YIELD IMPROVEMENT IN TRANSPLANTED GINGER BY SEED PRIMING AND BIOSTIMULANT SPRAY

by

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(2018-12-005)

DEPARTMENT OF PLANTATION CROPS AND SPICES

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680 656

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THESIS

Submitted in partial fulfilment of the requirements for the degree of

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DEPARTMENT OF PLANTATION CROPS AND SPICES

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DECLARATION

I, hereby declare that this thesis entitled **"YIELD IMPROVEMENT IN TRANSPLANTED GINGER BY SEED PRIMING AND BIOSTIMULANT SPRAY"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Ann Sneha.

Vellanikkara,
Date: 19.08.2020

Ann Sneha Baby
(2018-12-005)

CERTIFICATE

Certified that this thesis entitled **"YIELD IMPROVEMENT IN TRANSPLANTED GINGER BY SEED PRIMING AND BIOSTIMULANT SPRAY"** is a record of research work done independently by **Ms. Ann Sneha Baby** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Date: 19.08.2020

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(Major Advisor, Advisory Committee)
Assistant Professor and Head (i/c)
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We, the undersigned members of the advisory committee of **Ms. Ann Sneha Baby (2018-12-005)**, a candidate for the degree of **Master of Science in Horticulture**, with major field in Plantation Crops and Spices, agree that this thesis entitled **"YIELD IMPROVEMENT IN TRANSPLANTED GINGER BY SEED PRIMING AND BIOSTIMULANT SPRAY"** may be submitted by Ms. Ann Sneha Baby, in partial fulfilment of the requirement for the degree.

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Ann Sneha Baby

Affectionately dedicated to

my family

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LIST OF ABBREVATIONS AND SYMBOLS USED

Symbols	**Abbrevations**
%	per cent
ha	Hectare
mg	Milli gram
g	Gram
kg	Kilo gram
cm	Centimeter
m^2	Meter square
ml	Milli litre
L	Litre
h	Hour
ºC	Degree Celsius
spp.	Species
DAS	Days after sowing
DAP	Days after planting
DAT	Days after transplanting
CRD	Completely randomized design
AMF	Arbuscular mycorrhizal fungi
cfu	Colony forming unit
ppm	Parts per million
EI	Emergence index
T_{50}	Time for 50% emergence
MET	Mean emergence time
et al.	and other co workers

Introduction

1. INTRODUCTION

Spices are exquisite merchandise valued for its flavour, fragrance, colour, medicinal and nutraceutical properties. Spices are considered as the pride crops of India, possessing great value in domestic as well as international market. In India, spice crops cover an area of 39,39,915 ha with a production of 92,69,036 tons in 2018-19 [DASD, 2020]. Ginger is a major spice crop in India and is cultivated in many states like Assam, Maharashtra, West Bengal, Gujarat, Kerala, Meghalaya, Mizoram, Karnataka, Nagaland and Uttarakhand. In India, ginger covers an area of 1,64,313 ha and production of 17,88,970 tons during 2018-19 [DASD, 2020]. Kerala, bestowed as home of spices stands in fifth position in terms of ginger production, with a share of 9.03 percent of total production in the country [NHB, 2018].

Ginger (*Zingiber officinale* Rosc.) is a herbaceous perennial, grown as an annual for its rhizomes, which is acclaimed for its value in flavour and pharmaceutical industry. It is grown for its fresh or dry rhizomes. Several processed products are prepared from ginger, namely, products from fresh ginger such as ginger pickle, ginger paste, ginger cocktail, ginger squash, ginger wine, ginger candy, ginger preserve and ginger in brine and products from dried ginger such as scraped and unscraped ginger, bleached ginger, ginger powder, ginger oil and oleoresin, ginger drop, encapsulated ginger, effervescent vitaminised ginger powder, and ginger beer. It also possess several medicinal properties. It is a widely used carminative, relieving flatulence and stimulating gastrointestinal tract. It also acts as rubefacient and counter irritant.

Though ginger is a widely grown crop for domestic and export purpose, there are several constraints in its production. High seed rate, difficulty in storage, prevalence of pest and disease in field as well as during storage are the major constraints faced by ginger growers. In conventional method, seed rhizomes weighing 20 - 25 g are used for planting, resulting in a higher seed rate of 1500 - 2500 kg ha^{-1} and this accounts for a major share in the total cost of production. Seed rhizomes alone contribute 40 percent of total production cost in ginger. As a result, there is always a dearth in availability of healthy and good quality planting material in ginger, especially for the newly released high yielding varieties. As a remedy for this, a transplanting technique in ginger by

using single bud sprouts of about 3-5 g has been standardized. The yield and quality of rhizomes produced through this method were found to be on par with the conventional method (Prasath *et al*., 2018). Shylaja *et al.* (2017) reported that when single bud transplants were used as planting material in ginger, high seed to yield ratio was observed in all three varieties tested, with highest seed to yield ratio of 1:47 being recorded in ginger variety Aswathy. This transplant system is highly advantageous since it produce large quantity of healthy planting material and help to reduce to the seed rate which indeed reduce the cost incurred on seed rhizomes.

Seed priming is a pre-germination treatment in which seeds are held at a water potential that permits imbibition, yet forestalls radicle expansion and afterward seeds are dried back to the initial moisture level (McDonald, 2000). Priming techniques improve seed vigour regarding germination potential and expanded stress resilience and thus imparts invigoration to seedling. Chittaragi (2018) reported that the seed priming treatments had significant effect on fresh rhizome yield in ginger. Menon *et al*. (2016) observed that biopriming of rhizomes prior to transplant production in ginger, enhanced the yield of ginger rhizome.

Chitosan is a versatile biopolymer having several applications in many fields including agriculture, due to its biocompatibility, biodegradability and non-toxic properties. It is a cationic polysaccharide obtained by the alkaline deacetylation of chitin, produced from waste resources such as marine crustacean shells. In agriculture, chitosan is mainly exploited for enhancing crop production due to its bioactivities such as increasing seed germination, plant growth, chlorophyll content, photosynthetic rate and nutrient uptake and reducing stress and disease severity. According to Sharif *et al*. (2018) application of chitosan enhances the photosynthetic activity, vegetative growth and yield of the crop along with rendering strong resistance against microbial diseases and various pests of crop plants.

In this context, the present study entitled, "Yield improvement in transplanted ginger by seed priming and biostimulant spray", has been proposed to find out the best priming treatment or an optimum concentration of chitosan spray, or a combination of both, that improves yield in transplanted ginger and effective against major pests and diseases.

Review of literature

2. REVIEW OF LITERATURE

Ginger is an important spice crop, esteemed for its aroma, pungency and medicinal properties. Rhizome being the part of commercial importance as well as the planting material for next season, possess high demand in market. However, high seed rate of 1500 - 2500 kg ha^{-1} and difficulty in handling the bulk is a major constraint in ginger production. Adoption of single bud transplant technology in ginger is a remedy for reducing the quantity of planting material used, thus saving the economically valuable rhizomes for other commercial purposes. Priming of rhizomes has been reported to enhance yield in transplanted ginger. Also, there is limited knowledge about the application of biostimulant in transplanted ginger. Chitosan is a widely accepted biostimulant, obtained by processing of crustacean shell waste. This study is an attempt to find out the best priming method and optimum concentration of chitosan spray or the combination of both, to improve the yield in transplanted ginger. This chapter is the review of available literature on these aspects.

2.1 EFFECT OF RHIZOME SIZE

Wiersema and Cabello (1986) analysed the comparative performance of different sized seed tubers *viz.* 1-5 g, 5-10 g, 10-20 g and 40-60 g in potato. Greater tuber weight per stem was seen in 40-60 g tubers, throughout the growing season. However, the number of main stems per unit weight of seed tuber was five times greater in 1-5 g tubers and this resulted in low seed weights per hectare when used as planting material and a high ratio of harvested to planted tuber weight.

According to Blay *et al*. (1998) the smallest set of size 1g resulted in highest multiplication ratio of 9.85 during harvest in ginger. Sets of various size such as 1, 2, 5 and 10 g were used for planting and it was found that there is an inverse relationship between set weight and multiplication ratio. Multiplication ratio of 1, 2, 5, 10 g setts were 9.85, 9.14, 6.80, 4.78 and 0.60 respectively.

Yaseen *et al.* (2013) verified that tubers of size 3-4 g with crown, when used as planting material, is effective in producing maximum yield, as evident by, larger number of tubers per plant and improved fresh yield of root per plant in safed musli.

Prasath *et al.* (2014) conducted an experiment to standardize protray based single sprout transplanting technique in ginger. Growth and yield performance of plants raised by single sprout transplanting (3-5 g), two-three bud transplanting (5-10 g), two-three buds direct planting and direct planting of 20-25 g rhizomes were analysed. Morphological parameters and yield level of all treatments were on par and single sprout transplanting was found to be superior with respect to reduced cost of production.

Nair (1977) cited by Shylaja *et al.* (2016) reported the use of detached sprouts from mother rhizomes as the planting material in ginger. The plants raised from detached sprouts were reported to yield an average of 1.16 kg green ginger per plant under Ambalavayal conditions of Kerala.

A transplanting technique in ginger by using single bud sprouts of about 3-5 g has been standardized. Adoption of this technology results in the production of healthy planting materials and reduction in bulkiness of seed rhizome, with reduced cost on seeds. The yield and quality of rhizomes in this method were on par with the conventional method (Thapa *et al.,* 2017).

A study conducted by Prasath *et al*. (2018) proved that ginger can be successfully grown in single sprout transplant system with comparable yield and quality of conventional rhizome planting under open field condition. The yield and quality of rhizomes from transplant were on par with that of direct planting system.

According to Shylaja *et al.* (2018) there is no additional advantage in yield of ginger, with higher amount of seed material used.

Ara *et al*. (2019) reported that the maximum benefit-cost ratio in ginger production was obtained when rhizomes weighing 5±2 g was used as planting material.

2.2 EFFECT OF TRANSPLANTS

A rapid multiplication technique for propagation of turmeric using single bud transplants was studied by Chitra and Jansirani (2014). It was observed that plants raised from single sprout rhizome bit of finger rhizome recorded highest shoot length, root length, vigorous index and crop establishment.

Ginger transplants raised in protrays using rhizomes weighing 4-5 g and having a prominent dormant bud was found to be a best option for raising seedlings in water scarce areas. This is an innovative method for ginger production and recorded rhizome yield of 12-15 t ha^{-1} (Mali *et al*., 2015).

Mali *et al*. (2016) studied the growth and yield parameters of turmeric raised using different planting material viz. mother rhizomes, primary rhizomes and portray seedlings from a single node of finger rhizome under Konkan agro-climatic conditions. It was observed that height and number of leaves per plant, suckers per hill and yield per plant were significantly higher in plants raised from portray seedlings. Also, raising of protary seedlings is suggested as a solution to the acute water shortage during the planting season of turmeric in April - May in Konkan region.

Single bud rhizome technique of turmeric result in reduction of seed rhizome requirement by 25 per cent, which indeed reduce the cost of production and save the valuable rhizomes for other commercial purposes. This method is also effective for production of disease free planting material and saves the land usage for 1-2 months from the normal duration period of the crop (Malhotra *et al*., 2016)

Protray seedlings of ginger, prepared by planting single bud sprouts (about 5 g) are gaining popularity, since it produce good quality planting materials at reduced cost. This method can be adopted for producing disease free planting materials. Reduction in seed rhizome requirement and the yield performance which is on par with the conventional method are the additional benefit of this technique (Malhotra and Cheriyan, 2017).

Shylaja *et al.* (2017) suggested that single bud transplants can be adopted for open precision farming and can be used for the multiplication of newly released varieties having less initial seed material. It exhibited high seed to yield ratio and the quality of rhizomes were also comparable to the conventionally raised rhizomes.

Prasath *et al*. (2017) reported that use of single bud sprouts of ginger weighing about 5 g can be utilized for quality planting material production of ginger in protrays. Though it is non-conventional, transplanting technique is found profitable as it reduced the quantity of planting material required and thereby reducing the cost of production.

A similar technique can be adopted in turmeric also. This provided an additional advantage of early rhizome development and increase in yield up to 25 percent along with reduced cost of production, extended period of planting and good crop establishment.

When three different planting material *viz*. seed rhizome of 20 g, single bud transplants and microrhizome were tested for yield performance, it was proven that single bud transplants performed better than the other treatments, under polyhouse condition (Shylaja *et al*., 2018).

2.3 EFFECT OF SEED PRIMING

Seed priming can result in a rapid establishment of healthy seedlings (Reddy *et al.*, 2011).

Bio priming of seeds before planting in okra and sunflower, enhanced the growth attributes and yield (Rafi and Dawar, 2015).

Menon *et al*. (2016) observed that biopriming of rhizomes prior to transplant production in ginger, enhanced the number of tillers, increased the plant height and exhibited a significant increase in yield of ginger rhizome.

The fresh rhizome yield of transplants from the primed rhizome bits (3-5 g) were found higher than the unprimed control (Chittaragi, 2018).

2.4. EFFECT OF PRIMING WITH ETHEPHON

Kumari and Singh (2000) conducted an experiment using ethephon to break dormancy and to increase germination in sunflower. Spraying of Ethephon 250 ppm on the capitulum from the first day of anthesis until harvest, at weekly intervals, was reported to be effective in increasing germination. This recorded a hike in germination percentage from 35.5 per cent to 69.1 per cent at 21 days after anthesis and from 62.1 per cent to 82.2 per cent at 28 Days after anthesis, compared to control.

Soaking of sunflower seeds in Ethrel 0.3 ml L^{-1} and 0.4 ml L^{-1} resulted in increased germination percentage *viz.* 100 per cent and 99 per cent and are termed as excellent seed treatment for breaking seed dormancy by Maiti *et al*. (2006).

Seed treatment with Ethrel 25 ppm resulted in highest viability (99%) and showed a higher germination percentage of 80 per cent and seedling vigour index , compared to control (Pallavi *et al*., 2010).

Mahesh and Karla (1998) cited by Shylaja *et al.* (2016) states that ethephon treatment can be used to improve yield in transplanted ginger. Ginger transplants produced by five gram pieces of rhizomes and treating with ethrel 200 ppm, recorded yield of 0.82 kg per plot.

Soaking sunflower seeds in ethrel 25 ppm was effective in increasing the germination (Adams and TeBeest, 2016).

Chittaragi (2018) observed that priming of ginger rhizomes with ethephon 200 ppm for one hour resulted in significantly highest increase in fresh yield of rhizomes from ginger transplants, than unprimed control.

2.5. EFFECT OF HYDROPRIMING

A study was conducted to know the effect of different priming methods in growth and yield of field sown rice. All the priming treatments were effective in obtaining better crop stand and yield, and it reduced the time taken from emergence to heading and from heading to maturity. Among the various priming treatments given, hydropriming increased the plant height and number of fertile tillers per m^2 (Farooq *et al*., 2006).

Maiti *et al*. (2006) conducted a study to increase germination in *Helianthus annuus* L. by soaking seeds in Ethrel (0.3 ml L^{-1} and 0.4 ml L^{-1}), water (5 h, 12 h, 24 h and 34 h), acetone (25%) and potassium nitrate (0.2%). Among this, soaking seeds in water 5 h and 12 h was considered to be economical, giving a satisfactory germination percentage of 91.5 and 85 per cent respectively.

Hydropriming increased the final emergence percentage, seedling fresh and dry weight, number of productive tillers, kernal yield and harvest index in transplanted rice, when compared to control (Farooq *et al*., 2007).

Aging followed by hydropriming for 8 hours in coriander seeds resulted in germination percentage ranging from 46.25±3.77 per cent to 84.75±3.77 per cent,

compared to germination percentage of 18.25±5.91 per cent to 35.25±2.22 per cent in non-primed seeds. Also, mean time for germination (MTG) and mean time of emergence (MTE) was lower in hydroprimed seeds, irrespective of aging treatments (Rithichai *et al.*, 2009).

Pallavi *et al*. (2010) observed that sunflower seeds soaked in water for 24 h, exhibited higher germination (82%) and increased vigour index than the control, where the germination was only 24%.

Ehsanullah *et al.* (2011) reported that hydropriming has enhanced the emergence index and final emergence percentage and lowered the mean emergence time and time taken for 50 per cent emergence in fresh primed achenes of sunflower.

Hydropriming resulted in early emergence and enhanced growth and yield, as evident by production of more branches, more number of pods, higher grain yield and biological yield in chickpea (Zarei *et al*., 2011).

Sowmya *et al*., (2013) conducted investigations on optimum temperature and time required for hydropriming in cucumber. The study revealed that hydropriming for 48 hours at 25 ºC, resulted in early emergence of seedlings and recorded lower T_{50} and MGT values.

Costa *et al.* (2013) worked with soybean seeds and observed that, when good quality seeds with low incidence of storage fungi was used for hydropriming, it accelerated the speed of germination. It was verified that presence of fungal pathogen may reduce the positive effects of hydropriming.

Seeds of rye when subjected to hydropriming with aeration significantly increased the germinaton percentage and higher length (Hamidreza *et al*., 2013).

Hydropriming resulted in increased shoot length, seedling fresh weight and enhanced the photosynthetic pigment content such as chlorophyll a and b, to an extent of 43 and 49 per cent respectively, even under induced stress conditions (Jisha and Puthur, 2014).

Sharma *et al.* (2014) reported that okra seeds subjected to hydropriming for 12 h, stimulated the growth and yield, as evident by acceleration in seed germination,

seedling vigour and mean germination time and finally resulting in 55 per cent increase in fruit yield as compared to control.

Ghassemi-Golezani *et al*. (2014) reported that hydropriming for 8 and 16 hours improved the mean emergence time of seedling, biological yield and grain yield per unit area, when compared to unprimed control in mung bean. Though both priming hours produced statistically similar results, hydropriming for 16 hrs produced better results.

Hydropriming enhanced seed performance of upland rice by increasing seed germination (97%), seedling vigour, establishment and growth, when compared to other priming treatments (Banjobpudsa *et al.*, 2017).

Nawaz *et al*. (2016) studied the effect of priming treatments in no till wheat and found that hydropriming, when compared to control, improved early sprouting, uniform seedling emergence, hastened the time taken for 50 per cent emergence, improved the emergence index, produced more productive tillers and yielded high as visible by increased grain yield and enhanced productivity.

Thakur *et al*. (2016) observed that hydropriming for six hours and biopriming with *Pseudomonas fluorescens* improved the vigour index, germination percentage, plant height, number of tillers, number of seeds per finger, grain yield, straw yield and harvest index in finger millet, when compared to control. However, on comparing both, hydropriming was found to be superior in all these aspects than biopriming.

2.6. EFFECT OF PRIMING WITH *Trichoderma* spp.

Mukhtar *et al.* (2012) studied the potential of six species of *Trichoderma* in enhancing the seed germination in soybean. Results revealed that seed treatment with *T. harzianum* and *T. hamatum* was effective in increasing germination and resulted in 96% germination. In addition to this, it also imparted earliness in germination and high germination index. However, seed treatment using other species such as *T. viridi, T. aureoviride* and *T. koningii* also enhanced the germination percentage significantly, compared to the untreated control.

Priming of ginger rhizome with *Trichoderma viride* 4 g L^{-1} before planting resulted in increased resistance to rhizome rot caused by *Fusarium oxysporum* f.sp *zingiberi* and exhibited higher plant height, number of tillers and yield (Khatso and Tiameren, 2013).

Biopriming of chilli seeds with *Trichoderma viride* at 60 per cent for three hours resulted in increased germination rate, germination percentage, mean root length and shoot length, biomass yield and seedling vigour index, when compared to the control (Ananthi *et al.*, 2014).

Bhargava *et al.* (2014) conducted an experiment to study the effect of seed priming in snapdragon and soaking of seeds in liquid culture of *Trichoderma harzianum* ($1x10^5$ cfu ml^{-1}) was found to be effective by exhibiting higher germination percentage, number of leaves, shoot and root length under nursery conditions. When transplanted to polyhouse, the effect of priming had a notable difference in growth, flowering and seed attributes.

Biopriming of okra seeds with *Trichoderma viride* and *Pseudomonas fluorescens* was studied by Rai and Basu (2014). Result showed that seed treatment with *Trichoderma viride* resulted in maximum plant height, pod length, pod diameter and seed yield per plant.

Lalfakawma *et al.* (2014) reported that treatment of seed rhizomes of ginger with *Trichoderma* spp. and neem extract, exhibited maximum plant height at 180 DAP in ginger plants. This also increased the number of tillers per plant and fresh yield of rhizomes and reduced the disease incidence but less effective than the chemical control using copper oxychloride.

Trichoderma harzianum 100 per cent pure conidal suspension, when used for bio priming of seeds of okra and sunflower before planting, augmented the growth parameters such as root length, shoot length, root weight and shoot weight and exhibited a significant reduction in incidence of fungal pathogens like *Rhizoctonia solani*, *Macrophomina phaseolina* and *Fusarium* sp. (Rafi and Dawar, 2015).

Menon *et al.* (2016) reported that priming of ginger seed rhizomes with *Trichoderma viride* and planting in AMF enriched rhizosphere resulted highest number of tillers and plant height and a significant increase in yield of ginger.

Lingyun *et al.* (2017) studied the effect of solid matrix priming with *Trichoderma harzianum* with an active ingredient concentration of 3×108 cfu g^{-1}, in eggplant. It was observed that the treatment resulted in a significant improvement in germination vigour, germination index and vitality index. It also accelerated seedling emergence and enhanced the height and weight of seedlings. Moreover, there was a significant increase in photosynthetic rate, which in turn promote the plant growth.

Chaurasia and Bara (2018) demonstrated that seed priming with *Trichoderma harzianum* 0.6 per cent enhanced field emergence, number of plants per plot, plant height, number of primary branches, number of pods, seed weight and seed yield in chickpea (*Cicer arietinum* L.).

2.7. EFFECT OF PRIMING WITH *Pseudomonas* spp.

Howell and Stipanovic (1978) studied the antagonistic effect of *Pseudomonas fluorescens* against *Rhizoctonia solani* in cotton. They observed that treating cotton seeds with *Pseudomonas fluorescens* prior to planting, resulted in an increase of seedling survival in pathogen infested soil.

Kumar *et al*. (2001) verified that plant growth promoting *Pseudomonas* strains produced siderophores, which has antifungal and antibacterial activity, thus reducing the disease incidence in crops treated with *Pseudomonas* sp.

Seeds of pearl millet primed with *Pseudomonas fluorescens* (10^8 cfu ml^{-1}), showed improvement in growth parameters and disease resistance, under green house and field condition (Raj *et al.*, 2004). It stimulated the germination, seedling vigour, plant height, leaf area, tillering, yield and 1000 seed weight. Earliness in flower emergence and higher induced resistance to downy mildew caused by *Sclerospora graminicola*, was also noticed in treated plants. This resistance was due to the development of induced systemic resistance (ISR) in plants, which is persistent throughout the crop growth period.

Maximum plant height and leaf area was reported in black pepper cuttings applied with *Pseudomonas fluorescens viz*., during the time of planting and after first and second month of planting. The same method of application of *Pseudomonas fluorescens* thrice during the crop growth period, combined with enriching the potting mixture with *Trichoderma harzinaum* had a synergestic effect and resulted in a significant increase in number of roots and biomass production (Thankamani *et al.,* 2005).

Hameda *et al*. (2010) found that *Pseudomonas* sp. was effective in inhibiting the infection of *Sclerotium rolfsii* in chickpea and reduced the disease incidence to 47 percent.

Pseudomonas fluorescens when used for priming, stimulated the germination and growth in sunflower. Germination and vigour index, growth parameters such as shoot and root length, fresh and dry weight of seedlings and production of roots were significantly improved with biopriming (Moeinzadeh *et al*., 2010).

Germination percentage was higher for seeds primed with *Pseudomonas fluorescens* when compared to biopriming with *Trichoderma viride* or *Trichoderma harzianum* and control, in tomato, chilli and brinjal seeds (Bhagat and Pan, 2010).

Pavlo *et al*. (2011) suggested that Pseudomonas sp. (10^8 cfu ml^{-1}) have some antagonist action towards bacterial pathogen and further observed that priming with *Pseudomonas* sp. was helpful for promoting growth as well as imparting resistance against bacterial pathogens causing soft rot in potato.

Reddy *et al*. (2011) observed that priming with *Pseudomonas fluorescens* resulted in high germination percentage, seedling vigour and higher plant height in chickpea, when compared to non-primed control. In addition, it was also found that priming of chick pea seeds with *Pseudomonas fluorescens* reduced the incidence of dry root rot disease in chickpea. It reduced the incidence to an extent of 45 per cent when compared to control.

Inoculation with *Pseudomonas fluorescence* resulted in growth improvement and stimulated phosphate uptake in rapeseed, as evident by, higher wet weight of shoots, plant height and number of pods per plant (Rad and Heshmatpoure, 2013).

Ananthi *et al.* (2014) demonstrated that, treating chilli seeds with *Pseudomonas fluorescens* 60 per cent for 12 h, augmented the germination rate (10.8) and germination percentage (95%) in chilli seeds. Moreover, it also enhanced shoot and root length and biomass yield.

2.8. CHITOSAN

Chitosan is a cationic polysaccharide obtained by the alkaline deacetylation of chitin, produced from waste resources, mainly marine crustacean shells. Both chitin and chitosan are important in agriculture due to its versatile properties. However, solubility of chitin is a constraint, since it is soluble only in strong acids. Hence, chitosan which is soluble in dilute acids such as acetic acid, formic acid *etc*. and its water soluble derivatives are more popular. Structurally, chitosan is a linear polymer composed of two subunits, D-glucosamine and N-acetyl-D-glucosamine, linked with 1,4-glycosidic bonds. Chitosan exhibits three functional groups, primary and secondary hydroxyl groups and amine groups. Due to these functional groups, they can easily undergo chemical modification. In addition, these functional groups affect the solubility and mechanical properties of chitosan.

2.9. FUNCTIONS OF CHITOSAN

In agriculture, chitosan is mainly exploited for enhancing crop production due to its activities such as increasing seed germination, plant growth, chlorophyll content, photosynthetic rate and nutrient uptake and reducing stress and disease severity (Van *et al.*, 2013). The mechanism for the biostimulant effect is not yet clear, but may involve, induced stimulation of antioxidant defence machinery (Agarwal *et al*., 2002), stimulation of nitrogen metabolism (Gornik *et al*., 2008), increased uptake of water and essential nutrients through adjusting cell osmotic pressure (Guan *et al*., 2009) and through improved water use efficiency by reduction of transpiration (Bittelli *et al*., 2001).

2.10. BIOSTIMULANT EFFECT OF CHITOSAN IN INCREASING GROWTH AND YIELD

Chitosan when added to the culture medium in *in vitro*, followed by foliar application during the acclimatisation phase, resulted in enhanced number, yield and quality of mini tuber under greenhouse condition, which can later be used to raise field plants with increased tuber yield (Kowalski *et al*., 2006).

Chitosan when used for dipping the cuttings of grapevine before planting, improved the rooting of the cuttings. Later such treated plants exhibited higher length, more number of internodes and new canes and higher chlorophyll content (Gornik *et al*., 2008).

Chitosan 500 mg L^{-1} in culture medium, improved the acclimatization of potato plantlets in *exsitu* conditions and exhibited increment in number and yield of minituber, when compared to control (Asghari-Zakaria *et al*., 2009).

Ramos-Garcia *et al*. (2009) studied the impact of chitosan in yield of gladiolus. Gladiolus corms were dipped in chitosan 1.5 per cent for 120 mins. Results indicated that chitosan treatment accelerated the corm emergence, augmented the number of flowers and cormlets and prolonged their vase life. Corm emergence was accelerated by approximately two days, number of flowers were higher, vase life was extended by approximately two days and number of cormlets were doubled in treated plants when compared to the control plants.

Foliar spray of 75 mg L^{-1} chitosan during the growth period, enhanced herbage yield in Indian spinach. An increase in plant height, leaf and branch number, leaf area and fresh weight of leaf and stem was observed in treated plants (Mondal *et al.*, 2011).

Mondal *et al*. (2012) conducted pot and field experiments to investigate the effect of foliar application of chitosan on morphological, growth and yield of okra. Chitosan concentrations *viz*. 0 (control), 50, 100 and 125 ppm was sprayed thrice during crop growth period. Results revealed that chitosan concentrations 100 - 125 ppm increased morphological parameters such as plant height and number of leaves per plant and growth parameters such as total dry mass per plant, absolute growth rate and

relative growth rate. Chitosan sprays also increased yield attributes such as number of fruits per plant, fruit size, single fruit weight and total fruit yield per ha when compared to the control.

Improvement in growth and yield was observed in chilli plants grown in soil mixed with 1.0 per cent chitosan. Such plants exhibited more height, greater canopy diameter, increment in leaf numbers and size and higher cholorophyll content. This resulted in significantly higher fruit and seed yield in chilli (Chookhongkha *et al*., 2012).

Enhancement in the accumulated cell biomass was seen when chitosan was added to the cell culture of *Ocimum basilicum* L. at a concentration of 200 mg L^{-1}. However, chitosan 50 mg L^{-1} was found best suited for exhibiting the same effect in *Ocimum gratissimum* L. and *Ocimum sanctum* L. (Mathew and Sankar, 2012).

Mahdavi (2013) reported the effect of chitosan in increasing seed germination and plant growth in isabgol. Chitosan at a concentration of 0.2 per cent, increased the germination percentage, shoot length and root length when compared to control and other concentrations. 42 per cent more germination was seen in seeds treated with chitosan 0.2 per cent, than the control. In addition to this, an overall increase in growth was also noticed.

Effect of chitosan nanoparticles on nutrient uptake in coffee seedlings has been investigated by Van *et al.* (2013). Application of chitosan nanoparticles 10-20 ppm significantly enhanced the uptake of nitrogen, phosphorous, potassium, calcium and magnesium compared to the control. Also, treated seedlings exhibited higher content of chlorophyll a, b and carotenoid than the control. Further it enhanced the photosynthetic rate that contributed to growth promotion of coffee seedlings.

Use of chitosan for seed coating for maintaining the seed quality was studied by Chookhongkha *et al.* (2013). Top-spray fluidized bed coating equipment was used for coating chilli seedlings with chitosan. Results revealed that seeds coated with chitosan showed greater germination percentage and lesser seed infection when compared to control. Also, no difference in seed moisture content was noticed, which suggest that

chitosan seed coating can also be carried out in orthodox seeds, as it does not increase the moisture content.

Saif-Eldeen *et al.* (2014) suggested that foliar application of chitosan 2 ml L^{-1} and seaweed extract 2 g L^{-1}, significantly enhanced the growth characters (plant length, number of leaves and dry weight of leaves), improved yield and quality parameters of heads such as weight and diameter of head, fresh and dry weight of receptacle and total soluble solids.

There was an increase in the number of corms in freesia plants when treated with chitosan (5 g L^{-1}) (Salachna and Zawadzinska, 2014).

Foliar application of chitosan 4 and 6 mg L^{-1} significantly improved the plant growth parameters such as height, number and fresh weight of leaves and resulted in higher yield along with increase in volatile oil. Also, weight loss on storage was least with chitosan applied garlic (Ahmed, 2015).

Foliar application of chitosan at a concentration of 75 mg L^{-1}, enhanced the growth as well as reproductive parameters and stimulated the yield as evident by increased number of fruits $plant^{-1}$ in summer tomato (Mondal *et al*., 2016).

Anusuya and Sathiyabama (2016) demonstrated the biostimulant effect of chitosan in turmeric. Foliar sprays of chitosan 0.1% was given to turmeric plants at monthly intervals upto 210 days. Results revealed that the growth parameters were increased with the application of chitosan. This inturn resulted in increased rhizome yield. Foliar application of chitosan increased the fresh weight of rhizome by 60 per cent and dry weight by 50 per cent. In addition to this, chitosan treatment elicited 4 fold increase in curcumin content in turmeric rhizomes compared to control.

Falcon-Rodriguez *et al*. (2017) conducted a field trial to study the effect of chitosan in increasing yield in potato. It was found that foliar sprays of high molecular weight chitosan at concentration 200-325 mg ha^{-1} increased the tuber yield to 15-30 percent in potato.

Chitosan can be applied in soil to improve plant productivity. Xu and Mou (2018) suggested that chitosan can be used as an organic fertilizer, as it contain 6-9 per

cent Nitrogen. It stimulate the growth of beneficial microbes in soil. It act as a carbon source for microorganisms and accelerates the conversion organic matter into inorganic form and thus improve the nutrient uptake. It act as a chelating agent and thereby increase the availability of nutrients like iron, copper and zinc. It also increases water holding capacity due to its porous nature.

Chitosan 3 g L^{-1} when applied as foliar spray significantly increased the plant height, leaf area, number of fingers, photosynthetic rate, stomatal conductance and fresh and dry weight of rhizome in Kasthuri turmeric. Fresh yield was 45 percent more than the control (Thengumpally, 2019).

2.11. BIOSTIMULANT EFFECT OF CHITOSAN IN SECONDARY METABOLITE PRODUCTION

In *Mentha piperita,* application of chitosan to suspension cultures at a concentration 200 mg L^{-1}, resulted in 40 fold increase in menthol production (Chang *et al.,* 1998).

Kim *et al.* (2005) demonstrated that chitosan 1 per cent when used for seed soaking and root dipping resulted in enhanced growth and secondary metabolite content in sweet basil. There was a significant increment in rosmarinic acid and eugenol levels say, 2.5 per cent and 2 per cent respectively.

Chitosan when applied as a foliar spray, increased artemisinin biosymthesis in *Artemisia annua* L. The optimum concentration to improve the artemisinin content was found to be 100 mg L^{-1} (Lei *et al*., 2011).

Yin *et al*. (2012) suggested that chitosan at a concentration of 200 mg L^{-1} sprayed on oregano plants two weeks before the estimated flowering time, resulted in upregulation of polyphenol content and increased height and growth in oregano.

The effect of various elicitors in secondary metabolite production in aswagandha plants was studied by Gorelick *et al*. (2015). Elicitors such as Methyl salicylate, chitosan and NaCl were provided to plants through hydroponic nutrient media. Results have shown that methyl salicylate and chitosan had significantly

increased the withaferin A content by 75% and 69% respectively in treated plants than the control.

2.12 EFFECT OF CHITOSAN AGAINST BIOTIC STRESSESS AND INCREASING PRODUCTIVITY

Chitosan act as a defence booster by enhancing plant immunity and through antimicrobial activity. For improving plant immunity, chitosan performs as an elicitor of plant defence responses through various mechanisms such as triggering nitric oxide pathway (Raho *et al.,* 2011; Zhang *et al*., 2011), producing reactive oxygen species (Khan *et al.,* 2003; Lin *et al.,* 2005), accumulation of pathogenesis related proteins such as chitinase and beta-1,3-glucanase (Satyabama *et al*., 2014; Ma *et al*., 2013), induction of plant defence enzymes such as phenyl alanine ammonia lyase (Ali *et al*., 2012; Kim *et al*., 2005) and through callose deposition and ligin biosynthesis (Bittelli *et al*., 2001; Faoro and Iriti, 2007; Kohle *et al*., 1985).

Anti-microbial activity includes anti-bacterial, anti-fungal and anti-viral mechanisms caused by chitosan. Three antibacterial mechanisms of chitosan were suggested such as ionic surface interaction resulting in cell wall leakage, binding of chitosan to the genetic material of microorganism and thereby inhibiting their protein and mRNA synthesis and the formation of an external film over the plant surface, limiting the nutrient availability for microorganisms (Goy *et al*., 2009). Ghaouth *et al*. (1992) suggested that anti-fungal mechanism of chitosan is by inhibiting spore germination, germ tube elongation and radial growth. Chirkov *et al*. (2001) reported anti-viral activity of chitosan. Chitosan treatment of plants may decrease inoculation efficiency, inhibit virus multiplication and constrain virus transport within the plant. Chitosan-induced callose deposition and ribonuclease activity are related to the mechanism of antiviral resistance.

Chirkov *et al.* (2001) studied the mechanism of anti-viral resistance provided by chitosan. Experiment was conducted in potato plants and leaves which which were pretreated with chitosan spray (1 mg ml^{-1}) were inoculated with potato virus X (PVX).

It was found that chitosan treatment increased the ribonuclease activity and callose deposition, which in turn decreased the virus load and disease severity in treated plants.

Effect of chitosan - copper complex in suppressing the activity of *Botrytis cinerea* causing grey mould in cucumber was studied by Ben-Shalom and Fallik (2003). Foliar application of 0.2 g L^{-1} chitosan with 1.6 mmole copper was found to be the optimum concentration, resulting in 75 per cent suppression of disease.

Algam *et al.* (2010) studied the effect of chitosan against bacterial wilt in tomato. Chitosan 10g L^{-1}, when applied as soil drench and seed treatment (10 mg ml^{-1}), reduced the incidence of tomato wilt caused by *Ralstonia solanacearum.* It was found that the biocontrol efficacy of chitosan was more when applied as soil drench than seed treatment.

Foliar spray of chitosan at a concentration of 0.1 per cent in turmeric has showed a significant decrease in disease severity of rhizome rot caused by *Pythium aphanidermatum* when compared to control (Anusuya and Sathiyabama, 2014).

Mishra *et al.* (2014) reported that chitosan when used along with *Pseudomonas* sp. was more effective in controlling the disease severity of Tomato leaf curl virus, than using chitosan or bacterial inoculant alone. Such plants also exhibited higher plant height, chlorophyll content, fruit number and yield than the diseased control. Quantification of viral load was done and it was found that plants treated with chitosan and *Pseudomonas* sp. exhibited lowest viral load.

Chitosan 0.1 per cent along with salicylic acid 2 mmL^{-1}, foliarly sprayed on tomato plants, provided induced resistance by increasing the chitinase activity, against Tomato mosaic virus. Plants sprayed with chitosan + salicylic acid showed symptoms later and less severe incidence of mosaic even after 30 days after inoculation. In addition such plants also exhibited better plant growth and yield when compared to other treatments (El-Gawad and Bondok, 2015).

Liu *et al*. (2016) studied the effect of chitosan and oligochitosan against rhizome rot of ginger in storage. Chitosan and oligochitosan, when applied as dip, both at a

concentration of 5 g L^{-1}, were effective in controlling rhizome rot in ginger, caused by *Fusarium oxysporum.*

Long *et al.* (2017) reported that dipping chilli fruits in0.8% chitosan for 1 minute, result in formation of a coating over the fruits, which significantly reduced the incidence of anthracnose disease caused by *Collectotrichum capsici.* It was also proved that chitosan have the ability to stimulate defense-related enzymes such as chitinase and β-1,3-glucanase and also enhanced the total phenolic content in flesh tissue of chili fruit.

Insecticidal action chitosan has also been reported. 100% mortality of third instar larvae of *Spodoptera littoralis* was observed when chitosan 5g kg^{-1} (w/w) was added to the artificial diet. This result was verified by exposing the larvae to field condition and thereafter spraying the plants with chitosan 5g L^{-1}, which showed 75 per cent mortality after 4 days (Rabea *et al*., 2005). Chitosan 3 g L^{-1} when sprayed on infected leaves resulted in mortality rate of 38.4 per cent after 24 hours and 40 per cent after 72 hours in *Helicoverpa armigera.* Similarly, 72 percent mortality was found within 48 hours against *Plutella xylostella,* with the same concentration of chitosan and this was comparable to the effect of commercial pesticides (Zhang and Tan, 2003).

Asif *et al*. (2017) studied the nematicidal effect of chitosan. Chitosan 1.5g kg^{-1} of soil was added to the potting mixture and each pot was inoculated with 1500 newly hatched second stage juveniles of root knot nematode. Results showed that chitosan application suppressed the nematode infestation. There was a decrease in eggmases/ plant and nematode population in 250 g soil sample. In addition, chitosan application enhanced plant growth characters such as height of the plant and resulted in increased yield.

2.13 EFFECT OF CHITOSAN AGAINST ABIOTIC STRESSES AND INCREASING PRODUCTIVITY

Bittelli *et al*. (2001) studied the antitransparent activity of chitosan and its influence in crop yield. Experiment was conducted in *Capsicum* sp. Results revealed that chitosan 1 g L^{-1} given as foliar spray was effective in reducing the water use by 26 - 43 per cent. At the same time, there was no decrease in biomass production and yield.

This was achieved by inducing stomatal closure and reducing transpiration. This suggest that chitosan can be used as an antitranspirant for agricultural uses.

Yang *et al*. (2009) studied the effect of chitosan in mitigating drought stress in apple seedlings. It was suggested that**,** foliar application of chitosan 100 mg L^{-1} is able to reduce the adverse effects of drought stress. This was achieved through the increase in production of antioxidant enzymes like super oxide dismutase and catalase, and thus helped to mitigate drought stress.

Jabeen and Ahamad (2013) reported that chitosan application can enhance the production antioxidant enzymes such as super oxide dismutase, peroxidase and catalase in plants grown under salt stress. This leads to effective scavenging of reactive oxygen species. Also, the treated plants exhibited a reduction in malondialdehyde content. Thus chitosan treated plants showed better tolerance to salt stress. Experiment was conducted in sunflower (*Helianthus annuus*) and safflower (*Carthamus tinctorius*) by pretreating the seed with 0.25 per cent chitosan, which resulted in increased germination percentage and increased enzyme activity so as to tackle salinity stress.

Mahdavi (2013) conducted a study in isabgol to find the effect of chitosan against salinity stress. Seeds were pretreated with chitosan and it was subjected to different levels of salinity after planting. With an increase in salinity levels from 0-12 ds m^{-1}, the germination percentage, shoot length and root length were reduced. However, treating with chitosan 0.2 per cent showed a significant increase in germination percentage, length and weight of root and shoot.

Another study conducted by Mahdavi and Rahimi (2013) proved that chitosan 0.2 per cent given as seed treatment was effective in alleviating salinity stress in Ajowan. Increase in shoot and root length and an overall enhancement in growth was seen even under the stress condition.

Ibrahim and Ramadan (2015) studied the effect of chitosan in mitigating heat stress in late sown crops of *Phaseolus vulgaris* L. Foliar sprays of zinc alone and zinc combined with humic acid and chitosan was given to plants. The results of this study showed that foliar spray of zinc combined with chitosan reduced the adverse effect of

heat stress and improved the seed yield and harvest index. An increase in nutrient uptake was also noticed.

Chitosan 0.4 g L^{-1} applied foliarly on *Ocimum basilicum* enhanced the plant growth even under drought conditions (Malekpoor *et al*., 2016).

Yahyaabadi *et al*. (2016) reported that seed treatment with chitosan 1 g L^{-1} in fenugreek (*Trigonella foenum-graecum* L.) was effective in reducing the adverse effect of salt stress and has shown improved leaf water content and photosynthetic parameters.

Bistgani *et al.* (2017) studied the effect of chitosan in *Thymus daenensis* Celak grown under drought stress. Chitosan 200–400 µl L^{-1} was given as foliar spray, thrice during the crop growth period and this reduced the ill effects of drought on dry matter and oil yield. This was achieved through increased accumulation proline in thyme plant.

In two species of sweet basil (*Ocimum ciliatum* and *O. basilicum*) grown under drought stress, chitosan application at a concentration of 0.2–0.4 g L^{-1}, was effective in mitigating the drought stress and increased the plant growth (Pirbalouti *et al*., 2017).

Li *et al*. (2017) studied the effect of chitosan in alleviating drought stress in white clover. It was proved that chitosan 1 mg mL^{-1} increased the accumulation of stress protective metabolites and amino acids such as proline, GABA, aspartic acid, valine, serine, lysine, threonine, isoleucine and phenylalanine.

Materials and methods

3. MATERIALS AND METHODS

This study entitled "Yield improvement in transplanted ginger by seed priming and biostimulant spray" was carried out at Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara from January 2019 to January 2020. The materials used and methods adopted for this study are mentioned in this chapter.

3.1. PLANTING MATERIAL

The study was conducted using seed material of ginger, stored in zero energy chamber of Department of Plantation Crops and Spices. The variety used was Aswathy, green ginger variety, released by Kerala Agricultural University. It is single plant selection from somaclones of cultivar Rio-de-Janerio, and is characterized by dwarf stature, more number of tillers per plant, dark green broader leaves, bold rhizomes, high yield and excellent quality with high recovery of oil and oleoresin. It is suitable for cultivation as pure crop or as intercrop.

3.2. DETAILS OF EXPERIMENT

3.2.1. Preparation of single bud transplants

Ginger rhizomes were cut into small pieces weighing 3-5g and having one bud in each bit. The priming treatments were imposed on cut rhizome bits (Plate 1) and were air dried overnight. The best priming treatments of previous study of Department of Plantation Crops and Spices were selected and are mentioned below:

3.2.2. Priming treatments

P1 : Absolute control

P2 : Soaking in ethephon 200 ppm for 1 hr

P3 : Hydropriming for 1 hour

P4 : Soaking in *Trichoderma* sp. (4 g L^{-1} of water for 0.5 h)

P5 : Soaking in *Pseudomonas fluorescens* (10 g L^{-1} of water for 0.5 h)

3.2.2.1. Soaking in ethephon

Commercially available formulation of ethephon 39% SL was used. 5.12 ml of ethephon 39% SL was dissolved in 10 L of water to prepare a concentration of 200

ppm. Priming treatment was done by soaking rhizome bits in this solution for one hour. After, one hour the solution was drained out and the rhizomes were spread on a clean surface for air drying to bring the rhizomes to initial moisture level.

3.2.2.2. Hydropriming

Rhizome bits were soaked in water for one hour. Later it was drained and air dried to its original moisture level.

3.2.2.3. Biopriming of rhizomes

The cut rhizomes bits weighing 3-5 g were soaked in a solution of biocontrol agents such as *Trichoderma* sp. and *Pseudomonas fluorescens*, at a concentration of 4 g L^{-1} and 10 g L^{-1} respectively for 30 minutes each. Then they were air dried under shade to its original moisture level.

3.2.2.4. Absolute control

The seed rhizomes were cut into small pieces of 3-5 g and planted immediately in the nursery.

3.2.3. Design and layout

Design : CRD

Treatments : 5

Replications : 6

Number of transplants per replication : 100

Planting season : April

3.2.4. Nursery management

The primed and unprimed seed rhizome pieces were planted in portrays with the bud facing upwards. Protrays of cavity size 1.5 cm were used for planting rhizome bits and 100 rhizome bits were sown in each tray (Plate 2). Potting mixture for protray was prepared by mixing coirpith compost, vermicompost, vermiculate and perlite in 3:1:1:1 ratio. Dried coconut leaves were used for mulching (Plate 3). These portrays were maintained in rain shelter for 45 days and observations were taken periodically.

Irrigation was given using a rose can, once in two days. In nursery, foliar sprays of 19:19:19 @ 2 g L^{-1} were given twice during a week, starting from 15 DAP.

3.2.5. Transplanting and management of plants in field

Transplants maintained in nursery for 45 days were transplanted in polybags of 30 cm diameter (Plate 4). Potting mixture for polybags was prepared by mixing Soil, Sand and FYM in the ratio of 3:1:1. Two transplants were planted in one bag and mulching was done using leaves of *Gliricidia sepium.* All recommended agronomic practices as per Package of Practices of KAU (KAU, 2016) were followed throughout the crop growth period to raise a good crop. Additionally, foliar sprays of biostimulant, chitosan were given at monthly interval as mentioned in Table 1.

3.2.6. Design and Layout

Design : Factorial CRD

Treatments : 30

Replication : 3

Number of bags per replication : 7

Number of plants per bag : 2

Nursery : April

Transplanting in polybag : June

Details of the treatment combinations are listed in Table 1.

3.2.7. Foliar application of chitosan

Biostimulant chitosan at various concentrations as detailed below was given as foliar spray at monthly intervals, starting from one month after transplanting (Plate 5). Five rounds of foliar sprays of chitosan were given during the crop growth period. Chitosan being insoluble in water, was dissolved in water mixed with 0.25 per cent glacial acetic acid before spraying.

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

Chitosan used for the present study was collected from Matsyafed Chitin and Chitosan plant, Neendakara, Kollam, Kerela. Low density chitosan flakes were used for the study.

Table 1. Details of the treatments given during the experiment

P1C1	Absolute control (no priming and no biostimulant spray)
P1C2	No priming + water spray
P1C3	No priming + chitosan 1 g L^{-1}
P1C4	No priming + chitosan 3 g L^{-1}
P1C5	No priming + chitosan 5 g L^{-1}
P1C6	No priming + chitosan 7 g L^{-1}
P2C1	Priming with ethaphon 200 ppm + no biostimulant spray
P2C2	Priming with ethaphon 200 ppm + water spray
P2C3	Priming with ethaphon 200 ppm + chitosan 1 g L^{-1}
P2C4	Priming with ethaphon 200 ppm + chitosan 3 g L^{-1}
P2C5	Priming with ethaphon 200 ppm + chitosan 5 g L^{-1}
P2C6	Priming with ethaphon 200 ppm + chitosan 7 g L^{-1}
P3C1	Hydropriming + no biostimulant spray
P3C2	Hydropriming + water spray
P3C3	Hydropriming + chitosan 1 g L^{-1}
P3C4	Hydropriming + chitosan 3 g L^{-1}
P3C5	Hydropriming + chitosan 5 g L^{-1}
P3C6	Hydropriming + chitosan 7 g L^{-1}
P4C1	Priming with *Trichoderma* sp. (4 g L^{-1}) + no biostimulant spray
P4C2	Priming with *Trichoderma* sp. (4 g L^{-1}) + water spray
P4C3	Priming with *Trichoderma* sp. (4 g L^{-1}) + chitosan 1 g L^{-1}
P4C4	Priming with *Trichoderma* sp. (4 g L^{-1}) + chitosan 3 g L^{-1}
P4C5	Priming with *Trichoderma* sp. (4 g L^{-1}) + chitosan 5 g L^{-1}
P4C6	Priming with *Trichoderma* sp. (4 g L^{-1}) + chitosan 7 g L^{-1}

P5C1	Priming with *Pseudomonas fluorescens* (10g L^{-1}) + no biostimulant spray
P5C2	Priming with *Pseudomonas fluorescens* (10g L^{-1}) + water spray
P5C3	Priming with *Pseudomonas fluorescens* (10g L^{-1}) + chitosan 1 g L^{-1}
P5C4	Priming with *Pseudomonas fluorescens* (10g L^{-1}) + chitosan 3 g L^{-1}
P5C5	Priming with *Pseudomonas fluorescens* (10g L^{-1}) + chitosan 5 g L^{-1}
P5C6	Priming with *Pseudomonas fluorescens* (10g L^{-1}) + chitosan 7 g L^{-1}

3.3. OBSERVATIONS

Observations were taken during nursery period and in field at 60 and 120 Days After Transplanting (DAT), at active tillering stage and at harvest. The following characters were recorded:

3.3.1. Nursery observations

3.3.1.1. Days to sprout

The number of days taken for the first sprout to appear was recorded as days to sprout.

3.3.1.2. Emergence index

Emergence index (EI) was calculated according to the formula suggested by the Association of Official Seed Analysts [AOSA] (1990) as cited by Ehsanullah *et al.* (2011), after modification.

$$EI = \frac{\text{Number of sprouted rhizomes}}{\text{Days of first count}} + \ldots\ldots\ldots\ldots + \frac{\text{Number of sprouted rhizomes}}{\text{Days of final count}}$$

3.3.1.3. Time to 50% emergence

The time to 50% emergence (T_{50}) was calculated according to the modified formula of that described by Coolbear *et al*. (1984):

$$T_{50} = t_i + \left(\frac{(N + 1)/2 - n_i}{(n_j - n_i)} \right) \times t_j - t_i$$

where N is the final number of rhizomes sprouted and n_i and n_j are total number of rhizomes sprouted by adjacent counts at time t_i and t_j respectively, where $n_i < (N+1)/2 < n_j$.

3.3.1.4. Mean emergence time (MET)

Mean emergence time (MET) was calculated in the modified formula as suggested by Ellis and Roberts (1981) cited by Ehsanullah *et al.* (2011):

$$MGT = \frac{\sum Dn}{\sum n}$$

where, n is the number of sprouts emerged on day D and D is the number of days counted from the beginning of emergence.

3.3.1.5. Per cent survival of sprouts (%)

This is the ratio of total rhizomes sprouted after 45 days and total number of rhizomes planted initially.

$$\text{Per cent survival (\%)} = \frac{\text{Number of rhizomes sprouted}}{\text{Number of rhizomes planted}} \times 100$$

3.3.1.6. Plant height (cm)

Plant height of each sprouts was recorded at 45 Days After Planting (DAP) by measuring the length of plant from base to the tip of the fully opened longest leaf using a centimetre scale. Ten plants were randomly selected from each replication of treatments and the mean plant height was calculated.

3.3.1.7. Number of leaves

Total number of leaves per plant were manually counted from ten randomly selected plants from each treatment replication at 45 DAP.

3.3.1.8. Number of roots

Ten plants were randomly selected from each treatment replications and the number of roots arising directly from the rhizomes (primary roots) were counted at 45 DAP.

3.3.1.9. Root length (cm)

The length of the longest primary root was measured using a centimetre scale at 45 DAP. Observations were taken from ten randomly selected samples from each treatment replication and the mean root length was calculated.

3.3.1.10. Vigour index of seed rhizomes

Vigour index of seed rhizomes is calculated by multiplying the emergence percentage (%) and transplant length (cm) *i.e.*, the sum of shoot length and root length. The treatment exhibiting higher vigour index is considered to be more vigorous (Abdul-Baki and Anderson, 1973).

Vigour index of seed rhizome = Emergence percentage x (shoot length + root length)

3.3.2. Field observations

3.3.2.1. Observations during growth stages

3.3.2.1.1. Plant height (cm)

The total height of individual plant was recorded at 60 and 120 DAT. Five plants were randomly selected from each treatment replication. The length from the base to the tip of longest and fully opened leaf was measured. The mean plant height was calculated and recorded in centimetre scale.

3.3.2.1.2. Number of tillers

The total numbers of tillers of individual plant were recorded at 60 and 120 DAT. Total number of tillers per plant were counted from five randomly selected plants from each treatment replication. The mean values were also calculated and noted.

3.3.2.2. Physiological observations

Physiological observations such as photosynthetic rate, stomatal conductance, transpiration rate were measured during the active tillering stage. The 4^{th} leaf from the top of each plant was used for recording observation (Lingyun *et al*., 2017).

3.3.2.2.1. Photosynthetic rate

Photosynthetic rate was measured using infrared gas analyser (IRGA), a portable photosynthesis system (model LI-6400, LiCor Inc. Lincoln, Nebraska, USA) at active tillering stage. Observations were recorded between 9 and 10 a.m. and expressesd as µ mol CO_2 m^{-2} s^{-1}.

3.3.2.2.2. Stomatal conductance

Stomatal conductance was measured using infrared gas analyser (IRGA), a portable photosynthesis system (model LI-6400, LiCor Inc. Lincoln, Nebraska, USA) at active tillering stage. Observations were recorded between 9 and10 a.m. and expressed as µ mol m^{-2} s^{-1}.

3.3.2.2.3. Transpiration rate

Transpiration rate was measured at active tillering stage, between 9 and 10 a.m., using infrared gas analyser (IRGA), a portable photosynthesis system (model LI-6400, LiCor Inc. Lincoln, Nebraska, USA) and expressed in units of mmol H_2O m^{-2} s^{-1}.

3.3.2.2.4. Leaf area

Leaf area was estimated at active tillering phase. Five plants were randomly selected from each replication and the fourth leaf from the top of each plant was used for measuring length and breadth. The model developed by Kandiannan *et al.* (2009) for ginger was adopted for the study and leaf area was expressed in cm^2. Leaf area (LA) = -0.0146 + 0.6621 x L x W, where L= length of leaf (cm) from the tip of lamina to the point of petiole intersection and W= maximum leaf width (cm), measured at the widest point perpendicular to midrib.

3.3.2.3. Observations at harvest

3.3.2.3.1. Number of fingers

Number of fingers per rhizome was recorded by counting the primary, secondary and tertiary fingers arising from it.

3.3.2.3.2. Fresh weight of rhizome per plant (g)

Plants were harvested after reaching the harvesting maturity indicated by the drying of leaves, after 210 DAT. Rhizomes were harvested from the plants and weight of rhizome was recorded after removing the soil and roots attached to it.

3.3.2.3.3. Dry recovery of rhizomes (%)

Cleaned rhizomes were taken and its initial weight was recorded. Then it was dried at 50 ºC in cabinet drier. Final dry weight was recorded when there was no further decrease in weight between two consecutive weights, which were recorded at periodic intervals. Dry recovery of rhizomes were calculated using the formula:

$$\text{Dry recovery (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

3.3.3. Incidence of pest and disease in field

Crop was monitored throughout the growth period and incidence of pest and diseases were recorded.

3.3.3.1. Bacterial wilt

Disease incidence was observed during July- August, one to two months after transplanting. Percent disease incidence was calculated using the formula:

$$\text{Percent disease incidence (PDI)} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

3.3.3.2. Phyllosticta leaf spot

Incidence of *Phyllosticta* leaf spot was observed during crop growth period and scoring of disease severity was done for knowing the effect of treatments on it. Five plants from each replication were randomly selected and three tillers from each plant were choosed for taking observations. Scoring was carried out by adopting a 1- 9 point scale as, 1 = no symptom, 2 = 1-5 spots per leaf, 3 = 6-10 spots per leaf, 5 = 20-25 per cent area covered, 7=26-50 per cent area covered and 9 = more than 50 per cent area

covered followed by drying of leaf (Singh *et al*., 2000). Per cent disease index (PDI) was calculated as follows:

$$\text{Percent Disease Index (PDI)} = \frac{\text{Sum of individual rating} \times 100}{\text{Number of leaves examined} \times \text{maximum disease grade}}$$

3.3.3.3. Pest and disease management

Control measures were adopted soon after the detection of pest and disease in all the above cases. In nursery, drenching of Copper oxychloride 3 g L^{-1} was done to control the spread of bacterial wilt. In field, drenching of copper oxychloride 3 g L^{-1} at an interval of 15 days, followed by a drenching with *Pseudomonas fluorescens* @ 2 percent was given irrespective of the treatments to tackle the infestation of bacterial wilt. Infestation of rhizome maggot was observed in few plants in a random manner and drenching of all polybags with Chloropyriphos 1.5 mL L^{-1} soon after the detection and removal and destruction of affected plants prevented the further spread of it. Another major infestation was that caused by *Phyllosticta zingiberi.* Scoring was done for knowing the effect of treatments on it and thereafter, three round spray of Hexaconazole 5% EC (Contaf), at an interval of fifteen days was given to plants inorder to tackle the disease.

3.4. STATISTICAL ANALYSIS

The data was statistically analysed by using OPSTAT Online Package software, to find out the best priming, best concentration of chitosan spray or the combination of both, by analysing the growth parameters and yield of transplanted ginger in nursery as well as field conditions. The rankings are indicated by superscripts in the significant tables, with 'a' denoting the highest position. Correlation between yield and biometric characters of ginger transplants was also analysed using Statistical Package for the Social Sciences (SPSS).

Results

4. RESULTS

This study entitled "Yield improvement in transplanted ginger by seed priming and biostimulant spray" was undertaken during 2019-2020 in Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara, to find out the best priming treatment, optimum concentration of chitosan or a combination of both, in yield improvement of transplanted ginger. Priming included treatments such as soaking in ethephon, hydropriming, biopriming using *Trichoderma* sp. and *Pseudomonas fluorescens* and unprimed plants were maintained as control. Five rounds of foliar application of chitosan were given to the transplanted ginger plants at four concentrations *viz*. 1, 3, 5 and 7 g L^{-1}. Water sprayed plants and plants grown without any spray served as control. Various growth parameters and yield characters were recorded during the experimental period and statistically analysed. This chapter comprises of results and statistical analysis of various parameters recorded during the experimental period.

4.1. EFFECT OF PRIMING ON PERFORMANCE OF GINGER TRANSPLANTS IN NURSERY

Effect of various priming treatments in stimulating the emergence of rhizomes and enhancing growth parameters was evaluated during the nursery period. Days to sprout (days for emergence) was noted and test for seed vigour such as, emergence index (EI), days taken for 50 percent emergence (T_{50}) and mean emergence time (MET) were computed. Also, effect of priming on growth parameters of sprouts like plant height (cm), number of leaves, number of roots, root length (cm), per cent survival of sprouts (%) and vigour index of seed rhizomes were recorded. The data pertaining to above mentioned characters are tabulated in Table 2 and 3.

4.1.1. Effect of priming on days to sprout

Rhizomes primed with *Pseudomonas fluorescens* (P5) was found superior in sprouting with least number of days to sprout (6.33 days). Rhizomes subjected to hydropriming (P3) (6.83 days) were on par with the superior treatment. In case of earliness in sprouting, the third best treatment was priming with ethephon (P2) (7.5

days). Rhizomes primed with *Trichoderma* sp. (P4) and control plants (P1) were late to sprout (7.83 days and 8.17 days respectively) (Table 2).

4.1.2. Effect of priming on emergence index (EI), time for 50% emergence (T_{50}) and mean emergence time (MET)

The vigour test was done by computing the emergence index (EI), time to 50% emergence (T_{50}) and mean emergence time (MET) and the data is depicted in Table 2. Priming treatments resulted in a notable enhancement in vigour of rhizome bits used as seed material in ginger.

4.1.2.1. Emergence index (EI)

Priming of rhizomes with *Pseudomonas fluorescens* (P5) (11.33) showed highest emergence index, though there was no significant difference among treatments. This was followed by ethephon (P2) primed plants with a germination index of 10.97, hydropriming (P3) (9.75) and priming with *Trichoderma* sp. (P4) (9.35). The lowest emergence index was recorded in control (P1) (7.84) and emergence index was improved by the priming treatments though not significant (Table 2).

4.1.2.2. Time to 50% emergence (T_{50})

Time taken for 50% emergence was lowest in rhizomes primed with *Pseudomonas fluorescens* (P5) (14.01days) though not significant. This was followed by priming with ethephon (P2), *Trichoderma* sp. (P4) and hydropriming (P3), recording T_{50} values of 14.53, 14.96 and 15.60 days respectively. Control plants (P1) grown without priming of rhizomes exhibited highest T_{50} of 16.28 days (Table 2). However, treatments were found statistically non-significant.

4.1.2.3. Mean emergence time (MET)

Although there was no significant difference between the treatments, lowest mean emergence time was observed in rhizomes primed with *Pseudomonas fluorescens* (P5) (17.51 days) indicating it as the superior treatment. Rhizomes primed with ethephon (P2) recorded MET of 18.03 days followed by rhizomes primed with

Trichoderma sp. (P4) (18.57 days) and those subjected to hydropriming (P3) (20.38 days). Highest MET (21.21 days) was found in unprimed rhizomes (P1) (Table 2).

4.1.3. Effect of priming on vigour index of seed rhizomes in ginger transplants

Effect of priming treatments on performance and vigour of ginger transplants were assessed at 45 DAP by recording the per cent survival of sprouts (%), plant height (cm), number of leaves, number of roots, root length (cm) and vigour index of seed rhizome and are mentioned in Table 3.

4.1.3.1. Per cent survival of sprouts

There was significant difference among the treatments regarding the percent survival of sprouts. Data pertaining to percent survival of sprout is furnished in Table 3. Highest per cent survival of sprouts was found in rhizomes given hydropriming for one hour (P3) (85.16%) and ethephon priming (P2) (84.16%). Biopriming with *Pseudomonas fluorescens* (P5) (81.67%) was on par with the highest. The per cent survival of transplants in control (P1) and in treatment primed with *Trichoderma* sp. (P4) were on par (76.33% and 75.00% respectively).

4.1.3.2. Plant height

Highest plant height was registered in ginger transplants raised from rhizomes primed with *Pseudomonas fluorescens* (P5) (26.90 cm). Other priming treatments such as hydropriming (P3), priming with ethephon (P2) and *Trichoderma* sp. (P4) resulted in seedling height of 26.60 cm, 24.95 cm and 24.35 cm respectively. Lowest height was recorded in control plants (P1) exhibiting 24.20 cm height. But the treatments were found non-significant statistically (Table 3).

4.1.3.3. Number of leaves

Highest number of leaves was observed in sprouts from rhizomes primed with *Pseudomonas fluorescens* (P5) (5.00). Priming with *Trichoderma* sp. (P4) and ethephon (P2) were similar in terms of number of leaves per sprout (4.60). Number of leaves in hydroprimed (P3) and control plants (P1) were 4.30 and 4.10 respectively (Table 3). However, there was no significant difference between the treatments.

4.1.3.4. Number of roots

Number of roots was found highest in sprouts raised from rhizomes primed with *Pseudomonas fluorescens* (P5) and ethephon (P2) (4.00) (Table 3). This was followed by hydropriming (P3) with an average of 3.70 roots per sprouts. The lowest number of roots was observed in control (P1) (3.60) and *Trichoderma* sp. (P4) primed transplants (3.60). However, treatments had no significant difference in number of roots in ginger.

4.1.3.5. Root length

Though there was no significant difference in root length of ginger sprouts, highest root length was recorded in transplants raised after hydropriming of rhizomes (P3) (10.60 cm). This was followed by treatments with *Pseudomonas fluorescens* (P5) (9.98 cm) and *Trichoderma* sp. (P4) (8.85 cm). Lowest root length was noted in ethephon (P2) (8.50 cm) primed and control plants (P1) (8.50 cm) (Table 3).

4.1.3.6. Vigour index of seed rhizome

Priming treatments exhibited a significant influence in improving the vigour index of seed rhizome in ginger transplants. Highest vigour index was observed in rhizomes subjected to hydropriming (P3) (3167.95) and *Pseudomonas fluorescens* (P5) (3011.99). This was followed by rhizomes primed with ethephon (P2) (2815.15) and was found on par with the highest. Lowest vigour index was exhibited by *Trichoderma* sp. (P4) (2490.00) and control (P1) (2495.99), which were on par (Table 3).

Table 2. Effect of priming on days to sprout and vigour in protray raised ginger transplants

Treatments	Days to sprout	Emergence index (EI)	Time to 50% emergence (T_{50}) (days)	Mean emergence time (MET) (days)
P1	8.17[a]	7.84	16.28	21.21
P2	7.5[ab]	10.97	14.53	18.03
P3	6.83[bc]	9.75	15.60	20.38
P4	7.83[a]	9.35	14.96	18.57
P5	6.33[c]	11.33	14.01	17.51
CD (0.05)	0.99	NS	NS	NS

Table 3. Effect of priming on performance and vigour index of protray raised ginger transplants

Treatments	Percent survival of sprouts (%)	Plant height (cm)	Number of leaves	Number of roots	Root length (cm)	Vigour index of seed rhizome
P1	76.33[b]	24.20	4.10	3.60	8.50	2495.99[b]
P2	84.16[a]	24.95	4.60	4.00	8.50	2815.15[ab]
P3	85.16[a]	26.60	4.30	3.70	10.60	3167.95[a]
P4	75.00[b]	24.35	4.60	3.60	8.85	2490.00[b]
P5	81.67[ab]	26.90	5.00	4.00	9.98	3011.99[a]
CD (0.05)	6.36	NS	NS	NS	NS	410.088

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

4.2. FIELD OBSERVATIONS

Morphological observations of plant height and number of tillers were taken at 60 and 120 DAT. Physiological observations like photosynthetic rate, stomatal conductance, transpiration rate and leaf area were measured, at active tillering stage. At the time of harvest, observations like fresh yield of rhizomes per plant and number of fingers were taken and thereafter, dry recovery percent of rhizome was calculated. Crop was monitored throughout the growth period for pest and disease incidence. Per cent disease incidence of bacterial wilt and per cent disease index of *Phyllosticta* leaf spot were computed.

4.2.1. Effect of priming and chitosan spray on growth parameters of ginger transplants

Priming and chitosan spray exhibited significant influence in promoting the plant growth. This was evident by significant improvement in plant height and number of tillers in plants given treatments, when compared to the control. Individual effect of priming and chitosan and also the combined interaction effects were analysed. The results are mentioned below.

4.2.1.1. Plant height at 60 DAT

Plant height at 60 DAT was significantly high in plants raised from rhizomes subjected to hydropriming (P3) (47.20 cm) and biopriming with *Pseudomonas fluorescens* (P5) (45.70 cm), irrespective of chitosan treatment. Plants primed with *Trichoderma* sp. (P4) exhibited a plant height of 41.39 cm which was on par with transplants primed with ethephon (P2) (41.25 cm). The lowest plant height was reported in control plants (P1) (37.89 cm). However, plants subjected to priming treatments showed significantly higher height at 60 DAT, than the unprimed control (Table 4).

When the effect of chitosan treatments were analysed irrespective of priming treatment, it was evident that the plants sprayed with chitosan at a concentration of 5 g L^{-1} (C5) (46.27 cm) and 7 g L^{-1} (C6) (44.88 cm) were significantly superior in plant height at 60 DAT. Lowest height was observed in plants set as control with no chitosan spray (C1) (40.19 cm) and plant height recorded in plants sprayed with chitosan 1 g L^{-}

^{1} (C3) (42.33 cm), water (C2) (41.67 cm) and chitosan 3 g L^{-1} (C4) (40.79 cm) were on par (Table 4).

Interaction effect of priming and chitosan spray on plant height of transplanted ginger was found to be significant, at 60 DAT. Significantly highest plant height was observed in plants primed with *Pseudomonas fluorescens* and sprayed with 7 g L^{-1} chitosan (P5C6) (50.61 cm), followed by those given a combination of hydropriming and chitosan 5 g L^{-1} (P3C5) (50.10 cm) and hydropriming with foliar application chitosan 7 g L^{-1} (P3C6) which were on par (49.99 cm) (Table 4).

4.2.1.2. Plant height at 120 DAT

At 120 DAT, highest plant height was observed in plants given hydropriming (P3) (69.67 cm), primed with *Pseudomonas fluorescens* (P5) (69.15 cm) and *Trichoderma* sp. (P4) (68.49 cm) (Table 4). Lowest plant height was recorded in control plants (P1) (64.90 cm), which was statistically similar to the plant height observed in plants primed with ethephon (P2) (65.09 cm).

Foliar application of chitosan at concentration of 7 g L^{-1} (C6) (71.20 cm) and 5 g L^{-1} (C5) (70.80 cm) exhibited significantly highest plant height at 120 DAT, irrespective of the priming treatments. Plant height observed in other treatments such as chitosan 1 g L^{-1} (C3) (67.20 cm), control (C1) (65.48 cm), water spray (C2) (65.06 cm) and chitosan 3 g L^{-1} (C4) (65.03 cm) were on par (Table 4).

Interaction effect of priming and chitosan was found significant with respect to plant height at 120 DAT (Table 4). Plants given hydropriming and sprayed with chitosan 5 g L^{-1} (P3C5) (74.77 cm) showed the highest plant height followed by those primed with *Trichoderma* sp. and sprayed with 5 g L^{-1} chitosan (P4C5) (73.94 cm), which was on par to the superior combination treatment. The lowest plant height was recorded in plants obtained a combination of ethephon priming and water spray (60.25 cm) (P2C2).

Table 4. Effect of priming and chitosan spray on plant height of transplanted ginger

Chitosan spray/ priming	Plant height at 60 DAT (cm)							Plant height at 120 DAT (cm)						
	C1	C2	C3	C4	C5	C6	Mean P	C1	C2	C3	C4	C5	C6	Mean P
P1	37.60^{h}	36.60^{h}	37.93^{h}	37.20^{h}	39.17^{gh}	38.87^{gh}	37.89^{c}	62.60^{hij}	63.67^{ghij}	64.20^{fghij}	64.53^{fghij}	68.60^{cdefg}	65.80^{efghi}	64.90^{b}
P2	39.30^{gh}	37.88^{h}	38.96^{gh}	38.71^{gh}	45.52^{bcde}	47.13^{abcd}	41.25^{b}	64.29^{fghij}	60.25^{j}	63.40^{ghij}	62.07^{ij}	67.38^{defgh}	73.16^{abc}	65.09^{b}
P3	43.11^{defg}	48.25^{abc}	47.12^{abcd}	44.61^{cdef}	50.10^{ab}	49.99^{ab}	47.20^{a}	68.08^{cdefg}	71.05^{abcde}	68.30^{cdefg}	65.13^{fghij}	74.77^{a}	70.68^{abcde}	69.67^{a}
P4	40.90^{efgh}	41.23^{efgh}	40.30^{fgh}	39.03^{gh}	49.05^{abc}	37.80^{h}	41.39^{b}	64.30^{fghij}	61.98^{ij}	71.53^{abcd}	65.91^{efghi}	73.94^{ab}	73.29^{abc}	68.49^{a}
P5	40.04^{fgh}	44.37^{cdef}	47.32^{abcd}	44.37^{cdef}	47.49^{abcd}	50.61^{a}	45.70^{a}	68.13^{cdefg}	68.36^{cdefg}	68.55^{cdefg}	67.51^{defgh}	69.29^{bcdef}	73.08^{abc}	69.15^{a}
Mean C	40.19^{b}	41.67^{b}	42.33^{b}	40.79^{b}	46.27^{a}	44.88^{a}		65.48^{b}	65.06^{b}	67.20^{b}	65.03^{b}	70.80^{a}	71.20^{a}	
CD (Priming)	2.05							2.17						
CD (Chitosan spray)	2.25							2.37						
CD (Priming x Chitosan spray)	5.03							5.31						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.1.3. Number of tillers at 60 DAT

When effect of priming on number of tillers at 60 DAT was compared irrespective of chitosan spray, highest number of tillers was observed in plants primed with *Pseudomonas fluorescens* (P5) (6.60). This was followed by plants subjected to hydropriming (P3) (6.15), *Trichoderma* sp. (P4) (5.67) and ethephon (P2) primed plants (5.32). The lowest number of tillers was found in control plants (P1) (4.40). Invariably, the number of tillers at 60 DAT was significantly high in primed plant, when compared to non-primed plants (Table 5).

Irrespective of priming treatments, chitosan sprays at concentrations 5 g L^{-1} (C5) and 7 g L^{-1} (C6) recorded the highest number of tillers at 60 DAT, with an average number of tillers of 6.11 in both cases. This was followed by chitosan sprays at concentration 1 g L^{-1} (C3), exhibiting a mean of 5.69 tillers per plant. Chitosan sprays at a concentration of 3 g L^{-1} (C4) (5.42) was on par with sprays of 1 g L^{-1} (C3) chitosan (5.69) with respect to number of tillers. Significantly lower number of tillers was observed in plants sprayed with water (C2) (5.20) and control (C1) (5.25) (Table 5).

Interaction effect of priming and chitosan spray on number of tillers of ginger was found to be significant at 120 DAT. Plants primed with *Pseudomonas fluorescens* and sprayed with chitosan 7 g L^{-1} (P5C6) recorded the highest number of tillers (7.30). Least number of tillers was observed in plants maintained as control with no priming along with water spray (P1C2) (4.07) and in absolute control plants with no priming and no chitosan spray (P1C1) (4.13) (Table 5).

4.2.1.4. Number of tillers at 120 DAT

Data regarding the number of tillers of ginger at 120 DAT is furnished in Table 5. Significantly highest number of tillers was observed in hydroprimed plants (P3) (14.79) and in plants subjected to biopriming with *Pseudomonas fluorescens* (P5) (14.79), irrespective of chitosan spray at 120 DAT. This was followed by priming with *Trichoderma* sp. (P4) (13.86) and ethephon (P2) (13.60) which were on par. The lowest number of tillers was observed in control (P1) (12.74) with no priming. Primed plants exhibited higher number of tillers than the unprimed control.

When the effect of chitosan spray on number of tillers at 120 DAT was compared irrespective of priming treatments, the highest number of tillers was observed in plants sprayed with 7 g L^{-1} chitosan (C6) (14.89), 5 g L^{-1} (C5) (14.77) and 1 g L^{-1} (C3) (14.33). Water sprayed plants showed the least number of tillers (C1) (13.13), which was on par with treatment with chitosan 3 g L^{-1} (C4) (13.24) and control (C1) (13.38).

Interaction effect of priming and chitosan spray was significant in improving the tiller production in ginger at 120 DAT. Highest number of tillers was recorded in plants given hydropriming and 5 g L^{-1} chitosan spray (P3C5) (16.97). Bio priming with *Pseudomonas fluorescens* and biostimulanat spray of chitosan 7 g L^{-1} (P5C6) was found to produce 16.47 tillers which was on par with the superior treatment. The least number of tillers was observed in plants primed with ethephon and sprayed with chitosan 3 g L^{-1} (11.21) (P2C4) (Table 5).

Table 5. Effect of priming and chitosan spray on number of tillers

Chitosan spray/ priming	Number of tillers at 60 DAT							Number of tillers at 120 DAT						
	C1	C2	C3	C4	C5	C6	Mean P	C1	C2	C3	C4	C5	C6	Mean P
P1	4.13^{r}	4.07^{r}	4.47^{pqr}	4.27^{qr}	4.53^{pqr}	4.93^{nopq}	4.40^{e}	12.33^{jkl}	12.60^{hijkl}	12.73^{hijkl}	12.40^{ijkl}	13.27^{fghijk}	13.13^{ghijkl}	12.74^{c}
P2	5.40^{klmn}	4.97^{nop}	5.30^{lmno}	4.64^{opqr}	5.50^{ijklmn}	6.10^{defghij}	5.32^{d}	13.50^{efghijk}	13.20^{fghijk}	14.70^{bcdefg}	11.21^{l}	12.91^{ghijkl}	16.05^{abc}	13.60^{b}
P3	5.81^{fghijkl}	5.44^{jklmn}	6.00^{defghijk}	6.15^{defghi}	6.87^{abc}	6.63^{abcd}	6.15^{b}	14.09^{cdefghij}	13.75^{defghijk}	15.31^{abcde}	14.36^{cdefghi}	16.97^{a}	14.27^{cdefghij}	14.79^{a}
P4	4.97^{nop}	5.07^{mnop}	6.20^{cdefgh}	5.70^{ghijklm}	6.50^{bcde}	5.57^{hijklmn}	5.67^{c}	12.99^{ghijkl}	11.99^{kl}	14.40^{cdefgh}	14.07^{defghij}	15.16^{abcdef}	14.52^{bcdefgh}	13.86^{b}
P5	5.93^{efghijkl}	6.44^{cdef}	6.49^{bcde}	6.32^{cdefg}	7.13^{ab}	7.30^{a}	6.60^{a}	13.98^{defghij}	14.11^{cdefghij}	14.51^{bcdefgh}	14.13^{cdefghij}	15.57^{abcd}	16.47^{ab}	14.79^{a}
Mean C	5.25^{c}	5.20^{c}	5.69^{b}	5.42^{bc}	6.11^{a}	6.11^{a}		13.38^{b}	13.13^{b}	14.33^{a}	13.24^{b}	14.77^{a}	14.89^{a}	
CD (Priming)	0.28							0.80						
CD (Chitosan spray)	0.30							0.88						
CD (Priming x Chitosan spray)	0.680							1.97						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.2. Effect of priming and chitosan spray on physiological characters of ginger

Physiological characters like photosynthetic rate, stomatal conductance and transpiration rate and leaf area were measured at active tillering stage (Plate 6) and the data pertaining to it were analysed to study the effect of priming and chitosan spray on it (Table 6, 7, 8 and 9).

4.2.2.1. Photosynthetic rate

Photosynthetic rate ranged from 16.23 to 23.75 µ mol m^{-2} s^{-1} under various priming treatments, irrespective of chitosan spray (Table 6). Highest photosynthetic rate was recorded in ginger plants which were given hydropriming (P3) by soaking of rhizomes in water for one hour before planting (23.75 µmol m^{-2} s^{-1}). Hydropriming was significantly superior to all other treatments. This was followed by plants primed with *Pseudomonas fluorescens* (P5) (19.11 µ mol m^{-2} s^{-1}), *Trichoderma* sp. (P4) (18.59 µ mol m^{-2} s^{-1}) and control (P1) (18.34 µ mol m^{-2} s^{-1}) which were on par. The lowest photosynthetic rate was seen in ethephon (P2) (16.23 µ mol m^{-2} s^{-1}) primed plants.

Considering the chitosan treatments alone, irrespective of priming treatments, significantly highest photosynthetic rate was registered in plants sprayed with chitosan 5 g L^{-1} (C5) (23.83 µ mol m^{-2} s^{-1}) (Table 6). Plants sprayed with chitosan at concentration of 7 g L^{-1} (C6) and 3 g L^{-1} (C4) recorded photosynthetic rates of 21.97 and 20.96 µ mol m^{-2} s^{-1} respectively, which were on par. Control plants given water spray (C2) (15.11 µmol m^{-2} s^{-1}) followed by control (C1) (14.87µmol m^{-2} s^{-1}), which were on par, resulted in the least photosynthetic rates compared to other treatments.

Table 6. Effect of priming and chitosan spray on photosynthetic rate of transplanted ginger

Photosynthetic rate (µmol m^{-2} s^{-1})							
Chitosan spray/ priming	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**Mean P**
P1	16.60	5.95	11.23	24.20	26.03	26.03	18.34^{b}
P2	18.27	13.03	18.07	14.63	18.50	14.87	16.23^{c}
P3	13.03	24.77	24.23	23.77	29.20	27.50	23.75^{a}
P4	6.73	10.47	18.53	23.67	28.07	24.10	18.59^{b}
P5	19.73	21.33	20.30	18.53	17.37	17.37	19.11^{b}
Mean C	14.87^{d}	15.11^{d}	18.47^{c}	20.96^{b}	23.83^{a}	21.97^{b}	
CD (Priming)	1.52						
CD (Chitosan spray)	1.67						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.2.2. Stomatal conductance

Effect of priming on stomatal conductance of ginger, measured during active tillering stage is given in Table 7. Significanty highest stomatal conductance was observed in plants raised by hydropriming of seed rhizomes (2.69 µ mol m^{-2} s^{-1}). Hydropriming (P3) was significantly superior in increasing the stomatal conductance, than other priming treatments, irrespective of chitosan application. This was followed by control (P1), priming with ethephon (P2), *Trichoderma* sp. (P4) and *Pseudomonas fluorescens* (P5), recording stomatal conductance of 2.22, 1.72, 1.24 and 0.97 µ mol m^{-2} s^{-1} respectively.

In case of chitosan sprays, irrespective of effects of priming, significantly highest stomatal conductance was noticed in plants sprayed with 5 g L^{-1} (C5) chitosan (2.78 µ mol m^{-2} s^{-1}) (Table 7). Stomatal conductance was 1.84 µ mol m^{-2} s^{-1} in plants sprayed with water (C2). Foliar spray of chitosan 7 g L^{-1} (C6) and 3 g L^{-1} (C4) resulted in stomatal conductance of 1.75 and 1.70 µmol m^{-2} s^{-1} respectively, which were on par. Significantly lowest stomatal conductance was recorded in control plants (C1) (1.00 µmol m^{-2} s^{-1}) grown without any biostimulant spray.

4.2.2.3. Transpiration rate

Transpiration rate was significantly high in ginger transplants raised from hydroprimed seed rhizomes (P3) (13.67 mmol m^{-2} s^{-1}), irrespective of chitosan treatments. This was followed by plants primed with *Trichoderma* sp. (P4) (10.52 mmol m^{-2} s^{-1}). Plants primed with *Pseudomonas fluorescens* (P5) (10.03 mmol m^{-2} s^{-1}) and ethephon (P2) (9.91 mmol m^{-2} s^{-1}), were on par. The lowest rate for transpiration was registered in control plants (P1) (9.04 mmol m^{-2} s^{-1}) (Table 8).

Among the treatments given with chitosan, foliar spray of 5 g L^{-1} chitosan (C5) exhibited highest transpiration rate of (13.07 mmol m^{-2} s^{-1}) irrespective of priming treatments (Table 8). This was followed by plants given chitosan sprays at concentration 3 g L^{-1} (C4) (11.40 mmol m^{-2} s^{-1}). Chitosan sprays at concentration 1 g L^{-1} (C3) (10.82 mmol m^{-2} s^{-1}) and 7 g L^{-1} (C6) (10.78 mmol m^{-2} s^{-1}) were on par. Lowest transpiration rate was observed in control plants (C1) (8.48 mmol m^{-2} s^{-1}).

Table 7. Effect of priming and chitosan spray on stomatal conductance in transplanted ginger

Stomatal conductance (μ mol m^{-2} s^{-1})							
Chitosan spray/ priming	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**Mean P**
P1	0.75	0.56	1.95	2.73	2.75	4.58	2.22^{b}
P2	1.1	2.48	1.23	1.66	3.01	0.82	1.72^{c}
P3	2.04	4.16	1.95	2.00	3.62	2.34	2.69^{a}
P4	0.14	0.2	0.91	1.57	3.97	0.62	1.24^{d}
P5	0.96	1.77	1.59	0.54	0.56	0.37	0.97^{e}
Mean C	1.00^{e}	1.84^{b}	1.53^{d}	1.70^{c}	2.78^{a}	1.75^{c}	
CD (Priming)	0.075						
CD (Chitosan spray)	0.082						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

Table 8. Effect of priming and chitosan spray on transpiration rate in transplanted ginger

Transpiration rate (mmol m^{-2} s^{-1})							
Chitosan spray/ priming	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**Mean P**
P1	7.10	5.16	8.25	10.80	11.10	11.80	9.04^{d}
P2	9.54	9.73	9.30	10.30	12.20	8.39	9.91^{c}
P3	11.00	13.40	13.10	13.40	16.20	14.90	13.67^{a}
P4	4.17	5.07	11.07	14.10	17.30	11.40	10.52^{b}
P5	10.57	12.80	12.40	8.41	8.57	7.43	10.03^{c}
Mean C	8.48^{e}	9.23^{d}	10.82^{c}	11.40^{b}	13.07^{a}	10.78^{c}	
CD (Priming)	0.33						
CD (Chitosan spray)	0.37						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.2.4. Leaf area

Leaf area was computed by using the model suggested for ginger by Kandiannan *et al*. (2009). Leaf area in ginger was significantly improved by priming and chitosan treatment and the data regarding the same is furnished in Table 9.

Leaf area was highest in plants primed with *Pseudomonas fluorescens* (P5) (30.71 cm^2), hydropriming (P3) (29.68 cm^2) and with *Trichoderma* sp. (P4) (29.17 cm^2), irrespective of chitosan treatments. Least leaf area was seen in ethephon primed plants (P2) (26.39 cm^2) which was on par with the control plants (P1) (26.74 cm^2) grown without any priming (Table 9).

Chitosan sprays at a concentration of 7 g L^{-1} (C6) had a significant effect in increasing the leaf area in ginger transplants, irrespective of priming treatments. Chitosan sprays of 7 g L^{-1} resulted in leaves with 30.76 cm^2 area. Chitosan application at 5 g L^{-1} (C5) and 3 g L^{-1} (C4) exhibited leaf area of 29.86 cm^2 and 29.40 cm^2 respectively, and were on par with chitosan 7 g L^{-1} (30.76 cm^2). Lowest leaf area was observed in plants sprayed with water (C2) (26.46 cm^2) which was on par with chitosan 1 g L^{-1} (C3) (28.04 cm^2) and control (C1) (26.72 cm^2) (Table 9).

Although interaction effect between priming and chitosan spray was found statistically non-significant, the largest leaf area was noted in plants given the treatment combination of *Pseudomonas fluorescens* and monthly sprays of chitosan 3 g L^{-1} (P5C4) (33.03 cm^2) as depicted in Table 9.

Table 9. Effect of priming and chitosan spray on leaf area in ginger

Leaf area (cm^2)							
Chitosan spray/ priming	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**Mean P**
P1	25.45	26.05	25.13	28.37	26.66	28.79	26.74^{b}
P2	24.09	24.04	24.75	24.95	29.52	31.00	26.39^{b}
P3	27.55	27.20	29.95	30.51	31.50	31.38	29.68^{a}
P4	27.64	27.27	29.39	30.14	30.76	29.83	29.17^{a}
P5	28.84	27.72	31.00	33.03	30.86	32.78	30.71^{a}
Mean C	26.72^{c}	26.46^{c}	28.04^{bc}	29.40^{ab}	29.86^{ab}	30.76^{a}	
CD (Priming)	1.66						
CD (Chitosan spray)	1.82						
CD (Priming x Chitosan spray)	NS						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.3. Effect of priming and chitosan spray on incidence of pest and disease in transplanted ginger.

Field incidence of disease and pest was recorded during the crop growth period (Plate 7). In nursery, incidence of bacterial wilt was observed. In field, bacterial wilt was noticed in during July- August. Infestation of rhizome maggot was seen in few plants in September and shoot borer in October- November. A severe infestation of *Phyllosticta zingiberi,* causing *Phyllosticta* leaf spot occurred in October- November. Field incidence of shoot borer was not severe in the experimental plot during the crop growth period. Rather, it occurred only in very few plants randomly, and a spray of Chlorantraniliprole 18 SC (Corragen) was given soon after it was noticed and was under control. This may be due to the prophylactic measures adopted beforehand.

Percent disease incidence for bacterial wilt and per cent disease index for *Phyllosticta* leaf spot were computed and analysed. Effect of priming and chitosan spray on disease incidence was evaluated as given hereunder.

4.2.3.1. Effect of priming and chitosan spray on incidence of bacterial wilt in ginger

Natural incidence of bacterial wilt caused by *Ralstonia solanacearum* was a major problem during the crop growth period. Bacterial wilt incidence was observed in the field one-two months after transplanting of ginger. Percent disease incidence (PDI) of bacterial wilt was computed and analysed statistically and is depicted in Table 10. The PDI of bacterial wilt ranged from 3.03 per cent to 22.99 per cent. But the values were found statistically non-significant.

When priming treatments were compared, lowest PDI was observed in plants given priming with *Pseudomonas fluorescens* (P5) (6.77%), followed by hydroprimed plants (P3) (8.76%). Highest disease incidence per cent was seen in control plants (P1) (15.17 %). Plants subjected to other priming treatments such as ethephon (P2) and *Trichoderma* sp. (P4), showed respective incidence of 11.39 and 15.14 per cent. Though treatments were statistically non-significant, priming had an influence on managing bacterial wilt especially treatments with *Pseudomonas fluorescens* and hydropriming (Table 13).

Occurance of bacterial wilt in the field was observed in the month of July-August and by that time only two rounds of chitosan sprays could only be completed. However, chitosan spray has no significant effect on field incidence of bacterial wilt as shown in Table 10. Irrespective of priming, when chitosan sprays were considered alone, least incidence of bacterial wilt was observed in plants sprayed with chitosan 5 g L^{-1} (C5) (6.78%). This was followed by spraying with water (C2) (9.75%) and different concentration of chitosan *viz*. 1 g L^{-1} (C3) (11.47%), 3 g L^{-1} (C4) (12.05%) and 7 g L^{-1} (C6) (13.22%). Highest percent disease incidence of bacterial wilt was observed in control plants (C1) (15.40%) (Table 13).

Interaction effect of priming and chitosan spray on field incidence of bacterial wilt was also non-significant statistically. The least incidence of 3.03 per cent were seen in plants given chitosan 5 g L^{-1} without any priming treatments (P1C5) (Table 13).

Table 10. Effect of priming and chitosan spray on percent disease incidence of bacterial wilt in ginger.

Chitosan spray/ priming	C1	C2	C3	C4	C5	C6	Mean P
P1	22.14(4.23)	16.40(4.11)	22.56(4.47)	16.19 (4.13)	3.03(1.73)	10.71(2.98)	15.17(3.61)
P2	13.23(3.77)	4.76(1.97)	10.32(3.04)	4.76(1.97)	12.26(3.64)	22.99(4.88)	11.39(3.21)
P3	12.64(3.16)	5.13(2.02)	5.41(2.34)	11.90(2.69)	8.89(2.84)	8.59(2.79)	8.76(2.64)
P4	21.43(4.02)	12.22(3.26)	14.29(3.45)	19.05(3.21)	4.76(1.97)	19.05(4.42)	15.14(3.39)
P5	7.54(2.66)	10.25(2.55)	4.76(1.97)	8.33(2.37)	4.94(2.27)	4.76(1.97)	6.77(2.30)
Mean C	15.40(3.57)	9.75(2.78)	11.47(3.05)	12.05(2.87)	6.78(2.49)	13.22(3.41)	
CD (Priming)	NS						
CD (Chitosan spray)	NS						
CD (Priming x Chitosan spray)	NS						

(Figures in parentheses are square root transformed values).

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.3.2. Effect of priming and chitosan spray on incidence of Pyllosticta leaf spot in ginger

Commencement of *Phyllosticta* leaf spot was noticed at four to five MAT during October- November. Scoring was done and per cent disease index was computed. It was observed that priming treatments had no significant influence in reducing the field incidence of *Phyllosticta* leaf spot but chitosan sprays had a significant effect in controlling it.

Plants primed with *Pseudomonas fluorescens* (P5) showed least incidence of *Phyllosticta* leaf spot though not significant statistically (41.79%). This was followed by plants given hydropriming (P3) and priming with ethephon (P2) and *Trichoderma* sp. (P4) resulting in a percent disease index of 42.78 percent, 44.96 percent and 46.79 percent respectively (Table 11). Highest index was observed in control plants (P1) (46.46%).

Chitosan sprays exhibited a notable difference in the disease incidence in the field (Table 11). Chitosan sprayed at a concentration of 7 g L^{-1} (C6) and 5 g L^{-1} (C5) exhibited significantly least percent disease index (25.65%, 30.79% respectively). These two treatments recorded significantly better results in prevention of leaf spot disease, than other concentration of chitosan and control. Application of 3 g L^{-1} (C4) chitosan resulted in percent disease index of 43.68 percent and this was significantly lower than the PDI recorded in sprays of lower chitosan concentration and control. Index of disease observed in plants sprayed with chitosan 1 g L^{-1} (C3) (51.79%) and those sprayed with water (C2) (57.49%) were on par. The highest incidence as indicated by highest percent disease index was seen in control plants (C1) with no spray (57.93%).

Interaction effect of priming and chitosan spray on field incidence of *Phyllosticta* leaf spot was found statistically non-significant. However, lowest percent disease index was observed in plants primed with *Pseudomonas fluorescens* and sprayed with 7 g L^{-1} chitosan (P5C6) (23.43%). Highest percent disease index for *Phyllosticta* leaf spot disease was recorded in absolute control with no priming and no chitosan spray (P1C1) (61.65%) (Table 11).

Table 11. Effect of priming and chitosan spray on incidence of *Pyllosticta* leaf spot in ginger

Chitosan spray/ priming	C1	C2	C3	C4	C5	C6	Mean P
P1	61.65	59.60	59.01	45.34	27.82	25.32	46.46
P2	54.04	56.07	50.35	47.28	35.47	26.50	44.96
P3	57.41	56.58	50.02	42.92	25.27	24.49	42.78
P4	58.50	58.07	50.35	48.70	36.62	28.51	46.79
P5	58.04	57.14	49.23	34.16	28.76	23.43	41.79
Mean C	57.93^{a}	57.49^{ab}	51.79^{b}	43.68^{c}	30.79^{d}	25.65^{d}	
CD (Priming)	NS						
CD (Chitosan spray)	1.59						
CD (Priming x Chitosan spray)	NS						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.4. Effect of priming and chitosan spray on yield parameters of transplanted ginger

Significant difference was observed in yield parameters of ginger with application of priming treatments and chitosan spray. Data pertaining to the number of fingers and fresh yield of rhizome per plant (g) were observed and dry recovery (%) of rhizome was calculated and presented in Table 10, 11 and 12 respectively. Images of harvested rhizomes are given in plate no. 8, 9, 10, 11, 12 and 13.

4.2.4.1. Number of fingers

Priming treatments had a significant influence on number of fingers per plant. All the priming treatments, produced significantly higher number of fingers, compared to the unprimed control, irrespective of chitosan sprays. Number of fingers in rhizomes obtained from plants subjected to hydropriming (P3), ethephon priming (P2), biopriming with *Pseudomonas fluorescens* (P5) and *Trichoderma* sp. (P4) were 10.84, 10.69, 10.48 and 10.16 respectively. Significantly lowest count of fingers was seen in control plants (9.61) (Table 12).

Chitosan spray had a significant effect on number of fingers of rhizome, irrespective of priming treatments (Table 12). Rhizomes obtained from plants sprayed with chitosan 5 g L^{-1} (C5) (12.12) exhibited highest number of fingers. Number of fingers in rhizomes obtained from plants sprayed with chitosan 7 g L^{-1} (C6) (11.11) followed this. Lowest number of fingers was seen in plants sprayed with water (C2) (9.04), which was on par with control plants receiving no sprays (C1) (9.35).

Interaction effect of priming and chitosan spray had no significant effect on number of fingers per plant as evident from the results given in Table 12. Though not significant, highest number of fingers was seen in plants given the treatment combination of hydropriming and 5 g L^{-1} chitosan spray (P3C5) (12.88). Lowest number of fingers was observed in absolute control with no priming and no chitosan spray (P1C1) (7.81).

Table 12. Effect of priming and chitosan spray on number of fingers in ginger

Chitosan spray/ priming	C1	C2	C3	C4	C5	C6	Mean P
P1	7.81	8.42	9.06	10.58	11.02	10.78	9.61^{b}
P2	9.61	8.70	10.36	11.62	12.18	11.71	10.69^{a}
P3	9.83	10.08	10.69	10.77	12.88	10.79	10.84^{a}
P4	9.73	7.98	10.25	9.89	11.77	11.54	10.36^{a}
P5	9.78	10.00	9.75	9.88	12.75	10.74	10.48^{a}
Mean C	9.35^{de}	9.04^{e}	10.02^{cd}	10.51^{bc}	12.12^{a}	11.11^{b}	
CD (Priming)	0.74						
CD (Chitosan spray)	0.81						
CD (Priming x Chitosan spray)	NS						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.4.2. Fresh yield of rhizomes

Fresh weight of rhizome per plant was analysed irrespective of chitosan treatments and superior yield was found in plants primed with *Pseudomonas fluorescens* (P5) (274.08 g plant^{-1}). Yield of rhizomes from hydroprimed plants (P3) (254.47 g plant^{-1}), ethephon primed plants (P2) (250.49 g plant^{-1}) and those primed with *Trichoderma* sp. (P4) (240.89 g plant^{-1}) were on par and next to superior treatment. However, it was apparent that the fresh yield obtained from plants grown without priming (P1) (212.73 g plant^{-1}) was the lowest. It is clear from the experiment that, all priming treatments in the experiment had a significant effect in increasing the fresh yield of ginger, when compared to unprimed control (Table 13).

When the effect of chitosan spray was compared irrespective of priming treatments, ginger plants sprayed with chitosan 5 g L^{-1} (C5) yielded highest fresh rhizome per plant (322.71 g plant^{-1}) (Table 13). Fresh rhizome yield obtained from plants sprayed with chitosan 7 g L^{-1} (C6) (297. 92 g plant^{-1}) followed the superior treatment. Yield of fresh rhizome obtained from plants sprayed with chitosan at a concentration of 1 g L^{-1} (C3) (266.19 g plant^{-1}) and 3 g L^{-1} (C4) (250.09 g plant^{-1}) were on par. Lowest yield was obtained from those sprayed with water (C2) (168.70 g plant^{-1}) and control plants (C1) (173.59 g plant^{-1}) grown without any treatment and were on par. There was a significant increase in yield on chitosan spray, irrespective of its concentration, when compared to the control. Among various concentrations of chitosan, a spray of 5 g L^{-1} chitosan at monthly interval recorded a significant increase in fresh yield of rhizome in ginger.

Interaction effect of priming and chitosan spray exhibited a significant effect on fresh yield of ginger rhizomes as depicted in Table 13. Considering the per plant yield, the highest yield of fresh rhizome was obtained from plants treated with a combination of hydropriming and monthly sprays of chitosan 5 g L^{-1} (P3C5) (337.20 g plant^{-1}), a combination of priming with as *Pseudomonas fluorescens* and chitosan 7g L^{-1} (P5C6) (335.58 g plant^{-1}) and with chitosan 5 g L^{-1} (P5C5) (334.35 g plant^{-1}). Synergistic effect of combination of priming and chitosan was superior in yield improvement in ginger, when compared to the individual effect of priming and chitosan alone.

Table 13. Effect of priming and chitosan spray on fresh yield of rhizomes in transplanted ginger

Chitosan spray/ priming	Fresh yield of rhizome per plant (g)						
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**Mean P**
P1	143.43^{lm}	141.75^{m}	229.90^{gh}	258.81^{fg}	281.04^{ef}	221.44^{hi}	212.73^{c}
P2	179.82^{jkl}	172.79^{jklm}	260.46^{efg}	233.69^{gh}	329.49^{ab}	326.70^{abc}	250.49^{b}
P3	180.37^{jkl}	165.30^{jklm}	289.75^{cdef}	228.58^{gh}	337.20^{a}	325.63^{abcd}	254.47^{b}
P4	177.96^{jklm}	161.41^{klm}	261.67^{efg}	232.61^{gh}	331.47^{ab}	280.25^{ef}	240.89^{b}
P5	186.37^{ijk}	202.25^{hij}	289.16^{def}	296.80^{bcde}	334.35^{a}	335.58^{a}	274.08^{a}
Mean C	173.59^{d}	168.70^{d}	266.19^{c}	250.10^{c}	322.71^{a}	297.92^{b}	
CD (Priming)	15.18						
CD (Chitosan spray)	16.63						
CD (Priming x Chitosan spray)	37.19						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.2.4.3. Dry recovery percent (%)

There was no significant influence of priming and chitosan spray on dry recovery of ginger rhizome as given in Table 14.

However, the highest dry recovery percentage was recorded from rhizomes of plants given ethephon priming (P2) (25.23%) though not significant statistically. This was followed by hydropriming (P3) (24.76%), control with no priming (P1) (24.21%), priming with *Pseudomonas fluorescens* (P5) (24.20%) and with *Trichoderma* sp. (P4) (23.91%).

Chitosan applications had not resulted in any significant difference in the dry recovery percent of ginger rhizome (Table 14). The highest dry recovery of rhizomes was observed in control plants (C1) (25.32%) followed by plants sprayed with chitosan 7 g L^{-1} (C6) (24.77%), 3 g L^{-1} (C4) (24.54%), water (C2) (24.50%), 5 g L^{-1} (C5) (24.45%) and 1 g L^{-1} (C3) (23.18%).

Interaction effect of priming and chitosan spray was also not significant statistically in case of dry recovery of ginger rhizomes.

Table 14. Effect of priming and chitosan spray on dry recovery of ginger rhizomes

Chitosan spray/ priming	C1	C2	C3	C4	C5	C6	Mean P
P1	24.65	23.96	22.24	25.03	23.59	25.79	24.21
P2	26.10	25.37	23.32	26.21	25.21	25.15	25.23
P3	26.14	24.94	24.92	24.44	24.73	23.34	24.76
P4	24.87	23.59	22.23	23.85	24.14	24.77	23.91
P5	24.86	24.62	23.20	23.15	24.57	24.79	24.20
Mean C	25.32	24.50	23.18	24.54	24.45	24.77	
CD (Priming)	NS						
CD (Chitosan spray)	NS						
CD (Priming x Chitosan spray)	NS						

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

4.3. CORRELATION STUDIES

Correlation coefficient represents the statistical relationship between two variables. Correlation between yield and parameters indicating the vigour and growth at nursery stage, which were typically affected by priming treatments, were worked out and correlation coefficients for different characters are depicted in Table 15. Similarly, the correlation between yield and growth and physiological characters are analysed and are mentioned in Table 16.

4.3.1. Correlation of fresh rhizome yield with vigour and growth parameters of ginger transplants

Rhizome yield in ginger showed a highly significant and positive correlation with emergence index (0.923*) and also showed a positive relation with vigour index of seed rhizome (0.765), height of transplants (0.84), number of leaves (0.832) and roots (0.729), root length (0.649) and percent survival of sprouts (0.622). Final rhizome yield exhibited a negative correlation with time to 50% emergence (-0.844) and mean germination time (-0.747). Emergence index which indicates the rate of emergence of sprouts showed a significantly higher positive correlation with number of roots (0.905*), and a positive correlation with other parameters such as vigour index of seed rhizome (0.627), height of transplants (0.642), number of leaves (0.854), and length of roots (0.342) and percent survival of sprouts (0.646). But the emergence index was negatively correlated with the time for 50% emergence (-0.929*) and mean emergence time (-0.868). Vigour parameters such as time for 50% emergence and mean emergence time showed high positive correlation with each other (0.984**) and significantly high negative correlation with number of leaves (-0.973** and -0.950* respectively). It also exhibited a negative correlation with vigour index of seed rhizome (-0.343 and -0.186 respectively), height of transplants (-0.453 and -0.292 respectively), number of roots (-0.811 and -0.749 respectively) and root length (-0.153 and -0.001 respectively) of transplants and percent survival (-0.318 and -0.196 respectively) of ginger sprouts. Vigour index of seed rhizome which is a measurement of vigour of the sprouts, have significantly high positive correlation with percent survival of sprouts (0.896*) and with height of transplants (0.936*) and also positive correlation with number of leaves

(0.301) and roots (0.526), and length of roots (0.857). Height of transplants and length of roots manifested a highly significant positive correlation (0.904*) and other parameters such as number of leaves (0.484) and roots (0.519) and percent survival of sprouts (0.708) were also positively related to height of transplants. Number of leaves and roots also exhibited a positive correlation with each other (0.72) and to length of roots (0.212 and 0.121 respectively) and to survival percentage (0.182 and 0.647 respectively). Length of roots in transplants also possessed a positive correlation with percent survival of sprouts (0.557).

Table 15. Coefficient of correlation between fresh rhizome yield and vigour and growth parameters of ginger transplants as affected by priming of rhizomes prior to planting

	Yield	Emergence Index	Time for 50% emergence	Mean emergence time	Vigour index of seed rhizome	Height	Number of leaves	Number of roots	Length of roots	Percent survival of sprouts
Yield	1									
Emergence index	0.923*	1								
Time for 50% emergence	-0.844	-0.929*	1							
Mean emergence time	-0.747	-0.868	0.984**	1						
Vigour index of seed rhizome	0.765	0.627	-0.343	-0.186	1					
Height	0.84	0.642	-0.453	-0.292	0.936*	1				
Number of leaves	0.832	0.854	-0.973**	-0.950*	0.301	0.484	1			
Number of roots	0.729	0.905*	-0.811	-0.749	0.526	0.519	0.72	1		
Length of roots	0.649	0.342	-0.153	-0.001	0.857	.904*	0.212	0.121	1	
Percent survival of sprouts	0.622	0.646	-0.318	-0.196	0.896*	0.708	0.182	0.647	0.557	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

4.3.2. Correlation of fresh rhizome yield with growth and physiological parameters in transplanted ginger

Yield of ginger manifested a highly significant positive correlation with plant height (0.673**), number of tillers (0.653**), leaf area (0.718**), photosynthetic rate (0.397*) and number of fingers (0.800**) and positive relation with stomatal conductance (0.147) and transpiration rate (0.257). Plant height possessed a significant positive correlation with number of tillers (0.784**), leaf area (0.719**), photosynthetic rate (0.382*) and number of fingers (0.637**) and a positive correlation with stomatal conductance (0.126) and transpiration rate (0.303). Number of tillers had a significant positive correlation with leaf area (0.673**) and number of fingers (0.541**). Also a positive correlation was found with photosynthetic rate (0.358), stomatal conductance (0.039) and transpiration rate (0.269). Leaf area has shown a positive correlation with photosynthetic rate (0.266) and transpiration rate (0.143) and a negative correlation with stomatal conductance (-0.086). Photosynthetic rate was significantly and positively correlated with both stomatal conductance (0.615**) and transpiration rate (0.869**). Transpiration rate and stomatal conductance (0.642**) were also found to be significantly and positively correlated.

Table. 16. Coefficient of correlation between fresh rhizome yield and growth and physiological characters of ginger transplants as affected by priming and chitosan spray.

	Yield	Plant height	Number of tillers	Leaf area	Photosynthetic rate	Stomatal conductance	Transpiration rate	Number of fingers
Yield	1							
Plant height	0.673**	1						
Number of tillers	0.653**	0.784**	1					
Leaf area	0.718**	0.719**	0.673**	1				
Photosynthetic rate	0.397*	0.382*	0.358	0.266	1			
Stomatal conductance	0.147	0.126	0.039	-0.086	0.615**	1		
Transpiration rate	0.257	0.303	0.269	0.143	0.869**	0.642**	1	
Number of fingers	0.800**	0.637**	0.541**	0.515**	0.396*	0.321	0.286	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Discussion

5. DISCUSSION

In ginger, dearth of healthy and good quality planting material is well pronounced. A transplant technique, utilizing ginger sprouts raised from small rhizomes bits grown in portrays for field transplanting has been proven to yield on par with ginger plants raised from conventional method of planting. Priming of seeds before planting has been reported to enhance vigour and establishment in ginger, which later reflects in higher yield. Chitosan is a widely known biostimulant, which is sought for its properties of enhancement in growth and yield and stimulating plant defence mechanism against biotic and abiotic stresses. In this context, this study entitled "Yield improvement in transplanted ginger by seed priming and chitosan spray" is an attempt to find out the best priming treatment, an optimum concentration of chitosan spray, or a combination of both, to achieve yield enhancement in transplanted ginger. Perusal of data shows that individual effect of priming and chitosan spray as well as the combined effect of both, were statistically significant in improving yield of crop. This chapter contains the discussion of the results obtained and whole experiment is divided and discussed as follows:

- Effect of priming on performance of ginger transplants in nursery
- Effect of priming and chitosan spray on performance of ginger transplants in field

5.1. EFFECT OF PRIMING ON PERFORMANCE OF GINGER TRANSPLANTS IN NURSERY

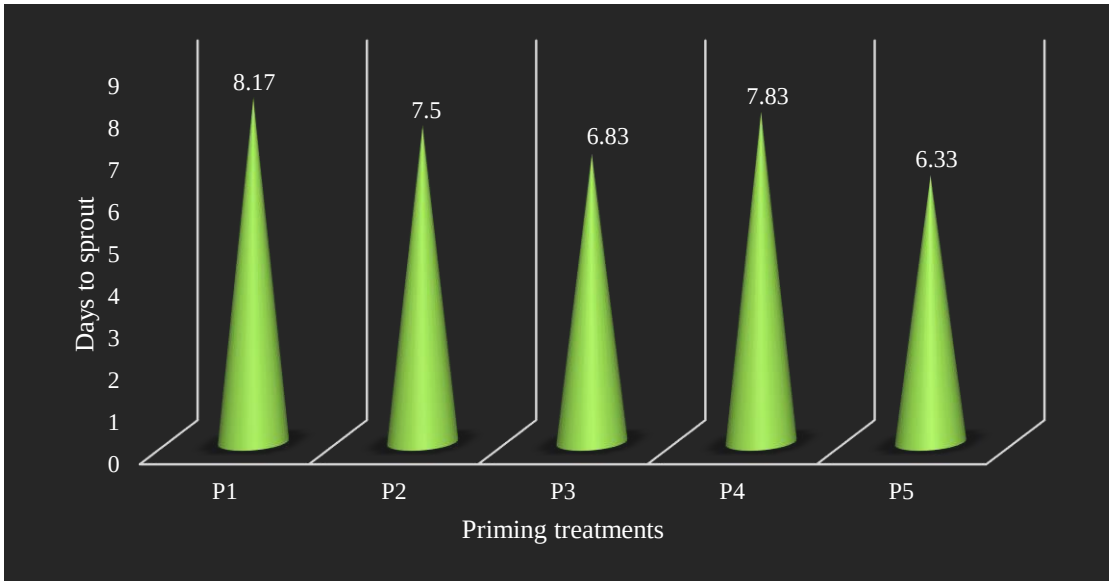
5.1.1. Effect of priming on days to sprout

Priming exhibited a significant improvement in earliness to sprout. Priming resulted in early sprouting when compared to unprimed control. Sprouting commenced from 6.33 days which was earliest and control plants were late to emerge (8.17 days) (Fig.1). The number of days to sprout was least in rhizomes subjected to priming with *Pseudomonas fluorescens* (6.33 days) which was on par with hydropriming (6.83 days). Effect of *Pseudomonas fluorescens* in improving the germination was also reported in chilli by Ananthi *et al.* (2014) and in sweet corn by Callan *et al*. (1991). Srivastava *et*

al. (2010) observed that tomato seeds when bioprimed with *Pseudomonas fluorescens* exhibited an advancement of 2 - 2.5 days in germination. In the present study, an advancement of 1.84 days was observed by priming the seed material with *Pseudomonas fluorescens* than the unprimed rhizomes.

Hydropriming was also found superior in promoting the days to emergence in ginger. Hydroprimed seeds sprouted in 6.83 days compared to 8.17 days in control. An advancement of 1.34 days in emergence of sprout was observed in hydroprimed rhizomes compared to control. This is in line with the findings of Zarei *et al*. (2011) in chickpea, in which hydropriming had a significant effect in planting to emergence time, resulting in 12.3 days for emergence in hydroprimed seeds compared to 16.3 days in control. Similar results were reported by Mabhaudhi (2009) in maize, Ghassemi-Golezani *et al*. (2014) in mung bean and Nawas *et al*. (2016) in wheat, in which hydropriming reduced the germination time and exhibited early emergence.

Fig.1. Effect of priming on days to sprout in ginger transplants



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

5.1.2. Effect of priming on emergence index (EI), time for 50% emergence (T50) and mean emergence time (MET)

Seed vigour was determined by computing the emergence index (EI), time to 50% emergence (T_{50}) and mean emergence time (MET). This study revealed that, priming had a prominent influence in improving the vigour of ginger transplants grown in nursery. All the parameters indicating the vigour of transplants *viz*. emergence index (EI), time for 50% emergence (T_{50}) and mean emergence time (MET) were superior for primed plants when compared to unprimed control and the data pertaining to this is depicted in Fig. 2 and 3. Priming of rhizomes with *Pseudomonas fluorescens* 10 g/L for 30 minutes resulted in highest emergence index (11.33), lowest T_{50} (14.01) and lowest MET (17.51). Emergence index indicate the rate of per day emergence of sprouts. Higher the emergence index, higher will be the vigour of sprouts, as affected by various priming treatments. In this study, emergence index ranged from 7.84 - 11.33. The highest per day emergence of sprouts was observed in rhizomes primed with *Pseudomonas fluorescens* and the lowest was with control resulting in per day emergence of 7.84 sprouts. Higher emergence index for rhizomes primed with *Pseudomonas fluorescens* indicate more rapid germination, thus leading to lowest days taken for T_{50} and MET. As a result, biopriming with *Pseudomonas fluorescens*, lowered the T_{50} (14.01 days) and MET (17.51 days), as compared to 16.28 days for T_{50} and 21.21 days for MET, in unprimed control. The above result are in conformation with the findings of Moeinzadeh *et al*. (2010) in which priming of sunflower seeds with *Pseudomonas fluorescens* improved germination index, germination percentage, germination rate and vigour index and enhanced the growth parameters thereafter. Ananthi *et al.* (2014) also observed high germination index (GI) of 10.8 in chilli seedlings primed with *Pseudomonas fluorescens*, as compared to GI of 7.8 in control.

Fig.2. Effect of priming on emergence index in ginger transplants

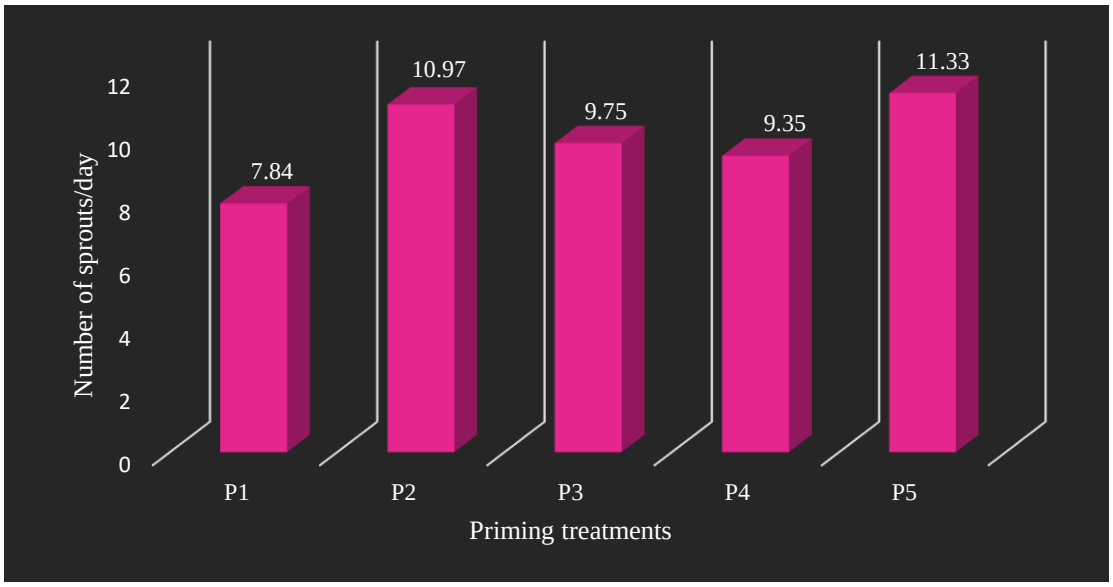
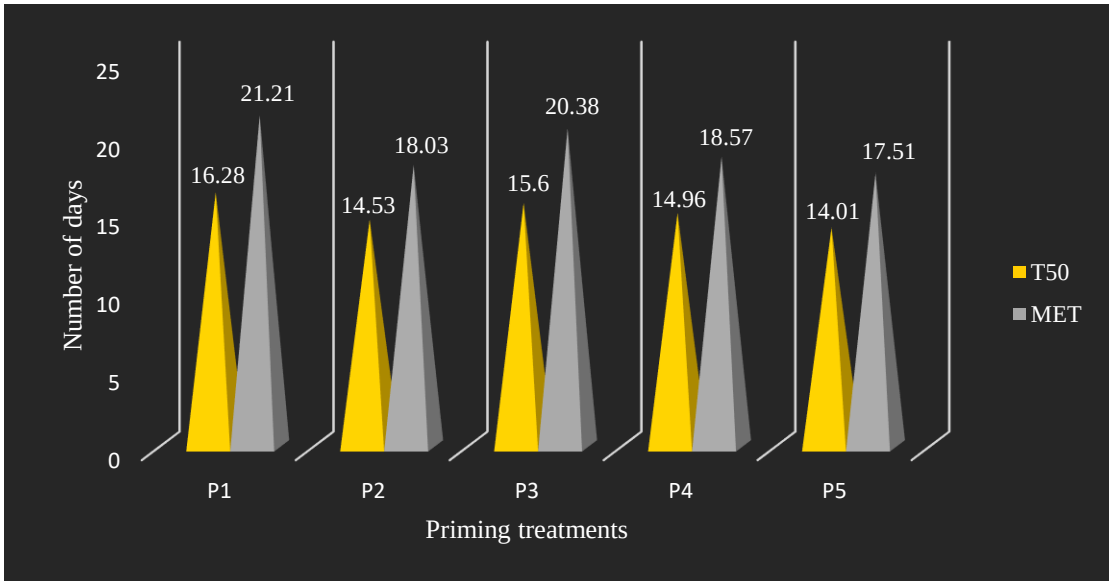


Fig.3. Effect of priming on time for 50% emergence and mean emergence time in ginger transplants



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

5.1.3. Effect of priming on vigour index of seed rhizomes in ginger transplants

Plant growth parameters such as percent survival of sprouts plant height, number of leaves and roots, root length and vigour index of seed rhizomes, as affected by priming treatments given before planting, are analysed and discussed hereunder.

5.1.3.1. Per cent survival of sprouts

Highest per cent survival of sprouts was found in rhizomes given hydropriming (85.16%) and ethephon (84.16%), followed by *Pseudomonas fluorescens* (81.67%) and the all three treatments were statistically similar (Fig.4). Chittaragi (2018) found than pre-soaking of seed rhizomes in water for one hour prior to planting, resulted in higher survival percentage of 88% in transplanted ginger planted in May. Hamidreza *et al*. (2013) observed significantly higher germination percentage of 74% in hydroprimed rye seeds. Similarly, hydropriming resulted in highest final emergence percentage in sunflower as reported by Ehsanullah *et al*. (2011). Also similar results were reported in crops like okra (Sharma *et al.* 2014), sunflower (Pallavi *et al*., 2010; Maiti *et al*., 2006) and upland rice (Banjobpudsa *et al.,* 2017).

Ethephon priming also exhibited a significant role in stimulating the germination percentage in ginger transplants. This is in line with the studies of Chittaragi (2018) in ginger transplants, recording highest per cent survival of sprouts in plants raised from rhizomes treated with 200 ppm ethephon during the planting season of April and May. Similar results are observed by Adams and TeBeest (2016) in sunflower, in which soaking of seeds in 25 ppm ethrel increased the germination rate.

Biopriming with *Pseudomonas fluorescens* was also found to have a significant effect in enhancing the per cent survival of sprouts in ginger transplants. The above results are in conformity with the studies conducted by Ananthi *et al.* (2014) in chilli, Bhagat and Pan (2010) in tomato, chilli and brinjal, Raj *et al*. (2004) in pearl millet, Reddy *et al.* (2011) in chickpea and Moeinzadeh *et al.* (2010) in sunflower.

5.1.3.2. Plant height

Priming of rhizomes with *Pseudomonas fluorescens* 10 g L^{-1} for 30 minutes resulted in highest plant height (26.90 cm), followed by hydropriming (26.60 cm). Lowest plant height was seen in control plants (24.20 cm) (Fig.5). Ananthi *et al.* (2014) also reported higher plant height in chilli seedlings primed with *Pseudomonas fluorescens* compared to non-primed seeds. Enhancement of plant height as a result of seed biopriming with *Pseudomonas fluorescens* was also reported by Callan *et al.* (1991) in sweet corn and Moeinzadeh *et al.* (2010) in sunflower.

Hydroprimed plants (26.60 cm) recorded slightly lower plant height than the seedlings given priming with *Pseudomonas fluorescens* (26.90 cm). Hamidreza *et al.* (2013) suggested that hydropriming had a significant effect in increasing the height of plants in rye.

5.1.3.3. Number of leaves

Highest number of leaves was observed in seedlings raised by priming rhizomes with *Pseudomonas fluorescens* (5.00). This was followed by priming with *Trichoderma* sp. and ethephon, both resulting in average leaf number of 4.60. Control plants (4.10) grown without priming exhibited least number of leaves in ginger seedlings (Fig.6). Bahl *et al*. (2013) opinioned that number of leaves on plant is an indication of vigour. Chittaragi (2018) observed that ginger transplants whose rhizomes were primed with *Pseudomonas fluorescens* prior to planting, produced more number of leaves than the control.

5.1.3.4. Number of roots

With respect to number of roots, plants primed with *Pseudomonas fluorescens* produced highest number of roots (4.00). Ethephon priming was also equally effective, producing the same number of roots (4.00) (Fig.6). Anandaraj and Sarma (2003) observed increased number of feeder root production and thereby increasing the absorptive surface area in black pepper plants primed with *Pseudomonas fluorescens.* Moeinzadeh *et al.* (2010) reported an enhancement in number of lateral roots in sunflower seedlings primed with *Pseudomonas fluorescens*. Similar results by

Thankamani *et al*. (2005) showed an increase in root production to the extent of 23%, in pepper plants dipped in *Pseudomonas fluorescens*, when compared to the control. This increment in number of roots may be due to the increase in auxin content near the root zone, occurring as a result of application of *Pseudomonas fluorescens*, resulting in high root production (Paul *et al*., 2001).

Another priming method using ethephon 200 ppm was also effective in stimulating root production, in this study. Chittaragi (2018) studied effect of various priming treatments in ginger transplants and found that maximum number of roots were recorded in rhizome bits treated with ethephon 200 ppm.

5.1.3.5. Root length

Root length was highest in sprouts in which rhizomes were subjected to hydropriming for one hour (10.60 cm), followed by biopriming with *Pseudomonas fluorescens,* resulted in a root length of 9.98 cm (Fig.5). The above result was in conformation with the findings of Chittaragi (2018) in which priming with *Pseudomonas fluorescens* and hydropriming for one hour resulted in significantly long roots of length 11.06 cm and 10.27 cm respectively, in ginger transplants. Hamidreza *et al*. (2013), observed that hydroprimed seeds on germination recorded longest roots in rye, when compared to control. The enhancement effect of *Pseudomonas fluorescens* on length of roots was reported in crops like chilli (Ananthi *et al.,* 2014) and sunflower (Moeinzadeh *et al.*, 2010).

5.1.3.6. Vigour index of seed rhizomes

Seed vigour index is an indication of healthy planting material. It is calculated as the product of emergence percentage and sum of shoot and root length. A treatment showing higher vigour index is said to produce plants with more vigorous plant growth characters (Abdul-Baki and Anderson, 1973). In this study, highest vigour index were found in sprouts raised from rhizomes subjected to hydropriming (3167.95) and bioprimed with *Pseudomonas fluorescens* (3011.99) (Fig.7). This is in agreement with the results of Sharma *et al*. (2014), in which it was found that hydropriming enhanced the vigour index in okra. Similar results were reported by Thakur *et al*. (2016) in finger

millet, Sowmya *et al*. (2013) in cucumber, Pallavi *et al.* (2010) in sunflower and Banjobpudsa *et al.* (2017) in upland rice. Effect of biopriming with *Pseudomonas fluorescens* is also studied in many crops and its enhancing effect has been verified. This includes studies of Reddy *et al.* (2011) in chickpea, Ananthi *et al.* (2014) in chilli, and Moeinzadeh *et al*. (2010) and Raj *et al*. (2004) in pearl millet. Though there are no reported works in enhancement of vigour index of seed rhizomes in rhizomatous crops like ginger, the transplant technology necessitates the requirement of priming to improve the vigour of seed material as the size of seed rhizome is comparatively one fourth of conventional planting material.

From this study, it can be concluded that, priming of rhizomes improved the performance of ginger sprouts in nursery, as evident by earliness in emergence, higher emergence index and lower time taken for fifty per cent emergence and mean emergence time. It also ensured better establishment of transplants as exhibited by higher percent survival, taller plants, more number of leaves and roots, lengthier roots and higher vigour index of seed rhizomes. Among the priming treatments, biopriming of rhizomes with *Pseudomonas fluorescens* 10 g L^{-1} for 30 minutes resulted in earliness in sprouting, highest EI (11.33), lowest T_{50} (14.01 days), lowest MET (17.51), highest plant height (26.90 cm), number of leaves (5.00) and number of roots (4.00). Priming using Ethephon 200 ppm produced same number of roots (4.00) as that of *Pseudomonas fluorescens* treated plants. Root length, per cent survival of sprouts and vigour index were highest in transplants raised by hydropriming of rhizomes for one hour (10.60 cm, 85.16 per cent and 3167.95 respectively). Results of this study revealed that, priming treatments irrespective of the type, can invigorate the growth of seedlings, as evident by the early emergence, increased vigour and better establishment of plants, when compared to the control. So, priming can be a recommended for raising healthy and vigorous ginger transplants, which is essential for rendering a stimulatory effect throughout the crop growth period.

Fig. 4. Effect of priming on percent survival of ginger sprouts in nursery

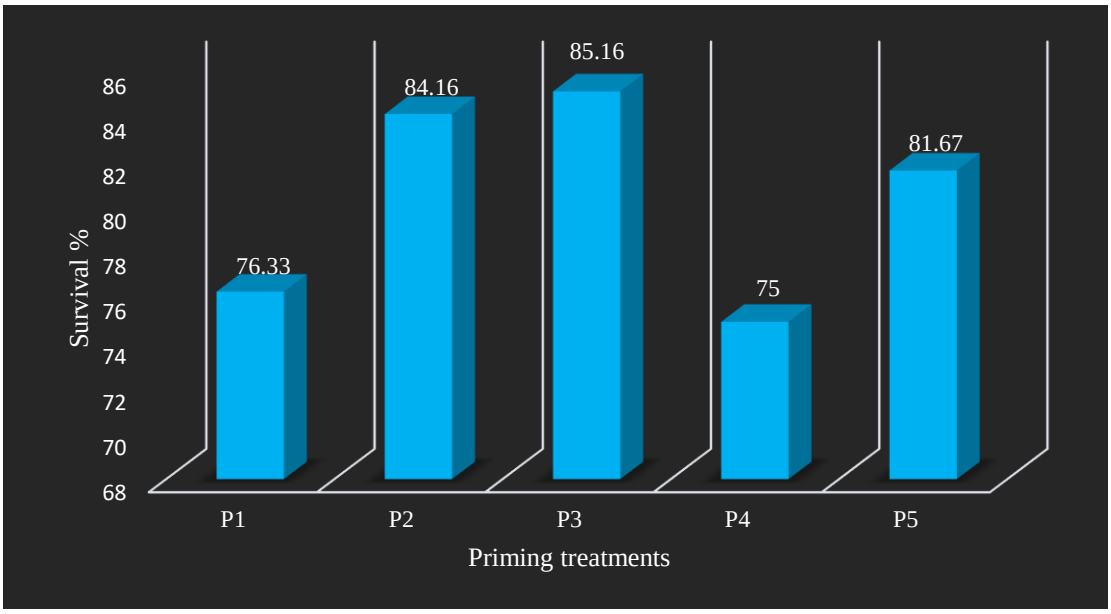
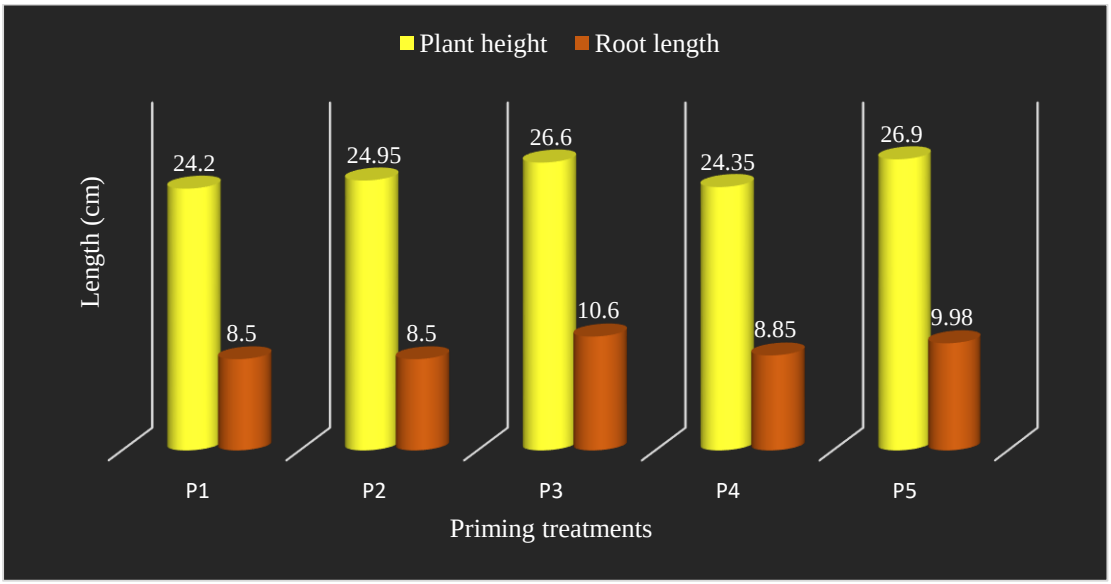


Fig.5. Effect of priming on plant height and root length in ginger transplants under nursery conditions



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

Fig.6. Effect of priming on number of leaves and number of roots in ginger transplants under nursery conditions

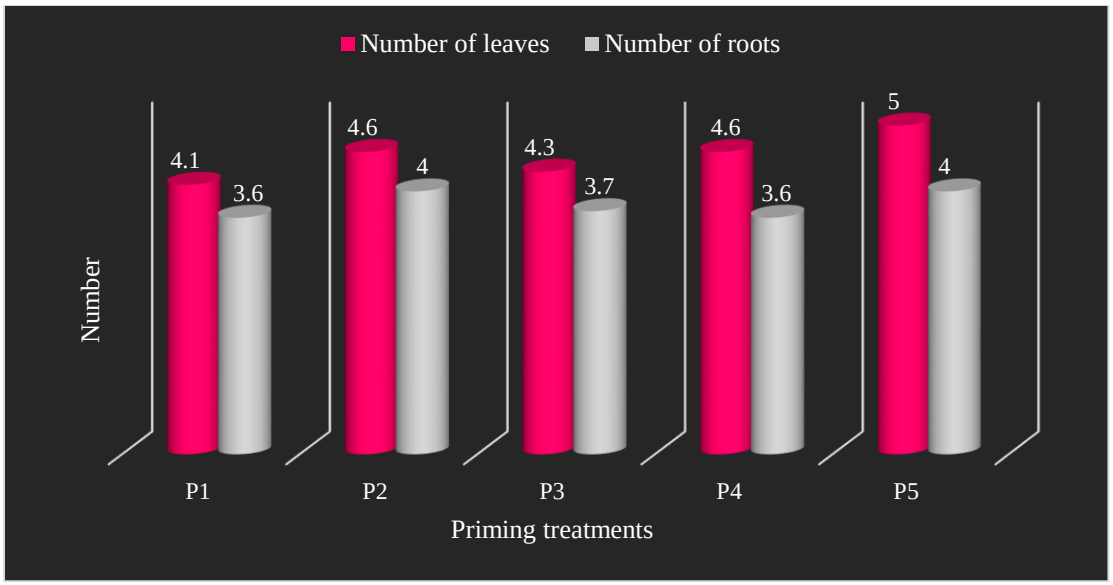
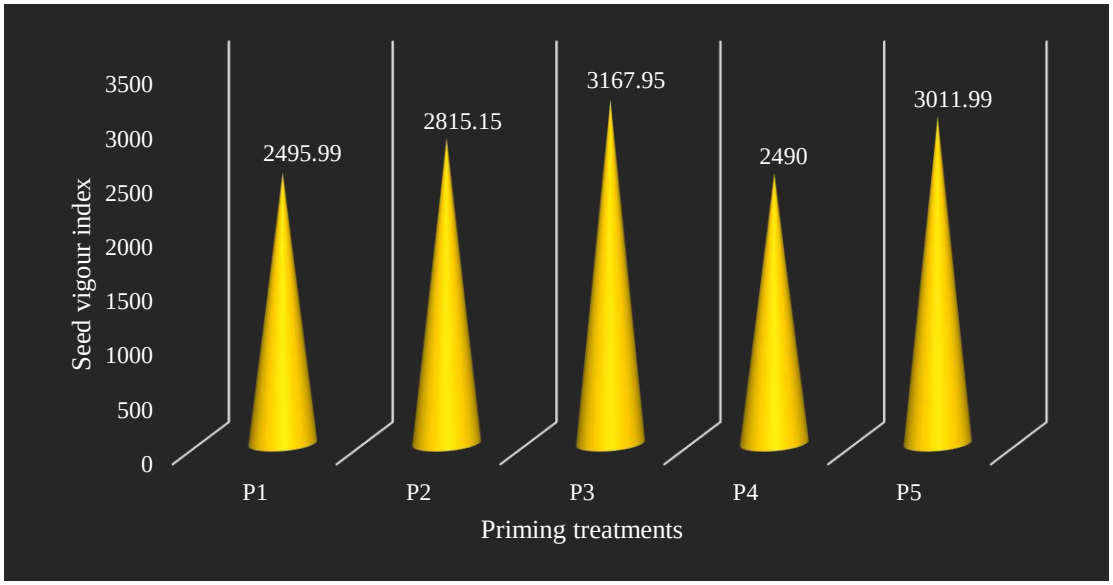


Fig.7. Effect of priming on vigour index of seed rhizomes in ginger sprouts



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

5.2. EFFECT OF PRIMING AND CHITOSAN SPRAY ON FIELD PERFORMANCE OF TRANSPLANTED GINGER

5.2.1. Effect of priming and chitosan spray on plant height of transplanted ginger

5.2.1.1. Effect of priming

In the present study, it was observed that, height of ginger plants varied with priming treatments. Highest plant height was recorded in plants transplanted in the field after giving hydropriming and bioprimng with *Pseudomonas fluorescens* (Fig.8). The plant height at 60 and 120 DAT were 47.20 cm and 69.67 cm respectively in hydroprimed plants. This was followed by plants primed with *Pseudomonas fluorescens* (45.70 cm, 69.15 cm), which was also significantly superior (Table 4). Lowest plant height was recorded for the control in both stages (37.89 cm and 64.90 cm). Data regarding the plant height at both growth stages are represented graphically in Fig.8. This result is in line with the findings of Thakur *et al*. (2016) in finger millet. In their study, it was observed that priming treatments such as hydropriming and biopriming of seeds with *Pseudomonas fluorescens*, exhibited statistically similar and significantly higher result in enhancing the height of plants. Farook *et al*. (2007) observed that, hydropriming improved the plant height in transplanted rice. Effect of *Pseudomonas fluorescens* priming in stimulating growth and enhancing plant height has been reported by many reseachers. Reddy *et al*. (2011) observed that priming with *Pseudomonas fluorescens* resulted in increased plant height in chickpea. Similar results were reported by Rad and Heshmatpoure (2013) in rapeseed, Raj *et al*. (2004) in pearl millet, Pavlo *et al*. (2011) in potato and Thankamani *et al*. (2005) in pepper.

In this study also it was found that, plants given the priming treatments, irrespective of the type of priming, recorded significantly higher plant height than the unprimed control. Chittaragi (2018) also observed similar results in which, growth performance of ginger transplants varied significantly with the priming treatments.

5.2.1.2. Effect of chitosan spray

The foliar spray of biostimulant chitosan at a concentration of 5 g/L or 7 g/L recorded the highest plant height and the values of both were statistically significant

(Table 4). Data pertaining to the same are plotted in Fig.9. At 60 DAT, highest plant height was reported in plants given the foliar spray of chitosan 5 g/L (46.27 cm) and 7 g/L (44.88 cm), whereas, at 120 DAT, highest plant height was recorded in chitosan 7 g/L (71.20 cm) and 5 g/L (70.80 cm), which were statistically similar. Role of chitosan as a biostimulant in enhancing the plant growth is widely studied. Satiyabama *et al*. (2016) reported an enhancement in plant height in turmeric as affected by monthly foliar application of chitosan 0.1%. Chitosan 3 g L^{-1}, when applied as foliar spray, exhibited a significant increase in plant height of Kasthuri turmeric (Thengumpally, 2019). In another study conducted by Salachna and Zawadzinska (2014) chitosan treatment increased plant height in freesia to an extent of 16.8 per cent. Shoot height and number of leaves in turmeric were increased as a result of chitosan application in turmeric (Anusuya and Satiyabama, 2016). Similar results were also observed in okra (Mondal *et al*., 2012), chilli (Chookhongkha *et al*., 2012), coffee (Van *et al*., 2013), strawberry (El-Miniawy *et al*., 2013), Indian spinach (Mondal *et al*., 2011) and grapevine (Gornik *et al*., 2008).

Interaction effect of priming and chitosan on plant height was found to be significant at both 60 and 120 DAT. The highest plant height was observed in plants primed with *Pseudomonas fluorescens* and sprayed with 7 g L^{-1} chitosan (50.61 cm) at 60 DAT, whereas, plants given hydropriming and sprayed with chitosan 5 g L^{-1} (74.77 cm) showed the highest plant height at 120 DAT. Synergistic effect of priming and biostimulant spray on improving the plant height is evident from the combination treatments. While comparing the absolute control treatment without any priming and chitosan spray, an increase of 34.6 percent at 60 DAT and 19.44 percent at 120 DAT was noticed in height of plants received the best combination treatments. This accounts for an increase of 1.35 times and 1.19 times in plant height at 60 and 120 DAT respectively. Above results prove that combination treatments involving priming and chitosan spray is effective in producing plants with better growth as evident by improved height, when compared to average height of plants receiving priming and chitosan spray alone.

Fig.8. Effect of priming on plant height of ginger transplants at 60 and 120 DAT

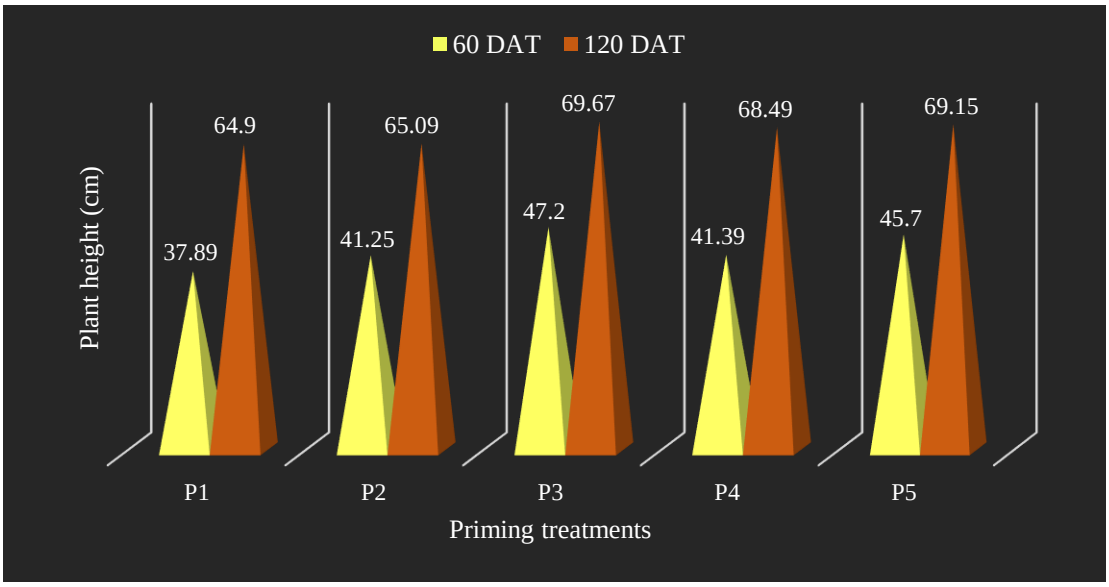
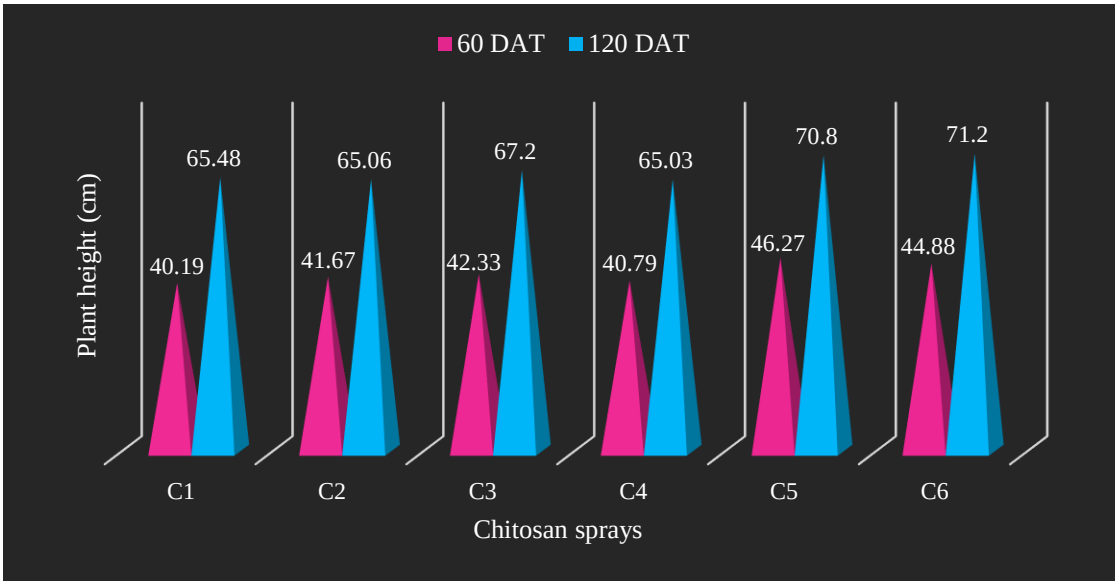


Fig.9. Effect of chitosan sprays on plant height of ginger transplants at 60 and 120 DAT



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

5.2.2. Effect of priming and chitosan spray on production of tillers in transplanted ginger

5.2.2.1. Effect of priming

Number of tillers were significantly higher in primed plants, than in the unprimed control at both growth stages of 60 and 120 DAT. A similar trend as that in plant height was noticed here also. Highest number of tillers were either produced by hydroprimed or *Pseudomonas fluorescens* primed plants, both producing equal number of tillers (14.79) at 120 DAT. At 60 DAT, *Pseudomonas fluorescens* primed plants produced 6.60 tillers and hydroprimed plants produced 6.15 tillers. In both cases, the lowest number of tillers (4.40 and 12.74) were observed in control plants raised without any priming (Fig.10).

Above result is in line with the findings of Chittaragi (2018) in transplanted ginger and Thakur *et al*. (2016) in finger millet, in which both hydropriming and biopriming with *Pseudomonas fluorescens*, recorded more number of tillers than the control. Enhancement effect of hydropriming in production of tillers has also described by Farook *et al*. (2007) in rice and Nawas *et al*. (2016) in wheat. Production of more number of lateral branches in chickpea as affected by hydropriming was reported by Zarei *et al*. (2011). Priming with *Pseudomonas fluorescens* also had a significant effect in improving the number of tillers, during the growth stages. Number of tillers was significantly increased by priming with *Pseudomonas fluorescens* in pearl millet (Raj *et al*., 2004).

Perusal of data about number of tillers at 60 and 120 DAT proves that, priming has a notable effect in stimulating the tiller production in ginger transplants, when compared to the non-primed control. This may be due to the better performance of primed plants in utilizing the available environmental resources, as reported by Zarei *et al*. (2011).

5.2.2.2. Effect of chitosan spray

The number of tillers at 60 and 120 DAT was significantly high in plants sprayed with chitosan at 5 g L^{-1} (6.11 and 14.77 respectively) and 7 g L^{-1} (6.11 and

14.89 respectively) (Table 5). However, plants sprayed with chitosan at a concentration of 3 g L^{-1} showed rather less number of tillers, and was on par with that of control plants. This pattern was observed during both observation period and similar trend was seen in plant height also. Lowest number of tillers after 60 DAT (5.20) and 120 DAT (13.13) was observed in control plants sprayed with water. Data pertaining to the above result are furnished in Fig.11.

This result showing the positive effect of chitosan spray in increasing the number of tillers is in conformity with the results obtained by Salachna and Zawadzinska (2014) in freesia. It increased the number of shoots in freesia to an extent of 45.9 percent, whereas in the present study an increase of 17.5 and 13.40 percent in tillers production was noticed by spraying chitosan 5 and 7 g L^{-1} at 60 DAT and 120 DAT, respectively. Satiyabama *et al*. (2016) observed that foliar application chitosan improved the shoot biomass in turmeric.

Interaction effect of priming and chitosan spray significantly improved the tiller production in ginger at 60 and 120 DAT. It was found that plants primed with *Pseudomonas fluorescens* and sprayed with chitosan 7 g L^{-1} recorded the highest number of tillers (7.30) at 60 DAT. At 120 DAT, highest number of tillers was recorded in plants given hydropriming and 5 g L^{-1} chitosan spray (16.97). When the superior combination at both stages were compared with absolute control maintained with no priming and no chitosan spray, an increase of 76.76 percent at 60 DAT and 37.63 percent at 120 DAT was observed. This indicates that the combination treatment involving priming using either *Pseudomonas fluorescens* or hydropriming prior to planting and later spraying at monthly intervals at a concentrations of 5 or 7 g L^{-1} is effective in increasing the number of tillers per plant than the individual application of priming and chitosan sprays alone.

Fig.10. Effect of priming treatments on number of tillers in ginger transplants at 60 and 120 DAT

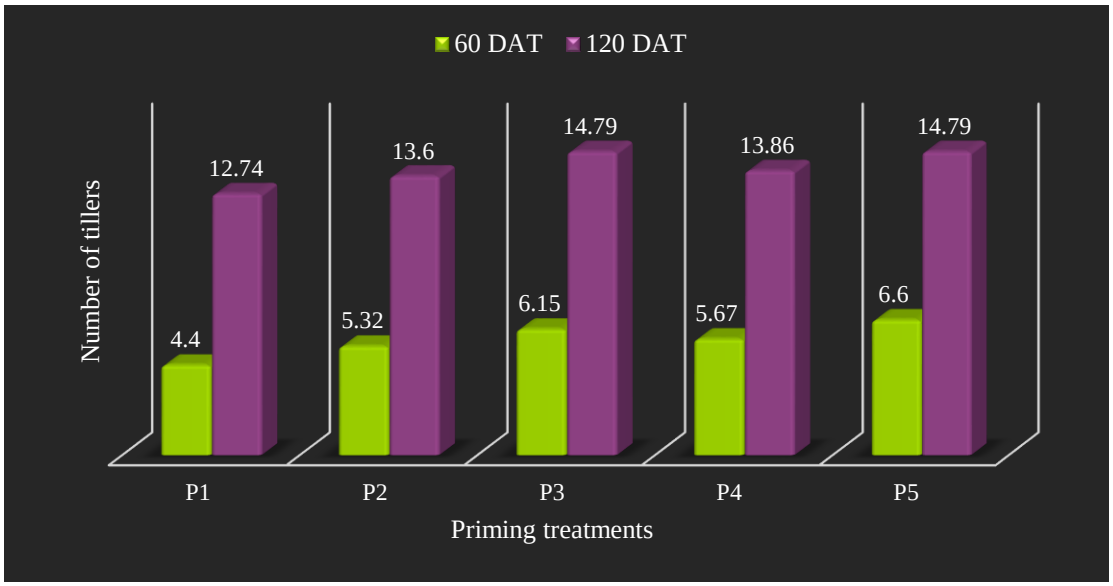
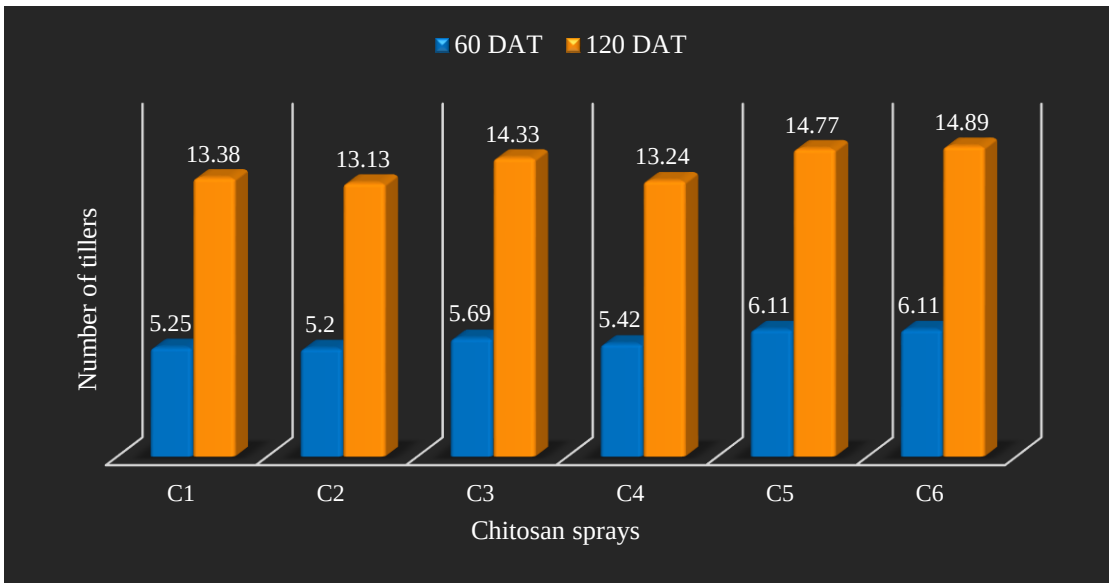


Fig.11. Effect of chitosan spray on number of tillers in ginger transplants at 60 and 120 DAT



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

5.2.3. Effect of priming and chitosan spray on physiological characters like photosynthetic rate, stomatal conductance, transpiration rate and leaf area

5.2.3.1 Effect of priming

At active tillering stage, the highest value for photosynthetic rate, stomatal conductance and transpiration rate were recorded in hydroprimed plants (23.75 µmol m^{-2} s^{-1}, 2.69 µmol m^{-2} $s^{-1}$and 13.67 mmol m^{-2} s^{-1} respectively). Except for plants primed with ethephon, all other priming treatments exhibited higher photosynthetic rate. All priming treatments recorded higher transpiration rate, compared to unprimed control (Table 17).

This was supported by the findings of Iqbal and Ashraf (2007) in which they verified that priming treatments are effective in increasing the photosynthetic rate, stomatal conductance and transpiration rate, even in crops grown under stress. Galhaut *et al*. (2014) reported that priming treatments had a positive correlation with photosynthetic rate in white clover. In another study by Iqbal and Ashraf (2005) it was found that priming agents have the ability to alter the stomatal conductance and different priming treatments differ in their ability to alter the same. This is highly relatable to the present study, in which different priming treatments exhibited different values for stomatal conductance. Generally, initial priming given to the planting material are known to enhance germination, improve growth and hasten physiological processes in plants. Priming was reported to enhance photosynthetic rate, stomatal conductance, transpiration rate, chlorophyll content and relative water content (Mohammadi *et al*. 2017). This supports the findings of present study, in which hydroprimed plants exhibited the highest values for physiological parameters and recorded highest emergence percentage, vigour index and good establishment in field.

A positive correlation of yield with physiological parameters such as photosynthetic rate, stomatal conductance and transpiration rate, has been reported by Tekalign and Hammes (2005) and Dwelle *et al*. (1981) in potato and Mathews (2018) in ginger and De-Gelder *et al*. (2012). Stomatal conductance and photosynthetic rate are highly correlated with each other (Dwelle *et al*., 1981). Also, photosynthetic rate is closely associated with transpiration rate and higher the transpiration rates, higher will

be the photosynthetic rate (Hamid *et al*., 1990). This is clearly seen in this study, in which the highest value for photosynthetic rate, stomatal conductance and transpiration rate was observed in hydroprimed plants, which later exhibited higher yield.

With respect to hydropriming, it is said to be advantageous since it enhances the physiological and biochemical events during germination (Barsa *et al*., 2003). This may be a reason for its better performance and vigour observed later in field. In addition, Afzal *et al*. (2015) opinioned that increased leaf area and net assimilation rate would result in enhanced photosynthetic activity, which inturn increases crop growth rate. Mabhaudhi (2009) reported that increase in leaf area is proportional to increase in photosynthetic rate, although green leaf area may not always be same as photosynthesizing leaf area. In this study, hydroprimed plants exhibited an increase of 11 percent in leaf area when compared to control. This can also be attributed to the enhanced photosynthetic rate in hydroprimed plants. According to Jisha and Puthur (2014), hydropriming resulted in an increase of chlorophyll a and b to an extent of 43 and 49 per cent respectively, which resulted in an enhancement of photosynthetic rate in rice. Similar reports by Sacala *et al*. (2016) shows that hydropriming before planting resulted in an enhancement of chlorophyll pigment which finally improved the photosynthetic ability in sugarbeet.

Highest leaf area was noted in plants primed with *Pseudomonas fluorescens* (30.71cm^2). This was followed by hydroprimed (29.68 cm^2) and *Trichoderma* sp. (29.17 cm^2) primed plants, which were on par with the highest (Fig.12). Biopriming with *Pseudomonas fluorescens* increased leaf area to an extent of 25% than control (Raj *et al*., 2004). Similar results were also reported in pepper plants in which higher leaf area was found in plants given treatment with *Pseudomonas fluorescens*, as compared to control (Thankamani et al., 2005). Farooq *et al*. (2007) reported higher leaf area index (LAI) in hydroprimed plants than control, in rice.

5.2.3.2. Effect of chitosan spray

Ginger transplants sprayed with 5g L^{-1} chitosan at monthly intervals, recorded significantly highest value for photosynthetic rate (23.83 µmol m^{-2} s^{-1}), stomatal conductance (2.78 µmol m^{-2} s^{-1}) and transpiration rate (13.07 mmol m^{-2} s^{-1}), at active

tillering stage. Chitosan sprays, irrespective of the concentration, improved the photosynthetic rate and least photosynthetic rate was observed in plants devoid of chitosan spray. Stomatal conductance was also significantly improved by chitosan application. A similar trend was observed in transpiration rate also, in which plants given chitosan spray exhibited significantly higher transpiration rate than the plants devoid of it.

Increase in photosynthetic rate can be related to the increase in stomatal conductance and transpiration rate. This increase in photosynthetic rate as affected by highest stomatal conductance and transpiration rate may be a reason for increased yield in ginger plants sprayed with chitosan 5 g L^{-1}. Mathews (2018) found that plants showing highest photosynthetic rate exhibited highest stomatal conductance and transpiration rate and resulted in improved yield in ginger. Chitosan application has been proved to enhance the photosynthetic rate. This is in conformity with the findings of Thengumpally (2019) in which foliar application of chitosan at 3 and 5 months after planting enhanced the photosynthetic rate and stomatal conductance in Kasthuri turmeric. In the present study also, chitosan sprayed plants, irrespective of concentration of spray, exhibited high photosynthetic rate when compared to the control. This is in line with the results of Khan *et al*. (2002) stating that, chitosan spray improved the photosynthetic rate in maize and this was highly correlated to the increase in stomatal conductance and transpiration rate. However, if an increase in the stomatal opening is the sole reason for enhancement in photosynthetic rate, a corresponding increase in leaf intercellular CO_2 concentration (Ci) would occur (Morison, 1998). In the present study, the values for intercellular CO_2 concentration (Ci) remains relatively stable without much fluctuation, indicating that enhancement in photosynthetic rate is based on the enhanced uptake of CO_2 within the leaf, which inturn improves stomatal conductance. This verifies that increase in photosynthetic rate may be due to increased uptake of CO_2 within the cell and hence improving stomatal conductance, rather than due to more number of opened stomata. This may be due to the effect of chitosan in improving the CO_2 uptake within the cells. This result is in line with the findings of Khan *et al*. (2002), in which foliar sprays of chitosan resulted in enhancement in photosynthetic rate, stomatal conductance and transpiration rate, without much

variation in intercellular CO_2. There are also reports showing that enhancement in photosynthetic rate as a result of chitosan application is due to the improvement in chlorophyll content. According to Zeng and Luo (2012) chitosan coating increased the chlorophyll content and thus exhibited a direct influence in photosynthetic capacity, which resulted in accumulation of organic matter and enhanced growth in wheat. Van *et al*. (2013) reported that foliar application of chitosan increased the chlorophyll by 30-50 per cent and as a result it enhanced the photosynthetic rate up to 30-60 per cent in coffee. Also, chitosan 0.5 percent used for soaking corms of freesia before planting increased the chlorophyll content to 13.4 per cent and hence stimulated the photosynthetic rate and growth (Salachna and Zawadzinska, 2014). Similar results were also found in grapevine (Gornik *et al*., 2008; Barka *et al*., 2004) and okra (Mondal *et al*., 2012).

With respect to chitosan spray, maximum leaf area was noted in plants sprayed with chitosan 7 g L^{-1} (30.76 cm^2). Foliar sprays of chitosan 5 g L^{-1} (29.86 cm^2) and 3 g L^{-1} (29.40 cm^2) followed the superior treatment. Leaf area in ginger as affected by chitosan spray and those devoid of it are represented in Fig.13. Effect of chitosan application in enhancing the leaf area, is in conformity with the results of Thengumpally (2019) in which foliar spray of chitosan 2.5 and 3 g L^{-1} increased the leaf area in Kasthuri turmeric. (Chookhongkha *et al*., 2012), reported that chitosan 1.0 per cent, when added to soil, enhanced the canopy diameter and leaf area in chilli. Foliar application of chitosan 75 mg L^{-1} resulted in enhancement of leaf number, branch number and leaf area in Indian spinach (Mondal *et al*., 2011). Similar results were obtained by El-Miniawy *et al*. (2013) in strawberry and Van *et al*. (2013) in coffee.

Table 17. Effect of priming treatments on photosynthetic rate, stomatal conductance and transpiration rate in transplanted ginger

Treatments	Photosynthetic rate (µmol m^{-2} s^{-1})	Stomatal conductance (µmol m^{-2} s^{-1})	Transpiration rate (mmol m^{-2} s^{-1})
P1	18.34[b]	2.22[b]	9.04[e]
P2	16.23[c]	1.72[c]	9.91[d]
P3	23.75[a]	2.69[a]	13.67[a]
P4	18.59[b]	1.24[d]	10.52[b]
P5	19.11[b]	0.97[e]	10.03[c]
CD (0.05)	**1.58**	**0.075**	**0.34**

P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

Table 18. Effect of chitosan spray on photosynthetic rate, stomatal conductance and transpiration rate in transplanted ginger

Treatments	Photosynthetic rate (µmol m^{-2} s^{-1})	Stomatal conductance (µmol m^{-2} s^{-1})	Transpiration rate (mmol m^{-2} s^{-1})
C1	14.87^{d}	1.00^{e}	8.48^{e}
C2	15.11^{d}	1.84^{b}	9.23^{d}
C3	18.47^{c}	1.53^{d}	10.82^{c}
C4	20.96^{b}	1.70^{c}	11.40^{b}
C5	23.83^{a}	2.78^{a}	13.07^{a}
C6	21.97^{b}	1.75^{c}	10.78^{c}
CD (0.05)	**1.73**	**0.082**	**0.38**

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

Fig.12. Effect of priming on leaf area of transplanted ginger at active tillering stage

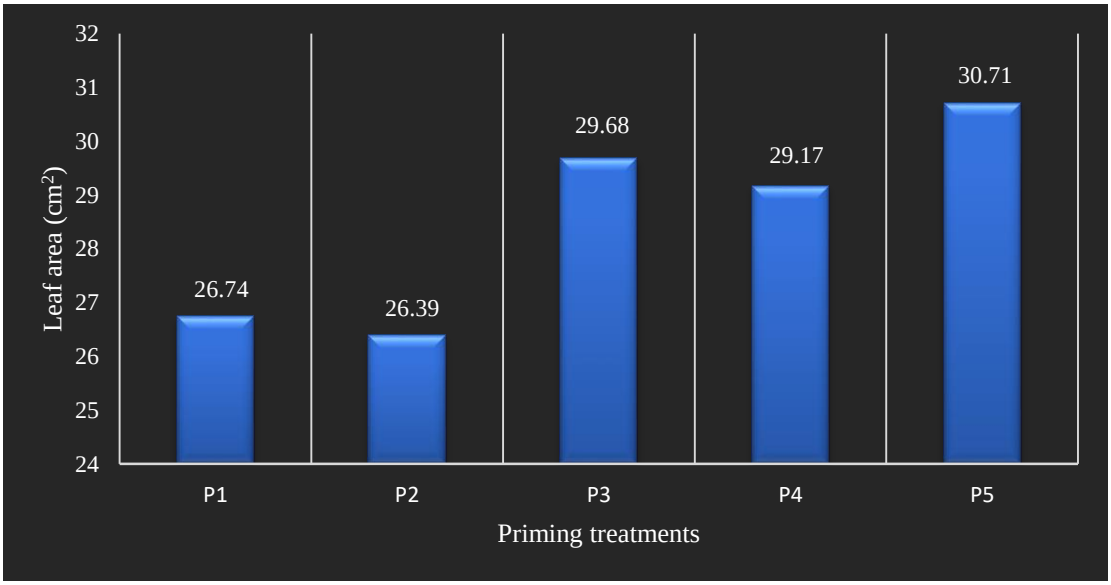
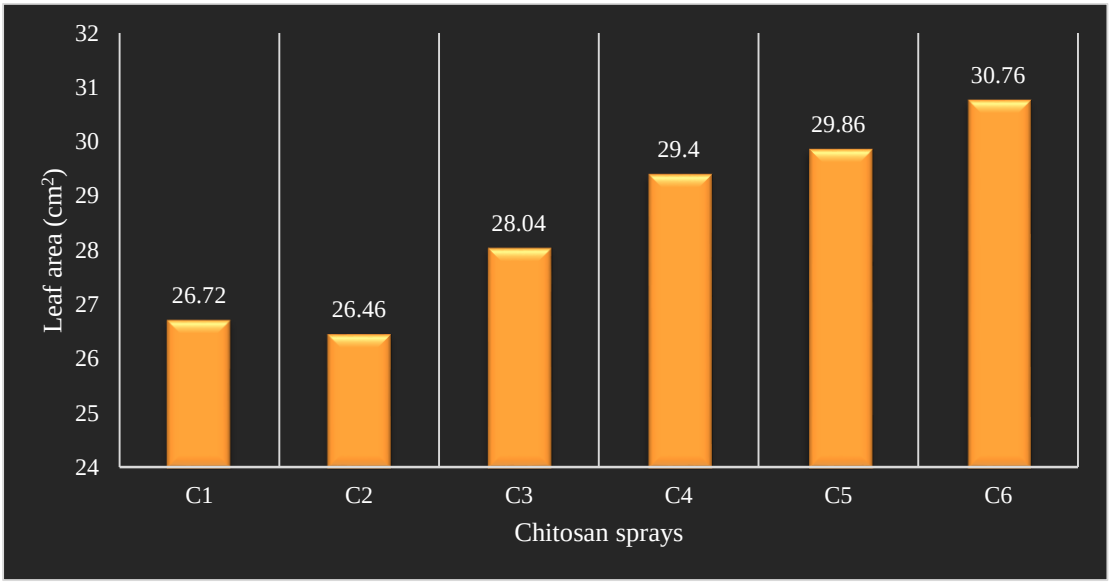


Fig.13. Effect of chitosan spray on leaf area of transplanted ginger at active tillering stage



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

5.2.4. Effect of priming and chitosan spray on disease incidence in transplanted ginger

Crop growth period witnessed two major infestation of disease, *viz.*, bacterial wilt incidence caused by *Ralstonia solanacearum* during July - August, and *Phyllosticta* leaf spot by *Phyllosticta zingiberi* during October - November. The effect of various priming treatments and chitosan spray in tackling the disease is analysed by assessing the percent disease incidence and percent disease index, for bacterial wilt and leaf spot respectively and are discussed hereunder.

5.2.4.1. Effect of priming on incidence of disease in ginger

In case of incidence of bacterial wilt, the least infestation as evident by lowest score for percent disease incidence was observed in plants primed with *Pseudomonas fluorescens* (6.77 %). This was followed by hydroprimed plants exhibiting an incidence of 8.76 per cent. The highest incidence of bacterial wilt was seen in control plants (15.17 %) (Fig.14). A similar trend was observed in the response of primed plants against *Phyllosticta* leaf spot also. The lowest incidence of this fungal disease was observed in plants primed with *Pseudomonas fluorescens* (41.79%) followed by hydroprimed plants (42.78%) (Fig.15).

From this, it is clear that priming with *Pseudomonas fluorescens* imparts some defence mechanism against both bacterial and fungal pathogen in ginger. This is in line with the findings of Van-Loon (2007), in which priming with non-pathogenic bacteria helps to induce a quicker defence reaction towards abiotic and biotic stresses including bacterial and fungal infestation. Pavlo *et al*. (2011) suggested that *Pseudomonas* sp. have some antagonist action towards bacterial pathogen and further observed that priming with *Pseudomonas* sp. was helpful for promoting growth as well as imparting resistance against bacterial pathogens causing soft rot in potato. Howell and Stipanovic (1978) studied the antagonistic effect of *Pseudomonas fluorescens* against bacteria, *Rhizoctonia solani* in cotton. They observed that treating cotton seeds with *Pseudomonas fluorescens* prior to planting, resulted in an increased seedling survival in pathogen infested soil. Similar results in chickpea such as priming of seeds with *Pseudomonas fluorescens* reducing the incidence of dry root rot to an extent of 45%

(Reddy *et al.*, 2011) and reduction in infestation of *Sclerotium rolfsii* to an extent of 47 percent (Hameda *et al*., 2010) has been reported.

Effect of *Pseudomonas fluorescens* in imparting resistance against bacterial and fungal pathogen is well known. Raj *et al.* (2004) suggested that priming with *Pseudomonas fluorescens* is an effective mechanism for imparting defence mechanism as it develop induced systemic resistance (ISR) in plants, which is persistent throughout the crop growth period. Kumar *et al*. (2001) suggested that antibacterial and antifungal mechanism of *Pseudomonas fluorescens* is due to the production of siderophores. All these findings proves that *Pseudomonas fluorescens*, can be used as an effective priming agent, which helps to reduce the disease incidence and enhance plant growth which ultimately results in more yield.

Fig.14. Effect of priming on the incidence of bacterial wilt

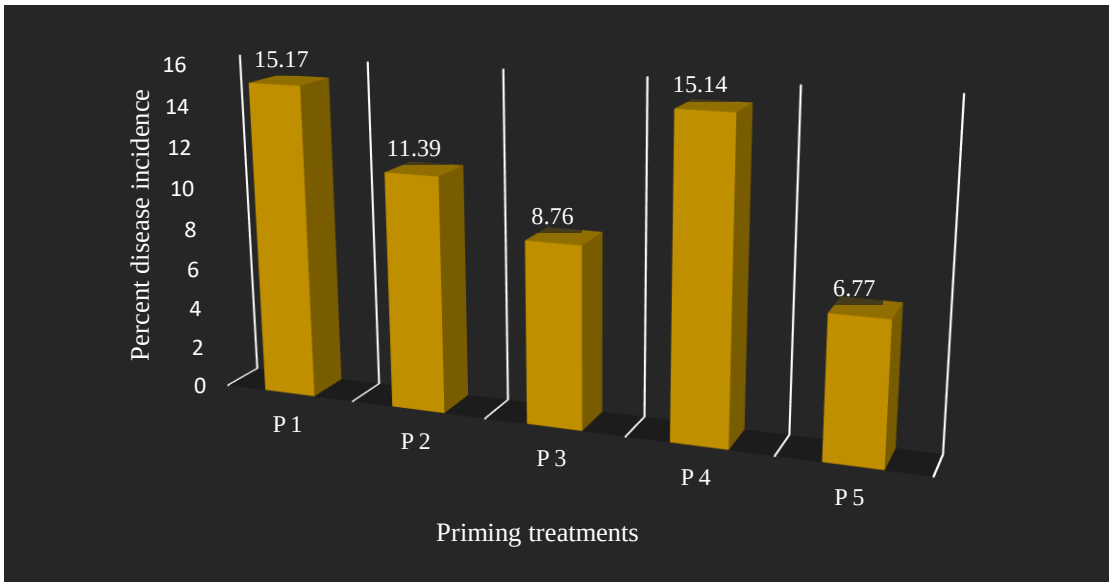
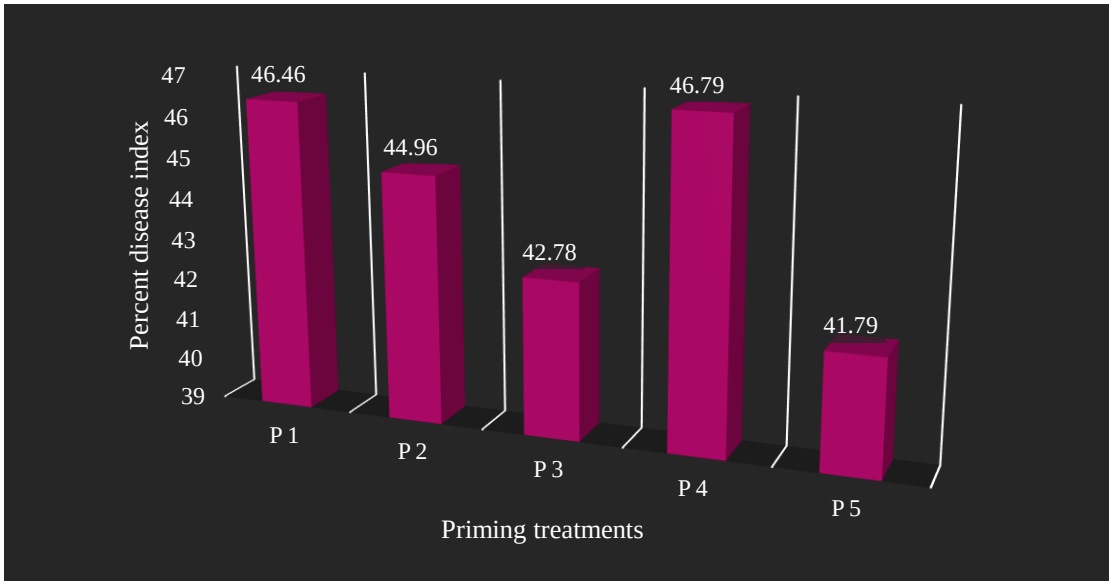


Fig.15. Effect of priming on the incidence of Phyllosticta leaf spot



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

5.2.4.2. Effect of chitosan spray on the incidence of disease in ginger

Chitosan application showed a notable reduction in both bacterial and fungal disease incidence under field condition. In case of bacterial wilt, the lowest incidence was noticed in plants sprayed with chitosan 5 g L^{-1} (6.78%), whereas the highest infection was observed in plants kept as control, without any chitosan spray (15.40%) (Fig.16). For *Phyllosticta* leaf spot, chitosan sprayed plants, irrespective of concentration, showed less incidence, and the best treatments were sprays of 7 g L^{-1} (25.65%) and 5 g L^{-1} (30.79%) chitosan. Both 7 g L^{-1} and 5 g L^{-1} sprays produced statistically similar results, so it can be concluded that lower dose of 5 g L^{-1} chitosan can be adopted for control of the disease. Also, when both cases are compared, spray of chitosan 5 g L^{-1} imparted some resistance in plants against both bacterial and fungal pathogen, as evident by reduced incidence of wilt and leaf spot. Incidence of *Phyllosticta* leaf spot on ginger transplants sprayed with chitosan and on those devoid of it are furnished in Fig.17.

Bacterial wilt is a major problem faced by ginger growers. It can cause widespread damage and reduction in yield and income. However, chitosan, which is widely known for providing biotic and abiotic stress tolerance, in addition to biostimulant activity, can be used for controlling this disease. In this study, natural incidence of bacterial wilt was observed one-two months after planting and only one round of foliar spray was completed by that time. So further studies of chitosan application in artificially inoculated plants has to be carried out to confirm the result.

Incidence of *Phyllosticta* leaf spot was seen during the later period of crop growth during October- November. Though it is considered as a minor disease in Kerala, in severe cases, it can be destructive. According to Singh *et al*. (2000) severe leaf spotting by *Phyllosticta zingiberi* will destroy the chlorophyllous tissues and thus reduce the yield of ginger. A reduction of 65.9 per cent in fresh rhizome yield in ginger is reported when the severity of this disease was 58.3 percent (Sood and Dohroo, 2005). In the present study, foliar sprays of chitosan was found to be effective in reducing the adverse effects of *Phyllosticta zingiberi*. Chitosan sprays significantly reduced the percent disease index, with the best treatments being spray of 5 or 7 g L^{-1}.

Effect of chitosan in tackling biotic stress has been studied extensively. Chitosan act as a plant defense booster against biotic stresses by enhancing plant immunity and through anti-microbial activity. It act as an elicitor of plants defence responses through various mechanisms such accumulation of pathogenesis related proteins such as chitinase and beta-1,3-glucanase (Satiyabama *et al*., 2014, Ma *et al*., 2013), by induction of plant defence enzymes such as phenyl alanine ammonia lyase (Ali *et al*., 2012; Kim *et al*., 2005), by scavenging of reactive oxygen species and through callose deposition and ligin biosynthesis (Bittelli *et al*., 2001; Faoro and Iriti, 2007; Kohle *et al*., 1985). Three antibacterial mechanisms of chitosan were suggested such as ionic surface interaction resulting in cell wall leakage, binding of chitosan to the genetic material of microorganism and thereby inhibiting their protein and mRNA synthesis and the formation of an external film over the plant surface, limiting the nutrient availability for microorganisms (Goy *et al*., 2009). Ghaouth *et al*. (1992) suggested that anti-fungal mechanism of chitosan is by inhibiting spore germination, germ tube elongation and radial growth of fungus. Anusuya and Satiyabama (2016), studied the effect of foliar application of chitosan 0.1 per cent on the incidence rhizome rot in turmeric. It was found that chitosan application significantly reduced the severity of disease, resulting in 30 per cent incidence, whereas control plants reported 95 percent incidence of rhizome rot. Algam *et al.* (2010) found that chitosan 10 g L^{-1}, when applied as soil drench and seed treatment (10 mg mL^{-1}), reduced the incidence of tomato wilt caused by *Ralstonia solanacearum.* Effect of chitosan and oligochitosan against rhizome rot of ginger in storage was studied by Liu *et al*. (2016). Chitosan and oligochitosan, when applied as dip, both at a concentration of 5 g L^{-1}, were effective in controlling rhizome rot in ginger, caused by *Fusarium oxysporum.* It is clear from the above results that, chitosan can be used as an efficient remedy against diseases.

Fig.16. Effect of chitosan spray on incidence of bacterial wilt in transplanted ginger

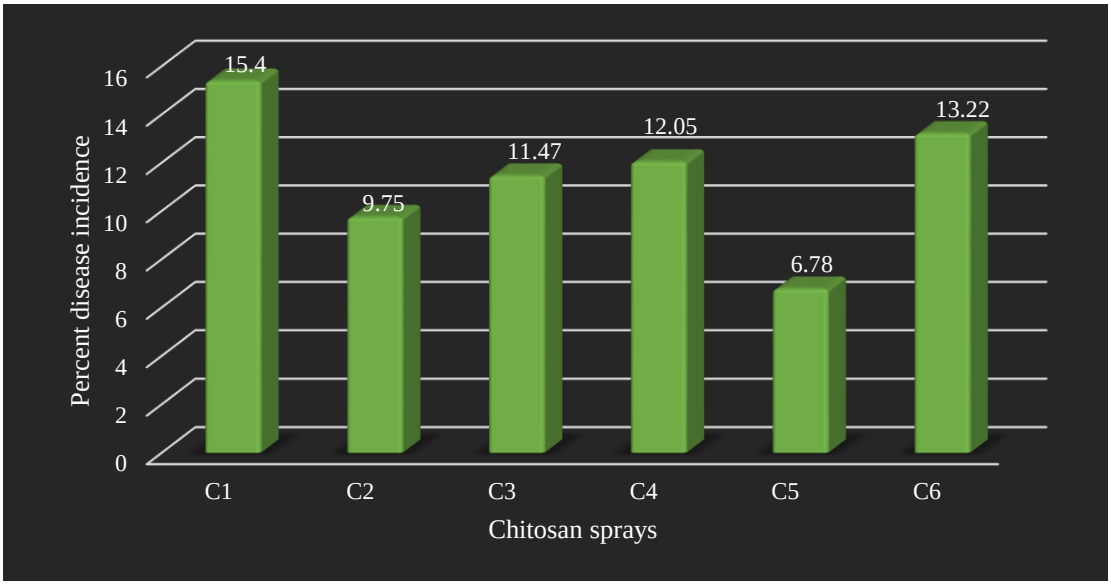
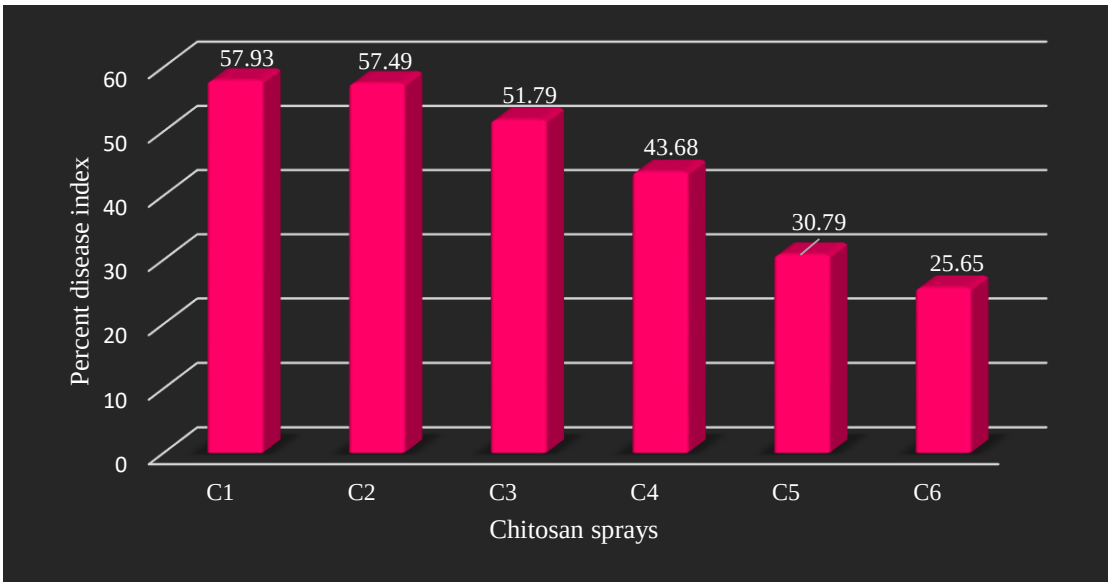


Fig.17.Effect of chitosan spray on incidence of Phyllosticta leaf spot in transplanted ginger



C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

5.2.5. Effect of priming and chitosan spray on yield parameters of transplanted ginger

5.2.5.1. Number of fingers

5.2.5.1.1. Effect of priming

Rhizomes from primed plants recorded higher number of fingers when compared to unprimed control. Number of fingers had a significant and positive correlation with yield (Table. 19) and hence, this can be related to the higher rhizome yield obtained from primed plants. Significantly highest number of fingers was observed in plants subjected to hydropriming (10.84), ethephon (10.69), *Pseudomonas fluorescens* (10.48) and *Trichoderma* sp. (10.36) (Fig.18). The lowest count was seen in control without priming (9.61) and this may be due to the lower yield obtained from it. This is comparable to the results of Chittaragi (2018) in transplanted ginger and Anu (2019) in turmeric, in which highest number of fingers in ginger and highest number of primary rhizomes in turmeric are associated with the treatment producing highest rhizome yield.

5.2.5.1.2. Effect of chitosan spray

Number of fingers where significantly highest in rhizomes obtained from plants sprayed with chitosan 5 g L^{-1} (12.12) (Fig.19). Lowest number of tillers were seen in plants sprayed with water (9.04) and absolute control plants (9.35), which were on par. Similar to the findings of count of fingers obtained as a result of priming, this is also can be related to the highest yield obtained from the chitosan 5 g L^{-1} treated plants. Plants given chitosan spray showed higher count of fingers than the control maintained. Anusuya and Satiyabama (2016) observed that higher number of nodes in rhizomes where associated with plants yielded highest as a result of chitosan spray.

Fig.18. Effect of priming on number of fingers in transplanted ginger

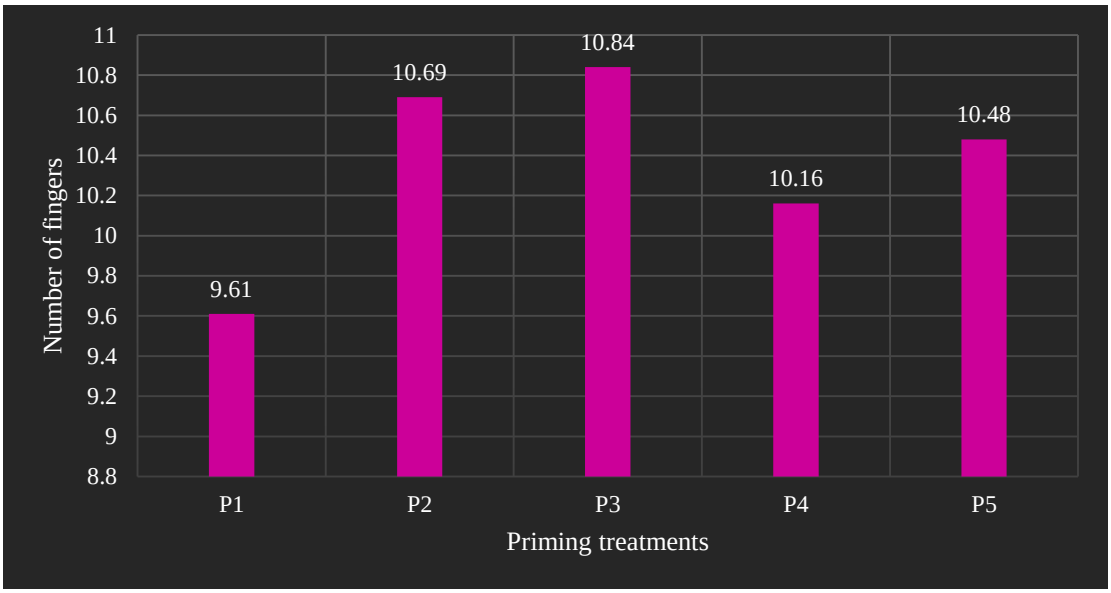
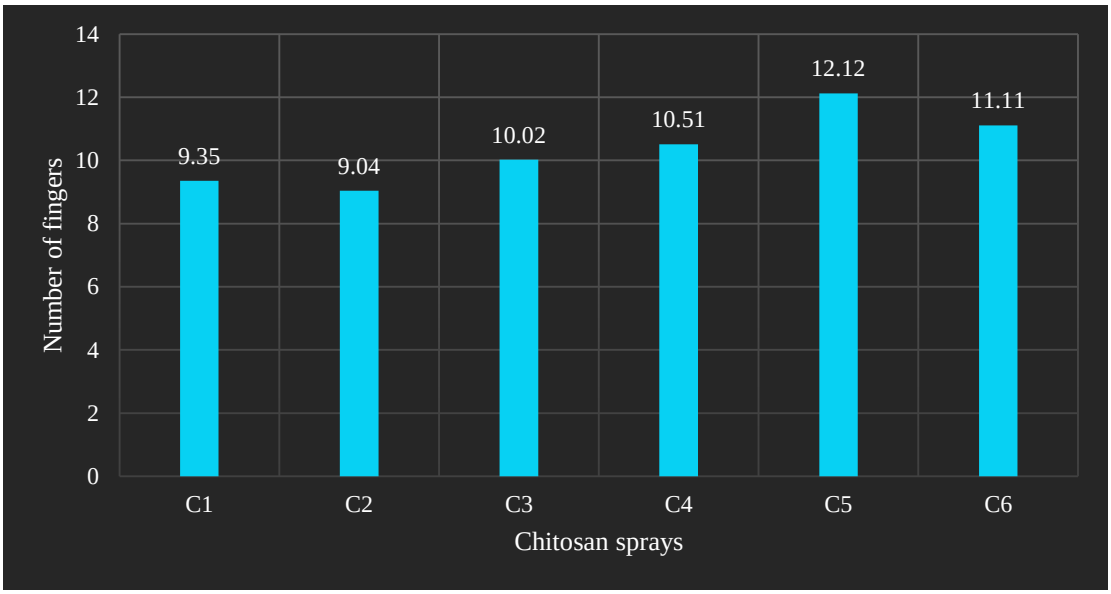


Fig.19. Effect of chitosan spray on number of fingers in transplanted ginger



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

5.2.5.2. Fresh rhizome yield of transplanted ginger

5.2.5.2.1. Effect of priming

Priming of seed rhizome found to improve yield of transplanted ginger irrespective of chitosan treatment. Highest yield was noted in plants primed with *Pseudomonas fluorescens* 10 g L^{-1} for 30 minutes (274.08 g $plant^{-1}$). Other priming treatments were on par recording 254.47 g $plant^{-1}$, 250.49 g $plant^{-1}$ and 240.89 g $plant^{-1}$ in fresh rhizome yield when rhizomes were subjected to hydropriming, priming with ethephon and *Trichoderma* sp. respectively. It is clear from the experiment that, priming can be adopted for transplanted ginger, for improving per plant yield. Rhizome yield from various priming treatments are depicted in Fig.20.

This study reveals that *Pseudomonas fluorescens* can be considered as an effective biopriming agent for enhancing germination, stimulating growth and improving yield. The above result is in agreement with the findings of Chittaragi (2018), in which priming with *Pseudomonas fluorescens* 10 g L^{-1} before planting, resulted in an increase of 13.3 per cent in fresh rhizome yield in ginger transplants. In the present study an increase of 28.84 percent in yield was observed in transplanted ginger. Reddy *et al*. (2011) reported yield increment of 18.4 per cent in chickpea plants primed with *Pseudomonas fluorescens* when compared to the unprimed control. Raj *et al*. (2004) confirmed that, biopriming with *Pseudomonas fluorescens* exhibited an increase of 22 per cent in grain yield in pearl millet. Similar result was reported by Thakur *et al*. (2016) in which seed priming with 20 percent *Pseudomonas fluorescens* resulted in increased number of seeds per finger, test weight, yield per plant and yield per plot in finger millet than control.

In this study, biopriming with *Pseudomonas fluorescens* resulted in highest rhizome yield and this may be due to high germination and vigour index of sprouts, early establishment and enhanced growth parameters in field as affected by the initial priming treatment with *Pseudomonas fluorescens*. The same treatment was effective in recording better growth parameters of plant height and higher number of leaves and roots in nursery. This is consistent with the findings of Farooq *et al*. (2007), which suggested that seed vigour as evident by earliness in mean emergence time is correlated

to final yield. Banjobpudsa *et al*. (2017) verified that priming increased not only seedling vigour but also enhanced seedling performance in the field.

Enhancement in yield as a result of priming with *Pseudomonas fluorescens* can also be attributed to its ability to synthesis growth hormones such as gibberellins, cytokinins and indole acetic acid, which increases growth and cell division and thus increasing the plant height, number of leaves per plant and production as reported by (Koocheki *et al*., 2008). Also, application of *Pseudomonas fluorescens* has been reported to stimulate plant growth by promoting extensive rooting and increasing water and nutrient uptake (Paul *et al*., 2001; Murunde and Wainwright, 2018; Ramamoorthy *et al*., 2001). In another study by Kumar *et al*. (2001) it was verified that plant growth promoting *Pseudomonas* strains produced siderophores, which has antifungal and antibacterial activity. Thus this reduction in disease can render an advantage for healthy establishment and development and final result of improved yield under field conditions. This is highly relatable to the present study, since *Pseudomonas fluorescens* primed plants exhibited lowest incidence of pest and disease under field condition.

5.2.5.2.2. Effect of chitosan spray

Chitosan sprays, irrespective of concentration, exhibited significantly higher rhizome yield than control plants which were maintained without chitosan spray. The highest rhizome yield is obtained in plants sprayed with five round of chitosan sprays at monthly interval at a concentration of 5g L^{-1} (322.71 g $plant^{-1}$). Foliar application of chitosan at 7 g L^{-1} (297.92 g $plant^{-1}$) followed this (Fig.21). Chitosan 3 g L^{-1} and 1 g L^{-1} when applied as foliar spray resulted in yield of 250.09 g $plant^{-1}$ and 266.19 g $plant^{-1}$ respectively and were on par. Chitosan sprayed plants yielded significantly higher than control. So it can be concluded that chitosan spray, whatever be the concentration, has the potential to increase yield in transplanted ginger, the best being foliar spray of 5 g L^{-1} chitosan at monthly interval.

Chitosan is a biopolymer which is mainly exploited as a biostimulant in agricultural sector for its activities such as stimulation of seed germination and plant growth, enhancement in chlorophyll content, photosynthetic rate and nutrient uptake, and reduction in biotic and abiotic stress severity (Van *et al.*, 2013). Effect of chitosan

on the plant differs, based on the structure and concentration of chitosan molecule, plant species and developmental stages of plant (Pichyangkura and Chadchawan, 2015). As a result, concentration of chitosan required for getting optimum response in each crop differs and has to be fixed through continuous experimentation. In present study, chitosan at a concentration of 5 g L^{-1}, given as monthly foliar spray, is found to be optimum for enhancing yield in transplanted ginger var. Aswathy.

Impact of chitosan application in enhancing yield, has been widely studied by several researchers. Satiyabama *et al*. (2016) found that chitosan at a concentration of 1 g L^{-1}, when applied as a foliar spray, enhanced the fresh and dry yield of rhizome in turmeric. Foliar spray of chitosan 3 g L^{-1} at three and five months after planting, resulted in significantly higher rhizome yield in Kasthuri turmeric (Thengumpally, 2019). Salachna and Zawadzinska (2014) observed that chitosan 0.5 per cent when used for soaking freesia corms before planting, resulted in increased yield. It also produced more number of corms by 40.4 percent and increased the weight of corms by 31.6 per cent than control. Similarly, chitosan at a concentration of 500 mg dm^{-1} when used in vitro culture, produced 3.33 minituber in potato when compared to 2.44 minituber in control (Asghari-Zakaria *et al*., 2009). Similar results in which chitosan application improving mini tuber production in potato was reported by Falcon-Rodriguez *et al*. (2017) and Kowalski *et al*. (2006). Hasegawa *et al*. (2005) observed that chitosan when added to growing medium increased diameter and height in corms of *Arisaema ternatipartitum.* Anusuya and Satiyabama (2016) verified that chitosan 0.1 percent application improved fresh yield of rhizome by 60 per cent. Similar results showing yield increment by chitosan application has been reported in other crops like wheat (Zeng and Luo, 2012), cucumber (Shehata *et al*., 2012), okra (Mondal *et al*., 2012) and strawberry (El-Miniawy *et al*., 2013).

5.2.5.2.3. Interaction effect of priming and chitosan

Interaction effect of priming and chitosan spray on fresh yield of ginger rhizomes was found to be significant. Considering per plant yield, highest yield of fresh rhizome was obtained from plants treated with a combination of hydropriming and monthly sprays of chitosan 5 g L^{-1} (337.20 g $plant^{-1}$), followed by those received a

combination of priming with *Pseudomonas fluorescens* and chitosan 7g L^{-1} (335.58 g $plant^{-1}$) and the same priming with chitosan 5 g L^{-1} (334.35 g $plant^{-1}$). Yield obtained from plants grown as absolute control was 143.43 g $plant^{-1}$. From the study, the best priming treatment for improving growth and yield was priming with *Pseudomonas fluorescens* and the best concentration of chitosan being 5 g L^{-1}. Plants subjected to biopriming with *Pseudomonas fluorescens*, without any chitosan spray yielded 186.37 g $plant^{-1}$ and plants sprayed with chitosan 5 g L^{-1}, grown without any prior priming treatments produced an average fresh yield of 281.04 g $plant^{-1}$ (Fig. 22). This indicates that yield obtained from plants receiving superior combination treatments were higher than yield from superior priming and chitosan sprays alone.

When the effect of superior treatments in priming, chitosan spray and combinations of priming and chitosan spray was compared with control (Plate.14) , it was evident that an increase of 135.1 percent (2.35 fold) in yield could be realized in plants given a combination of hydropriming and five round spray of biostimulant chitosan 5 g L^{-1} at monthly interval. Biopriming with *Pseudomonas fluorescens*, along with foliar application of 7 g L^{-1} chitosan and *Pseudomonas fluorescens* and 5 g L^{-1} chitosan resulted in respective increase of 133.97 per cent (2.34 fold) and 133.11 per cent (2.33 fold) in fresh rhizome yield of transplanted ginger. Chitosan spray alone gave 95.94 per cent (1.96 fold) increase in yield, whereas priming with *Pseudomonas fluorescens* alone gave only 29.94 per cent (1.29 fold) increase in yield (Fig.23).

Fig.20. Effect of priming on fresh yield of rhizome in transplanted ginger

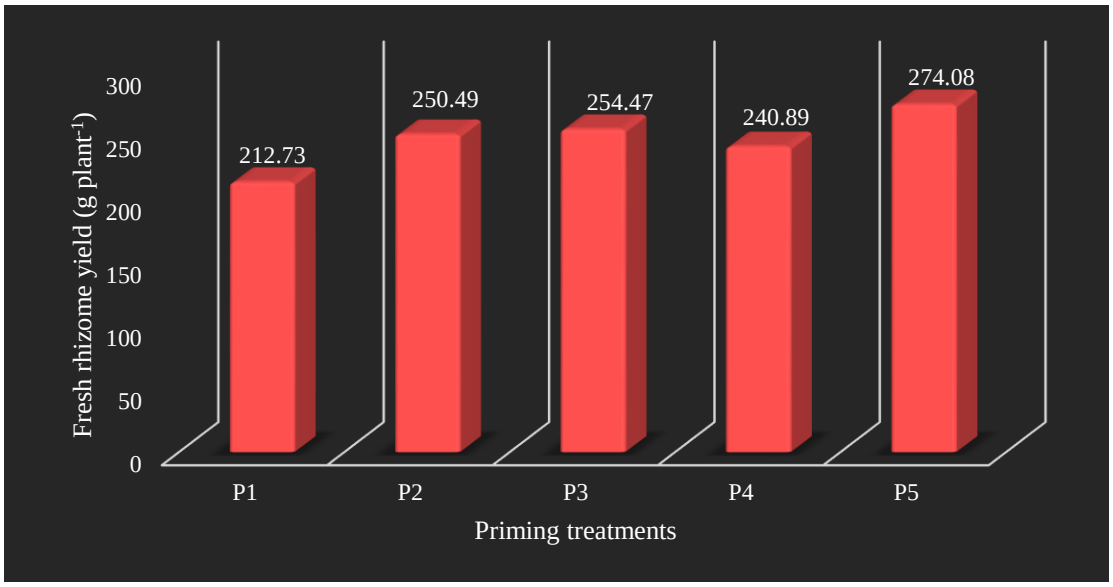
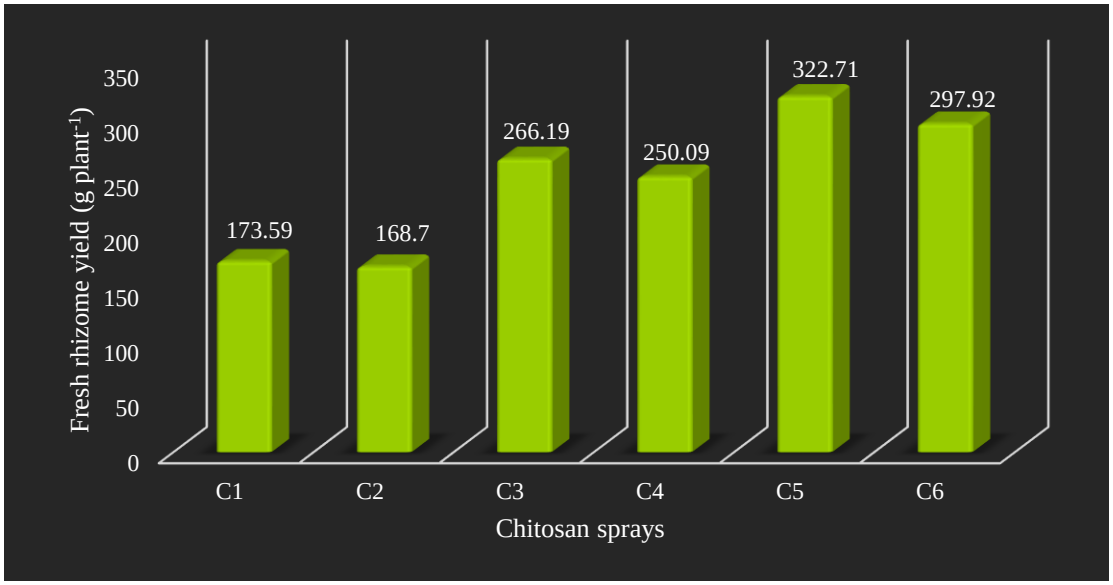


Fig.21. Effect of chitosan spray on fresh yield of rhizome in transplanted ginger



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

Fig.22. Comparison of yield improvement by priming, chitosan spray and combination of both

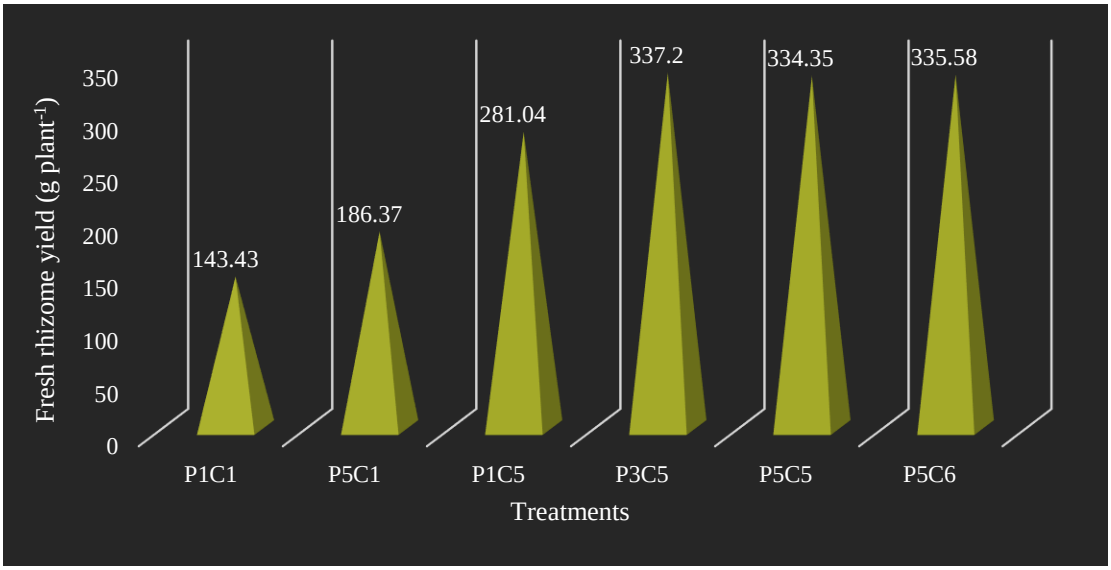
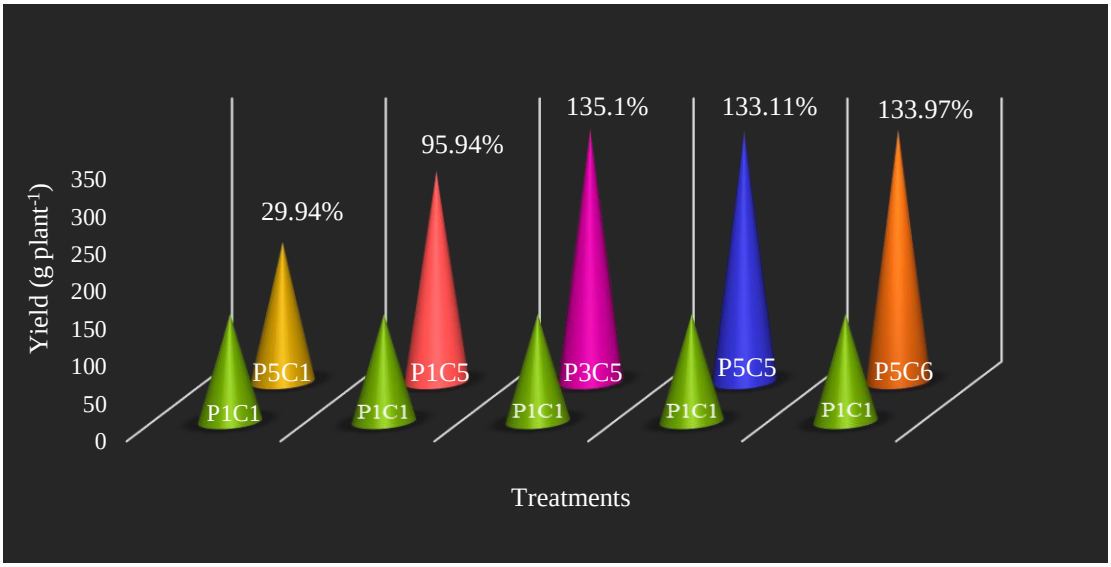


Fig.23. Percent increase in yield of transplanted ginger by priming, chitosan spray and combination of both



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

5.2.5.3. Dry recovery percentage

5.2.5.3. Dry recovery (%)

5.2.5.3.1. Effect of priming

Priming treatments did not exhibit any significant difference in dry recovery percentage of ginger rhizomes. However, highest dry recovery per cent was observed in ethephon primed plants (25.23%). Dry recovery percentage obtained from differently primed rhizomes are shown in Fig.24.

5.2.5.3.2. Effect of chitosan spray

With respect to chitosan spray, it also did not produce any significant difference in dry recovery percentage of rhizomes. Highest dry recovery was seen in control plants (25.32%), grown without any spray (Fig.25). This result is a contradiction to the findings of Thengumpally (2019), in which foliar application of chitosan 3 g L^{-1} resulted in highest dry recovery percentage when compared to those obtained from plants sprayed with lower doses of chitosan and non-sprayed control in Kasthuri turmeric.

Fig.24. Effect of priming on dry recovery percentage of transplanted ginger

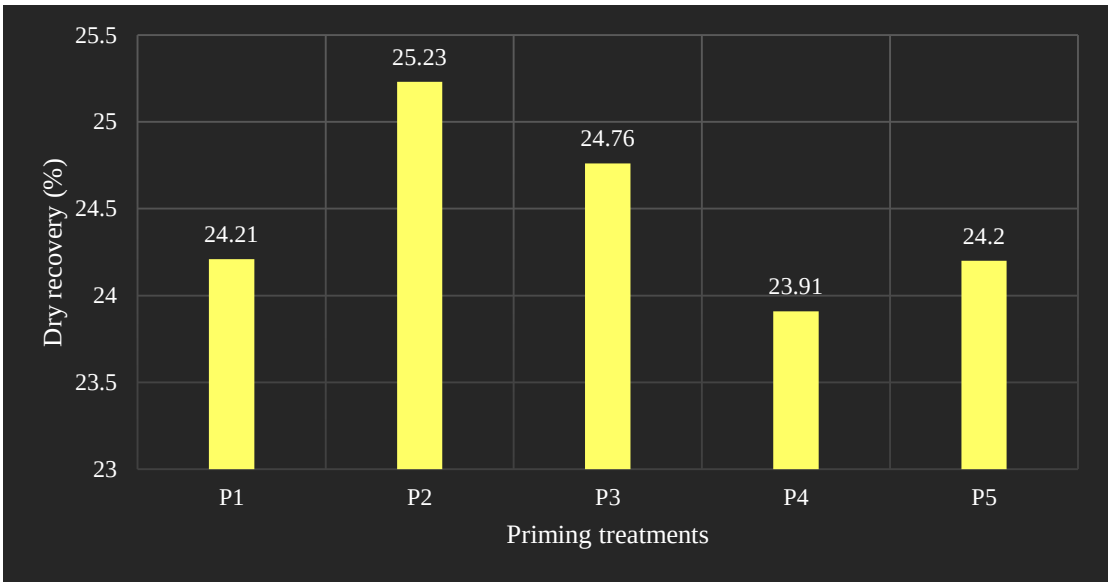
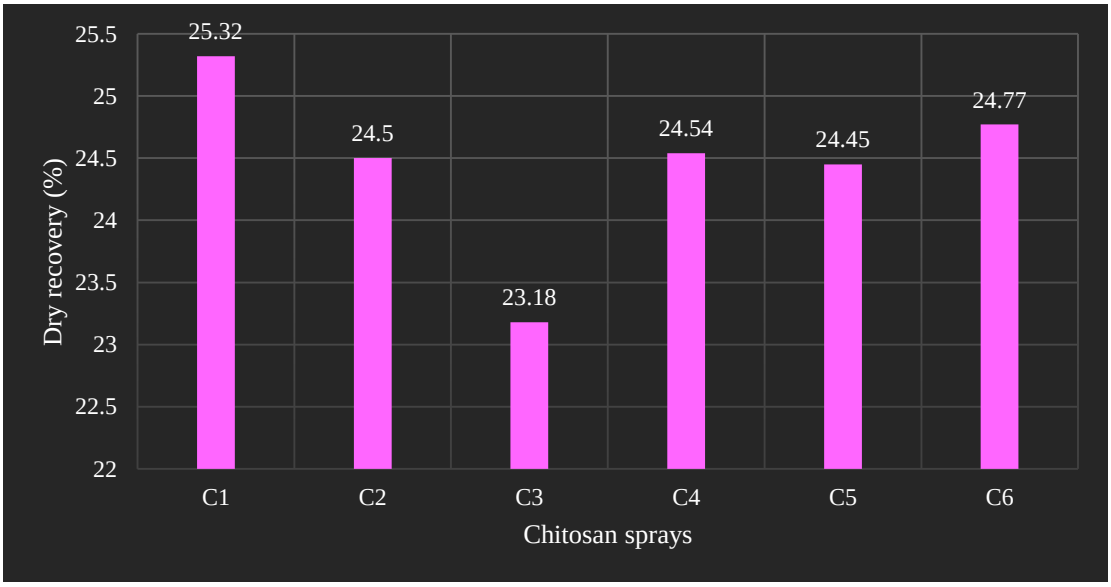


Fig.25. Effect of chitosan spray on dry recovery percentage of transplanted ginger



P1 : Absolute control

P2 : Ethephon 200 ppm

P3 : Hydropriming

P4 : *Trichoderma* sp. (4 g L^{-1})

P5 : *Pseudomonas fluorescens* (10 g L^{-1})

C1 : Absolute control

C2 : Water spray

C3 : Chitosan 1 g L^{-1}

C4 : Chitosan 3 g L^{-1}

C5 : Chitosan 5 g L^{-1}

C6 : Chitosan 7 g L^{-1}

5.3. CORRELATION STUDIES

Correlation studies have shown that yield of ginger is positively and highly correlated with parameters such as emergence index, vigour index, height of transplants, number leaves and roots of transplants, length of roots and percent survival of sprouts. Also, a negative correlation was obtained between yield and mean emergence time and time for 50% emergence. This indicates that, higher the values of vigour index and growth parameters and lower the time taken for 50% emergence and mean emergence time, higher will be the growth and establishment rate. This may lead to rapid development of healthy transplants, which finally result in enhancement of yield. In this study, highest emergence index, lowest T_{50} and MET, and highest values for growth parameters such as plant height, number of leaves and roots were associated with rhizomes primed with *Pseudomonas fluorescens.* Highest percent survival of sprouts, vigour index and root length were found in hydroprimed plants. Altogether, all the priming treatments had a notable increase in all vigour and growth parameters than the unprimed control. So it can be concluded that priming treatments have a significant influence in producing healthy and vigorous transplants which will ultimately result in enhanced yield. Similar results were also obtained by Banjobpudsa *et al*. (2017) in upland rice in which, emergence index was found to be significantly and positively correlated with seedling establishment, shoot length and shoot length, whereas, T_{50} and MET was significantly and negatively correlated with the same parameters. Farooq *et al*. (2007) found that mean emergence time and kernel yield were highly correlated in rice. Lower the value for MET, more vigorous will be the seedling, resulting in enhanced yield.

In this present study, seedlings thus primed and kept in nursery for 45 days were planted out in field in polybags. Later, they were given monthly foliar sprays of chitosan at different concentration so as to attain yield improvement in transplanted ginger. Plant growth parameters and physiological parameters, as affected by initial priming and further spray of biostimulant chitosan was measured and correlation was worked out. It was found that yield in transplanted ginger was significantly and positively correlated to growth parameters such as plant height, number of tillers, leaf area, number of fingers and with physiological parameter such as photosynthetic rate. Positive relation was also

found with stomatal conductance and transpiration rate. Results from the present study reveals that priming prior to planting and foliar application of chitosan during growth stages, has led to an enhancement in yield. This correlation analysis supports this result. Treated plants resulted in superior growth characters and physiological parameters, with the best priming treatments being biopriming with *Pseudomonas fluorescens* and best concentration of foliar spray of chitosan being 5 g L^{-1} at monthly interval or a combination of hydropriming for one hour with foliar application of chitosan 5 g L^{-1} or biopriming with *Pseudomonas fluorescens* along with sprays of chitosan 5 g L^{-1}. The improvement in growth parameters has resulted in more healthy and vigorous plants and this is reflected in final yield too. This result is in agreement with the findings of (Iqbal and Ashraf, 2005) in which plant height, number of fertile tillers, photosynthetic rate, stomatal conductance and transpiration rate manifested positive correlation with yield in wheat. Dordas and Sioulas (2008) found a positive correlation between yield and physiological parameters such as photosynthetic rate, stomatal conductance and transpiration rate in safflower. Mathews (2018) found that plants showing highest photosynthetic rate exhibited highest stomatal conductance and transpiration rate and resulted in improved yield in ginger.

Table 19. Correlation coefficients between yield and its components

Sl.No.	Characters	Correlation coefficients
	Nursery observations	
1	Emergence index	0.923*
2	Time for 50% emergence	-0.844
3	Mean emergence time	-0.747
4	Vigour index of seed rhizome	0.765
5	Height	0.84
6	Number of leaves	0.832
7	Number of roots	0.729
8	Length of roots	0.649
9	Percent survival of sprouts	0.622
	Field observations	
10	Plant height	0.673**
11	Number of tillers	0.653**
12	Leaf area	0.718**
13	Number of fingers	0.800**
14	Photosynthetic rate	0.397*
15	Stomatal conductance	0.147
16	Transpiration rate	0.257

Summary

6. SUMMARY

The present study entitled, "Yield improvement in transplanted ginger by seed priming and biostimulant spray" was carried out at Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara during January 2019 to January 2020. The main objective of this study was to find out the best priming treatment, an optimum concentration of chitosan spray or a combination of both, to enhance yield in transplanted ginger.

The planting material used for the study was collected from farm of Department of Plantation Crops and Spices. The variety used was Aswathy, a green ginger variety, released by Kerala Agricultural University. The seed rhizomes of ginger were cut into small pieces of 3 to 5 g. The rhizome bits were primed with best treatments reported from the previous study of Department of Plantation Crops and Spices *viz*., hydropriming, biopriming using *Trichoderma* sp. and *Pseudomonas fluorescens* and priming with ethephon 200 ppm, keeping the unprimed rhizome bits as control. The seed rhizome materials were planted in portrays of 1.5 cm cavity depth. The experiment was laid out in completely randomised block design (CRD). Transplants were maintained in rain shelter and were transplanted to field in polybags after 45 days. In the field, the experiment was laid out in CRD comprising thirty treatment combinations. Treatments followed were initial seed priming prior to planting and foliar sprays of biostimulant chitosan after planting out in field. Foliar sprays of chitosan at various concentrations *viz*. 1, 3, 5 and 7 g L^{-1}, were given at monthly interval starting from one month after planting. Water sprayed plants and plants without any spray were served as control. Five rounds of sprays were given to ginger transplants starting from July to November. The salient findings of the study are summarized hereunder in this chapter.

Priming treatments exhibited a significant improvement in performance of ginger transplants in nursery. The emergence of sprout was superior in rhizomes primed with *Pseudomonas fluorescens* (6.33 days) followed by hydropriming (6.83 days). The sprouting was advanced by 1.84 days in rhizomes primed with *Pseudomonas fluorescens*, than the unprimed rhizomes.

Vigour of rhizomes was analysed by computing emergence index (EI), time taken for 50 per cent emergence (T_{50}) and mean emergence time (MET). Priming treatments exhibited a positive influence in improving the vigour of ginger transplants grown in nursery as evident from the high germination index, lesser time taken for 50 per cent emergence and low mean emergence time. Priming of rhizomes with *Pseudomonas fluorescens* 10 g L^{-1} for 30 minutes resulted in highest emergence index (11.33), lowest T_{50} (14.01 days) and lowest MET (17.51 days). Germination index indicating the rate of per day emergence of sprouts, was 11.33 in rhizomes primed with *Pseudomonas fluorescens* whereas it was only 7.84 in control. This was reflected in an advancement of 3.7 days in MET and 2.27 days in T_{50}.

Priming exhibited a significant influence in improving the percent survival of sprouts. The highest per cent survival of sprouts was found in rhizomes given hydropriming for one hour (85.16%) and rhizomes subjected to priming with ethephon (84.16%), followed by priming with *Pseudomonas fluorescens* (81.67%). Priming treatments were also found effective in promoting the growth characters of ginger sprouts under nursery conditions, though not significant. Plant height ranged from 24.35 cm to 26.90 in primed rhizomes compared to 24.20 in unprimed material. The root length ranged from 8.5 to 10.60 cm in primed plants.

The vigour index of seed rhizome was also calculated from percent survival of sprout and length of root and shoot. The highest vigour index was found in hydroprimed sprouts and rhizomes subjected to biopriming with *Pseudomonas fluorescens* (3167.95 and 3011.99 respectively). From the study it is clear that, priming treatments can invigorate the growth of seedlings, as evident by the early emergence, higher percent survival and superior vigour index, when compared to the control. Thus, priming can be adopted for raising healthy and vigorous ginger transplants, which is essential for rendering a stimulatory effect throughout the crop growth period.

These transplants were planted in the main field and given biostimulant spray at monthly interval. The performance of transplants was assessed interms of plant height, number of tillers produced, physiological parameters like photosynthetic rate, stomatal conductance, transpiration rate and leaf area, incidence of disease and fresh rhizome yield per plant.

The plant height was significantly high in plants given hydropriming (69.67 cm) and biopriming with *Pseudomonas fluorescens* (69.15 cm) and *Trichoderma* sp. (68.49 cm), irrespective of chitosan sprays, at 120 DAT. Foliar application of chitosan at concentration of 7 g L^{-1} (71.20 cm) and 5 g L^{-1} (70.80 cm) exhibited the highest plant height at 120 DAT, irrespective of the priming treatments. When the interaction effect was studied, the plants given hydropriming and sprayed with chitosan 5 g L^{-1} showed the highest plant height (74.77 cm), at 120 DAT. A positive correlation of plant height with fresh rhizome yield of ginger was also observed.

The highest number of tillers was observed in hydroprimed plants (14.79) and in plants subjected to priming with *Pseudomonas fluorescens* (14.79), irrespective of chitosan spray at 120 DAT. When the effect of chitosan spray on number of tillers at 120 DAT was compared irrespective of priming, the highest number of tillers was observed in plants sprayed with 7 g L^{-1} chitosan (14.89), 5 g L^{-1} (14.77) and 1 g L^{-1} (14.33). With respect to the interaction effect at 120 DAT, the highest number of tillers was recorded in plants given a combination of hydropriming and 5 g L^{-1} chitosan spray (16.97), at 120 DAT. Correlation study implies that number of tillers exhibited a positive correlation with final rhizome yield in ginger transplants.

However, it is clear from the present study that when compared to control, plants subjected to priming and chitosan sprays alone and plants which received combination of priming and chitosan spray exhibited significantly taller plants with more number of tillers. When a combination of hydropriming and chitosan 5 g L^{-1} was given, an increase of 19.44 percent in plant height and 37.55 percent increase in tiller production was noticed, when compared to absolute control with no priming and no chitosan spray.

Photosynthetic rate, stomatal conductance and transpiration rate were found to possess a positive correlation with yield. The highest values for photosynthetic rate (23.75 µ mol m^{-2} s^{-1}), stomatal conductance (2.69 µ mol m^{-2} s^{-1}) and transpiration rate (13.67 m mol m^{-2} s^{-1}) were observed in hydroprimed plants. In case of chitosan spray, highest value were observed in plants sprayed with chitosan 5 g L^{-1} (23.83 µ mol m^{-2} s^{-1}, 2.78 µ mol m^{-2} s^{-1}, 13.07 m mol m^{-2} s^{-1} respectively). Leaf area of ginger was found to be the highest in plants primed with *Pseudomonas fluorescens* (30.71 cm^2), hydropriming (29.68 cm^2) and *Trichoderma* sp. (29.17 cm^2), whereas in case of

chitosan application, sprays at concentration of 7 g L^{-1} (30.76 cm^2) was found effective for improving leaf area.

There was no significant influence on field incidence of bacterial wilt in ginger by priming and chitosan spray. Though not significant, the incidence of bacterial wilt was lowest in plants primed with *Pseudomonas fluorescens* (6.77%), irrespective of chitosan application. Also, a low incidence of 6.78% was observed in chitosan sprayed (5 g L^{-1}) plants irrespective of priming treatments. Significantly lowest infestation of *Phyllosticta* leaf spot was observed in plants sprayed with chitosan 7 g L^{-1} (25.65%) and 5 g L^{-1} (30.79%). Irrespective of priming treatment the chitosan sprayed plants were effective in field control of *Phyllostica* leaf spot as evident from the significanltly higher percent disease index in control plants (57.93%).

Priming treatments had a significant influence on fresh rhizome yield of ginger. Significantly highest number of fingers was found in plants sprayed with 5 g L^{-1} chitosan (12.12). Invariably, all priming treatments were effective in improving the number of fingers. The highest rhizome yield was obtained from plants subjected to bioprimng with *Pseudomonas fluorescens* (274.08 g $plant^{-1}$), irrespective of chitosan spray. Bioprimed plants exhibited an increase of 28.84 percent yield improvement than the control plants without priming. Foliar application of chitosan (5 g L^{-1}) at monthly intervals during the crop growth period was found superior in increasing fresh rhizome yield of ginger (322.71 g $plant^{-1}$), irrespective of priming treatments. Yield enhancement of 85.9 per cent was observed in plants sprayed with 5 g L^{-1} chitosan when compared to control without any spray. With respect to interaction effect, the highest yield was recorded in plants given the combination treatments of hydropriming with 5 g L^{-1} chitosan spray (337.20 g $plant^{-1}$) and biopriming with *Pseudomonas fluorescens* along with sprays of chitosan at a concentration of 7 g L^{-1} (335.58 g $plant^{-1}$) and 5 g L^{-1} (334.35 g $plant^{-1}$).

When the effect of superior combination of priming and chitosan spray was compared with the control, it was evident that 2.35 fold (135.1%) increase in yield could be realized in plants given a combination of hydropriming and five round spray of biostimulant chitosan 5 g L^{-1} at monthly interval. Biopriming with *Pseudomonas fluorescens*, along with foliar application of 7 g L^{-1} chitosan and *Pseudomonas*

fluorescens with field spraying of 5 g L^{-1} chitosan resulted in 2.34 fold (133.97%) and 2.33 fold (133.11%) increase in fresh rhizome yield of transplanted ginger respectively. Chitosan spray alone gave 1.96 fold increase (95.94%) in yield and priming with *Pseudomonas fluorescens* alone gave only 1.29 fold increase (29.94%) in yield. However, neither priming nor chitosan spray resulted in any significant change in dry recovery percentage of ginger.

The study reveals the effect of priming in improving growth parameters and physiological characters of ginger transplants, which ultimately results in enhanced fresh rhizome yield. Chitosan is a widely accepted biostimulant in agriculture, which enhances yield and boost the plant immune system to tackle biotic and abiotic stresses. However, no studies on application of chitosan in ginger is reported until now. In the present study, it was observed that chitosan at a concentration of 5 g L^{-1} is effective in enhancing the plant growth characters, by stimulating the growth and defence system of plant and resulted in improved fresh rhizome yield in transplanted ginger.

Ginger transplants are prepared from single bud rhizomes bits, which are meant to reduce the cost of production by reducing the quantity of seed rhizomes used. In such cases, methods to improve vigour and growth of single bud sprouts, which can result in yield enhancement are highly desirable. From this study, it is discernible that priming of rhizomes prior to planting and foliar application of chitosan can be an option to improve yield in ginger transplants. The combination of both priming and foliar application of chitosan was found more effective than the individual effect of priming and chitosan. Hence either priming with *Pseudomonas fluorescens* 10 g L^{-1} for 30 minutes or hydropriming for one hour and foliar application of chitosan at a concentration of 5 g L^{-1} can improve fresh rhizome yield per plant in transplanted ginger.

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Appendices

Appendix 1. Weather data

Months	Max temperature (ºC)	Min temperature (ºC)	Relative humidity (%)	Sunshine hours per day (h)	Rainfall (mm)	Number of rainy days	Evaporation per day (mm)
January	32.9	20.4	55	8.4	0.0	0	4.7
February	35.3	23.4	59	8.7	0.0	0	5.1
March	36.8	24.8	65	8.6	0.0	0	4.8
April	36.1	25.5	70	8.0	76.4	3	4.7
May	34.6	24.9	74	6.8	48.8	4	4.0
June	32.2	23.5	83	3.7	324.4	15	2.8
July	30.4	22.8	85	2.6	654.4	21	2.4
August	29.5	21.7	89	1.5	977.5	24	1.9
September	31.2	22.0	85	3.3	419.0	19	2.5
October	32.4	21.4	80	5.5	418.4	16	2.7
November	32.9	21.7	71	7.5	205.0	5	3.4
December	32.3	22.1	63	6.7	4.4	1	4.5
January	34.1	22.4	60	9.4	0.0	0	4.9

YIELD IMPROVEMENT IN TRANSPLANTED GINGER BY SEED PRIMING AND BIOSTIMULANT SPRAY

by

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ABSTRACT OF THESIS

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ABSTRACT

Ginger (*Zingiber officinale* Rosc.) is a herbaceous spice acclaimed for its value in flavour and pharmaceutical industry. A dearth in availability of healthy and good quality planting material is well pronounced in ginger. Hence, a transplant technique, utilizing ginger sprouts raised from small rhizome bits of 3 to 5 g grown in protrays, has been proven to yield on par with conventional planting of 20 g seed rhizome. In such cases, methods to improve vigour and growth of ginger plants, which can result in yield enhancement are highly desirable. The present study, 'Yield improvement in transplanted ginger by seed priming and biostimulant spray' was conducted in the Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara during January 2019 to January 2020 to find out the best priming treatment, optimum concentration of chitosan spray and a combination of both, that improve fresh rhizome yield in transplanted ginger.

In nursery, priming treatments significantly invigorated the growth of sprouts, as evident by the early emergence, high survival per cent and seed vigour index. The emergence of sprouts were early in rhizomes primed with *Pseudomonas fluorescens* 10 g L^{-1} for 0.5 hour (6.33 days) followed by hydropriming for one hour (6.83 days). Hydropriming and priming with ethephon 200 ppm for one hour resulted in significantly superior survival per cent of 85.16 and 84.16 respectively. Significantly higher vigour index of seed rhizome was noticed in sprouts subjected to hydropriming and bioprimed with *Pseudomonas fluorescens* (3167.95 and 3011.99 respectively).

Plant height and tiller production were significantly higher in plants raised from hydroprimed seed rhizome and given foliar sprays of biostimulant chitosan 5 g L^{-1} at monthly interval for five months, resulting in 74.77 cm height and 16.97 tillers. Invariably, plants subjected to priming or chitosan spray or a combination of both were significantly taller with more number of tillers.

Photosynthetic rate, stomatal conductance and transpiration rate were significantly higher in hydroprimed plants (23.75 µmol m^{-2} s^{-1}, 2.69 µmol m^{-2} s^{-1}, 13.67 mmol m^{-2} s^{-1} respectively) and in plants sprayed with chitosan 5 g L^{-1} (23.83 µmol m^{-2} s^{-1}, 2.78 µmol m^{-2} s^{-1}, 13.07 mmol m^{-2} s^{-1} respectively). Leaf area of ginger was found to be highest in plants primed with *Pseudomonas fluorescens* (30.76 cm^2),

hydropriming (29.68 cm^2) and *Trichoderma* sp. (29.17 cm^2). Monthly spraying of chitosan 7 g L^{-1} was found effective for improving leaf area (30.71 cm^2) compared to control (26.72 cm^2).

Significantly lowest incidence of *Phyllosticta* leaf spot was observed in plants sprayed with chitosan 7 g L^{-1} (25.65%) and 5 g L^{-1} (30.79%), irrespective of the priming treatments.

Priming and chitosan sprays exhibited significant improvement in fresh rhizome yield of ginger transplants. Significantly highest number of fingers was found in plants sprayed with 5 g L^{-1} chitosan (12.12). Invariably, all priming treatments were effective in improving the number of fingers. A combination of hydropriming and field spraying of chitosan 5 g L^{-1} (337.20 g $plant^{-1}$), biopriming with *Pseudomonas fluorescens* along with sprays of chitosan 7 g L^{-1} (335.58 g $plant^{-1}$) and biopriming with *Pseudomonas fluorescens* with field spraying of chitosan 5 g L^{-1} (334.35 g $plant^{-1}$) were identified as the best three combinations for yield improvement in ginger transplants. All the priming treatments and chitosan sprays recorded significantly higher fresh rhizome yield than the control.

From this study, it is evident that priming of seed rhizomes and foliar application of chitosan can be adopted to improve yield in transplanted ginger. A combined application of priming and foliar sprays of chitosan was found more effective than the individual effect of priming and chitosan. Hence, combination of priming with *Pseudomonas fluorescens* 10 g L^{-1} for 30 minutes or hydropriming for one hour, followed by foliar application of chitosan at a concentration of 5 g L^{-1} at monthly intervals can improve fresh rhizome yield in transplanted ginger.