	35.66^{a} (5.82)	NS
Digitaria ciliaris	19.00^{b} (4.35)	10.33^{b} (3.20)	5.33^{c} (2.23)	9.00^{b} (2.914)	16.33^{b} (3.54)	8.00^{b} (2.55)	NS
Echinochloa colona	17.66^{bc} (4.18)	4.66^{c} (2.08)	17.33^{b} (4.15)	2.00^{b} (1.33)	7.66^{c} (2.67)	8.00^{b} (2.82)	NS
Oryza sativa	10.00^{c} (3.15)	9.00^{b} 2.99	6.00^{c} (2.43)	1.00^{b} (1)	8.00^{c} (2.95)	8.33^{b} (2.88)	NS
Cleome viscosa	2.00^{d} (1.414)	1.33^{d} (1.13)	1.33^{d} (1.13)	-	2^{d} (1.71)	2^{b} (1.33)	NS
CD (0.05)	1.1	0.818	0.831	1.97	2.99	2.138	
Harvest							
Weed species	**Control**	**Water**	**GA**	**Borax**	**$MnSO_4$**	**Tank mix**	**CD (0.05)**
Melochia corchorifolia	19.66^{b} (4.429)	26^{ab} (5.043)	16.33^{bc} (4.029)	18.00^{b} (4.06)	20.66^{b} (4.45)	20.00^{b} (4.41)	NS
Digitaria ciliaris	61.66^{a} (7.843)	51.66^{a} (6.861)	55.66^{a} (7.23)	64.66^{a} (7.69)	32.66^{a} (5.65)	48.33^{a} (6.66)	NS
Echinochloa colona	48.00^{a} (6.637)	34.00^{a} (5.522)	28.00^{ab} (5.15)	23.66^{ab} (4.79)	24.66^{ab} (4.94)	27.00^{ab} (5.14)	NS
Oryza sativa	2.33^{c} (1.471)	1.33^{c} (1.138)	3.33^{cd} (1.80)	3^{b} (1.71)	1^{c} (1)	3.00^{c} (1.66)	NS
Cleome viscosa	5.00^{c} (2.236)	5.00^{bc} (2.236)	1.00^{d} (1)	-	1.00^{c} (1)	1.00^{c} (1)	NS
CD (0.05)	2.01	3.091	2.301	3.524	1.135	2.142	

4.2.5.1.2. *Weed count*

Weed count from different treatments in the unweeded plots of sesame are given in Table 49. The weed flora present in the unweeded plots were classified under grasses and broad leaved weeds. Seed priming could suppress the weed growth. At 10 DAS broad leaved weeds were significantly higher than grasses. There was no significant variation observed in the number of grasses with treatments. But the number of broad leaved weeds were high in control (50.00) and $MnSO_4$ (42.33) primed plots. Among the treatments lowest total weed count was observed in the priming treatments Borax (51.33), Tank mix (56.00), water (58.67) and GA (61.00). At the time of harvest grasses were significantly higher than broad leaved weeds. Count of grasses was lowest in the treatments $MnSO_4$ (49.00), Tank mix (59.66), Borax (67.00) and GA (75.66). The broad leaved weeds were found to be lowest in treatments GA (16.66) and borax (18.00). The treatments, $MnSO_4$ (69.66), Tank mix (79.66), Borax (85.00) and GA (92.33) were statistically on par and recorded significantly lower total weed count than water priming (139.00) and control (211.33).

Table. 49. Effect of seed priming on weed count (number per square metre)

Treatments	10 DAS			Harvest		
	Grasses	Broad leaved weeds	Total	Grasses	Broad leaved weeds	Total
Control	27.00	50.00^{a}	77.00^{a}	183.33^{a}	28.00^{a}	211.33^{a}
Water	21.67	37.00^{b}	58.67^{bc}	112.00^{b}	27.00^{a}	139.00^{b}
GA	23.33	37.67^{b}	61.00^{bc}	75.66^{bc}	16.66^{d}	92.33^{cd}
Borax	15.33	36.00^{b}	51.33^{c}	67.00^{c}	18.00^{cd}	85.00^{d}
$MnSO_4$	23.33	42.33^{ab}	65.67^{ab}	49.00^{c}	20.66^{b}	69.66^{d}
Tank mix	19.33	36.67^{b}	56.00^{bc}	59.66^{c}	20.00^{bc}	79.66^{d}
CD (0.05)	NS	9.01	12.97	44.84	2.144	46.3

4.2.5.2 *Weed dry matter production*

Weed dry matter production from different treatments in the sesame field at 10 DAS and harvest are given in Table 50. Priming treatments helped to suppress weed growth. At 10 DAS there were no significant difference in weed dry weight with different treatments. At the time of harvest the lowest weed dry weight was recorded for $MnSO_4$ priming (104.33 g) which was statistically similar to Tank mix (112.00 g). Priming with borax (116.66 g) and water (127.46 g) were statistically on par and recorded lower weed dry weight than GA priming (133.33 g).

Table. 50. Weed dry matter production (gm^{-2}) in sesame fields from different treatments

Weed dry matter production (gm^{-2})		
Treatments	**10 DAS**	**Harvest**
Control	3.36	170.00 ^{a}
Water priming	2.72	127.46 ^{bc}
GA	2.96	133.33^{b}
Borax	2.13	116.66^{cd}
$MnSO_4$	3.06	104.33^{e}
Tank mix	2.39	112.00^{de}
CD (0.05)	NS	11.672

4.2.5.3 *Weed control efficiency (WCE)*

Weed control efficiency of seed priming treatments are given in Table 51. The highest weed control efficiency of 38.76 per cent was recorded from $MnSO_4$ priming. Weed control efficiency of Tank mix (34.11%) and borax (31.40%) were statistically on par and superior to water (25.00%) and GA (21.60%) priming.

Table. 51. Weed control efficiency (per cent) of seed priming treatments

Treatments	**WCE**
Water priming	25.00^{c}
GA	21.60^{c}
Borax	31.40^{b}
$MnSO_4$	38.76^{a}
Tank mix	34.11^{b}
CD	4.138

4.2.6. Soil Analysis

Soil analysis was done before sowing (Table 52). The results show that potassium content was low and magnesium and boron were deficient in the experimental plots. All the other nutrients were sufficient.

Table. 52. Soil analysis

Parameters	Quantity	Remarks
Ph	5.6	Moderately acidic
Electrical conductivity (dS/m)	0.12	Normal
Organic carbon (%)	1.10	Medium
Available phosphorus (kg/ha)	52.05	High
Available potassium (kg/ha)	97.44	Low
Available calcium (mg/kg)	448.00	Sufficient
Available magnesium (mg/kg)	34.00	Deficient
Available sulphur (mg/kg)	15.91	Sufficient
Micronutrients		
Copper (mg/kg)	1.91	Sufficient
Iron (mg/kg)	90.76	Sufficient
Zinc (mg/kg)	1.65	Sufficient
Manganese (mg/kg)	1.17	Sufficient
Boron (mg/kg)	0.02	Deficient

Discussion

5. DISCUSSION

Weed competition is the major biotic stress that causes yield decline in sesame. Since there are no recommended herbicides available for weed control, integrated weed management has to be practiced. Improving the early vigour of sesame plants by seed priming treatments can suppress the weed growth.

The present study focuses on identifying the most suitable priming agent for sesame and also to evaluate the carry over effect of these priming treatments in the field to suppress weed growth and improve productivity.

5.1. EFFECT OF PRIMING TREATMENTS ON SEED GERMINATION AND SEEDLING VIGOUR

Priming treatments on sesame seeds significantly improved the germination vigour of seedlings and speed of germination. Among the different treatments tried maximum improvement in germination (Figure 2), vigour of seedlings (Figure 3) and speed of germination (Figure 4) was observed for priming with micronutrient, followed by hormones, water and biofertilizers. The micronutrient $MnSO_4$ gave the best result (11.53 per cent improvement over control). Imran *et al.* (2008) had reported similar results. Manganese has been reported to accelerate seed development, improve the ability to withstand environmental stress and increase germination (Dordas, 2009). It also plays a role in cell elongation (Abbott, 1967) as seen in the improved shoot length. Borax improved the germination by 7.91 per cent (Table 5). Boron is reported to facilitate remobilization of stored seed nutrients during germination (Bonilla *et al.,* 2004). Acceleration of shoot meristem growth by borax has been indicated by Marschner (1995). The ability of nutrients to facilitate germination and speed of germination is in agreement with the suggestion that adequate nutrient supply improves seed development, germination and seedling vigour (Romheld and Marschner, 1991).

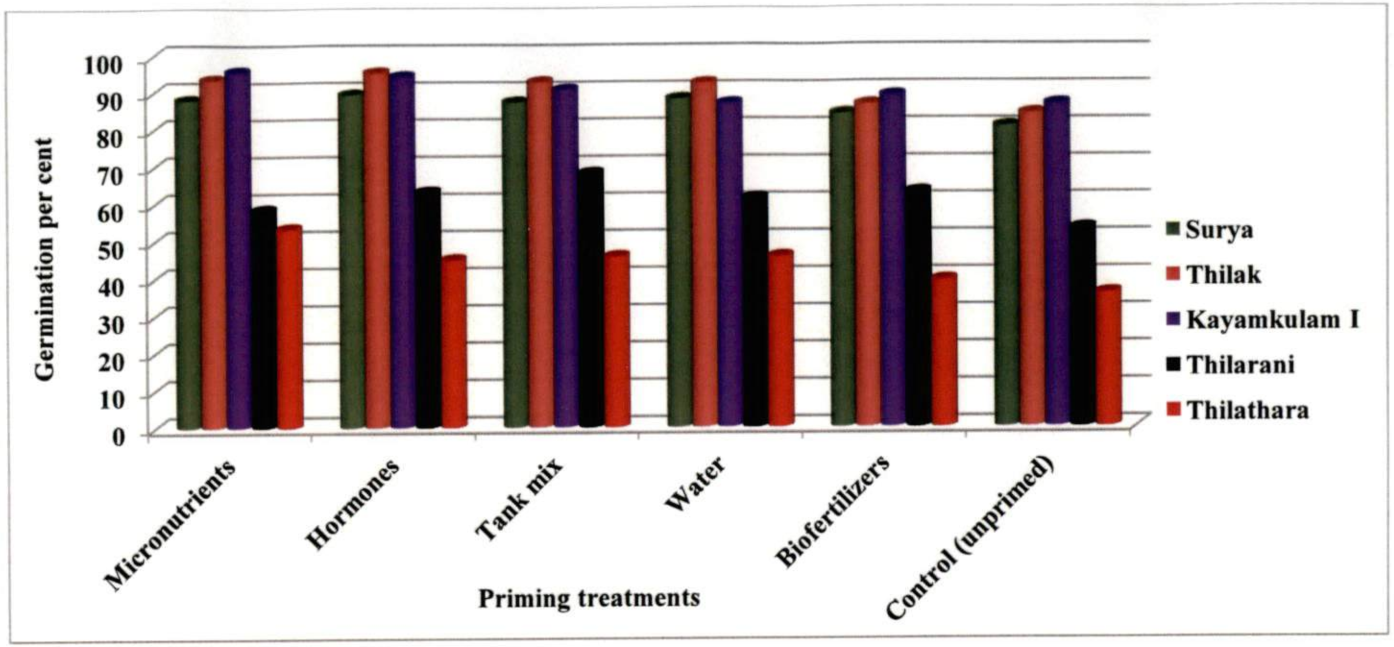

Fig. 2. Effect of seed priming with micronutrients, hormones, biofertilizers, Tank mix (Mixture of $MnSO_4$, Borax and GA) and water on germination per cent of sesame varieties

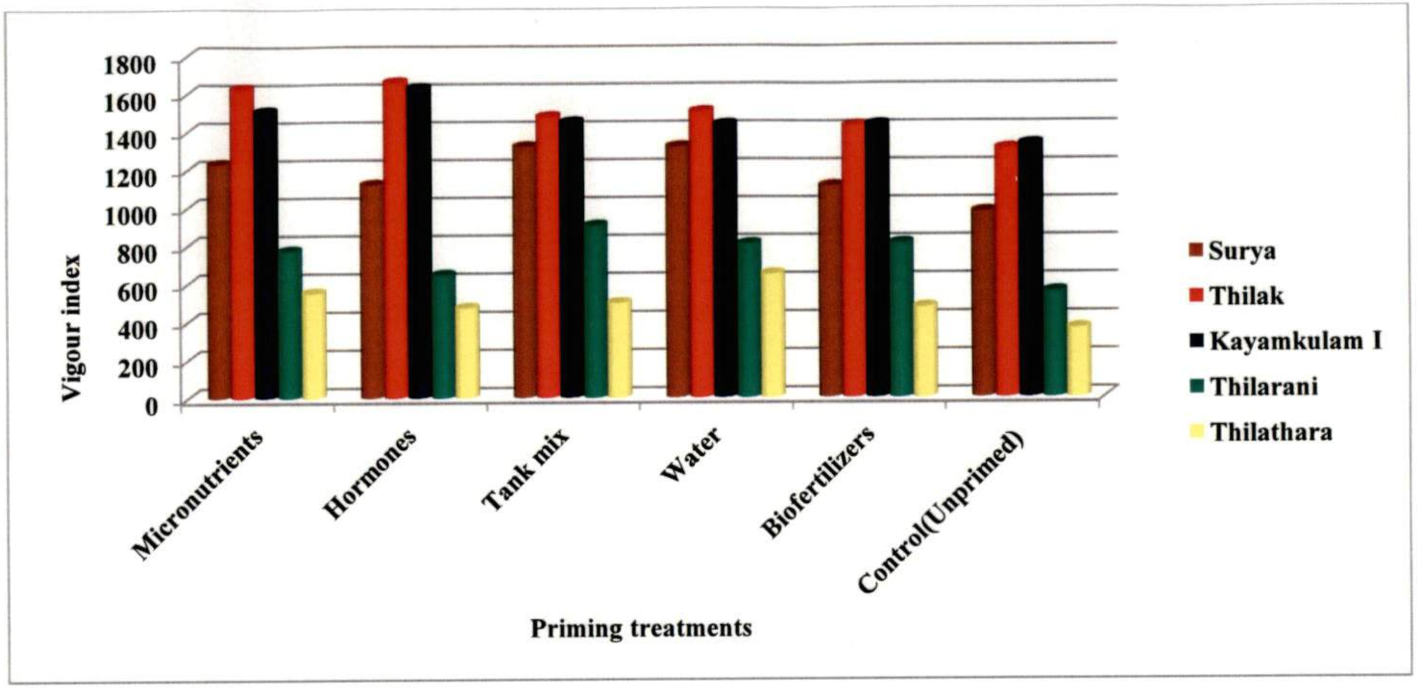

Fig. 3. Effect of seed priming with micronutrients, hormones, biofertilizers, Tank mix and water on vigour index of sesame varieties

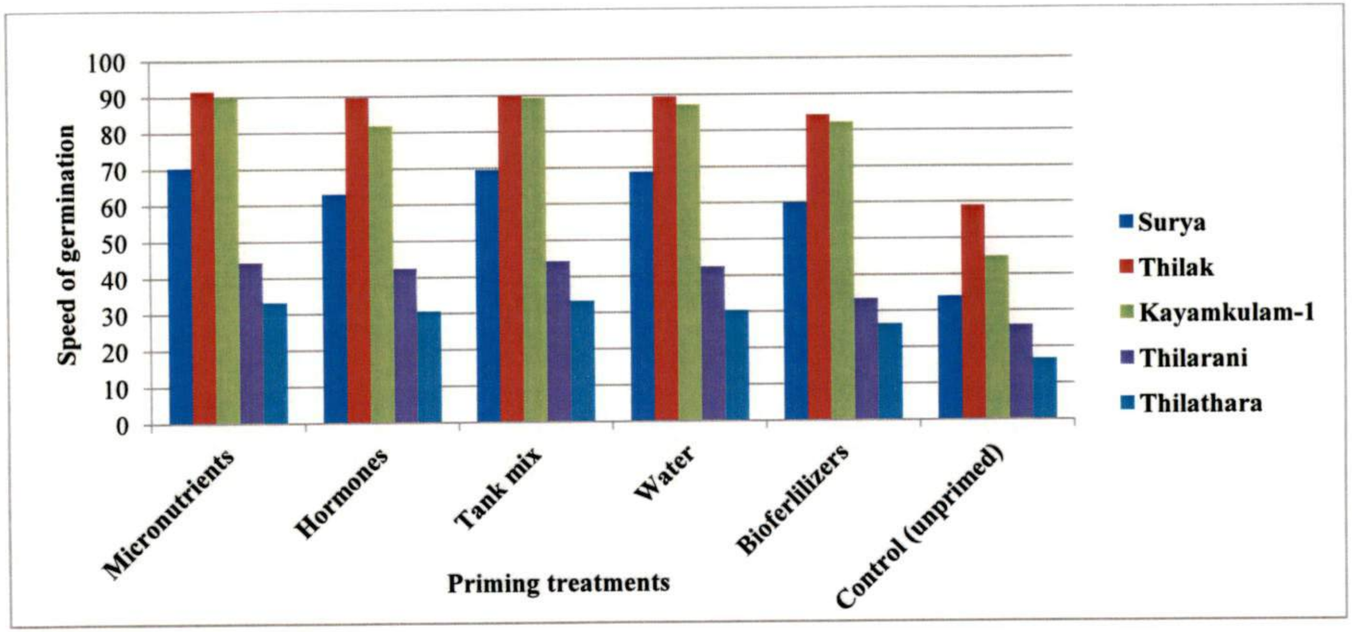

Fig. 4. Effect of seed priming with micronutrients, hormones, biofertilizers, Tank mix (Mixture of $MnSO_4$, Borax and GA) and water on speed of germination of sesame varieties

In the current study hormones such as GA and IAA contributed to 10.19 and 8.54 per cent improvement in germination respectively (Table 3). Improvement in seed germination and seedling growth of sesame by GA and IAA priming has also been reported by Suma *et al.* (2006), Mura *et al.* (2015) and Subash *et al.* (2015). The role of GA in the production and secretion of the hydrolytic enzyme, α amylase required for the solubilization of endosperm reserves has been well authenticated. IAA is an important hormone having a role in improving cell elongation and root growth (Taiz and Zeiger, 2010).

Priming with water alone gave a significant improvement to germination (Table 6) due to better revival of metabolic processes in the seed (Meena *et al.* 2014). According to Dell'Aquila and Taranto (1986) water priming leads to a rapid resumption of DNA synthesis and initiation of cell division. Tank mix (T_6) being a combination of micronutrients and GA also gave best results.

Biofertilizers marginally improved the germination (Table 4), vigour (Table16) and speed of germination (Table 20) which was less than water priming, indicating that the action of the biofertilizers is not by activating the metabolic activity of seed. Ahemad and Kibret (2014) have reported that plant growth promoting rhizobacteria are the bacteria inhabiting the soil around or on the root surface and are directly or indirectly involved in promoting plant growth and development by the production and secretion of various regulatory chemicals in the vicinity of rhizosphere thereby assisting in resource acquisition.

The level of response of sesame varieties to priming treatments was also different. Seed priming improved the germination and vigour of all the five varieties tested. The germination per cent showed an improvement of 9 to 26 per cent. Among the varieties maximum improvement in germination per cent was observed in the variety Thilathara (26.65) with $MnSO_4$ priming (Table 5) and Thilarani (18.33) with GA priming (Table 3) which had only 36 and 53 per cent initial germination respectively. However priming treatments improved the germination to 62.5 and 71.65 per cent respectively. This might be due to the low initial germination per cent of these two varieties, Thilatara (35.85) and Thilarani (53.32). The vigour indices of these two varieties were also poor as compared to Thilak and Kayamkulam-1, indicating that the seed lot was of poor quality. The poor quality of the seed lot may be due to the accumulation of damaged DNA as a result of seed aging which leads to faulty translation and transcription of enzymes necessary for germination (Mc Donald and Kwong, 2005). The improvement in germination of low vigour seeds by priming treatments might be due to the repair of damaged proteins, RNA and DNA (Koehler *et al.*, 1997).

Laboratory studies indicated that seed priming with micronutrients and hormones contributed to a significant improvement in germination per cent and vigour of sesame seedlings. Hence five best treatments among the ten treatments were selected for the field study and the variety selected was Thilak which recorded maximum vigour. This will help to evaluate the carry over effect of these treatments on the performance of the crop in the field and also to ascertain the effect of early vigour on weed suppression.

5.2. EFFECT OF SEED PRIMING TREATMENTS ON BIOCHEMICAL PARAMETERS

Biochemical parameters were assessed during vegetative as well as the reproductive stages of the crop. The results revealed that the biochemical parameters such as chlorophyll content, total soluble protein content and GA content were higher during the reproductive phase as compared to the vegetative phase. However the treatment effects during both the stages showed a similar trend. The chlorophyll content (Figure 5) and total soluble protein content (Figure 6) showed maximum increase with micronutrient priming treatments such as $MnSO_4$, borax and GA followed by combination of micronutrients with GA (Tank mix). Total chlorophyll including chlorophyll a, chlorophyll b and soluble protein content showed maximum improvement in $MnSO_4$ primed plots. This might be because Manganese is reported as an essential element for the structural integrity of thylakoid membrane (Simpson and Robinson, 1984) and for the activation of specific enzymes for chlorophyll synthesis (Millaleo *et al.*, 2010). Spreitzer and Salvucci (2002) have reported that 30 per cent and 50 per cent of soluble protein in leaves of C_4 and C_3 plants are due to the enzyme RUBISCO. Manganese is an essential element in protein synthesis, hence the improvement in soluble protein content of sesame seedlings was justified. Under manganese deficiency it has been reported that gene expression and activation of Rubisco is destroyed (Gong *et al.*, 2011).

The GA content was higher in treatments T_3 (GA), T_2 (water) and T_6 (tank mix). In T_3 and T_6, GA was used as the priming agent while T_2 (water priming) also had higher GA content even during the reproductive phase.

The nitrate reductase enzyme plays a major role in nitrogen metabolism of the plant. In the present study the nitrate reductase enzyme activity was found to be higher during the reproductive phase of the crop in all the treatments except for control (Figure 7). Cheng-Husun *et al.* (2009) has reported a number of nitrate induced responses in plants such as shoot and root growth, stomatal conductance, seed germination etc. The improvement in growth, flowering and yield attributes of the primed seed may be attributed to the increased activity of the enzyme during the reproductive phase of the crop. In nitrogen metabolism manganese acts as a cofactor of the enzyme nitrite reductase (Harper and Paulsen, 1969). This may be the reason of highest nitrate reductase enzyme activity observed in $MnSO_4$ primed plots.

The IAA content also was higher in the reproductive phase in all the treatments. Major improvement was observed with borax priming (Table 38). According to Dugger (1973), boron plays an important role in auxin metabolism. In the current study the estimation of soil nutrient status of the experimental site (Kayamkulam) (Table 52) showed that the soil was deficient in boron content. Hence boron priming might have activated auxin metabolism of the crop which may be the reason for the improved response of this nutrient. Cohen and

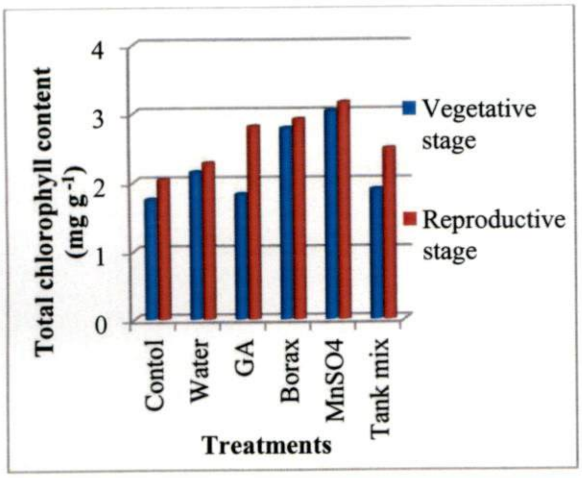

Fig. 5. Variation in total chlorophyll content (mg g^{-1}) with priming treatments in Thilak at vegetative and reproductive stages

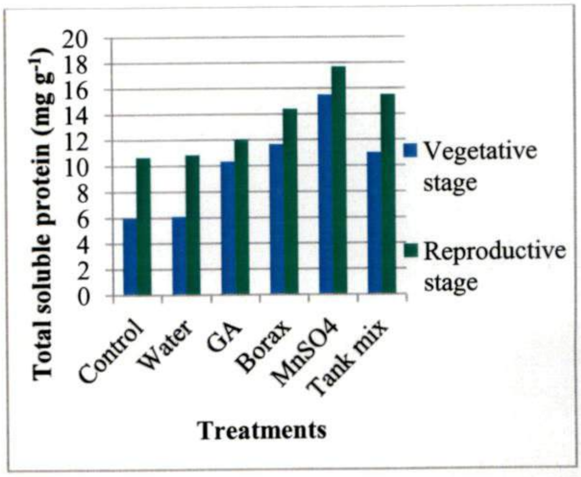

Fig. 6. Variation in total soluble protein content (mg g^{-1}) with priming treatments in Thilak at vegetative and reproductive stages

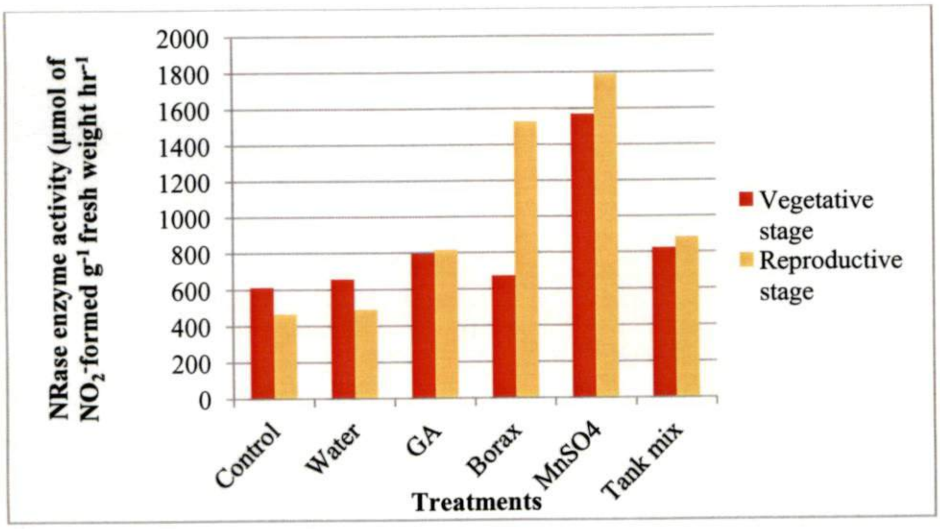

Fig. 7. Variation in NRase enzyme activity (µ mole of NO_2^- formed g^{-1} fresh weight hr^{-1}) with priming treatments in Thilak at vegetative and reproductive stages

Bandurski (1978) have suggested that deficiency of boron leads to reduction in the free auxin content in the plant.

5.3. EFFECT OF SEED PRIMING ON PHYSIOLOGICAL PARAMETERS OF SESAME

The growth indices such as CGR (Table 29), RGR (Table 30), NAR (Table 31) and LAI (Table 32) were estimated during four stages of the crop at 20 days intervals. The variation in the growth was evident during the stages 20-40 and 40-60 days hence these stages have been considered for the study. Weed competition reduced the growth indices of all the treatments studied. However, the reduction in the CGR (upto 2-5 %) was higher in unprimed control (T_1) as compared to the treatments where primed seeds were used for planting. Reduction in CGR was higher at 40-60 DAS as compared to 20-40 DAS. Among the treatments $MnSO_4$, Tank mix and borax recorded higher CGR under both weeded and unweeded condition, indicating that these treatments were able to sustain the growth of sesame even under high competition from weeds (Table 29). Reduction in CGR due to weed competition has been reported by Amini *et al.* (2013) in jack bean and Ghanizadeh *et al.* (2014) in corn.

When RGR of plants were estimated, the treatments $MnSO_4$, Tank mix and borax showed statistically similar values in both weeded and unweeded condition during the early stages of growth which was significantly superior to the unprimed control (Figure 8). As growth proceeded a slight reduction in the RGR of the unweeded plots was evident (40-60 DAS). However the per cent reduction in treatment T_4, T_5 and T_6 where borax, $MnSO_4$ and tank mix were used as the priming agent were less. This shows that the above mentioned priming treatments have been able to accelerate the growth of the plant which was successful in enhancing the weed competitiveness of the crop.

Weed competition significantly reduced the LAI in all the treatments throughout the crop growth period (Figure 9). This is in concurrence with the findings of El Naim and Eldouma (2011). However the percentage reduction was

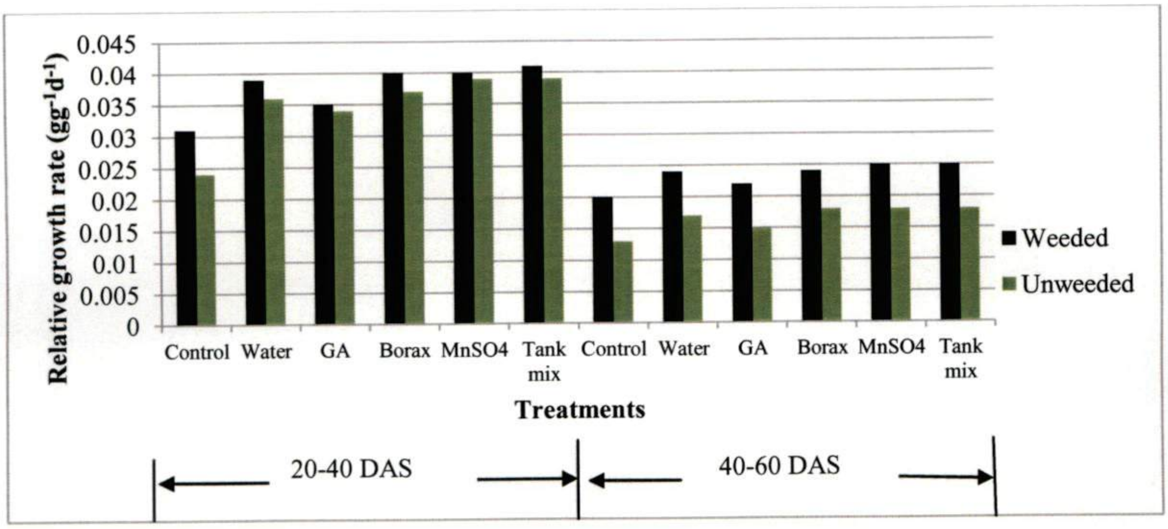

Fig. 8. Variation in relative growth rate (g $g^{-1}d^{-1}$) with priming treatments in weeded and unweeded conditions of Thilak

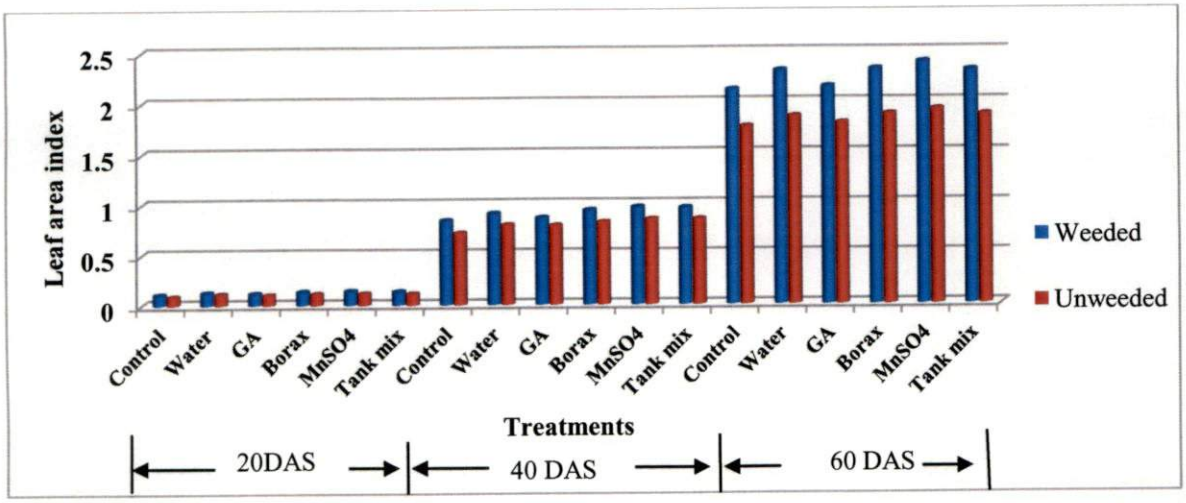

Fig. 9. Variation in leaf area index with priming treatments in weeded and unweeded conditions of Thilak

lower in the treatments where primed seeds were used. Among the treatments $MnSO_4$, Tank mix and Borax recorded higher leaf area (Table 24), which accounted for the higher LAI of these treatments.

The NAR of the plants depends on LAI. The improvement in NAR with the priming treatments $MnSO_4$, Tank mix and Borax might be due to the higher LAI recorded for these treatments compared to the control (Table 32). Higher assimilation of nutrients in turn would contribute to higher CGR which is evident from the results. Improvement in NAR by priming treatment has also been reported by Ogbuehi *et al.* (2013) in groundnut.

The estimation of photosynthetic rate during the vegetative and reproductive stages of the crop showed significant increase in $MnSO_4$ and borax primed seeds as compared to other treatments (Table 33). This may be due to the significant role of manganese in the water splitting complex of PSII (Marshner, 1995). It is a key activator of a number of critical metabolic enzymes (Millaleo *et al.*, 2010).

Highest transpiration rate was recorded for borax and Tank mix priming at vegetative and reproductive phases respectively (Table 34). This might be due to the role of boron in the movement of potassium to the stomata Memon *et al.* (2013).

Highest stomatal conductance was observed in borax and $MnSO_4$ treatments at both the vegetative and reproductive stages (Table 35). Sharma and Ramchandra, (1990) reported that boron plays a major role in stomatal conductance. The increase in stomatal conductance is also a factor that influences the photosynthetic rate.

5.4. EFFECT OF PRIMING TREATMENTS ON MORPHOLOGICAL CHARACTERS

Morphological observations like plant height (Figure 10) and leaf area were measured at 20 days interval till harvest in weeded and unweeded plots. Both plant height and leaf area were higher in weeded plots compared to

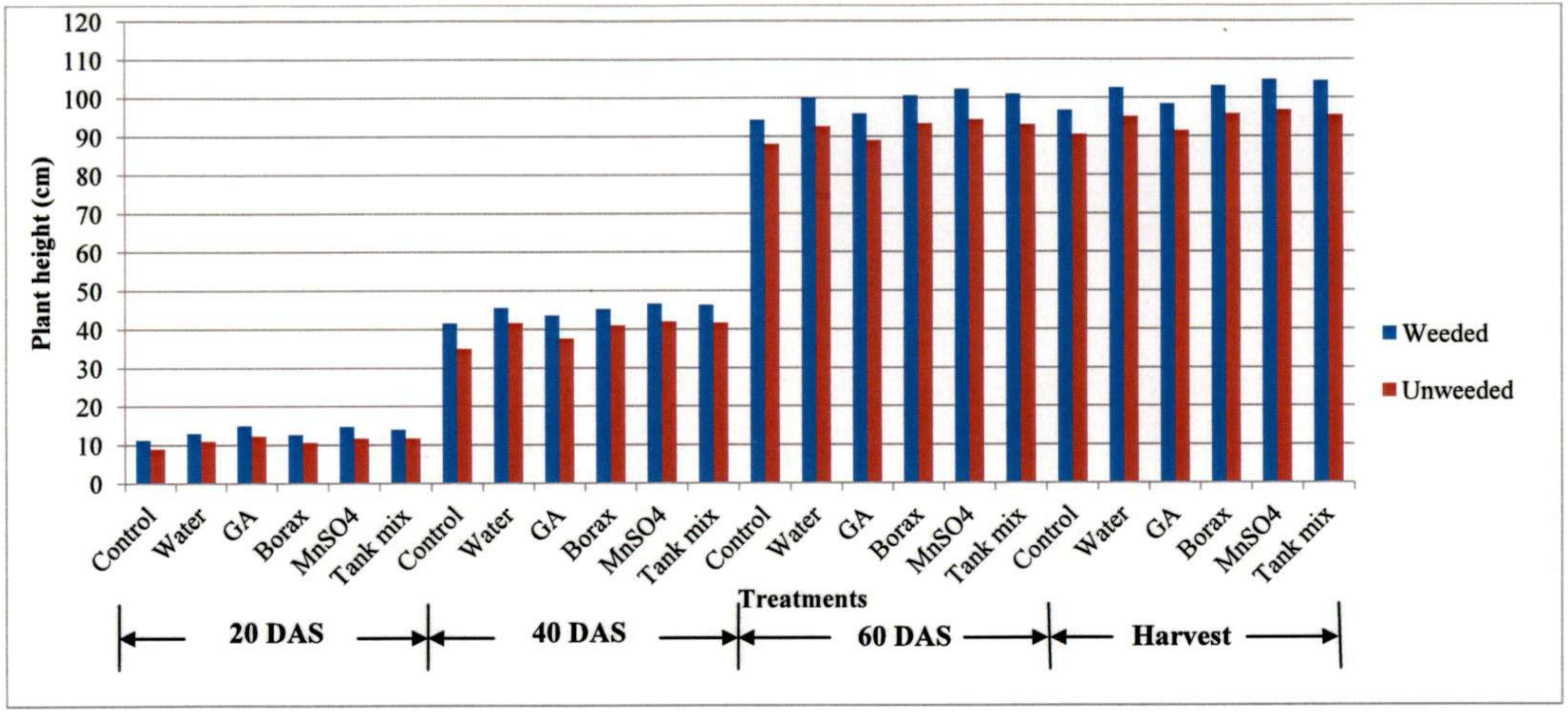

Fig. 10. Variation in plant height of sesame variety Thilak with priming treatments in weeded and unweeded conditions

unweeded plots. Among the seed priming treatments, GA improved the plant height significantly at vegetative stage (Table 23). This is in agreement with the findings of Namadev (2010). Increase in plant height by GA might be due to its ability to induce cell elongation and cell division (Taiz and Zeiger, 2010) Priming with $MnSO_4$ maintained greatest height throughout the growth period (Table 23). This may be due to the improvement in the vigour of seeds germinated (Abbott, 1967). Priming with Tank mix, borax and water also showed better plant height up to harvest (Table 23).

At all growth stages weeded plots recorded higher leaf area than unweeded plots (Table 24). At 20 DAS all the treatments were statistically similar and superior to control with highest leaf area from $MnSO_4$ primed seeds. At 40 DAS priming with $MnSO_4$, Tank mix, and borax were statistically similar and superior to all other treatments. At 60 DAS priming with $MnSO_4$ showed highest leaf area compared to others. Priming with $MnSO_4$ could maintain highest leaf area in all growth stages (Table 24).

5.5. EFFECT OF SEED PRIMING ON YIELD AND YIELD ATTRIBUTES

Yield attributes such as number of branches per plant (Table 42), number of capsules per plant (Table 43), number of seeds per capsule (Table 44) were significantly higher in plants which were subjected to seed priming. In the present study maximum yield was obtained for $MnSO_4$ and Tank mix, which was significantly superior to all other priming treatments (Figure 11). The yield components such as number of branches, number of capsules and seeds per capsules has improved considerably with these treatments. The increase in LAI (Table 32) and photosynthetic rate (Table 33) of the crop could have accounted for the improvement in vegetative features such as number of branches as a result of which the capsule number would have also increased. Boron in turn improves the translocation efficiency of sugars thereby improving the seed filling (Davis, 1983). Tank mix is a combination of nutrients and GA which has contributed to a balanced increase of yield attributes.

In the unweeded condition, plants had to compete with weeds. Priming treatments $MnSO_4$, Tank mix and borax improved the competing ability of the plants which resulted in less reduction of yield under unweeded condition.

5.6. EFFECT OF SEED PRIMING TREATMENTS ON WEED SUPPRESSION

The weed count (Table 48, 49) and weed dry weight (Table 50) showed a decreasing trend with the seed priming treatments. This indicates that improvement in seedling vigour by seed priming can lead to weed suppression. The priming treatments significantly reduced the weed count as compared to control both at 10 DAS and at harvest. Weed control efficiency was found to be maximum for $MnSO_4$ followed by Tank mix and borax indicates that these priming treatments could give 30 per cent weed control (Figure 12).

The studies indicate that seed priming treatments improved the vigour of the seed. The improvement in vigour was the result of enhancement in the metabolic activities of the seed which were reflected in higher enzymatic and hormonal content of the plant. The enhancement in the metabolism of plants may have contributed to sustainable improvement in the morphological, physiological and phenological characters of the crop.

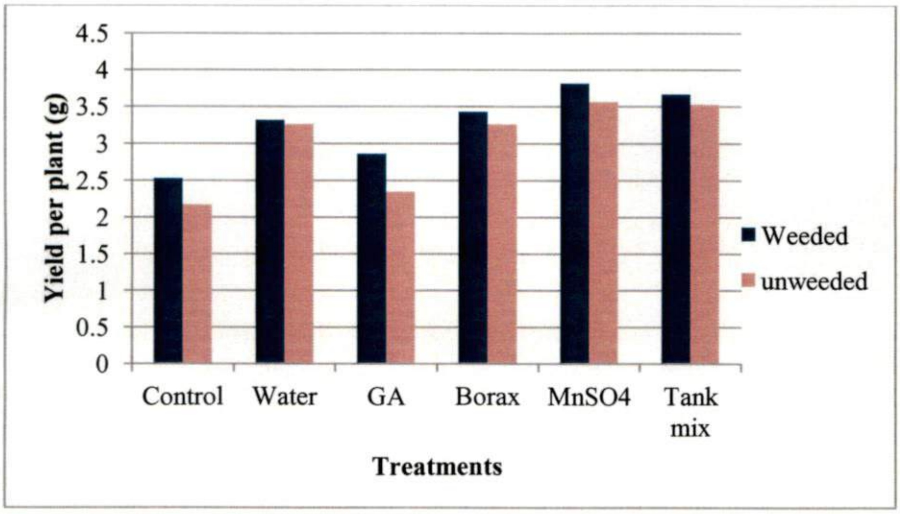

Fig. 11. Yield per plant of Thilak with priming treatments in weeded and unweeded condition

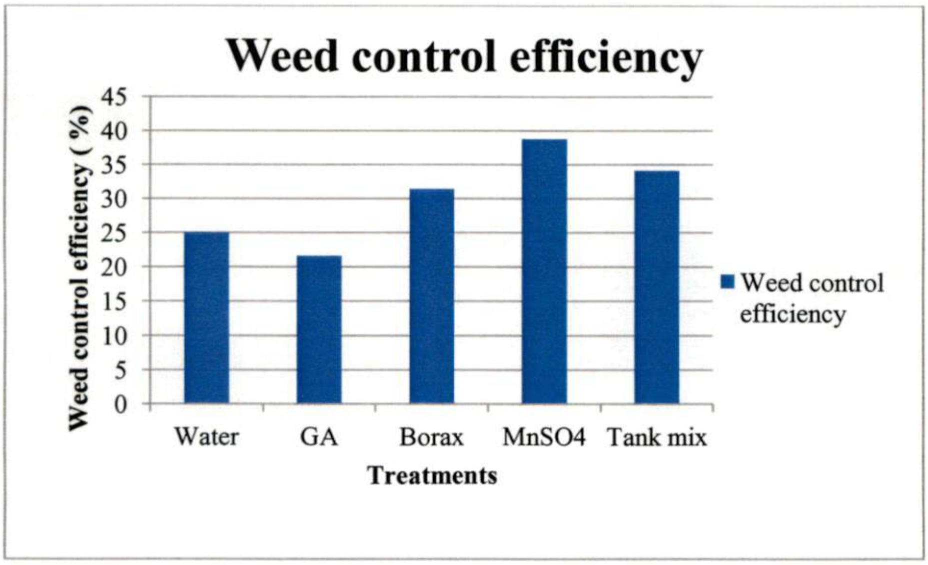

Fig. 12. Weed control efficiency of priming treatments in sesame variety Thilak

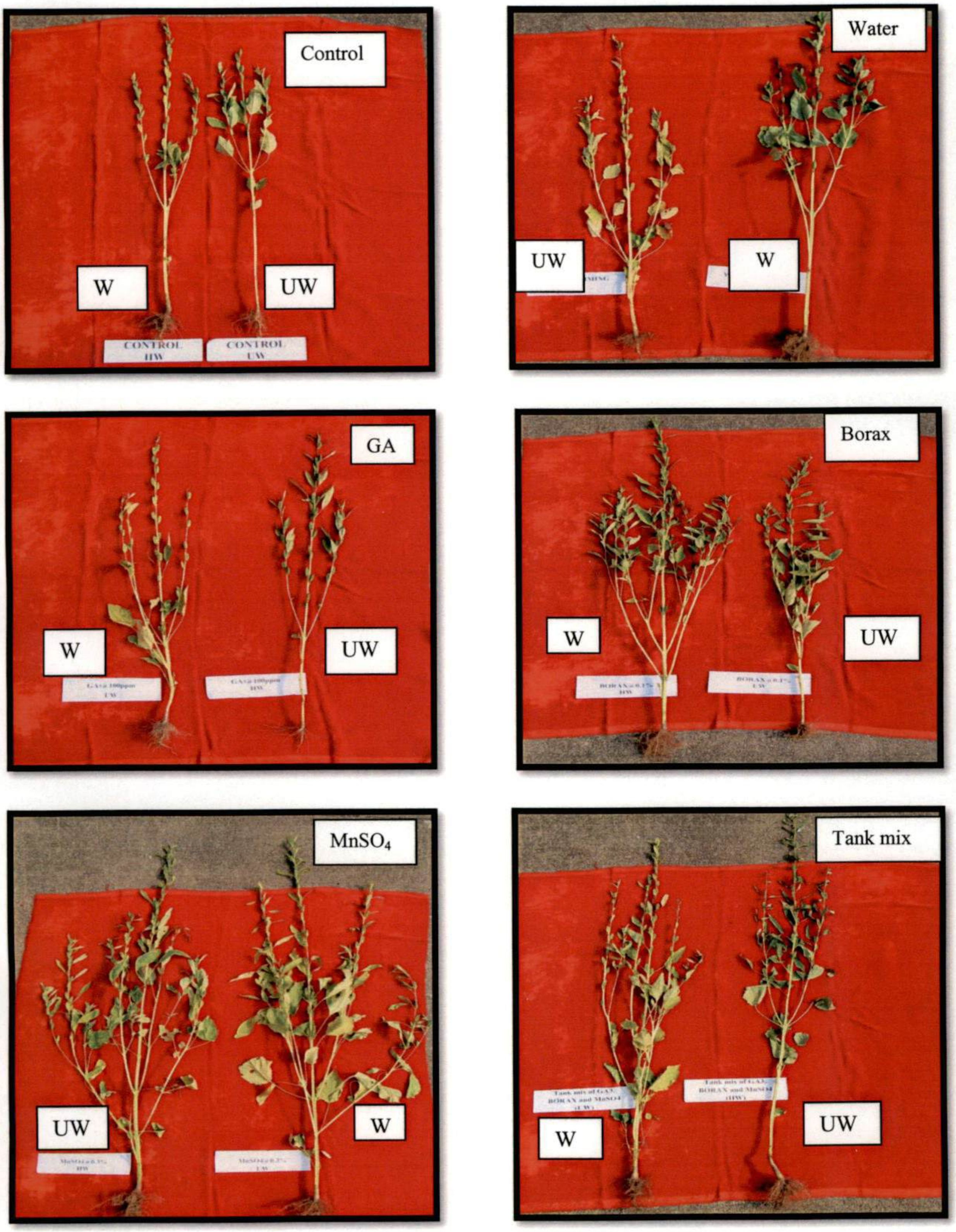

Plate 6. Sesame plants from different treatments at harvest

Summary

6. SUMMARY

Among the biotic stresses, weed competition is considered to be the most important factor responsible for low productivity of sesame. The slow initial growth of sesame seedling makes them poor competitors to quick-growing weeds. The aim of the present study was to enhance the seedling vigour of sesame by seed priming treatments so that they could compete better with the weeds and thereby improve productivity.

A laboratory study was conducted with ten priming agents to improve the initial germination and vigour of five popular varieties of sesame *viz.*, Surya, Thilak, Kayamkulam 1, Thilarani and Thilathara, released from Kerala Agricultural University. The ten priming treatments were plant growth regulators (IAA, GA), micronutrients ($MnSO_4$, borax), mixture of $MnSO_4$ and borax with GA (Tank mix), biofertilizers (phosphobacteria, azospirillum, PGPR mix-1). The variety which gave maximum response to the priming treatments was selected for the field studies. The five best priming agents were selected based on the values of vigour index and speed of germination. The field experiment was laid out in split plot design at ORARS, Kayamkulam. Weeded and unweeded treatments formed the main plots and five selected treatments along with control (unprimed seeds) were the sub-plot treatments. Observations on morphological characters were studied at 20 days interval and yield characters were recorded at the time of harvest. Physiological and biochemical effects of the priming treatments were studied at vegetative and reproductive stages of the crop. Weed count and weed dry matter was recorded at 10 DAS and at the time of harvest in the unweeded plots. Weed control efficiency of the priming treatments was computed at the time of harvest.

The salient findings of the study are:

6.1 Laboratory study

- Priming treatments improved the germination, shoot length, root length, vigour index and speed of germination of all the five varieties. However the response of the varieties to the treatments were different
- The varieties Thilak and Kayamkulam-I showed maximum response to most of the priming treatments studied
- Surya showed better response to biofertilizers as compared to other varieties
- Poor initial germination per cent of Thilathara and Thilarani improved significantly with priming treatments
- Biofertilizers marginally improved the germination, vigour and speed of germination which was less than water priming.
- Among the biofertilizers studied, PGPR mix-1 was best in improving seedling vigour
- Priming with water alone improved the germination by a maximum of 9 per cent
- Among the priming treatments and varieties used, highest improvement in shoot length of 30.63 per cent was obtained by priming with GA in the variety, Thilak

6.2 Field study

- Chlorophyll a, chlorophyll b and Total chlorophyll content and soluble protein content showed maximum improvement with $MnSO_4$ priming at vegetative and reproductive stages
- The nitrate reductase enzyme activity of primed seeds was higher during the reproductive stage and the maximum improvement was recorded with $MnSO_4$ primed seeds.
- The GA content was higher in seeds treated with GA while IAA content was higher with borax treatment.

- Weed competition reduced the growth indices of all the treatments studied. However the reduction in growth indices was higher at 40-60 DAS as compared to 20-40 DAS.
- The CGR, RGR, NAR and LAI values were higher in primed seeds among which, maximum improvement was with the treatment $MnSO_4$
- Photosynthetic rate showed significant increase in $MnSO_4$ and borax priming during the vegetative and reproductive stages of the crop respectively as compared to other treatments.
- Highest stomatal conductance was observed in borax and $MnSO_4$ treatments at vegetative and reproductive stages respectively
- Priming with $MnSO_4$ maintained greatest height and leaf area throughout the growth period followed by TM, borax and water
- Priming reduced the number of days taken for branching
- Priming seeds with GA resulted in early flowering
- $MnSO_4$ primed plants showed highest number of branches
- The priming treatments $MnSO_4$, tank mix, borax and water increased the number of capsules and number of seeds per capsules
- Maximum yield was obtained for $MnSO_4$ and TM primed seeds
- The main weed flora present in the sesame field were *Melochia chorchorifolia, Echinochloa colona*, *Digitaria ciliaris* and *Cleome viscosa*
- The weed count and weed dry weight showed a decreasing trend with the seed priming treatments. This indicates that improvement in seedling vigour by seed priming can lead to weed suppression.
- The least weed dry weight was recorded with MnSO4 primed plots at the time of harvest.
- The study revealed that seed priming with $MnSO_4$ or Tank mix can contribute to 30 per cent control of weed growth in the crop. Hence, these treatments can be used as a component in the integrated management of weeds in sesame.

- Priming with water alone gave a significant improvement in yield and weed suppression (upto 25 per cent). Water priming can be recommended as a cost effective method for improving productivity of sesame.

Future line of work

- Study the factors that contribute to germination decline in sesame varieties
- Standardizing pelleting treatments in sesame for improving the vigour and competitiveness of the crop
- Developing an integrated weed management package for sesame

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Abstract

ENHANCING MORPHO-PHYSIOLOGICAL VIGOUR OF SESAME SEEDLINGS FOR IMPROVING PRODUCTIVITY AND WEED COMPETITIVENESS

By

Sreepriya S

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ABSTRACT OF THE THESIS

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Kerala Agricultural University, Thrissur

Department of Plant Physiology

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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Abstract

Sesame is one of the oldest oilseed crops grown in summer rice fallows of Kerala. Weed infestation is a major biotic stress affecting the yield of sesame. Seedling growth of sesame is slow during the first four weeks, making it a poor competitor during this period. Weed suppression during the early stages of crop establishment (10 to 30 DAS) is important for improving the productivity of the crop. The present study was initiated to enhance the early vigour of sesame plants by suitable seed priming treatments and also to assess the effect of early vigour on weed competitiveness and analyse the carry over effect of these treatments on the productivity of the crop. The variation in varietal response to these priming treatments were also studied.

A laboratory study was conducted with five popular varieties of sesame viz., Surya, Thilak, Kayamkulam 1, Thilarani and Thilathara, released from Kerala Agricultural University. Ten priming treatments with plant growth regulators (IAA, GA), micronutrients ($MnSO_4$, borax), mixture of $MnSO_4$ and borax with GA (Tank mix), biofertilizers (phosphobacteria, azospirillum, PGPR mix-1) and water were tried. Results on observations showed that seed priming improved the germination and vigour of all the five varieties tested. Among the treatments, priming with micronutrients and hormones gave the best results. Based on the vigour index, five priming treatments were selected for the field trial and the variety Thilak, which gave maximum response to these treatments, was used as the test variety in the field.

The experiment was laid out in split plot design at ORARS, Kayamkulam. Weeded and unweeded treatments formed the main plots and five selected treatments along with control (unprimed seeds) were the sub-plot treatments. Observations on morphological characters were studied at 20 days interval and yield characters were recorded at the time of harvest. Physiological and biochemical effects of the priming treatments were studied at vegetative and reproductive stages of the crop. Weed count and weed dry matter were recorded at

10 DAS and at the time of harvest in the unweeded plots. Weed control efficiency of the priming treatments was computed at the time of harvest.

The biochemical parameters such as contents of chlorophyll, total soluble protein and GA were higher during the reproductive phase as compared to the vegetative phase. Chlorophyll including chlorophyll a and chlorophyll b, and soluble protein content showed greatest improvement in $MnSO_4$ primed plants. The nitrate reductase enzyme plays a major role in nitrogen metabolism of the plant. In the present study, the nitrate reductase enzyme activity was found to be higher during the reproductive phase of the crop in all the treatments except for control (unprimed seeds) and water priming. The IAA content was also higher in the reproductive phase in all the treatments. Major improvement in IAA content was observed with borax priming.

The growth indices such as crop growth rate, relative growth rate, net assimilation rate and leaf area index were improved with priming treatments in both unweeded and weeded plots. Yield and yield attributes such as number of branches, number of capsules and seeds per capsule improved significantly with $MnSO_4$ and tank mix treatments, which contributed to higher yield.

The improvement in vigour of sesame plants with seed priming treatments reduced the weed count and weed dry matter production in the unweeded plots as compared to the control (unprimed seeds) due to the higher competitiveness of the primed seeds.

The study revealed that seed priming with $MnSO_4$ or Tank mix of GA, borax and $MnSO_4$ can be an effective component in the integrated management of weeds in sesame as it can contribute to 30 per cent control of weed growth.